Fire Safety Guide

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1 Introduction

1.1 Fire – Constant Hazard with Highest Hazard Potential

Since the middle ages, when whole cities burnt down, mankind has learned a lot and has taken constant efforts to avoid and contain fires. These efforts, however, have been compensated by additional sources of ignition and increasing combustible loads.

Today, virtually every household and every company features PCs, TV, halogen lamps, coffee machines and other electrical appliances, heating and air conditioning equipment, etc. Most of these devices include a power supply unit and other electronic modules, thus constituting potential sources of ignition. But fires may also be laid deliberately. The share of arson is already 25 to 40%, and figures are increasing[1]. Deliberately laid fires often spread quickly and fire fighting is extremely difficult. On average, such fires are three times as expensive as an average event of fire[2].

In our affluent society, buildings are furnished with more and more luxurious textiles, carpets, etc. In addition, the use of economic, easy-to-process and moldable die-cast synthetic material is permanently increasing. Apart from the increasing combustible load, these substances are mostly highly inflammable and react as fire accelerants. This effect is much more fatal than the mere combustible load would reveal.

A conflagration releases approximately as much power as a nuclear power plant – such conflagrations may reach several hundred MW to some GW. A limited paper fire during which 3g of paper are burned per second already generates 40kW and a flame height of 0.8m.

In addition to heat, each fire, whether large or small, produces toxic waste and highly toxic smoke gases. These gases contain, among other substances, carbon monoxide, hydrochloric acid gas, chloric gas, various sulfur compounds, nitrogen oxides (NO_x), hydrocyanic acid gas and many other highly toxic substances, even phosgene. The loss of human life and financial damage caused either directly or indirectly by smoke gases is accordingly high.

All over Europe, more than 4'000 people die every year because of fire events[3] – most of them from smoke poisoning. It is difficult to assess the number of injured persons even approximately – it might amount to ten times as many seriously injured and hundred times as many slightly injured persons. Altogether, this amounts to approximately half a million people who fall victim to fires every year, and who partly suffer permanent damage.

The expenditures for direct fire-related damage in Europe amount to 1 to 3 tenth of a percent of the GNP[4]. This means that the direct damage caused by fires in Western Europe amounts to more than 15 billion €[5]. The indirect consequential damage may be ten times higher. In comparison: The upper limit of expenses of the EU-25 household for 2005 is approximately 120 billion €. Examinations have shown that the largest part of this enormous damage is caused by smoke gases and their corrosive constituents. Damage caused by smoke is approximately ten to hundred times higher than the actual fire damage[6]. Approximately one third of this smoke damage can be traced back to hydrochloric acid (HCl) released by fire, which results in corrosion of installations and devices.

For an individual company this may be fatal. According to estimations by experts[7], a conflagration in a company's premises may have the following, disastrous effects:

- For approximately one third of the companies concerned, direct fire damages result in bankruptcy.
- For another third of the companies concerned, the loss of their customer base results in bankruptcy within three years.
- The residual third often has to merge with other companies or needs to be sold. Sometimes, however, the company has the force to survive.

Damage caused by fire shows that fire prevention, fire detection and fire fighting are highly up-to-date topics we have to face.

1.2 Purpose of the Fire Safety Guide

It is the goal of fire protection to effectively save people, material goods and the environment from the dangers and effects of fire. In addition, material damage resulting from operational interruption or the loss of the customer base shall be minimized. Good fire protection is based on the relevant, harmonized structural, technical and organizational fire protection measures.

In contrast to many other investments, fire protection aims at preventing events. Success is thus mostly not visible – only failure becomes visible in the form of major fire events. Practice has shown that the investment in a well conceived fire protection concept is not normally higher than the investment in a suboptimal concept. Good fire protection is thus not a short-term investment but an economically motivated way of thinking.

For many years, Siemens has been and still is a committed, worldwide active provider of detection, evacuation and extinguishing systems as well as danger management systems. It is our concern to provide an overview of the most important topics in technical fire protection and showing the most significant correlations with this Fire Safety Guide. The Fire Safety Guide supports you in evaluating fire protection systems, so that you may have the highest possible benefits from your choice of fire protection solution.

To guarantee sufficient safety from fires, national and regional directives have been laid down in most countries. Personal safety is generally regulated by laws and official requirements. Protection of material assets is mainly a matter of insurance companies that have laid down corresponding guidelines and directives.

Such claims and requirements in laws, rules, directives and standards unambiguously take priority over the recommendations in this Fire Safety Guide and must be taken into account in planning your fire protection solution.

If fire protection measures are not called for, fire protection matters are the responsibility of the fire detection system planners.

Siemens and the former Cerberus have conducted basic research for many decades and have worked out many documents on fire protection. Most of them have been made available for internal use only. This Fire Safety Guide is based on these documents and on the extensive knowledge and experience of Siemens and the former Cerberus. References appear only where they refer to documents that have been made publicly available.

2 Integral Fire Protection

2.1 Summary

Due to the increasing complexity of our infrastructure, it becomes more and more difficult to implement further improvements in fire protection, at the same time keeping expenditures at an acceptable level. Fire protection therefore requires a holistic approach: Which measures provide the highest possible safety at the lowest possible costs?

Measures must thus be taken where they are most effective, in comparison to the required expenditures. The earlier a measure is applied in the chain of measures "preventing – detecting – fighting – learning", the better.

The well-established measures of structural fire protection are preventive and have proven well. Unfortunately, additional structural means are often very expensive. The possibilities of technical fire protection are manifold, reaching from hazard detection and danger management to evacuation and automatic extinguishing. Here, good planning is crucial.

How shall the different fire protection aspects interact? Which boundary conditions must be adhered to, and how? The fire protection concept finds answers on these questions, assesses risks and compiles a package of measures, so that a building can be protected in the best possible way.

Structural and technical fire protection is basically highly reliable – in contrast to organizational fire protection. In fire protection, human failure constitutes the highest risk, which is why adherence to the organizational measures must be continuously ensured.

Fire protection is an investment in safeguarding human life and assets. This investment must be planned and ensured in the best possible way.

2.2 Basics

One of the characteristics of human beings is their ability to plan. Planning means to set up different measures in advance, so that they correlate optimally in the end.

Based on experience gained with fires, the laws of fire protection were simple to learn, and rules were set up laying down what doors must have which fire resistance values, for example. Today, building structures become more and more complex, and increasing optimization makes it harder to recognize real possibilities for improvement at minimal costs.

To be able to still make progress that can be afforded under such conditions, a holistic approach is required – Integral Fire Protection. This concept shall ensure that a risk is eliminated or at least reduced at the lowest possible costs.

2.2.1 Objective

The approach of Integral Fire Protection was made based on this perspective: Fire protection as a result of a holistic fire protection concept with target-oriented measures averting the relevant threats in an economic way. How and where shall the financial means be applied to achieve the highest possible protection, at the same time ensuring the lowest possible expenses? These questions can best be answered by a holistic or comprehensive approach embracing the complete system.

2.2.2 Guiding Idea

The top maxim of every protection strategy is the chain of measures “preventing – detecting – fighting – learning”. Damage events shall be avoided wherever possible. If an event nevertheless occurs, this must immediately be recognized and immediate reaction must be initiated. After the event has occurred, it is about learning the consequential lesson, so that future events can indeed be prevented.

Completely ruling out the physical event “fire” would be the optimum solution. Unfortunately, this is virtually impossible in daily life, as unwanted fires can occur even when unrealistically high efforts are taken.

Fortunately, fire has a very special characteristic: It grows exponentially. Fires that are detected at an early stage often cause no damage at all, or only very limited damage. Mostly, a glass of water or the disconnection of a device from the power supply or the use of a portable extinguisher is often sufficient to extinguish incipient fires. Although a physical fire has occurred, such fire events may be considered “prevented economic events”. In other words: It is not only the chemical reaction called “combustion” that is considered a damaging fire but also (and especially) the damage to human life, or the company’s economical prosperity. The primary goal of fire protection is thus to avoid damage to human life as well as material damage.

If a damaging fire can no longer be avoided, the fire effects have to be limited as efficiently as possible. The priority is again on the life and health of human beings. This is followed by the protection of material assets. The secondary goal of fire protection is therefore damage mitigation.

Integral fire protection consists of two parts:
– avoiding damaging fires
– damage mitigation

Preventing events is the goal of preventive fire protection, whereas fire fighting aims at damage mitigation.

2.2.2.1 Avoiding Damage by Fire (Preventive Fire Protection)

Preventive fire protection aims at preventing damaging fires. In doing so, two approaches are followed:

- The physical event “fire” shall be prevented, i.e. any possibility of unwanted combustion shall be ruled out. To avoid unwanted combustion, ignition sources and combustible load, or in case of danger of explosion, explosive gases or vapors must be eliminated and separated (see also chapter 6.3 starting on page 191). A complete prevention of unwanted combustion processes, however, is unrealistic. The second approach is therefore mandatory.
- The economic event of a damaging fire must be prevented. This means that unwanted combustion must be detected as early as possible to prevent relevant economic damage. Thanks to automatic fire detection systems, one is usually able to detect incipient fires at an early stage and thus intervening as early as possible, so that relevant damage can indeed be avoided.

Event prevention seamlessly merges with the next phase: Damage mitigation.

2.2.2.2 Damage Mitigation (Fire-Fighting)

A fire event endangers the life of the people concerned. They must therefore be informed and requested to leave the fire sector if need be (evacuation). This self-rescue on the one hand eliminates personal danger. On the other hand, it is the prerequisite for quickly beginning with extinguishing. The fire brigade first saves lives before they begin to extinguish fires. Efficient self-rescue thus accelerates extinguishing, essentially contributing to damage mitigation. If there are valuable assets in the building, or in case of high general danger, the use of automatic evacuation and extinguishing systems is extremely recommendable.

2.2.2.3 Integral Fire Protection Concept

Implementing the measures chain “preventing – detecting – fighting – learning” can be represented as a closed loop:

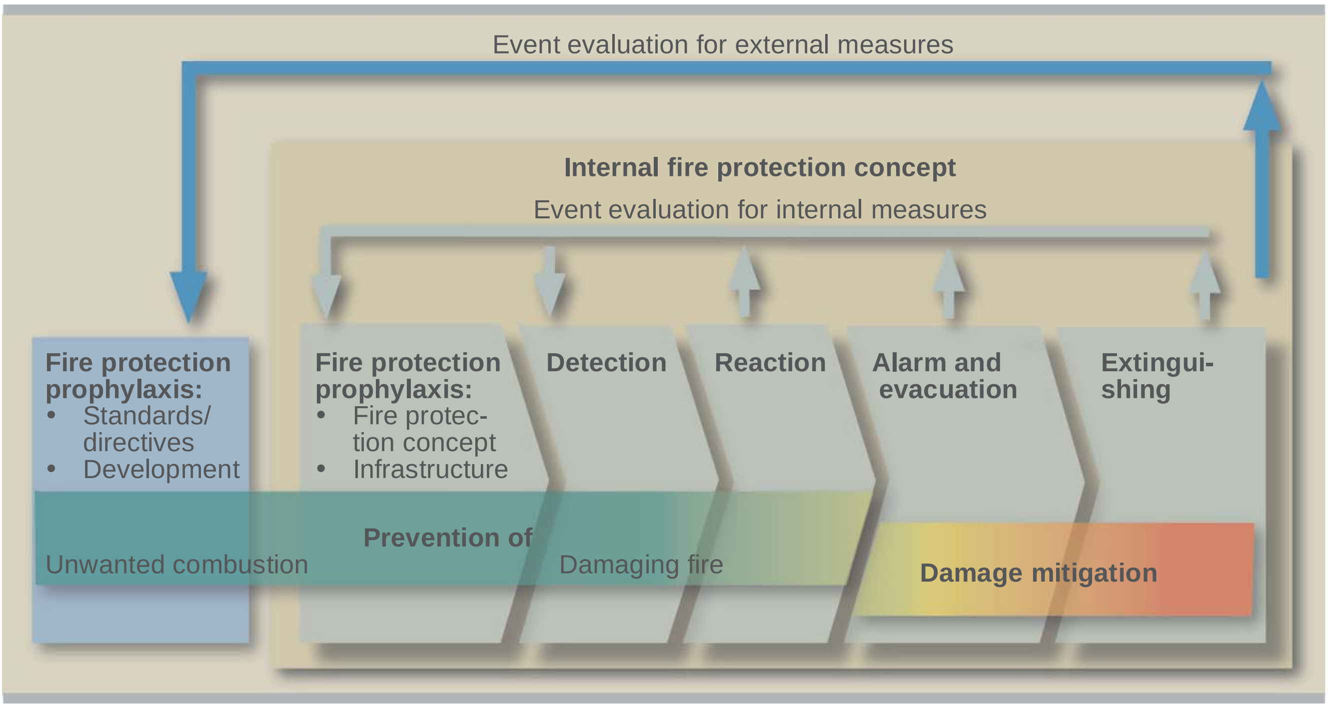


Figure 2.1: Integral fire protection concept

If damage cannot be prevented, fire fighting comes into operation. It is crucial that preventive fire protection ensures early alarm and that the geographical propagation of the fire can be limited.

Each event must be evaluated. If its significance is rather low, the measures to be initiated are limited to the company itself. In case of conflagrations, society is essentially interested in avoiding them in the future. The experience gained from such events can thus be integrated in fire protection regulations. These two closed loops ensure that events become less frequent and that the remaining events are less damaging and less urgent.

This representation refers to fire protection in general. It encompasses all aspects of fire protection as described in detail in the next sections.

2.3 Structural Fire Protection

Structural fire protection is a preventive fire protection measure. It aims at preventing the further propagation of fires. Its maxim is “divide and conquer” (“divide et impera”): Fires spreading over a limited surface area can be extinguished relatively easily and quickly, whereas conflagrations almost always result in the total loss of the building.

The most important elements of structural fire protection are:
- accessibility for the fire brigade
- protection intervals between buildings and installations
- fire walls between adjacent buildings
- construction materials and construction parts made of hardly combustible material
- high fire resistance of girders and load-bearing parts
- creation of fire compartments to limit smoke and heat propagation
- sealing off installation ducts and channels
- short and safe escape routes and emergency exits
- if possible, separate ignition sources from combustible materials
- lightning protection systems

Manufacturing a door with a predefined fire resistance value is no longer a problem today, and this door will most probably retain this fire resistance value throughout its complete service life. But making sure that the fire door will indeed be locked tight in case of fire – this is the real challenge for fire protection management (see chapter 2.5).

2.4 Technical Fire Protection

Technical fire protection comprises equipment and systems serving for personal safety and damage mitigation in case of fire.

2.4.1 Safety Systems

An “installation” is the collectivity of all devices installed in a building, devices which interact so that the purpose of the system can be fulfilled. For example, in gas warning installations, gas detectors, control units and alarm devices interact to alert and protect from gases.

A “system” is the collectivity of all products required to set up a particular installation, harmonized by the system provider so that they interact without problems. The smooth communication between detectors and control unit, for example, must be coordinated.

A “product” is an individual device used in a system or an installation. System components consist of one or several products.

2.4.2 Gas Warning Systems

Gas warning systems detect dangerous concentrations of gases or vapors in the air. In case of danger, they automatically control:
- acoustic and optical alarm devices to alert people
- the calling-up of controlling bodies and decision-makers
- ventilation systems, gas feeding pipes, pumps, motors and valves

The Fire Safety Guide explicitly restricts itself to combustible gases and vapors.

2.4.3 Fire Detection Systems

Automatic fire detection systems enable an early detection of fires and the initiation of preprogrammed control functions. This includes:
- alerting people in the hazard zones
- calling up fire extinguishing and intervention forces
- activating installations to limit smoke and fire spread, e.g. closing fire doors and fire dampers
- activating smoke and heat extraction systems
- disconnecting technical systems (equipment) from the power supply
- controlling building automation systems, especially heating and ventilation systems and elevators
- switching on emergency lighting
- activating evacuation systems
- activating stationary extinguishing systems

With a non-automatic fire detection system, alarms are triggered manually. The presence of people is a prerequisite for alarm initiation.

A non-automatic fire detection system may as well be part of an automatic fire detection system. However, the manually activated control functions are identical with those of the automatic fire detection systems.

A “false alarm” is an alarm that has been triggered without a fire having occurred. The practice of fire detection has shown that false alarms cause severe problems. Europe-wide, about 90 to 95% of all alarms triggered by fire detection systems are false alarms. Their significance can best be expressed in more than 200'000 unnecessary efforts of Germany’s fire brigades[8], largely due to false alarms.

2.4.4 Alarm and Evacuation Systems

Fire detection has its sense in initiating alarms. Both intervention forces and building operators or other endangered people in the building shall be alerted. The tasks of the intervention forces are traditional: 1. recognizing, 2. safeguarding, 3. extinguishing. The earlier an alarm is triggered, the easier it is for the people concerned to leave the danger zone on their own initiative. This so-called self-rescue is the goal of evacuation systems. If possible, all people shall leave the building by themselves. This makes it easier to rescue people depending on help, at the same time considerably shortening the rescue phase, which is equivalent to early extinguishing.

As a general rule, evacuation systems transmit automatic, easy-to-understand voice messages via loudspeakers to people inside the building. As experience has shown, these voice messages are more frequently and more consequently followed than sirens – often not even the meaning of sirens is clear. What is the purpose of a siren if people stay where they are? But sooner or later, people become aware of the seriousness of the alarm, which should have been followed. In such situations, panic is only a question of time – often constituting a more serious hazard than the actual fire. Evacuation systems effectively avoid panic reactions. State-of-the-art systems manage a step-by-step evacuation: Especially the directly endangered zones are evacuated first, massively reducing the danger of crowded escape routes.

2.4.5 Escape Routes and Emergency Lighting

Escape routes must be identified by signs and markings so that they serve their intended purpose of making it possible for people to leave the building as quickly as possible and without any risk. Depending on national and local regulations, escape routes in high-rise buildings must be sized larger, especially when there is no evacuation system supporting step-by-step evacuation.

Emergency lighting is switched on as soon as the normal room lighting breaks down. Emergency lighting must provide for a safe finding and accessing the escape routes and emergency exits. These systems are relatively expensive as they must be fed via the emergency power supply system and require separate cabling.

Tests have revealed that light-storing optical danger management systems with continuous guiding marks are superior to back-lit optical danger management systems, both regarding their subjective comfort and their objective operating efficiency[9].

2.4.6 Smoke Protection Systems

In the event of fire, smoke and smoke gases are produced. For different reasons it may become necessary to extract smoke or smoke gases by special systems and guide them to the outside. The most important reasons are:

- The building structure must be saved from hot fire gases, which considerably extends its load-bearing capacity and its service life in the event of fire.
- Escape routes must be kept free from smoke as far as possible, extending their usability and making the complete evacuation of the building possible, which in turn facilitates intervention by the fire brigade.

In addition to smoke and heat extraction systems, there are also pressurization systems for mechanic smoke clearance. Pressurization systems can be activated either manually or automatically by means of smoke or heat detectors.

2.4.7 Fire-Fighting Systems

Extinguishing devices and extinguishing installations for manual fire fighting are means to accelerate and facilitate fire fighting on the spot. This includes:

- wall hydrants
- extinguishing water risers (dry / wet)
- hydrants
- manual call points

Fire lifts serve for transporting fire fighters and their equipment as well as for safe-guarding handicapped persons. Special demands are made on fire lifts, which generally are also available for normal transport purposes.

Emergency communication facilities enable the communication of fire fighters with each other as well as with building staff. Normally, fire brigade telephone systems are used for that purpose which are common in the United States.

2.4.8 Fire Extinguishing Systems

In case of an accordingly high risk – mostly of valuable property – a stationary automatic extinguishing system can be installed. There are water, foam, powder and gas extinguishing systems. Each basic type of extinguishing system can be divided into different subsystems and variants partly based on different principles (see chapter 6 starting on page 185).

2.5 Organizational Fire Protection

Organizational fire protection encompasses all organizational and personal measures contributing to fire prevention, or at least to limiting fire spread.

Organizational fire protection encompasses:
- normal building maintenance
- retaining order and cleanliness
- periodic operational checks and elimination of deficiencies
- working out a fire fighting plan
- instructing staff regarding:
  - operational fire threats
  - existing fire protection equipment
  - rules of fire prevention
  - behavior in the event of fire
- monitoring repair work
- control and preventive maintenance of fire protection equipment
- use of safe devices and machines
- keeping transportation and escape routes freely accessible
- removing unnecessary, mobile fire load
- issuing smoking bans and introducing smoking zones
- fire fighting training sessions
- evacuation training sessions

Organizational fire protection also includes all concepts for the protection against arson. Combined measures in the fields of intrusion protection and access control have proven to be highly efficient.

2.6 Fire Protection Concept

The fire protection concept is the basis for all measures aiming at improving fire protection. In comparison to individual, independent measures, a good fire protection concept contributes to more safety at lower costs. Fire protection concepts are often required by authorities or the plant managers in charge. Authorities normally draw upon legislation, for example:
– fire protection regulations
– construction rules
– environment protection laws
– statutory orders on hazardous incidents
– accident prevention provisions

2.6.1 Contents and Extent

A complete fire protection concept encompasses the following:

- **Description of the system:** What is the structure, setup, state, appearance, current and future use, risks, etc.?
- **Protection objectives:** Which goals shall be achieved? What is acceptable, and with what probability?
- **Structural fire protection:** Which materials are to be used, in which construction type and with what sealing?
- **Automatic and manual fire detection:** How can an incipient fire be recognized at an early stage (mostly automatic fire detection or gas warning) and how and by whom shall the alarm be performed (control unit, alarm transmission, alarm receiving stations, alarm processing)?
- **Building evacuation:** Which measures must be taken (e.g. voice alarm, automatic evacuation system) and how can people safely leave the building even in case of a power failure, for example (optical escape route guidance)?
- **Automatic and / or manual extinguishing systems:** Which automatic, fixed wet or dry extinguishing systems are required? How is intervention by the fire brigade ensured, what extinguishing posts, manual fire extinguishers, hydrants are available for manual extinguishing?
- **Organizational fire protection:** How is intervention and presence controlled, which smoking bans, restrictions on fire loads, fire-retardant measures (e.g. dustbins) are necessary?

2.6.2 Risk and Fire Protection Planning

The term “risk” expresses the degree of hazard. The risk extent can be calculated by multiplying the probability of occurrence of an event with its potential effects. The probability of occurrence must be determined for each room. Effects are all expectable results of an event. This includes all results inside and outside the room. The different results must be summed up in order to calculate the effects. The risk is then calculated by multiplying the effects with the probability of occurrence.

The table below shows a possible approach:

Probability of occurrence (P)	Effects (E)	
1 = highly improbable	1 = small or none	Danger to life and / or assets (material or immaterial)
2 = improbable	2 = medium	
3 = probable	3 = large	
4 = occasional	4 = very large	
5 = frequent	5 = danger to existence	

Table 2.1: Scheme for determining the risk level

Risk = probability of occurrence x effects

By multiplying the probability of occurrence with the effects, the following risk levels (R = P x E) are determined:

Risk level (R)	Description	Priority level	Urgency of protective measures
16, 20, 25	Highest risk	1	Immediately
8, 9, 10, 12, 15	High risk	2	Short-term
4, 5, 6	Average risk	3	Medium-term
2, 3	Low risk	4	Long-term
1	Negligible risk	5	No protective measures required

Table 2.2: Risk levels and urgency

Important: This table is based on the assumption that each risk with medium or higher effects must be eliminated or at least reduced. Examinations have shown that after a conflagration more than two thirds of all companies concerned may become insolvent even years after the event (due to loss of the customer base; see last but one section in chapter 1.1 on page 14). In addition, experience shows that just such events labeled improbable or even "impossible" may nevertheless occur in practice.

Fire protection planning is based on a risk analysis as described above. Its task is to find out how the defined protection objective can be achieved, based on optimized economic use of financial means. The result is the fire protection concept.

The following factors have to be taken into account:
– physical laws such as fire development, smoke, flame propagation, etc.
– preconditions given by the building: Building substance, geometry, escape routes, ventilation, infrastructure (e.g. energy ducts), installations, etc.
– boundary conditions by the building operator: Fixed and variable fire load, processes, staff organization, etc.

The fire protection concept thus provides an answer to the question "Which fire protection measure is to be realized and how, so that the risk can be minimized with the least financial means?" The task of a fire protection planner is thus highly demanding and requires first class qualification in many different disciplines.

Last but not least, the authorities in charge, insurance companies and building owners must assess whether the measures provided by the fire protection concept could fulfill the legally defined protection objectives. As a general rule, such expertise is supported by the following principles:
– expert's assessment (habitual, but hardly reliable)
– prevailing regulations and guidelines (often insufficient in special cases)
– deterministic calculations (fire simulations, thermodynamic models)
– probabilistic analyses (risk determination based on probability calculation, similar to the method described above)

2.6.3 Simulation of Fires and Calculation Methods

To validate objective-oriented fire protection concepts that do not come under the said regulations and guidelines, calculation methods are used today. These calculation methods may show that the provided measures fulfill the protection objectives.

Advanced calculation methods are, among others, characterized by the fact that they conduct fire simulations on consideration of the following influencing factors:
– different categories of combustible substances
– extraordinary combinations of combustible substances
– fire development
– smoke development
– propagation of smoke gases
– local temperature gradients (radiation, convection, hot gases)

For cost reasons, people continue trying to demonstrate by means of fire simulation that the measures laid down in the regulations or guidelines are not necessary – for example, to show that automatic extinguishing is not really required because fire detection and smoke extraction systems are completely sufficient.

In doing so, people neglect the fact that the calculation of the fire progression strongly depends on the once selected conditions. The chosen solution may already become invalid with minor changes of use.

For this reason, utmost care must be taken in applying fire simulation models. Mere cost reduction must never be the goal; at last, each model provides the results one expects and one wants to prove.

Furthermore, the conservative use of fire simulation shall furnish additional information for borderline cases and situations that are not covered by regulations. According to experience, approximately 10% of all customer demands are not covered by official rules and guidelines or internal regulations.

The application of fire simulation is thus especially recommendable when one is faced with a situation that is not covered by a standardized package of measures. Especially the following fields are not, or only inadequately, covered by standards:

- **Installation:** Internationally acknowledged installation guidelines for fire protection are widely missing.
- **Object protection:** Guidelines for goal-oriented object protection are widely missing, as installation guidelines focus on room protection.
- **Extraordinary fire loads:** Often, they cannot be assigned to the conventional fire classes, which is why coincidence often plays a key role in implementing guidelines.

2.6.4 Cost-Optimized Risk Management

The correct measures chain is:

prevent – detect – fight – learn

The prevention of fires should have top priority. However, prevention of fire development is as manifold as the possible reasons for a fire – and correspondingly expensive.

Therefore, the possibility of incipient fires, i.e. unwanted combustion, is frequently deliberately tolerated, and in doing so, it is ensured that the fire is detected as quickly as possible by the fire detection system and that fire propagation is additionally hindered by structural and other measures, so that the effects remain as low as possible (see section 2.2.2).

Conventional fire fighting is mostly taken care of by the fire brigade. However, it may as well be automated. Automatic fire extinguishing is applied especially when the risk of a small fire not to be detected and extinguished by conventional intervention (i.e. the fire brigade) is still too high. This is the case if extinguishing by the fire brigade would be too late (e.g. if the building is very remote).

Fires have their causes. If a fire has occurred, one must give account for the reasons. Depending on the progression of the event, the conclusions regarding the prevention, detection and / or fighting of the event must be drawn. They help to either recognize a specific kind of hazard or to recognize general principles of fire propagation and allow damage mitigation or reduction. With increasing extent of the event, the general public becomes more and more interested in learning from this damage event. Learning is the most abstract and most important step in the chain of measures. The present state of the art could only be reached thanks to our ability to learn.

2.6.5 Customized Protection

Each protective measure is preceded by a protection concept. The fire protection concept takes into account all relevant influencing factors and must thus be worked out individually. This is more than worthwhile – after all, it means the difference between wasted resources and intelligently invested means!

The expenditures for working out a fire protection concept are relatively low in comparison to the complete expenditures for fire protection. The correlation and the mutual influence of different measures are not always immediately obvious. It is thus worthwhile to use a professional fire protection planner, as the overall situation regarding fire protection is rather complex and can be sufficiently simplified on the basis of experience and knowledge.

A fire protection planner has a standardized method to assess risk (risk assessment, classification according to extent and danger level, approximation of the consequential costs of risk minimization) and knows which approaches are best to reduce a particular risk in the most economic way.

However, regarding all the planning, we must never forget that in our daily life it is mostly human being that constitute the weakest point – after all, the reliability of structural and active fire protection is significantly higher than that of the people involved.

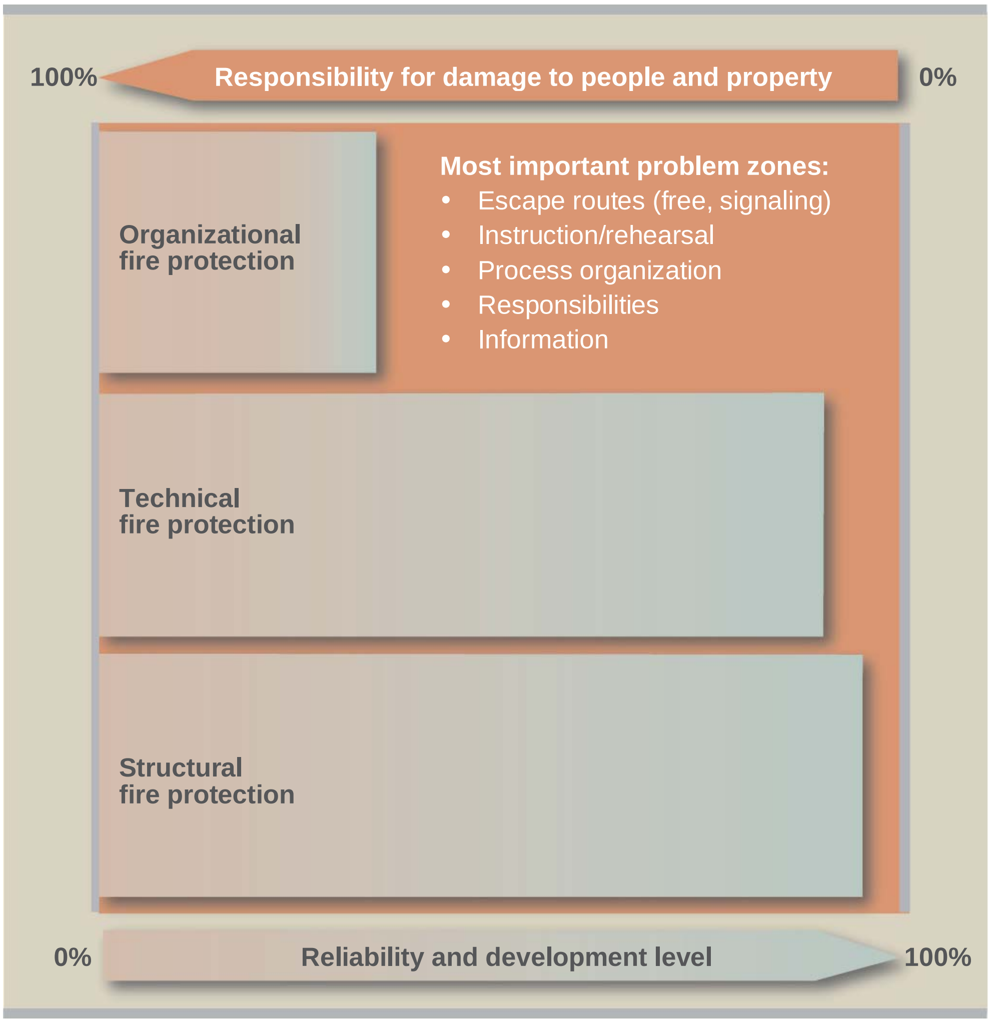


Figure 2.2: Weak point organizational fire protection

A good fire protection concept not only provides for good active and structural fire protection but also lays a solid foundation for organizational fire protection.

The fire protection concept must encompass safety reserves, as individual measures may always fail. It must be ensured that, for example, an alarm is triggered even when the night watchman does not come back from investigating the cause of a fire, or that a fire cannot propagate uncontrollably because a fire door has not been closed. Human failure is a vast field and must not lead to disaster.

2.7 Safeguarding Investments

An investment is a long-term financial commitment. Investments in safety are lost when the intended protection effect is no longer guaranteed. Safety is thus not simply a package of measures but an economic way of thinking, aiming at developing economic action in the field of safety in such a way that highest benefits can be achieved even at lowest costs.

The investment can only be safeguarded if the safety concept functions as requested in case of emergency. Preventive maintenance must therefore make sure that the systems work faultlessly and organizational processes run seamlessly. From this perspective, it is obvious that the systems must be provided with a self-monitoring function.

If the investment in corporate safety amounting to a few ten or a few hundred thousand Euros fails in a critical situation, it would be better not to invest at all! The decision on a safety concept is therefore equivalent to the decision on the constant maintenance of the installed solutions.

This does not only mean safeguarding the operability, but also the continuous adaptation of the safety concept to new conditions. A building extension, a room partition or even a change of use of premises or change of staff have an impact on the protection concept. Accordingly, the protection concept is not a one-time, laid-down document but the basis for corporate risk management, which has to be updated continuously.

3 Gas Detection

3.1 Summary

Depending on their composition, combustible gases and vapors may be lighter or heavier than air. Accordingly, the highest concentration may be reached either directly below the ceiling or at the lowest point of the room.

As the amount of energy required to ignite an explosive gas is extremely low, a gas warning system ensures that no explosive gas-air mixture may occur even in extremely endangered spots and that the lower explosion limit (LEL) cannot be reached. To ensure that the gas detector itself does not become an ignition source, it must be provided with the required ignition protection features for explosion-hazard areas.

The gas detectors work according to many different principles. Semiconductor sensors and pellistors are less expensive in their acquisition than opto-acoustic sensors or infrared absorption sensors. However, relating to operation and maintenance, they have important financial disadvantages. For special tasks, there is also the electrochemical cell, which is more expensive regarding maintenance. The right selection of the best suited detection principle is decisive for trouble-free behavior of the gas warning system.

Even today, gas detectors are still connected to the gas warning control unit by means of star-shaped cabling, but state-of-the-art bus systems are increasingly applied.

As gases are distributed faster by air flow than by diffusion, the correct positioning of gas detectors requires experience and sometimes accurate testing.

State-of-the-art gas detectors are calibrated in the factory. As, however, complete self-monitoring of the sensor is often impossible and there is danger of sensor toxification, most gas detectors must be periodically tested for their sensitivity. This is also necessary after a major gas leakage.

Selecting and planning a gas warning system requires exact knowledge of all important ambient conditions and must absolutely incorporate maintenance and servicing aspects. This is the only way to ensure that maintenance costs can be kept at a reasonable level and that the system is easy to handle.

3.2 Basics

Gas detection generally follows one of three goals:
– detection of toxic substances (toxic gases)
– detection of oxygen deficiency
– detection of combustible substances (explosive gases and gas mixtures)

To avoid damage, a gas detection system must thus detect gases in the earliest possible stage, and in a concentration that is still harmless. As toxic gases and oxygen deficiency are wide-spread phenomena which would exceed the objective of this introduction, we shall restrict our explanations to combustible gases and vapors. Combustible gases with a relevant degree of toxicity (e.g. CO or ammonia) have not been considered either. All information contained hereinafter always refers to combustible gases and vapors, even if not explicitly stated. Gas warning is an important part of the protection concept. Gas explosions are disastrous and frequently cause fires.

3.2.1 Gases

Matter consists of small particles, the atoms. Atoms comprise a positively charged atomic nucleus and a surrounding negatively charged electron shell. The electron shell determines which types of bonds with other atoms are possible. Chemistry thus takes place in the electron shell. As atoms compound either metals, salts or molecules may result. The objective of gas detection is to detect molecules contained in air, i.e. molecules occurring in gaseous form.

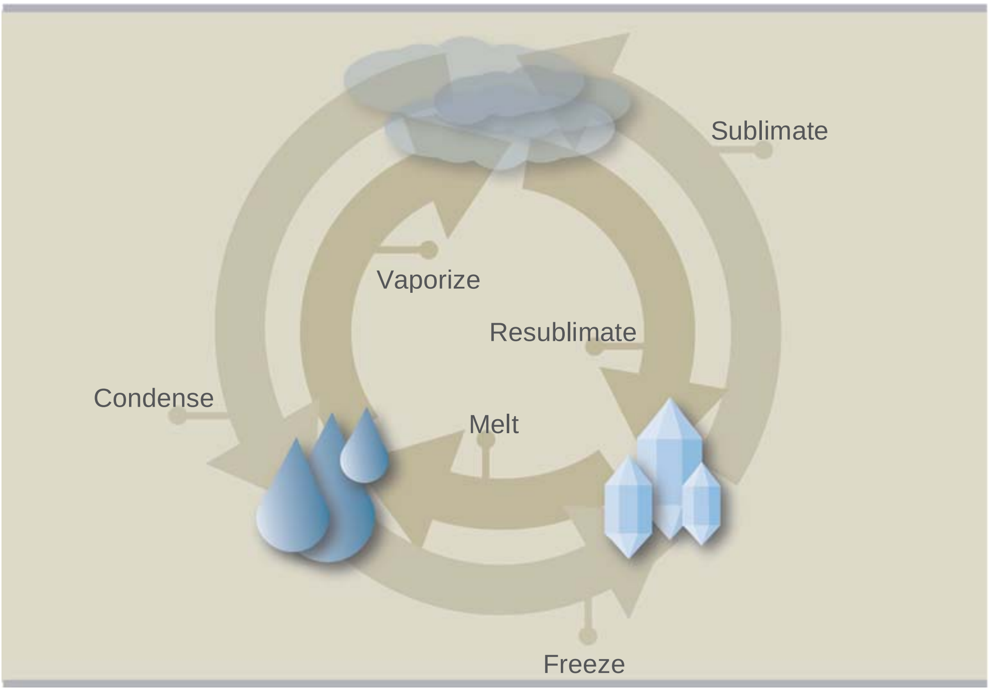


Figure 3.1: Physical states

All pure substances may occur in any of the three physical states (see Figure 3.1). The lighter a molecule, the more frequently it occurs in gaseous form. Molecules with a molecular weight of less than that of air quite quickly diffuse in calm air. These molecules reach their highest concentration at the highest point of a room. Gases heavier than air – which is the case for most gases –, diffuse more slowly and reach their highest concentration level at the lowest point of a room.

3.2.2 Explosion and Explosion Protection

Gas and vapor are physically seen the same. Nevertheless, everyday usage established the differentiation as follows: One speaks of a gas if the substance is gaseous at room temperature and normal pressure. Vapor is used to address the evaporated (=gaseous state) part of a substance that is under normal conditions mainly liquid.

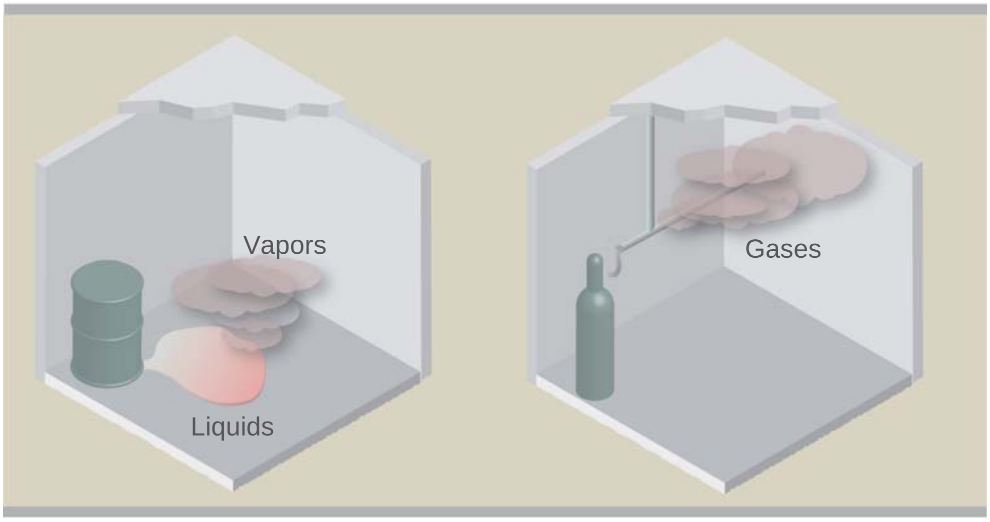


Figure 3.2: Explosion hazard due to escaping gas or liquid leakage

Combustible gases and vapors mixed with air can explode only within a certain concentration range. This so-called explosion range is defined by the lower and upper explosion limit (LEL and UEL). Below the LEL, most substances are harmless; above the UEL, they remain combustible and are thus potentially hazardous. (In addition, a toxic effect sets in with most substances.)

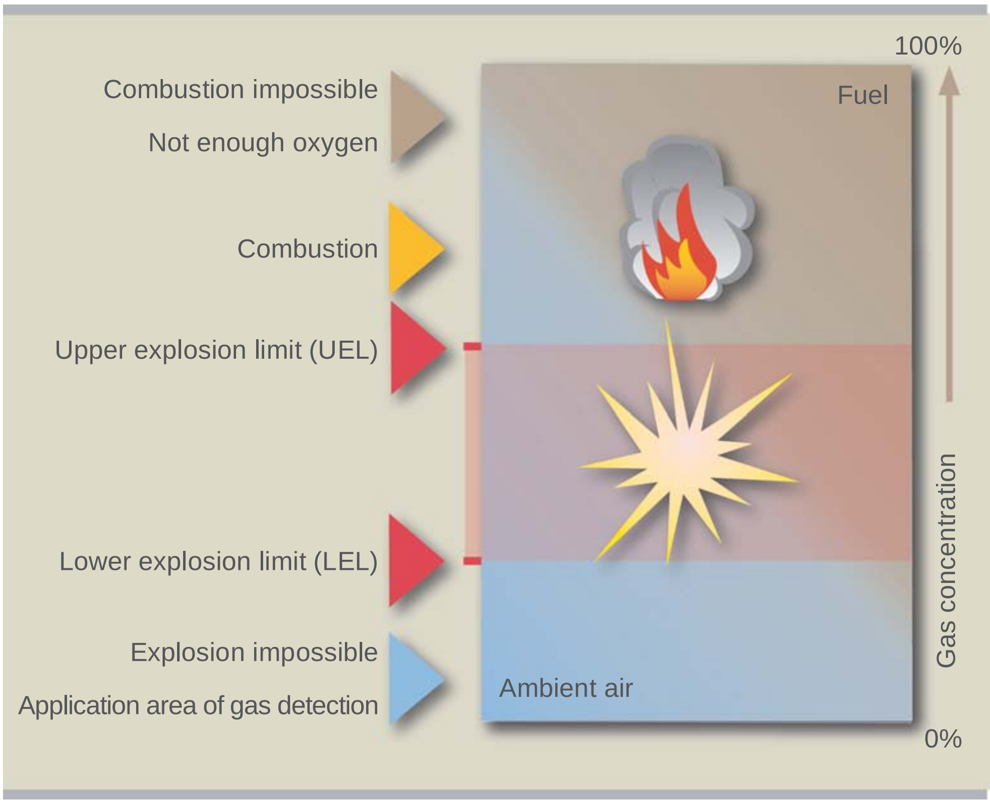


Figure 3.3: Explosion limits

An important factor in evaluating the explosion risk of combustible liquids is the flash point. This is the temperature at which the vapor pressure of a liquid is so high that the gas concentration exceeds the lower explosion limit (LEL). Substances whose flash point is approximately 20°C above the highest ambient temperature to be expected do not form explosive mixtures and thus need not be detected for reasons of explosion protection (e.g. toluol). However, with sensitive sensors, leakage monitoring in accordingly clean environments is possible (fire protection!).

An explosive fuel-air mixture requires only a source of ignition (e.g. a spark from a light switch or a hot object) to cause an explosion. The ignition energy needed is very low [minimal at 0.009mWs for carbon disulphide (CS_2) and, for example, 0.2mWs for hydrocarbons]. Thus, for CS_2, the energy is approximately one tenth of a thousandth of the energy emitted every second by a mobile phone, for instance! For this reason, the development of explosive gas mixtures must be prevented whatever happens!

The ignition temperature of a gas corresponds to the lowest temperature at which the most highly inflammable gas mixture can be caused to explode by a heated metal plate. On this basis, gases are classified in the temperature classes T1 to T6 (see section “Temperature Classes” in the appendix, page 318).

Devices to be used in explosion-hazard areas can be enclosed in sealed, sufficiently strong housings (flame-proof enclosure) or may be set up in a way that they are intrinsically safe, i.e. they must be set up in such a way that no sparks may occur. Apart from this, there are several other, less frequent designs (see table in the appendix “Ignition protection classes” on page 317).

The explosion group defines the application area for which a device is intended:
– group I: electric appliances for mining
– group II: electric appliances for areas with potentially explosive mixtures

Group II is subdivided into the sub-groups IIA, IIB and IIC, with IIC being the strictest, required for gases such as carbon disulphide (CS_2), hydrogen (H_2) or acetylene (C_2H_2) (see section “Explosion Groups” on page 318). In selecting the gas detection system, make sure that its specifications are sufficient for the gases to be detected. With a gas like ethylene, for instance, the system must be specified at least according to sub-group IIB. With hydrogen, acetylene or carbon disulphide, the system must meet the requirements of sub-group IIC.

3.3 Using Gas Detection Technology

Gas detection technology should be used wherever hazardous gas concentrations may develop unnoticed. In case of temporary threats, portable gas warning systems may help to ensure safety. However, in case of a permanent risk, fixed installations are economically favorable.

Dangerous concentrations can occur when, in case of leakage, the content of a gas cylinder is sufficient to reach the lower explosion limit in the room. With even lower concentrations, the gas remains combustible and may burn off and consequently produce a conflagration. The “Fire Protection Concept” (see page 28) should, at any rate, take such risks into account, considering the entire danger scenario.

In case permanent supply of fresh air is ensured even in case of danger (e.g. redundant ventilation) the tolerable gas volume may increase.

Areas in which combustible gases and vapors can occur are frequently assigned to so-called ex-zones (explosion protection zones). The type of ex-zone determines the nature of the risk. Please also refer to “Zone Division of Explosion Areas” on page 316.

3.4 Measuring Principles

In the course of the last decades, gas warning technology has constantly been improved and perfected. Thanks to this effort, today proven detection technologies are available that are very reliable if their application limits are respected.

Only few areas know such different measuring principles as gas detection. For this reason, we will restrict our explanations to the most important principles in safety engineering, which fully automatically detect combustible gases or vapors.

3.4.1 Semiconductor Sensor

Semiconductor sensors consist of ceramic bodies of approx. 5mm length, for example, coated with zinc oxide. The electrical resistance of the coating changes under the influence of the gas to be detected. To make this effect possible, the ceramic body must be heated by means of a built-in heating coil, resulting in surface temperatures of 300 to 400°C.

For ex-applications, the surface temperature of the semiconductor body requires a flame barrier, usually in the form of a sintered metal disc.

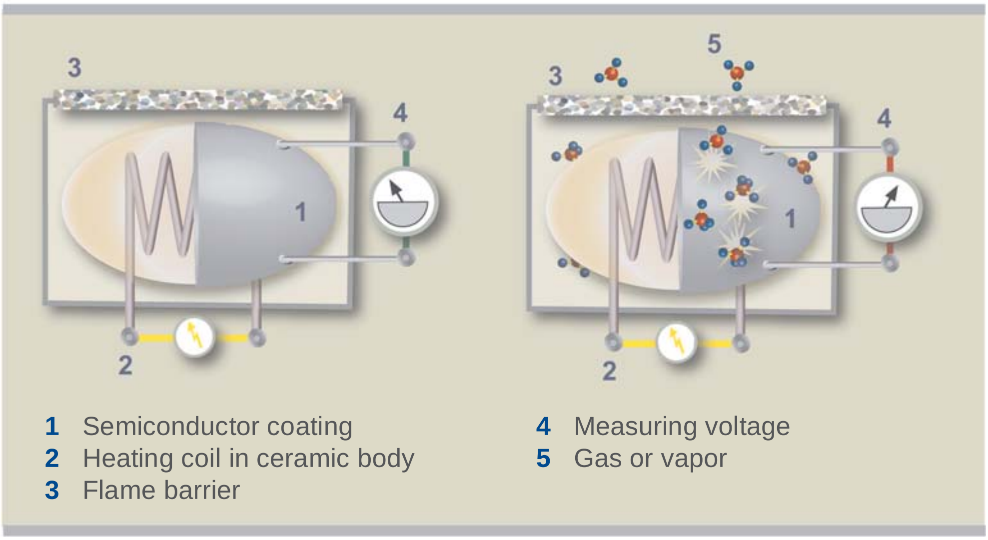


Figure 3.4: Operating principle of a semiconductor sensor

This principle reacts on a whole range of gases, with the composition of the surface coating having an influence on the detectable gases and determining the cross sensitivity. The semiconductor sensor also responds to air humidity and temperature fluctuations. The measuring signal changes more or less logarithmically to the gas concentration.

The application area of the semiconductor sensor is limited, based on these properties. In most cases, the gas concentration cannot be determined sufficiently accurate, and false alarms cannot be ruled out completely due to the cross sensitivity to other gases.

3.4.2 Reaction Heat Sensor (Pellistor)

The pellistor consists of a ceramic pellet (a pearl-shaped ceramic body), approx. 2mm in size, which is coated with a catalyst, usually platinum. When the surface temperature is increased to 500 to 600°C by means of the heating coil embedded in the pellet, combustible gases begin to oxidize on the surface of the pellistor already significantly below their lower explosion limit. This oxidation increases the surface temperature of the pellet due to the reaction heat, and thus also the heating coil temperature.

As the temperature of the heating coil of the catalyst body increases, its electric resistance increases as well. This change can be measured by means of an uncoated reference pellet – which is neutral as regards combustible gases – in a second ceramic body, which otherwise is identical in construction and heated as well. In most cases, a simple electric circuit (Wheatstone bridge) is used for this measurement.

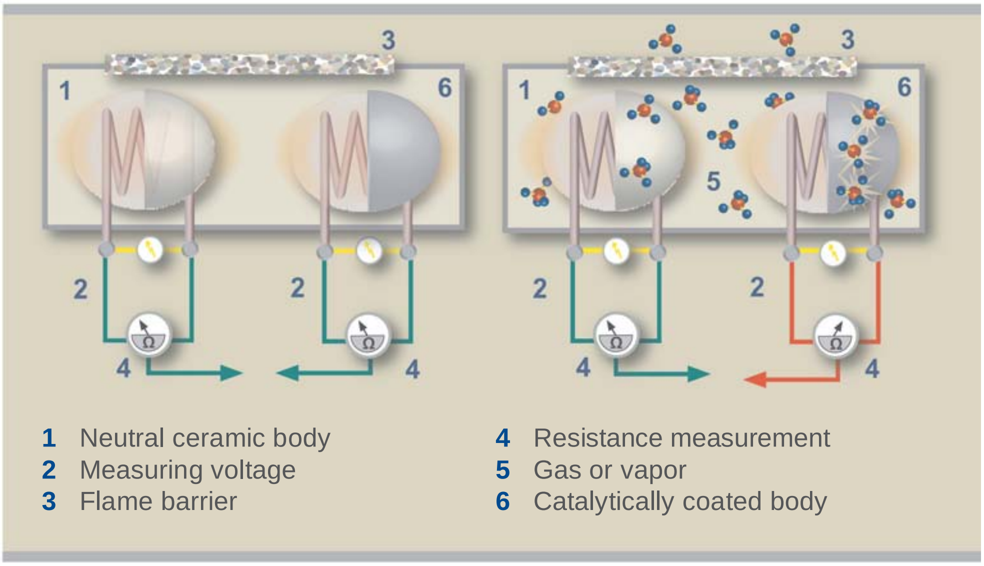


Figure 3.5: Operating principle of the pellistor

The pellistor's advantage, namely its high measuring accuracy and the possibility to exactly determine the gas concentration, is counteracted by the disadvantage of catalyst poisoning and inhibition (temporary signal disturbance), caused by catalyst poisons such as silicon and inhibitors such as chloric gas.

In an explosive environment, a flame barrier (sintered disc, grid, etc.) is required.

3.4.3 Electrochemical Cell

The electrochemical cell can simply be described as an incomplete battery, whose electrolyte is completed by the gas entering through a semi-permeable membrane. Electric current can only flow in the electrolyte between the two electrodes if a gas is present. The flow of current is proportional to the gas concentration.

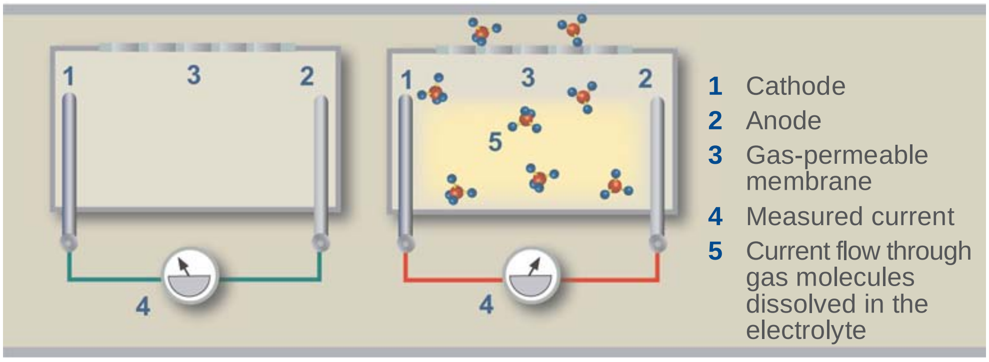


Figure 3.6: Operating principle of an electrochemical cell

The electrochemical cell is very sensitive. This, however, may have a negative effect if the cell is too frequently exposed to high gas concentrations, possibly even reducing the cell's service life.

The service life of the sensor is basically determined by its ambient temperature and humidity. The expenditures for new sensors and their replacement have a significant impact on maintenance costs.

3.4.4 Opto-Acoustic Sensor

The opto-acoustic sensor makes use of the gas molecules' characteristic to oscillate at a specific frequency. When a gas is illuminated with pulsed light of a specific wavelength, a pressure fluctuation occurs in the closed chamber which is synchronous to the light pulses. This is easily detected as sound by means of a microphone.

The signal generated by the sensor can be linearized, i.e. gas concentrations can be accurately determined.

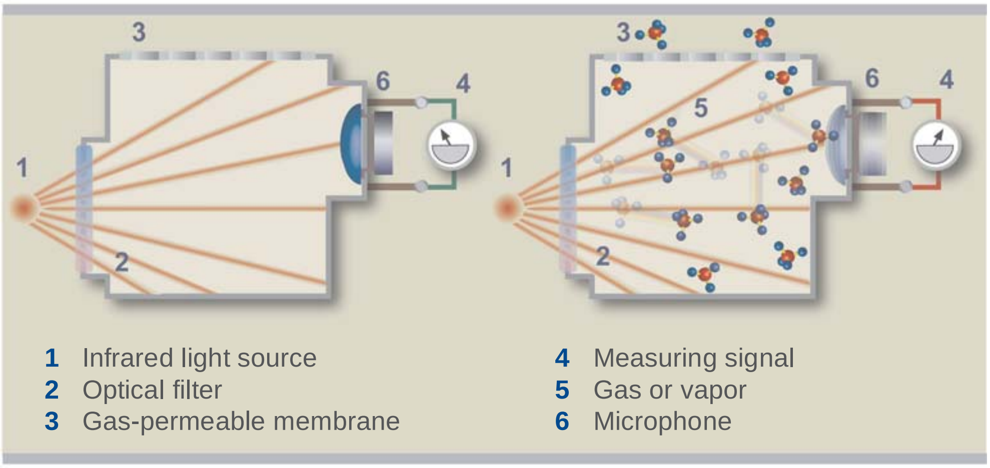


Figure 3.7: Operating principle of an opto-acoustic sensor

The microphone and also the other components are simple, stable devices which rarely fail. Therefore, this sensor has a significantly long service life.

3.4.5 Infrared Absorption Sensor

Light with the same natural oscillation frequency as that of the gas to be detected is absorbed by the gas. This means that, in the presence of the gas, the photosensor no longer detects the light in the same intensity. This signal attenuation allows exact measuring of the gas concentration.

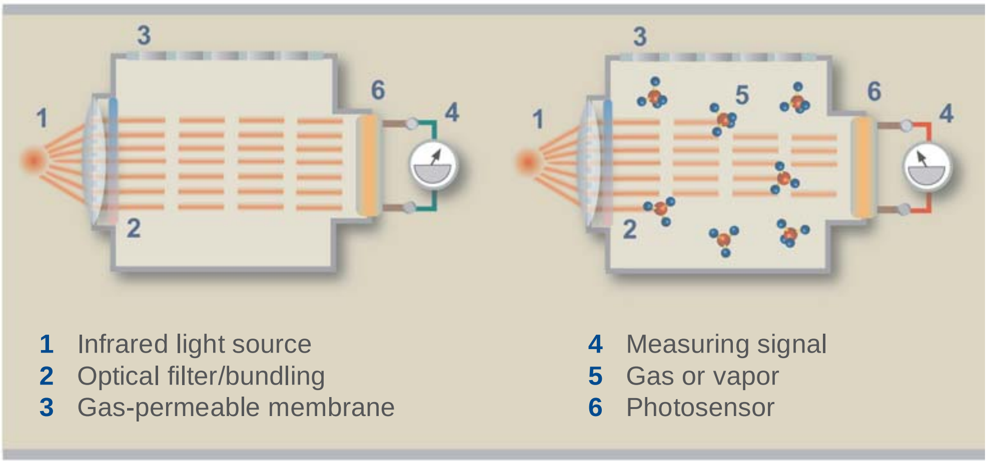


Figure 3.8: Operating principle of the infrared absorption sensor

The absorption sensor does not directly measure a signal proportional to the gas concentration but the decrease of the primary signal. As this method measures a very small decrease of a relatively large signal, it is principally more susceptible to long-term drift effects.

3.4.6 Comparison of the Detection Methods

The different detection methods are compared in the following table.

	Property / Sensor type	Semi-conductor	Pellistor	Electro-chemical cell	Opto-acoustic sensor	Infrared absorption sensor
Quality criteria	Detection range	ppm - %LEL	%LEL	ppm	%LEL	%LEL
	Selectivity / cross sensitivity	- -	++	+	++	++
	Stability (drift)	+	-	+	++	++
	Background noise (lower measuring threshold)	1% mr	1% mr	5% mr	1% mr	1% mr
	Measuring accuracy	- -	+	++	++	++
	Response time t_{90} [sec.]	10	15 - 30	10 - 60	<30	<10
	Temperature dependence	- -	+	- -	++	++
	Humidity impact	- -	+	+	+	+
	Characteristics	Logarithmic	Linear	Linear	Linearized	Linearized
	Sensor poisoning	+	- -	-	++	++
	Sensor inhibitors	-	- -	-	++	++
	Sensor service life [years]	1 - 5	1 - 3	<1 - 3	5 - 10	5 - 10
Costs						
	Cost price	++	+	-	-	-
	Maintenance costs	+	-	- -	++	++

mr : Measuring range
t_{90} : Time until the detector measures 90% of the actual gas concentration
++ : Very good
+ : Good
- : Poor
- - : Very poor

Table 3.1: Comparison of the gas sensor principles

Summarizing this table, one may state that semiconductor sensors can only be used when the ambient atmosphere is constant and when no concentration details are required. False alarms cannot be completely ruled out.

The pellistor as the classic detector of combustible gases is endangered by sensor poisoning and sensor inhibitors. If these substances can be excluded, there is no other obstacle to using a pellistor.

The electrochemical cell is rather expensive, especially regarding maintenance. However, it is the first choice due to its selectivity when a particular gas must be detected in very small concentrations. Due to its working principle, using the opto-acoustic sensor is more elegant than the infrared absorption sensor. Both methods are extremely well-suited to detect combustible gases and vapors and have the best properties of all the options considered.

However, it must be stated that conventional gas sensors of these types only respond to the hydrocarbon part of the gas, meaning that pure hydrogen, for example, is not detected. The still quite expensive purchase price of these sensors is balanced by the longer service life and the lower maintenance costs.

When catalyst poisons or inhibitors cannot be completely ruled out, the opto-acoustic or infrared absorption principle must be favored. After all, not working detectors are worse than none at all!

3.5 Control Unit and Systems Engineering

Gas warning systems are basically made up of the control unit, the detectors and the communication links between detectors and control unit. With most systems, different gas detector types can be mixed on one line.

3.5.1 Topology of Monotype Systems

The classic cabling topology for gas warning systems is a star-shaped cabling topology. This type is perfectly suited for compact systems. When the system expands, cabling costs will increase disproportionately.

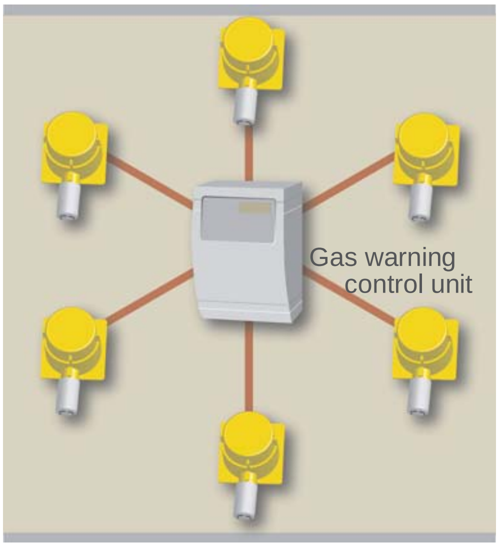


Figure 3.9: Gas warning control unit with star-shaped cabling

Cabling costs decrease significantly when detectors can be wired in series (e.g. bus wired). This may theoretically be effected without addressing, but this would unnecessarily complicate the localization of the usually invisible gas. For this reason, only addressable systems shall be used in gas detection.

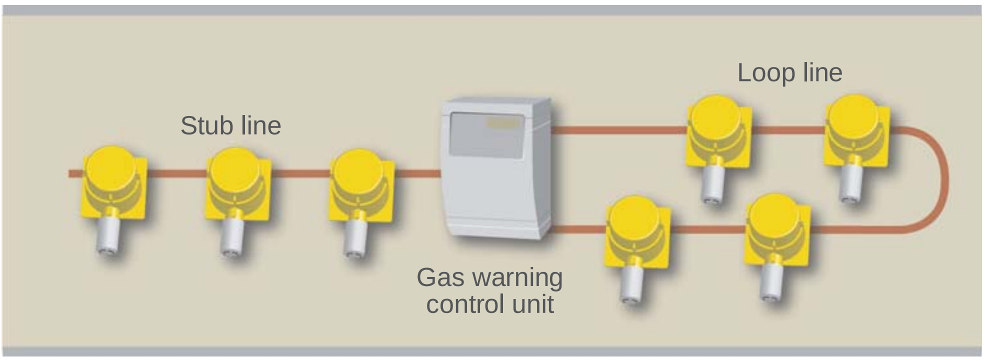


Figure 3.10: Gas warning control unit with detector bus

The highest degree of fail-safe operation at the periphery is achieved by loop line systems. Detectors remain fully functional even in case of an open line, as the control unit addresses the detectors from both ends of the loop. When the detectors are provided with a separator function, they are able to uncouple from a possibly short-circuited line segment, thus remaining completely functional. Such systems are significantly safer than stub line systems.

3.5.2 Topology of Hybrid Systems

As gas warning in general requires a significantly less dense arrangement of the gas detectors than other safety-related building automation disciplines (e.g. fire detection), gas detectors should for cost reasons be switched on to the networks of such systems. This is a very interesting network variant which, however, entails some problems that can only be eliminated when the gas detectors and fire detection engineering are harmonized. The gas detectors can be switched on to the fire detector bus with or without electronic modules, depending on the technical feasibility.

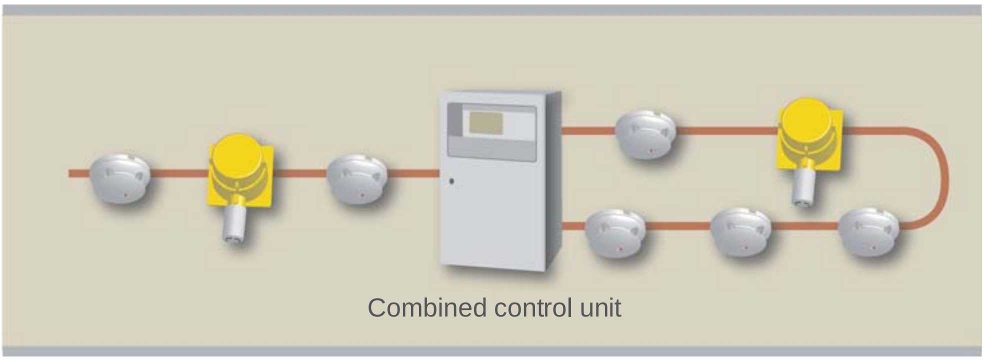


Figure 3.11: Connecting gas detectors to a combined control unit

Caution: Local regulations may prohibit the connection of gas detectors to a fire detection system! As both system types are classified as safety engineering systems, such restrictions are usually merely historic or regulative.

3.5.3 Comparison of System Technologies

In the following table, some selected properties of the various network types are compared.

Properties	Star-shaped cabling	Bus cabling	Hybrid cabling
Complexity of cabling	- -	0	++
System costs	++	+	-
Maintenance costs	0	0	+
Typical systems	Up to 10 detectors	Starting from 10 detectors	1 to many
Most important benefits	Simple	Relatively low cabling costs	Easier organization
Typical protocols	4 - 20mA	Proprietary, gas detection	Proprietary, fire detection
Safety: Line monitoring	Unclear / product depending	With loop, yes	Analogous to fire detection

++ : Very good
+ : Good
0 : Mediocre
- : Poor
- - : Very poor

Table 3.2: Comparison of cabling topologies

A generally valid comparison of the various cabling types is difficult since also the 4-20mA protocol is not a standard. Important characteristics of its data transmission are not standardized und were amended in the course of the last decades with individual supplementations. For this reason, all protocols are virtually proprietary.

3.5.4 Positioning the Control Units

The control unit, or the control and indicator panels respectively, should be positioned in such a way that they meet the following requirements:

- easy and quick access
- outside the explosion zone
- normal ambient conditions regarding
  - lighting
  - temperature
  - humidity
  - dust
  - vibrations and mechanical load

With hybrid systems, the location is always determined by the fire detection system. State-of-the-art fire detection systems also facilitate satellite, i.e. decentralized control and indicator panels. In this case, the ideal position is determined by the responsibility and organization of the staff.

3.5.5 Integration in the Building Infrastructure

Unfortunately, many gas warning control units are still implemented as standalone devices. The relatively small savings are contrasted by an inadequate overview of the hazard situation in case of emergency and the extra effort required for the staff organization.

Integrated systems facilitate easier handling and system interventions become safer, as the actions performed are also indicated elsewhere in the system, for example by the danger management system. Although this aspect is rather universal, it is of particular significance in gas warning, as many suppliers of gas detection systems have their roots in gas measuring technology and thus consider the integration of gas warning systems into the building infrastructure as relatively unimportant.

Cost-optimized organization thanks to good system integration

When the system integration into the building infrastructure is taken into account as early as possible, ideally already during the system evaluation phase, this will result in an essentially optimized organization.

3.6 Planning

To plan a gas warning system, it is essential to know the ambient conditions. The status of the environment must be recorded in a checklist. This includes:

- substances to be detected
- prevailing / associated substances
- handling of these substances
  - wherefrom stem which substances?
  - how are they transported, stored and processed?
- temperatures
- humidity situation
- wind conditions / ventilation
- cleanliness of the atmosphere (sensor poisons and inhibitors!)

Based on this information, the type, number, and position of the detectors can be determined.

The question whether gas detectors are to be placed above the floor or below the ceiling is discussed in section 3.6.1. In doing so, the following aspects must be taken into account:

- Gases and vapors are transported significantly faster by air currents than by diffusion.
- Room geometry, room equipment, machine temperature conditions, ventilation, etc. ultimately determine the spreading of gases and vapors in case of leakage.

Assessing the room geometry and ambient conditions is thus often more important for the detector arrangement than simple deliberations based on gas density.

3.6.1 Vertical Detector Positioning

Most gases and vapors are heavier than air, which is why they mostly concentrate at the floor level and propagate the room in the form of plumes.

Only very few gases, such as hydrogen (H_2), methane (CH_4), ammonia (NH_3) and acetylene (C_2H_2) are lighter than air. Air has a relative molecular weight of 28 to 29 g/mole (depending on the composition). The molecular weight of a gas is easy to calculate by multiplying the molecular weight of the atoms and by adding them according to the molecular formula. Example: The molecular formula of acetylene (welding gas) is C_2H_2. This means that the molecule consists of 2 carbon atoms (C) and 2 hydrogen atoms (H).

According to the table below, the relative molecular weight is 2x12 (for 2 carbon atoms) + 2x1 (for 2 hydrogen atoms) = 26g/mole. This means that acetylene is only insignificantly lighter than air. When there is no index in a substance's molecular formula (e.g. in CH_4), there is only one atom of the substance (in this case carbon) in the molecule.

Substance / element	Relative atomic weight [g/mole]
Hydrogen (H)	1
Carbon (C)	12
Nitrogen (N)	14
Oxygen (O)	16

Table 3.3: Relative atomic weight of some important substances

The diameter of gas molecules is at least 10 times smaller than that of the smallest fire aerosols. This means that gases principally spread faster than smoke. Combustible gases are often under pressure which is why, in case of leakage, the gas may be significantly colder than its environment due to the decompression (adiabatic expansion). With acetylene, for instance, this results in initially higher concentrations on the floor level.

3.6.1.1 Gases Lighter than Air

The detectors must be installed on the ceiling, analogous to fire detectors. The heat cushions, as they are known from fire detection, are no barrier for gases. The detector should thus be effectively placed at the highest point.

False ceilings are extremely endangered, as gas may conglomerate unnoticed, especially in case of smaller leakages. In contrast to smoke, small chinks already enable the gas to penetrate the false ceiling.

3.6.1.2 Gases Heavier than Air

The detectors must be installed above the floor. The following factors must be taken into account:

- The detector must not be placed below a level of approx. 30cm above the floor when the floor is sprayed with water (moisture and soiling of the flame barrier).
- Make sure that the detector is accessible for tools.
- In contrast to fire detection, false floors must always be monitored, even if they do not constitute or contain combustible loads. Gas principally flows to the lowest point, i.e. into the false floor.

3.6.2 Monitoring Areas

With light gases, the area to be monitored per detector can be up to $60m^2$ – analogous to fire detection – or, at room heights over 3m, up to $80m^2$.

With gases heavier than air, the maximum monitoring area is $40m^2$ per detector.

3.6.3 Extent of Monitoring

Hazards need to be controlled. Also simple battery-charging stations did trigger explosions and need consequently to be monitored. Since it is often difficult to predict where a gas escape will exactly take place in endangered rooms, detectors should be spread evenly over the room surface.

In case the risk in a larger room is locally restricted, object surveillance can be used instead of room surveillance. However, it must be ensured that in case of a modification to the system, the gas warning system is adapted accordingly.

Object surveillance is often implemented in such a way that the detectors are installed directly above the equipment and not on the high ceiling. This prevents time delay and gas attenuation. To make sure that the gas reaches the detector, gas collectors are installed directly above the gas pipe or the machine.

Rooms with unsealed connections to channels through which combustible gases or liquids are guided must also be monitored.

When a high-sensitivity gas detection system is used, the possible leakage of combustible liquids can be monitored via the vapor phase. This facilitates fire protection of liquids which, under normal ambient conditions, do not form an explosive vapor-air mixture (high flash point).

Regarding the detector arrangement, it can be summarized that laypersons may quickly be swamped with this task, as different factors are intertwined. Competent, expert consulting is thus of utmost importance.

Reliable gas warning thanks to correct planning

3.7 Installation, Commissioning and Acceptance

Today, detector calibration can be omitted in most cases, as the detectors are already calibrated in the factory prior to delivery. When periodic maintenance necessitates recalibration, this is essentially done with modern system support. Gas detection systems with the outdated two-men calibration cause additional maintenance costs in the long run.

As there are many kinds of combustible gases and vapors, a calibration with the specific gas to be detected would be too complex and labor-intensive. For this reason, only few gases are still used for calibration purposes. These gases simulate those to be detected, based on detector-specific conversion tables.

After a gas escape has taken place, pellistor sensors always need to be checked. Besides the risk of accompanying catalyst poisons, there is the risk of sensor overload. This check is not required for opto-acoustic detectors, for example, which increases safety and lowers maintenance costs.

Only perfect operation is sufficient. This is also valid in gas detection. Correspondingly important are the selection of the suppliers and the quality of services delivered. Starting from planning the installation to maintenance, gas warning is a matter of confidence.

3.8 Profitability and System Evaluation

At the beginning of every planning, a careful situation and requirements analysis is a must. This defines largely which sensor technology is to be applied. Only with this technology a gas warning system will work properly and show reasonable maintenance costs. Quotations with other technologies may only be considered if they demonstrate clearly that they are able to operate even better with a still reasonable maintenance cost level.

Cross sensitivities are sometimes welcome, but in most cases they represent a big nuisance in gas detection. Therefore, it is paying out to take the edge off the cross-sensitivity problem by taking architectural measures, for example with a partition wall.

Among other things, system evaluation should also cover the following aspects:

- The right networking is decisive for the installation costs as well as for further expansion steps. Many manufacturers have their roots in the (in earlier times difficult) gas detection and therefore neglect the networkability of their products.
- Flexible system technology is paying off many times during the system's life, because additional detectors may easily be added or detector locations may be changed without problems if the system is easily adaptable.
- Maintenance, testing, regular calibration and replacement of the sensors are important issues of gas detection. The supplier must be in a position to carry out this work efficiently. It is especially important that the replacement of the sensors is included in the maintenance contract. If the supplier is not in position to estimate the sensors' life expectancy in the specific environment, he should at least provide a from-to indication of the costs including material, services and expenses for the sensor replacement.
- As soon as the word ”gas” is mentioned, some customer employees do not think they can cope with it. Hence, the supplier should be in a position to take care of the system short-term (e.g. acting as a deputy of the individual responsible for gas).

4 Fire Detection

4.1 Summary

The task of an automatic fire detection system is to detect fire as early as possible, to alarm and activate the preprogrammed control functions. State-of-the-art fire detection systems are capable of detecting fire extremely early and thus of minimizing the damage that may be caused by fire. By an optimal product selection and appropriate knowledge it is possible to set up systems that virtually rule out false alarms.

A fire detection system consists of the control unit, the peripherals such as fire detectors and contacts, as well as alarm and control devices activated by the control unit.

In selecting, setting and positioning fire detectors, it is crucial to consider – in addition to the actual prevailing risk – the type of fire to be expected, the room height, ambient conditions such as air changes and possible deceptive phenomena. In high-risk areas, multisensor fire detectors with state-of-the-art signal processing are used more and more frequently. For medium and lower risks, usually optical smoke detectors with conventional signal processing (algorithm technology) are applied.

State-of-the-art fire detectors allow an exact configuration of the detector behavior, which meets the environmental conditions and the prevailing deceptive phenomena. A fire detector in a hospital room must respond in a completely different way than a fire detector in a foundry.

When arranging the fire detectors, one must be sure that the fire phenomena (smoke, heat, radiation, gas) reach the fire detectors, giving special consideration to the ceiling's construction (e.g. the ceiling joists, special roof or ceiling shapes), and a possible room division by alcoves, furniture or fixtures and fittings.

In rooms where strong deceptive phenomena occur, the ideal arrangement of the fire detectors is of central significance. Even small changes of the detector position bring about massive improvements of the immunity to deception, without reducing the detection reliability.

In selecting the fire detection control unit, user-friendliness, a high degree of flexibility and a very high degree of fail-safe operation must be taken into consideration. The control unit is the point of interaction between people and the system and must thus make easy and intuitive alarm and fault processing possible.

High flexibility in networking and parameter setting facilitate extensions and the adaptation of the system behavior to a change of customer requirements.

The availability of a fire detection system is crucial, which is why emergency power supply and an integrated emergency operating function are mandatory, making fire alarms possible in spite of a failure to a module or a power failure.

For economic reasons, a fire detection system's technology is chosen according to the requirements and the specific risk situation. For an office building, a fire detection system with manual call points and optical smoke detectors with normal signal processing is usually sufficient, but if production facilities in the chemical industry shall be protected, for example, the use of advanced technology is a must.

A comprehensive product portfolio, highly reliable fire detectors with multisensor technology and the use of an exceptional logic, high flexibility of the fire detection control unit and its connection to the danger management system are topics to be considered in setting up a fire detection system.

Minimize damage through reliable and early detection

4.2 Basics

The knowledge of the outbreak of a fire and its development is decisive for fire prevention and fire fighting. To ensure reliable, early detection in the case of fire, it is equally important to be familiar with the different fire phenomena and the possible types of fire. The following four topics will be handled in detail hereinafter:
– outbreak of a fire
– development of a fire
– fire phenomena
– types of fire

Section 4.2.5 shows the setup of a fire detection system and the aspects to be considered in its planning and implementation.

4.2.1 Outbreak of a Fire

For a fire to break out, combustible material (fuel) and an oxidation agent (usually oxygen) must be available. Our environment is to a large extent made up of combustible materials – and oxygen is virtually always sufficiently available. But another condition must be fulfilled for a fire to break out: The ignition energy must be the driving force to initiate oxidation. Ignition energy sources are manifold: Electrical discharge (e.g. lightning), short-circuits, flying sparks, hot surfaces (light bulbs, heating equipment, etc.), direct exposure to flames or bundled light, to name only the most important ones. If a fire occurs, it provides the necessary energy to maintain the combustion process.

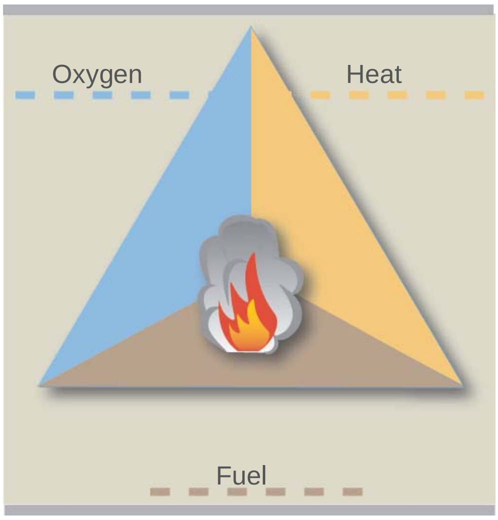


Figure 4.1: The fire triangle

Fire thus occurs by the interaction of fuel, oxygen and heat (energy).

4.2.2 Development of a Fire

Apart from explosion-type processes, a fire normally develops more or less quickly, depending on the combustible material. As fuel and oxygen are sufficiently available at the beginning of the fire development, it is to a large extent determined by the available energy. Especially a flaming fire releases a lot of energy resulting in exponential fire growth at this stage.

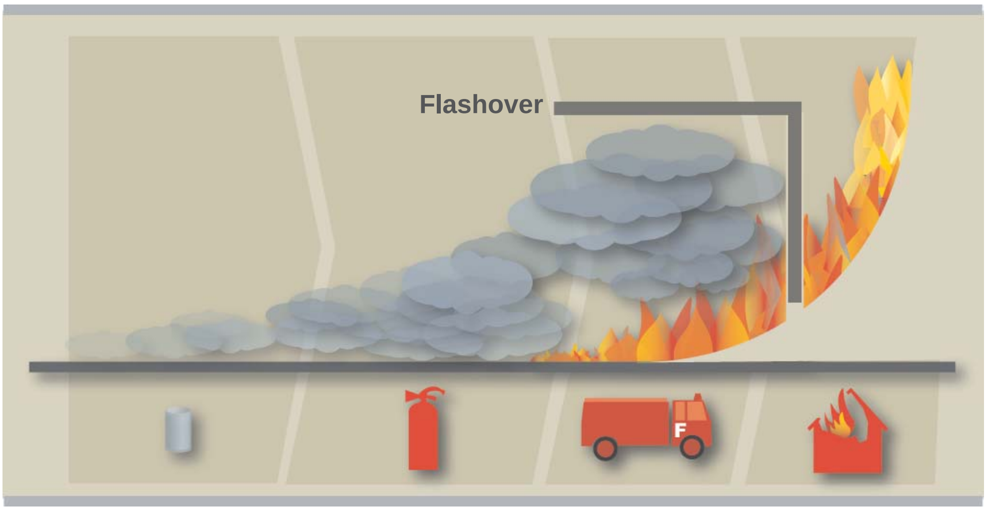


Figure 4.2: Typical fire development

As shown in Figure 4.2, most fires pass through the following phases and events:

- **Early stage:** The incipient fire can be extinguished with a few deciliters of water; little visible smoke occurs, but especially invisible aerosols are generated.
- **Smoldering phase:** In this phase, the fire can be extinguished by means of a fire extinguisher or a similar extinguishing agent. Visible, partly dense smoke occurs. Usually, combustion is incomplete, which is why rather a lot of (toxic) CO is produced in this phase.
- **Flaming phase:** We are faced with an open fire to be fought by the fire brigade. As enough energy is available, the combustion process is rather complete, resulting in a high production of CO_2.
- **Flashover:** The transition between an open, flaming fire and a total fire is called flashover. This is the explosive fire spread, taking place exactly at the point when the gases and aerosols produced during the previous phases ignite and carry the fire into all rooms already penetrated by the smoke gases.
- **Total fire:** In this phase, the fire has reached larger building parts. In most cases, the building or fire sector can no longer be saved and the fire brigades concentrate their efforts on the protection of neighboring buildings and fire sectors.

Fire detection must occur as early as possible, so that intervention can start before the flashover. Incipient fires should thus be detected in the early stage or in the smoldering phase at the latest, so that there is enough intervention time left. The problem is that the early stage and the smoldering phase can be of completely different intensity and duration. Some smoldering fires may continue to smolder for hours or even days before an open fire occurs.

With liquid fires, there is no smoldering phase at all; they directly develop flames. With such fires, the intervention time is extremely short. Usually, damage can only be limited by an automatic extinguishing system. Of course, there are other possibilities, such as constructive measures, to slow down fire spread, thus prolonging the intervention time – but this is usually very expensive.

Conclusion: The earlier a fire is detected, the more time there is for fire fighting, and the less damage occurs. Earliest possible detection is thus the key to minimizing damage and winning precious intervention time.

4.2.3 Fire Phenomena

Fire phenomena are physical values that are subject to measurable change in the development of a fire (e.g. temperature increase, light obscuration or flames).

The processes in material combustion can be principally viewed from the perspective of a conversion of energy and substances. The energetic conversion releases energy into the environment. The substantial conversion produces – depending on the substances present at the seat of fire – products in any physical state, ranging from non-toxic to highly toxic.

The figure below indicates the concomitant phenomena of a fire with the associated fire phenomena (in parentheses).

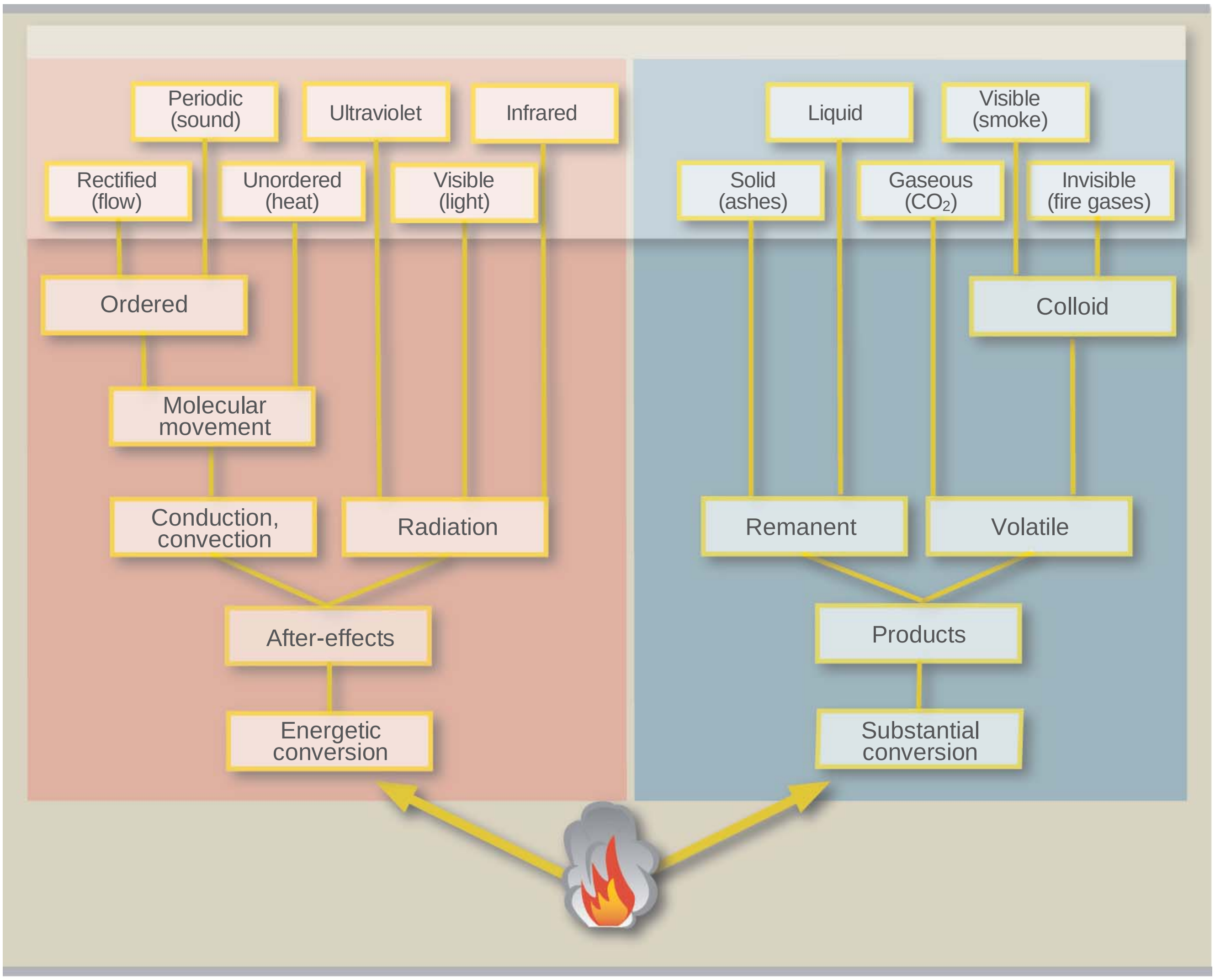


Figure 4.3: Schematic representation of fire phenomena

The energetic conversion releases energy by radiation and convection. The range of radiation released during a fire can be divided, by wavelength, into ultraviolet (UV), visible light and infrared (IR). Energy release by convection essentially takes place through the ambient air. First, the kinetic energy of the air molecules is increased, resulting in a temperature increase. The associated expansion leads to an upward air flow. Due to this flow, cooler air and thus oxygen is guided to the fire seat. These processes can also lead to periodic pressure fluctuations that are perceived as sound in certain frequency ranges (e.g. the typical crackling of a fire).

The conversion of substances taking place in a fire is characterized by the various chemical reactions that can occur at the seat of fire, depending on the substances present.

The substantial conversion of a fire is determined by the different chemical reactions that may go on at the seat of fire. The solid or liquid conversion products either remain at the fire seat (e.g. ashes) or are distributed into the direct environment of the fire. In the latter case, they form a so-called aerosol, as finely distributed solid or liquid suspended matters mixing with the ambient air. Gaseous conversion products always spread through the air.

4.2.4 Types of Fire

The fire phenomena occurring with a smoldering or open fire differ in terms of type and intensity.

Type of fire / Properties and fire phenomena	Smoldering fires (non-flaming fires)		Open fires (flaming fires)		
	Pyrolytic decomposition (carbonization process)	Glowing fires	Solid matters (mostly ember-forming fire)	Liquid matters (flame combustion)	Gaseous matters (flame combustion)
Combustion process	Not independent, requires continuous energy supply	Independent after ignition	Independent after ignition	Independent after ignition	Independent after ignition
Type of smoke (aerosol)	Very light smoke	Light smoke	Dark smoke	Very dark smoke	Depending on the carbon share of the gas, its chemical properties and mixing with oxygen
Optical properties of smoke	Quickly spreading	Quickly spreading	Strongly absorbing, spreading little	Strongly absorbing, spreading little	
Aerosol volume	High	High	High	High (except pure alcohol: none)	
UV / IR radiation	Low	Low to medium	High	High	Increases with C-share
Heat convection	Low	Low to medium	High	High	High
Combustion gases	Much CO, little CO_2	Much CO, little CO_2	Little to much CO, much CO_2	Little CO, much CO_2	Little CO, much CO_2
Sound	None	None	None to much	None to much	None to much
Pressure increase	None	None	Low to medium, depending on the fuel	Low to high, dep. on fire phenomenon	Low

Table 4.1: Fire types and fire phenomena

The main property of the pyrolysis fire is that it does not go on independently but requires the continuous supply of new energy. The fire can be extinguished by stopping the energy supply. The propagation of that fire type is thus restricted to the size of the heat source, which is why we can also speak of overheating accompanied by chemical decomposition. As soon as the ignition temperature is reached, the fire develops to a glowing or even an open fire.

The glowing fire is an independent process. The glowing temperatures are high and the particles produced are thus relatively small. The visible particles are only a small part of the particle spectrum generated. Typical for a glowing fire are incipient fires in hay or cotton bales.

Characteristic for open fires – with the exception of alcohol fires – is the production of soot, i.e. black smoke. Although here, too, the major part of the particles generated is in the non-visible range. Studies have shown that in almost all cases, including the early stage and smoldering phase, more invisible particles than visible ones are generated.

Summarizing, we can state that large volumes of volatile fire aerosols are produced with almost all hostile fires. Smoke has thus become the most important fire phenomenon for an early detection of fire. Depending on the size and concentration of the fire aerosols, they may be visible or invisible. In general, fire aerosols are 10 to 10'000 times the size of gas molecules.

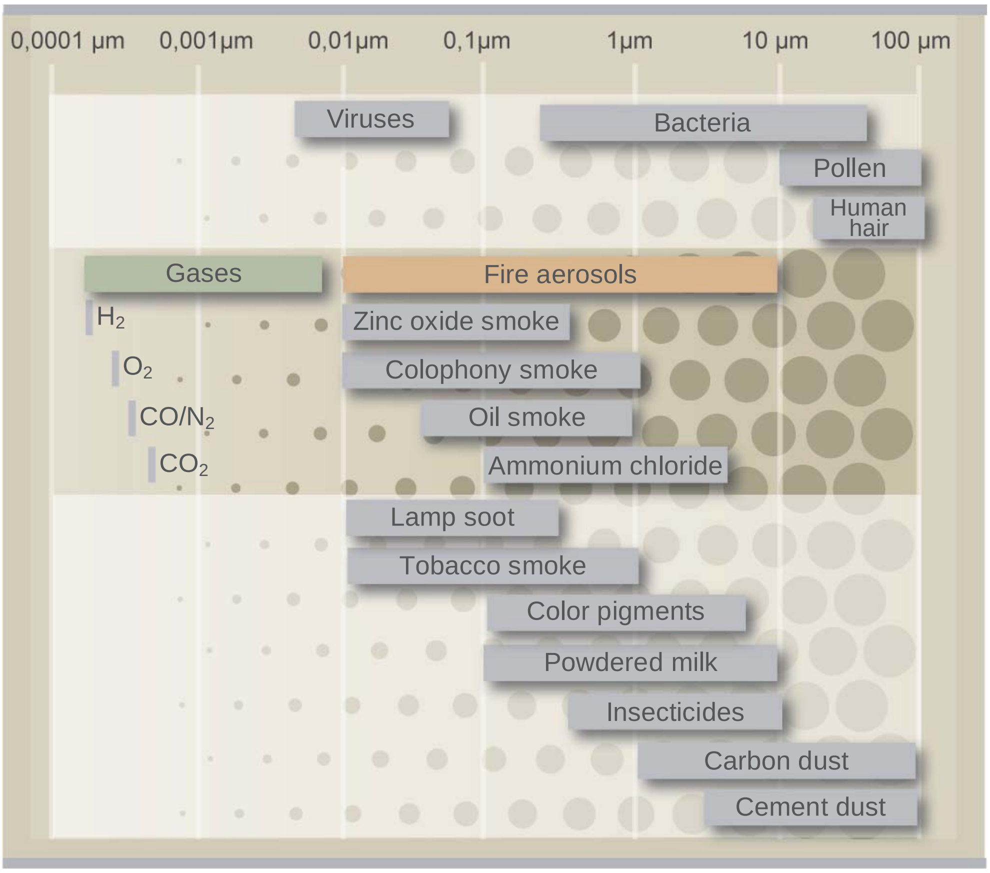


Figure 4.4: Diameter of different molecules and suspended matters

4.2.5 Fire Detection System

The main task of an automatic fire detection system is to reliably identify a fire at the earliest stage possible, to alarm and to activate the preprogrammed control functions.

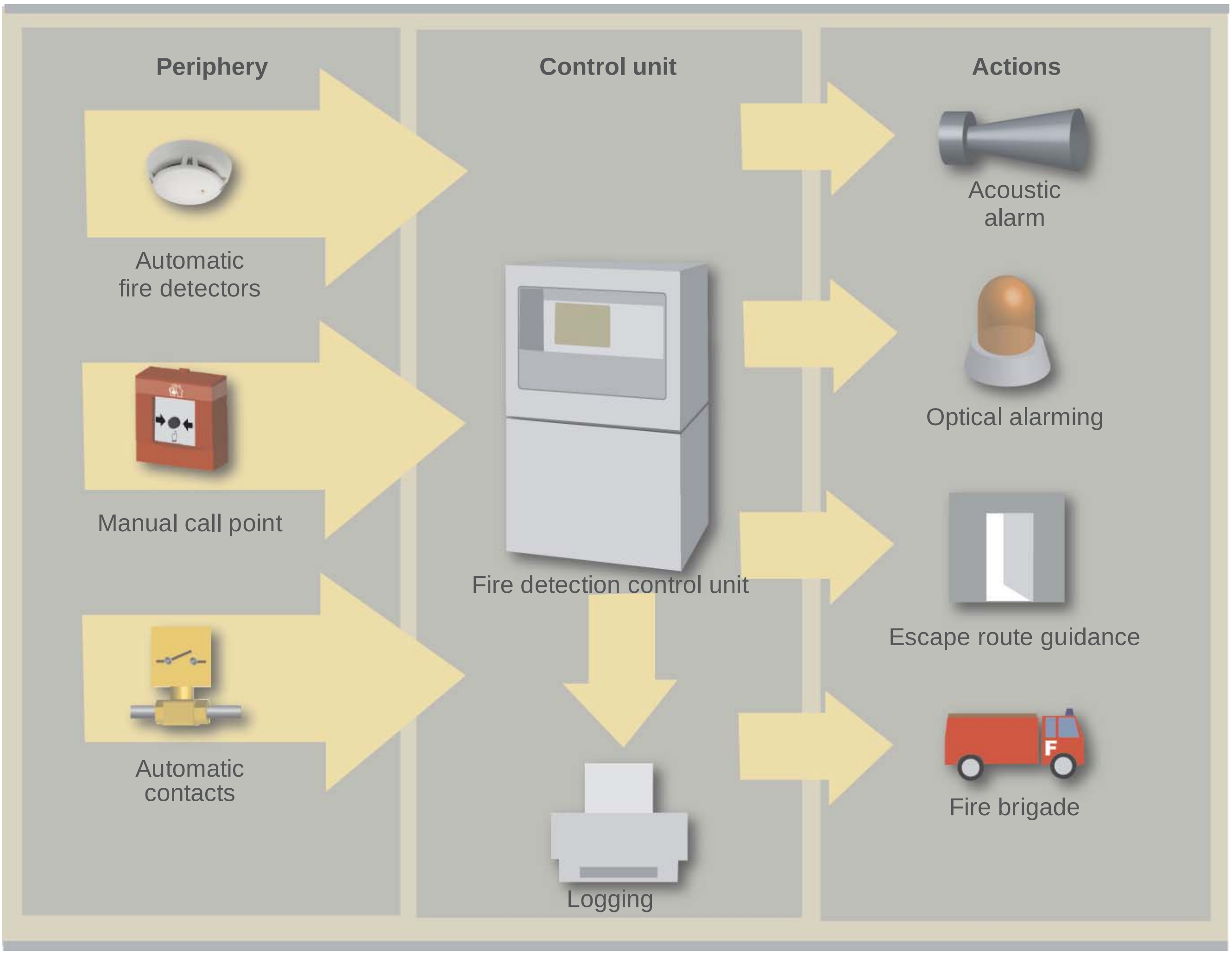


Figure 4.5: Setup and function of a fire detection system

The periphery comprises all field elements acquiring the actual state on site, which is transmitted to the control unit in the form of hazard levels. The intelligent, automatic fire detectors detect and analyze the different fire phenomena on site and automatically report prevailing hazards to the control unit. Manual call points serve for the direct alarm activation by people present in the danger zone. Automatic contacts (e.g. from an activation of a sprinkler extinguishing system) report a fire alarm indirectly.

The fire detection system is monitored, controlled and operated by the control unit, which evaluates the hazard messages from the peripheral devices and activates alarm and fire control installations. Additionally, it serves for operating the fire detection system itself.

The measures initiated by the control unit serve for alarm and intervention. Optical and acoustic alarm devices inform the people in the building and those responsible for the building and call the fire brigade. Controls activate smoke extraction systems and stationary extinguishing systems. Optical escape route guidance and voice alarm safely evacuate people from the building.

4.3 Fire Detectors

The following categories of fire detectors are basically distinguished:

- **Non-automatic fire detectors:** Manual call points are non-automatic fire detectors that have to be activated by a person in the case of fire.
- **Semi-automatic fire detectors:** We speak of semi-automatic fire detectors when a fire detector may recognize a fire but alarm is activated manually. These are usually camera systems equipped with appropriate software, which are capable of detecting changes to the recorded images, for example the generation of smoke or open fires. As the reliability of these systems is presently not sufficient to activate actions such as the direct alarm of the fire brigade or extinguishing activation, these systems are usually semi-automatic. The system alerts people to a possible danger, while the actual alarm must still be verified.
- **Automatic fire detectors:** These most frequently used fire detectors capture fire phenomena such as smoke, heat, flames or gas and activate an alarm via the control unit in the case of fire.
- **Fire detectors for special applications:** For applications with an increased fire risk, where a normal fire detector cannot be used for different reasons, special detectors are required. In mining or heavy industry, very robust systems are required that are capable of reliably detecting fires under extreme environmental conditions. For example, sparks in transport ducts used in the textile industry must be detected and appropriate measures must be initiated immediately, as otherwise devastating consequences can occur. Normal fire detectors react much too slow for such applications – systems reacting within a few milliseconds are required here.

The following chapters exclusively handle detection principles, detection reliability and the available networking technologies of automatic fire detectors.

4.3.1 Detection Principles

A fire detector must be capable of detecting at minimum one fire phenomenon (smoke, heat, radiation, gas) reliably at an early stage. Increasingly, state-of-the-art fire detectors are used that can detect several phenomena at once. These fire detectors generally have a significantly better response behavior and are highly immune to deception.

Of course, a smoke detector’s sensitivity does not only depend on the detection principle but also on the specific detector design, the type of smoke and other environmental factors, such as air humidity, etc. To be able to exactly determine the sensitivity of a detector, a standardized procedure is used (see also section 4.4.1.1).

4.3.1.1 Point-Type Smoke Detectors

Most fires produce smoke, which can be detected by relatively simple detectors. This is also the reason why state-of-the-art fire detection systems consist to more than 80% of smoke detectors.

Based on the great significance of this fire detection principle, new and improved point detectors have been continually developed in the past. The most important principles are scattered light, extinction (light absorption) and ionization. Until about 1990, ionization was the most important principle. Today, however, most point detectors work according to the scattered light principle. People speaking of optical smoke detectors today usually refer to scattered light smoke detectors.

Scattered Light Smoke Detectors

As the name indicates, the scattered light smoke detector measures the light scattered by smoke. The construction type, especially the position of light source and receiver, has a strong influence on the detection behavior. In a scattered light smoke detector, the photoelectric cell is arranged in such a way that it cannot receive any direct light from the light source. When there is no smoke, the light hits a labyrinth and is completely absorbed. If there are any smoke particles in the area of the light beams, the light is scattered. Some light beams impinge the photoelectric cell, which in turn generates a signal. Decisive for the signal intensity are the smoke density and the optical properties of the smoke particles.

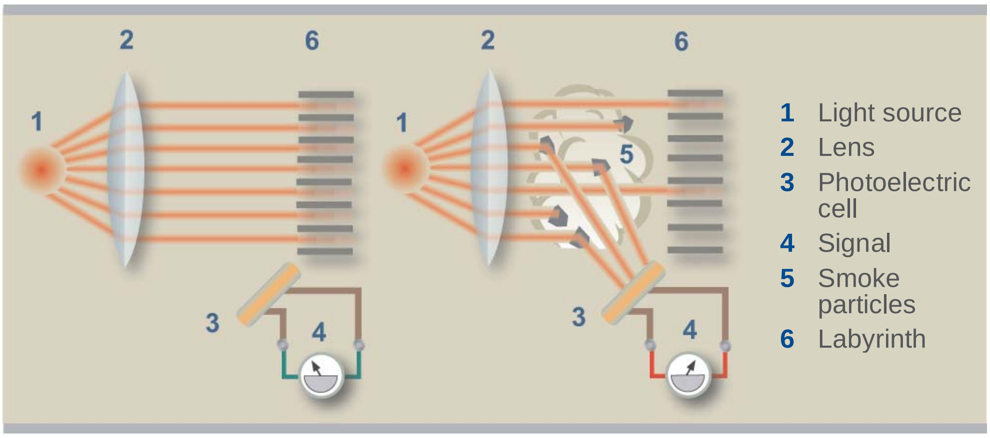


Figure 4.6: Functional principle of the scattered-light smoke detector (forward scatter)

The scattering capability of large, light smoke particles is extremely high. Soot particles and black smoke scatter the light only faintly, which is why the scattered-light smoke detector rather captures visible, light smoke particles and is especially suited for the detection of such fire types whose smoke spectrum is marked by light smoke. With a forward scatter detector, light smoke particles produce a much stronger signal on the photoelectric cell than dark particles could. For this reason, forward scatter detectors are best suited for the detection of smoldering fires with light smoke particles. With the backscatter detector, the signal difference between light and dark smoke particles is less distinct. Backscatter smoke detectors are thus much more balanced in their detection behavior and are equally suited for the detection of fires producing dark smoke particles.

Extinction Smoke Detectors

The word “extinction” originates from Latin, designating physical processes resulting in attenuation or obliteration.

An extinction smoke detector measures the light attenuation caused by absorption and scattering. A light source is focused on by a photoelectric cell from a certain distance. When there is no smoke, the photoelectric cell measures a signal. When smoke penetrates the space between the light source and the photoelectric cell, the signal measured is slightly reduced. This signal reduction caused by absorption and light scattering is proportional to the smoke density.

If the distance between light source and receiver measures only a few centimeters, as it is the case with a point detector, this signal reduction in case of smoke is very low (0.05% to 0.2%). Although the evaluation of such a low signal change is measurable with state-of-the-art electronics, the required long-time stability still constitutes a great challenge.

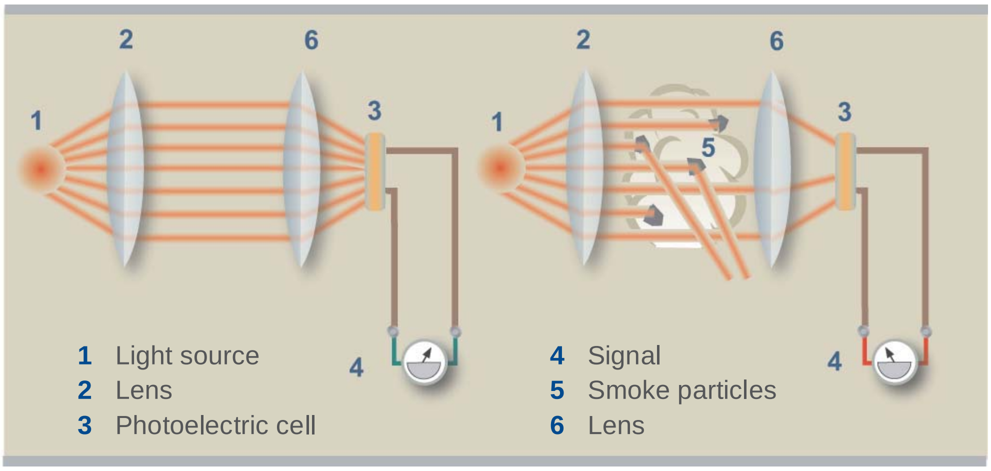


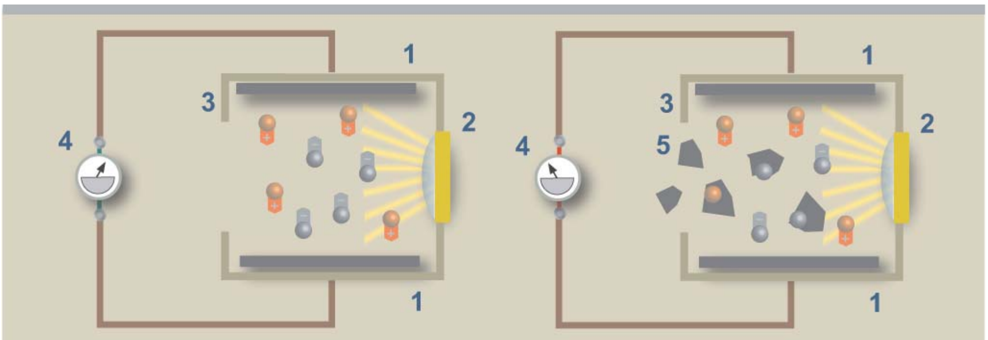
Figure 4.7: Functional principle of the extinction smoke detector

The extinction smoke detector detects light and dark, large and small aerosols and is characterized by its uniform response behavior. This detector is suited for the early detection of all fires producing visible smoke.

Ionization Smoke Detector

As this detector produces electrically charged particles (ions) from neutral particles, it is called ionization smoke detector.

The air between two electrodes, biased by a DC voltage, is ionized, i.e. made conductive, by means of a slightly radioactive radiation source. Due to this ionization, a weak electric current begins to flow in the sampling chamber. When smoke particles penetrate the sampling chamber, ions attach to the smoke particles, reducing the flow of electricity. This reduction is proportional to the number of smoke particles in the measuring area.



1 Electrodes
2 Radioactive radiation source
3 Sampling chamber
4 Signal (electric current)
5 Smoke particles

Figure 4.8: Functional principle of the ionization smoke detector

The signal coming from the ionization smoke detector is proportional to the number of smoke particles in the sampling chamber. Ionization smoke detectors are thus particularly suited for the detection of open fires, as such fires produce a large number of small, primarily invisible smoke particles. They are less suited for detecting smoldering fires that produce only few, large smoke particles.

4.3.1.2 Linear Smoke Detectors

Linear smoke detectors work according to the extinction principle, i.e. they measure the light attenuation caused by smoke. Systems accommodating the emitter and receiver in the same housing use a remote reflector and have the advantage that they need to be connected to the detector line at one point only, and that maintenance is easier. In systems without a reflector, the emitter and receiver are separate. Both systems, however, work according to the same measuring principle.

The emitter sends out a focused light beam. When there is no smoke, this light beam reaches the receiver in its unattenuated intensity. However, if there is smoke between the emitter and the receiver, the light is partly absorbed when impinging the smoke particles and partly scattered by them, meaning that it changes direction. Only a part of the emitted light can reach the receiver. The signal reduction indicates the average smoke density over the measuring section.

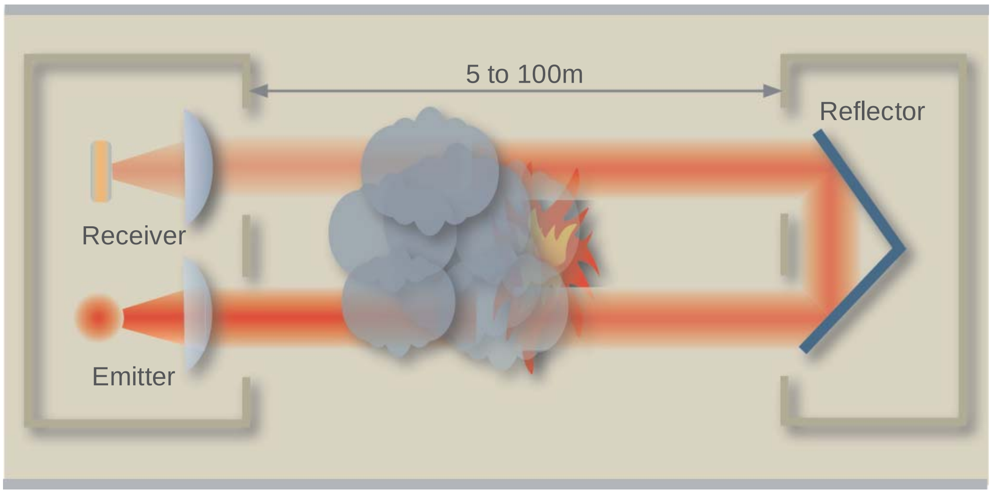


Figure 4.9: Functional principle of the linear smoke detector

Linear smoke detectors are used for measuring sections between 5m and 100m. Even a low smoke concentration causes a signal attenuation of several percent. The stability problem, which must be considered with point-type extinction smoke detectors, virtually does not exist with linear smoke detectors.

As the linear smoke detector reacts on absorption and scattering, it is suited for light and dark, large and small aerosols. It is characterized by its uniform response behavior and is suited for the early detection of all fires generating visible smoke.

4.3.1.3 Aspirating Smoke Detectors

Aspirating smoke detectors are also known as air sampling smoke detection system or aspiration smoke detection (ASD). In the air sampling smoke detection system, air samples from the monitored area are guided to the detection chamber via a pipe network by means of a powerful suction system.

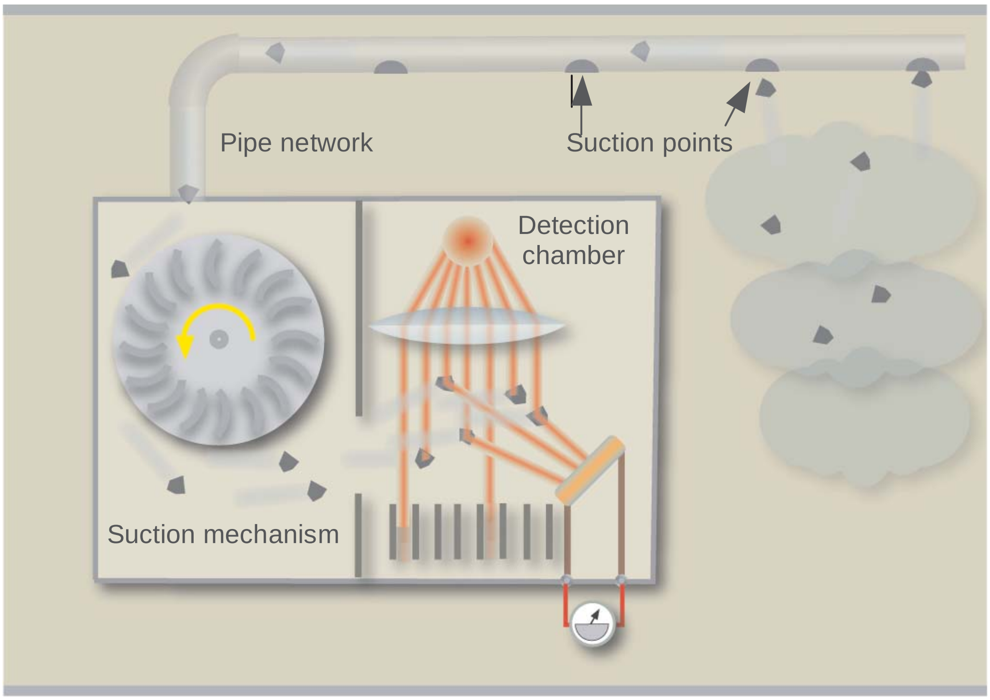


Figure 4.10: Functional principle of an ASD system

Depending on the manufacturer and the desired sensitivity, the detection chamber accommodates a smoke detector, employing one of the detection principles described in the following.

Point-Type Smoke Detector

When no high sensitivity levels are required, the ASD systems are equipped with point detectors. The smoke detectors used for ASD are usually of the same construction as normal point detectors, but they are set to the highest sensitivity level.

Cloud Chamber

In a closed area, high air humidity is generated by means of a water bath. Then, the smoke particles are guided through this zone. The high humidity condenses on the smoke particles which act as condensation nuclei, resulting in fog. This fog is illuminated with a pulsating LED to determine its density. The higher the density of the fog, the higher the smoke density.

Optical Smoke Detector

The sensor consists of a high-energy light source emitting a focused light beam (e.g. laser) and of a receiver. Aerosols in the measuring section deflect the light, which in turn impinges on the receiver's sensor electronics. This signal is evaluated and serves for triggering an alarm.

Xenon

Permanently aspirated air is guided through a detection chamber and is illuminated by a xenon lamp over a distance of several centimeters. Smoke particles deflect the beams and produce a correspondingly strong signal due to the relative length of the detection chamber. This signal is evaluated and serves for triggering an alarm. These aspiration smoke detectors require periodic calibration, which is reflected in the expenditures for maintenance. Xenon detectors work according to the scattered light smoke detector principle.

Particle Counter

A focused light beam illuminates aspirated air. Smoke particles deflect the beam, which impinges on an optical mechanism and generates an electric pulse. The number of pulses per unit of time is proportional to the smoke density. When the number of particles exceeds a predefined value, an alarm is triggered. With this measuring principle, the air flow must be regulated, as an inconstant air flow would disturb the result.

Comparison of the Detection Principles

A comparison of the different detection principles shows that there are both advantages and disadvantages to each principle. In general, the higher the sensitivity, the more susceptible the detector is to deceptive phenomena. In selecting the system, the required maintenance expenditures must be taken into account.

Property / Detector type	Sensitivity	Immunity to deception	Easy servicing
Point-type smoke detectors	0	+++	++
Cloud chamber	+	0	0
Optical smoke detectors	++	++	++
Xenon	++	+	0
Particle counter	+++	+	+

+++ : Excellent
++ : Very good
+ : Good
0 : Moderate

Table 4.2: Comparison of ASD principles

4.3.1.4 Point-Type Heat Detectors

Heat detectors are equipped with a temperature-sensitive element and are only suited for the detection of open fires.

Maximum Temperature Detector

With maximum temperature detectors, a maximum temperature is defined. Upon achieving this temperature, the detector switches to alarm mode. These detectors are based on the functional principle of a thermistor (semiconductor element with temperature-sensitive resistor), a fusible element, a bimetal strip or the expansion of a liquid.

These detectors only react when a certain temperature is exceeded, independent of the smoke density and other characteristic values. For this reason, maximum temperature detectors are suited for simple applications with a relatively low risk only.

Rate-of-Rise Temperature Detector

With the rate-of-rise temperature detector, the temperature increase per unit of time required to trigger an alarm is defined (°C/min). If the measured temperature increase per unit of time exceeds this threshold, an alarm is triggered. Rate-of-rise temperature detectors are usually based on the functional principle of a thermistor.

In practice, rate-of-rise temperature detectors are usually designed so that they also switch to alarm mode when a predefined maximum temperature is exceeded – similar to the maximum temperature detector.

As the reference value for alarm activation is the rate of rise, these detectors are clearly superior to the maximum temperature detectors. However, they are still restricted to low-risk applications and are only applied in situations where a smoke detector would be subject to massive deceptive phenomena.

4.3.1.5 Linear Heat Detectors

Linear heat detection systems consist of a line-type sensor (a cable with a number of sensors or a tube) and an evaluation unit. These systems are usually applied for special applications only. For this reason, this type of fire detection is handled separately in chapter “Linear Heat Detection Systems” starting on page 135.

4.3.1.6 Flame Detectors

Flame detectors convert the electromagnetic radiation emitted by flames into an electric signal.

To rule out faults and deception by sunlight, reflected light, lamps and other light sources as far as possible, the detection range of the detectors is shifted from the visible to the invisible range. Most flame detectors therefore operate in the ultraviolet or infrared range.

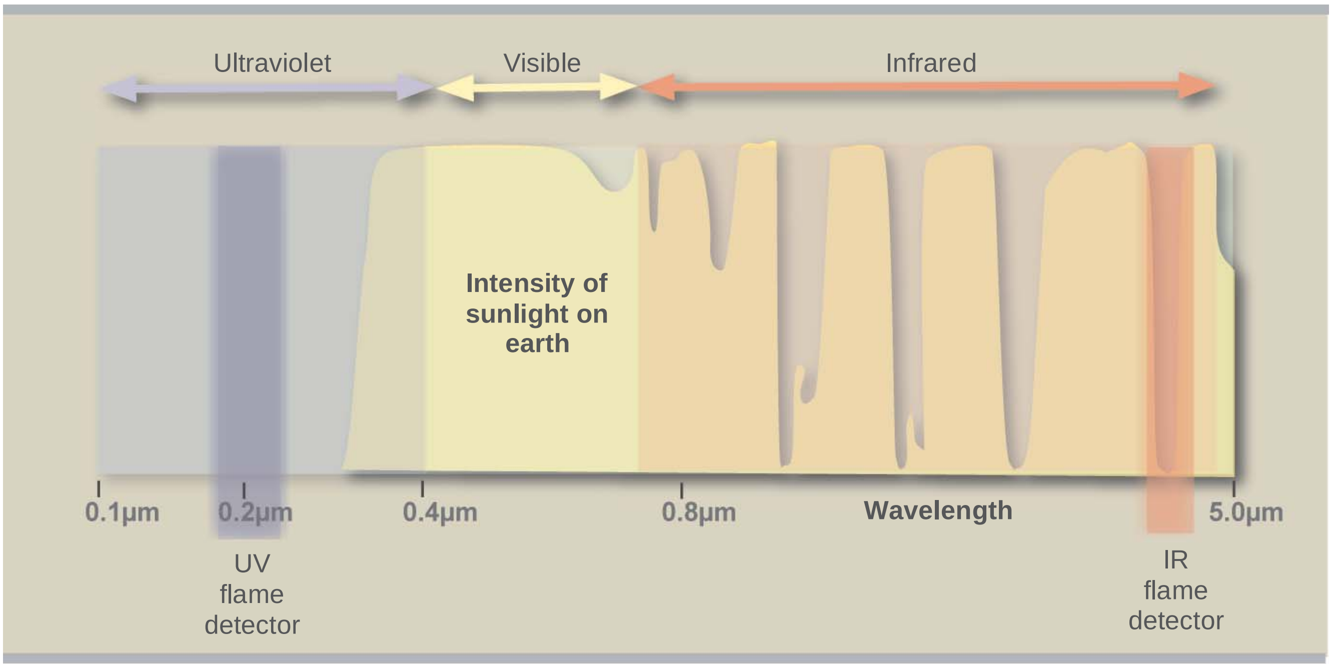


Figure 4.11: Application of UV and IR flame detectors

UV Flame Detector

UV flame detectors react on the electromagnetic radiation emitted by an open flame in the short-wave range of UV radiation (at a wavelength of approximately 0.2µm).

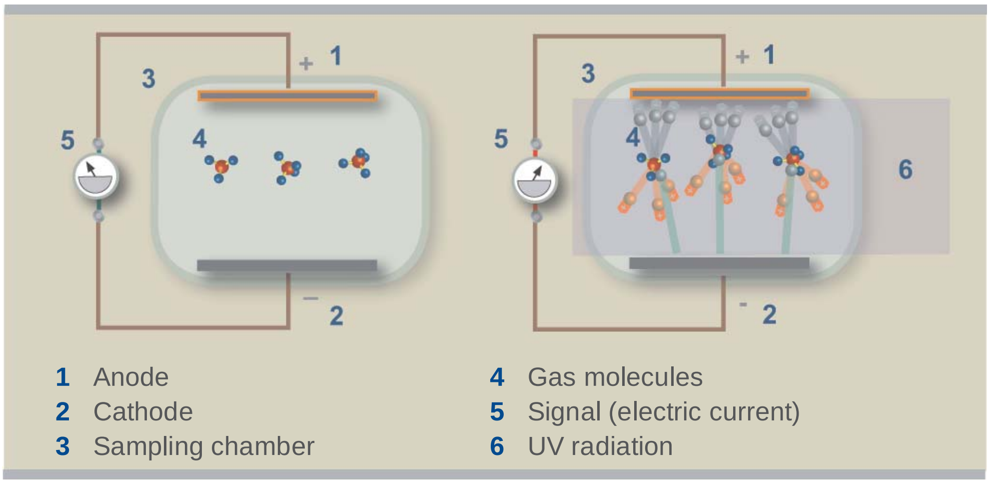


Figure 4.12: Functional principle of the UV flame detector

High-voltage is applied between the cathode and the anode. As soon as UV rays impinge on the cathode, its surface emits electrons. These electrons hit the gas molecules in the tube, ionizing them and thus initiating a snowball-type electron flow from the anode to the cathode. The result of this process is a striking increase of the current flow that is proportional to the intensity of the UV radiation emitted by the fire.

UV flame detectors are capable of detecting all types of open fires. With appropriate sensitivity settings, they are also resistant to sunlight, special fluorescent lamps and spark discharge. However, strong UV sources, such as welding flames, special lamps, electric arc lamps and ionizing radiation (radioactivity or X-rays) may cause false alarms. Any soiling of the detectors must be avoided as their sensitivity will decrease. Especially an oil film on the sensor lid immediately renders a detector completely inoperable.

IR Flame Detector

IR flame detectors make use of the maximum intensity of the infrared-active flame gases in a frequency range of 4.3µm, occurring during the combustion of carbonaceous materials (emission spectrum of hot CO_2).

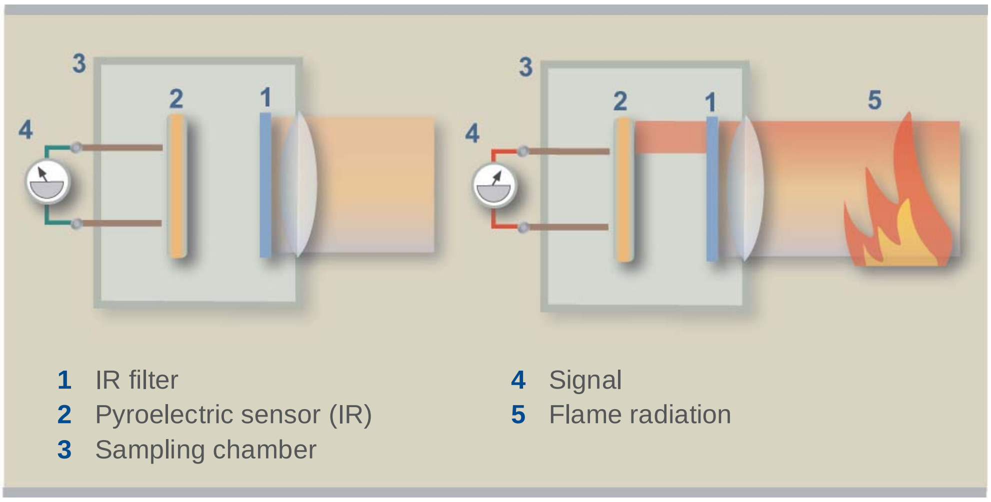


Figure 4.13: Functional principle of the IR flame detector

The flame irradiation on the IR flame detector is filtered by the infrared filter in such a way that only radiation with a wavelength between 4 and 5µm impinges on the pyroelectric sensor. This sensor only responds on a change of the radiation intensity (energy change) and generates an electric current proportional to that value.

Infrared flame detectors are suited for the detection of smokeless liquid and gas fires as well as smoke-generating, open fires of carbonaceous materials. All organic, combustible materials such as wood, plastics, gases and oil products contain carbon. Fires of purely inorganic materials such as hydrogen, phosphorus, sodium, magnesium or sulfur cannot be detected by infrared detectors. As soon as such materials are burned together with organic materials, like for example packaging material, detection can be ensured.

4.3.1.7 Gas Detectors

The gas sensors used in fire detectors detect either carbon monoxide (CO) that is produced in case of incomplete combustion or carbon dioxide (CO_2) produced in case of complete combustion.

CO Detectors

With smoldering and glowing fires, combustion is mostly incomplete due to the low temperatures. For this reason, the aerosol particles agglutinate to larger and thus more easily visible parts (strong smoke generation), and a lot of toxic CO gas is produced.

Most CO sensors in fire detection work according to the semiconductor principle (for measuring principle, see section 3.4.1 on page 45). However, the market also offers CO sensors based on an electrochemical cell (for measuring principle, see section 3.4.3 on page 47).

CO sensors are suited for the early detection of smoldering fires but are only fit for limited detection of open fires.

CO sensors based on the semiconductor principle have the disadvantage of high cross-sensitivity (response to different gases) and are strongly influenced by humidity. Gases and humidity thus bear an influence on the exact determination of the CO concentration. Electrochemical sensors do not have this disadvantage. However, they have a shorter service life and generate higher maintenance costs (for a comparison, see Table 3.1 on page 49).

CO_2 Detectors

In contrast to smoldering and glowing fires, open, flaming fires burn a considerable load per unit of time. This is associated with a striking temperature increase and high CO_2 production.

CO_2 is a very durable gas, which is why its chemical detection is rather difficult. To detect CO_2, opto-acoustic sensors and infrared absorption sensors are used today (for measuring principles, see sections 3.4.4 and 3.4.5 starting on page 47).

CO_2 sensors are suited for the detection of open fires but are only fit for limited detection of smoldering fires.

CO_2 is particularly produced by open fires generating a lot of fire gases. As thermal sensor electronics are much more cost-efficient than CO_2 measuring, and as the two phenomena occur largely in parallel, gas measuring hardly has any additional benefits.

Summary

CO fire detectors have serious problems in detecting open, flaming fires, while CO_2 fire detectors reach their limits when it comes to detecting smoldering fires. In fire detection, pure gas sensors are thus rarely used. For special applications, however, they are used together with other sensor types, mostly in combination with an optical and / or a temperature sensor (multisensor fire detector).

4.3.1.8 Multisensor Fire Detectors

Multisensor fire detectors are equipped with two or more sensors whose signals are interlinked in an appropriate way. Such detectors are often – and rather imprecisely – referred to as "multi-criteria detectors". They often detect different fire phenomena and can thus detect fires earlier and more reliably. The market offers multisensor fire detectors in virtually all conceivable combinations of smoke, heat and gas sensors:

- smoke sensors (scattered light, extinction, laser, ionization)
- heat sensors (maximum, differential)
- gas sensors (CO, CO_2)

Today, the most frequently used multisensor detectors identify smoke by means of an optical sensor and heat with a heat sensor. Flame detectors also include multiple sensor products. By intelligently interlinking the different sensor signals, the response behavior and immunity to deception can be largely improved, resulting in a much higher detection capability that it would be the case with separate sensors. The crux of developing a multisensor fire detector is the selection of the best suited sensor principles and combination of the sensors with optimum characteristics, so that both the detection properties and the immunity to deception can be optimized.

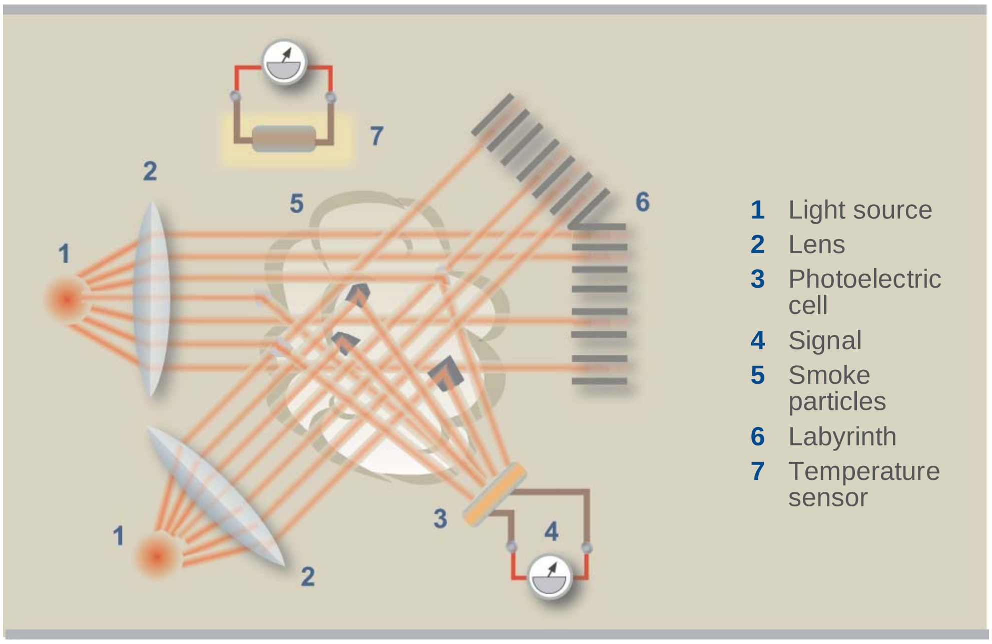


Figure 4.14: Example of a multisensor fire detector

The multisensor fire detector shown here is equipped with two scattered light sensors (forward scatter and backscatter) and a heat sensor. The detection behavior of such a detector is characterized by the following properties:

- Excellent detection of smoldering fires with light smoke particles by the forward scatter sensor.
- Good detection of fires with black smoke particles by the backscatter sensor.
- Reliable detection of fires without visible smoke by the heat sensor.
- High reliability and immunity to deceptive phenomena such as vapor, exhaust gases or heat sources due to the combination of the individual sensor signals.

The main advantage of multisensor fire detectors is that not only the strengths and weaknesses of the different sensors can be balanced due to the combination of the different measured quantities, but an interpretation of events becomes possible. The result is an essential improvement of the response speed (early detection of fires) and a considerably higher immunity to deceptive phenomena (no false alarms).

4.3.2 Detection Reliability

The detection reliability is the key property of a state-of-the-art fire detection system. The system shall only trigger a fire alarm when a fire has indeed occurred. False alarms, i.e. alarms that have been triggered although there is no fire, result in extra costs due to operational interruptions and unnecessary intervention by the fire brigade. In addition, there is the risk that people become used to false alarms and will not react quickly enough in case of emergency (see chapter “Information Transfer of the Alarm” starting on page 162).

Type of false alarm	Reason for triggering alarm
Deception alarm caused by fire-simulation event	Phenomena occurring are the same as, or similar to those of fire (deception)
Fault	Detectors are soiled, influence of electromagnetic fields, defective components
Erroneous operation	Improper manipulation of the system, or improper maintenance work
Willfully triggered false alarm	Willful triggering of a fire detector
Not identifiable	Reasons unknown

Table 4.3: False alarms

Most false alarms are triggered by deceptive phenomena such as cigarette smoke, water vapor from showers or aerosols produced during welding. Fire detectors without automatic drift compensation frequently cause false alarms when the detector is excessively soiled.

Basically, false alarms can never be completely ruled out. However, they can be significantly reduced by taking appropriate measures:

- False alarms caused by fire-simulating events can be reduced by the correct selection and arrangement of the fire detectors (detectors with intelligent signal processing in locations with fewer deceptive phenomena).
- False alarms caused by faults can be reduced by paying attention to the quality of the products applied in selecting the system.
- False alarms caused by erroneous operation can be reduced by user-friendly control units and appropriate user training.
- Reducing willfully caused false alarms can usually be combated with additional expenditures (e.g. access control, video monitoring).

4.3.2.1 Detector Sensitivity

State-of-the-art technology makes possible the production of highly sensitive fire detectors. These detectors are capable of detecting incipient fires at an early stage. However, they are also more sensitive to deceptive phenomena. The probability of deception can thus be reduced by using fire detectors with a lower sensitivity level – which in turn reduces the possibility of detecting fires at an early stage. The figure below shows the general correlation between detection reliability and the probability of deception.

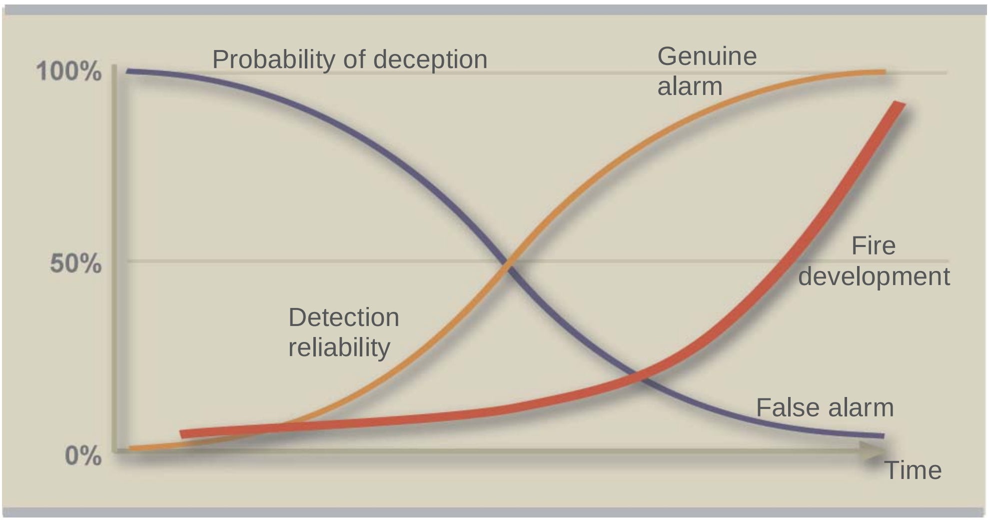


Figure 4.15: Detection reliability and probability of deception

At the beginning of a fire, the intensity of the fire phenomena is still very low. Possible deceptive phenomena at this stage may produce a signal many times higher than the signal actually wanted. To reduce the risk of false alarms, it would thus seem logical to simply give enough time to fire detection – which, however, contradicts the desire of early fire detection and the associated damage mitigation.

4.3.2.2 Detector Design

A soiled detector sooner or later causes faults or even false alarms. It may as well happen that the detector becomes less sensitive and responds too late in case of fire. Since the point-type, optical smoke detectors are by far the most frequently applied fire detectors, the aspects of detector design are explained using the example of such a detector.

Soiling of detectors cannot be generally ruled out or avoided. The detector must thus be designed in a way that particle deposits inside or at the outside of the detector do not impair the detection behavior. In designing a detector, corresponding measures must be taken in addition to the intelligent signal processing with drift compensation. The following aspects must be taken into account:

- The inlet openings must be designed in a way that the penetration of fibers, dust and insects is aggravated, at the same time ensuring the unhindered penetration of smoke.
- The distance between the detection volume and the labyrinth must be long enough, so that fibers and other particles that have nevertheless penetrated the detector cannot reach the detection area.
- The encapsulation of the optics must be designed in a way that particles can neither settle on the emitter nor on the receiver.

In addition to soiling, especially the penetration of external light can cause faults or malfunction. This can be avoided by the design and nature of the labyrinth. To reduce malfunction due to the impact of electromagnetic fields, corresponding measures must be taken regarding the detector electronics. A sophisticated layout of mechanics, sensor unit and detector electronics is the prerequisite for reliable signal processing.

4.3.2.3 Signal Processing

By far the most effective way to improve detection reliability is the use of highly intelligent fire detection systems capable of distinguishing between deceptive phenomena and genuine fires. Apart from the high quality of sensor electronics, especially the fire detection system's intelligence plays a key role, particularly the processing and interpretation of the sensor signals.

The market offers fire detection systems in which the fire detectors transmit the signals to the fire detection control unit, which is in turn responsible for signal processing. Modern fire detection systems, however, almost exclusively work on the principle of decentralized data processing. The sensor signals are directly processed in the detector, and only the evaluated results are transmitted to the control unit. The following paragraphs cover signal processing in the fire detector used in systems with decentralized data processing.

Threshold Value Technology

With this technique, the sensor signal is amplified and if an alarm threshold is exceeded, the alarm is transmitted to the control unit either directly or after a preprogrammed delay. Detectors are equipped with simple electronics and know the two states: Alarm and quiescent condition.

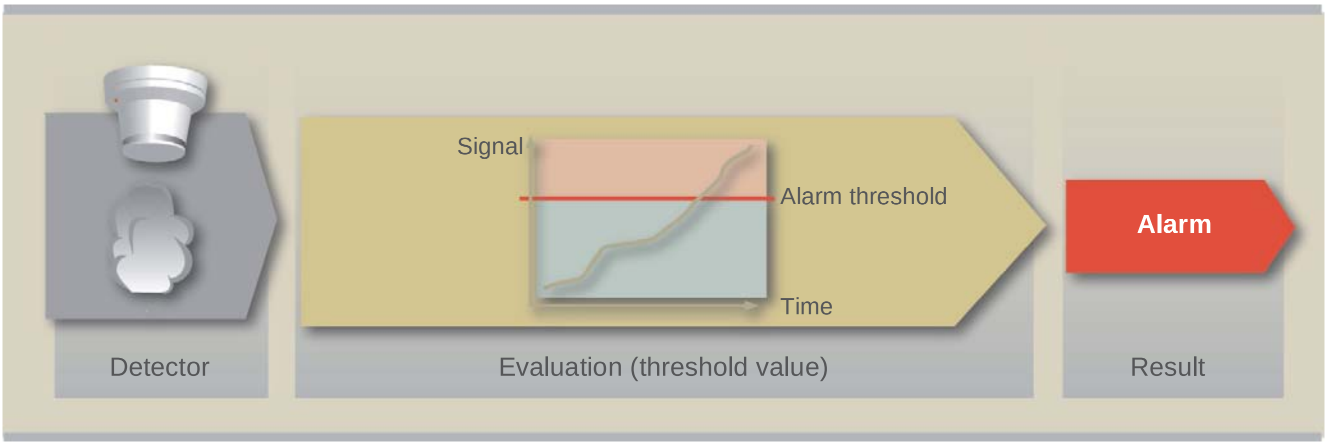


Figure 4.16: Signal processing based on threshold value technology

ASIC Technology

Detectors employing ASIC technology are equipped with comprehensive electronics featuring an ASIC (Application Specific Integrated Circuit). These highly integrated modules enable fast and intelligent signal processing, making the detector capable of detecting faults or soiling in addition to several hazard levels. In case of minor soiling, the sensitivity is corrected automatically (drift compensation).

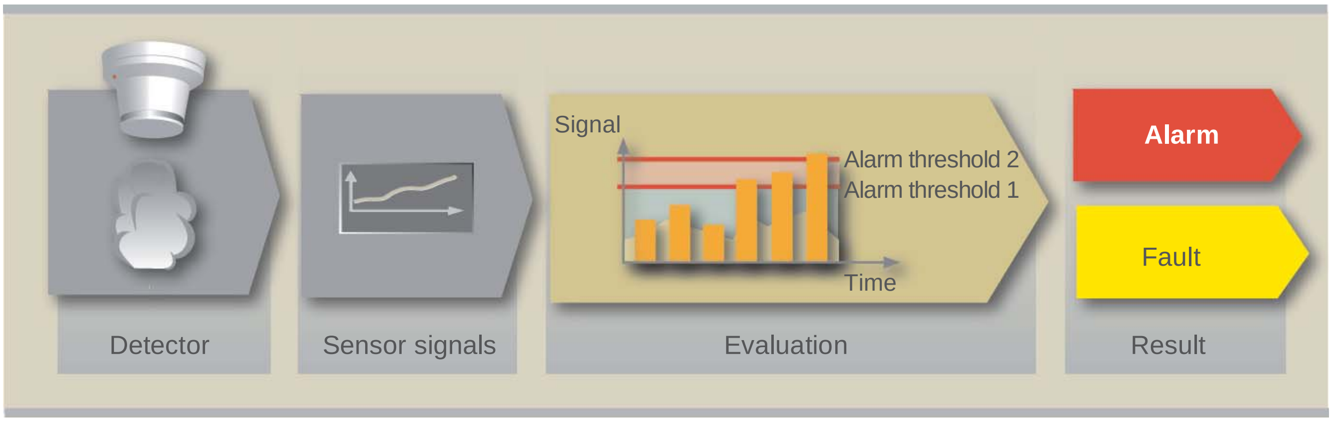


Figure 4.17: Signal evaluation based on ASIC technology

Algorithm Technology

Fire detectors based on algorithm technology perform complex signal analyses at short intervals and process large data volumes. They are therefore equipped with a microprocessor. The sensor signals are broken down into mathematical components and are offset against the defined and programmed algorithms (mathematical rules). The character of these algorithms is defined by their parameter setting. The comparison of the calculated values with the default values stored in the detector results in the corresponding hazard level.

Fire detectors with algorithm technology do not automatically guarantee an excellent detection behavior, which is affected by the way the sensor signals are broken down, the mathematical rules applied, the parameter sets available and the comparison with the default values stored in the detector. This is where knowledge comes into play. Detectors using a sophisticated algorithm technology have the following properties:

- **Sensor signals:** Dynamic detection behavior is only possible when the signal progression is observed and compared throughout the complete period of time the respective phenomenon is effective.
  Signal progression is the collectivity of the following determinants:
  - signal strength — sensor signal (amplitude)
  - rate of rise — change of sensor signal
  - fluctuation — sudden changes of the sensor signal
- **Mathematical rules:** The mathematical rules must be set up in such a way that, in combination with the available parameter sets, they allow for all types of fire developments.
- **Parameter sets:** A parameter set is a set of data having an impact on the mathematical rules and on the comparisons with the default values. By loading the respective parameter set, the fixed mathematical rules are specifically set to the fire phenomena and ambient conditions to be expected, and the results are compared to the corresponding defaults. If a fire detector is installed in a production hall, a parameter set must be loaded that assesses sudden changes normally caused by deceptive phenomena as relatively insignificant. If the same fire detector is installed in a hospital room, however, a parameter set must be selected that responds to rapid changes to the sensor signals, guaranteeing earliest possible fire alarm. As state-of-the-art fire detectors can be operated with a wide array of parameter sets, they are suited for all types of special applications.
- **Comparison with the stored default values:** The stored default values are based on a large number of real fires, thus reflecting the characteristics of many different types of fire. The comparison between the calculated values and the stored default values results in the danger level (e.g. 1 = possible hazard, 2 = hazard, 3 = alarm). Additional evaluations enable statements about the detector status (e.g. soiling or fault, diagnostic level).

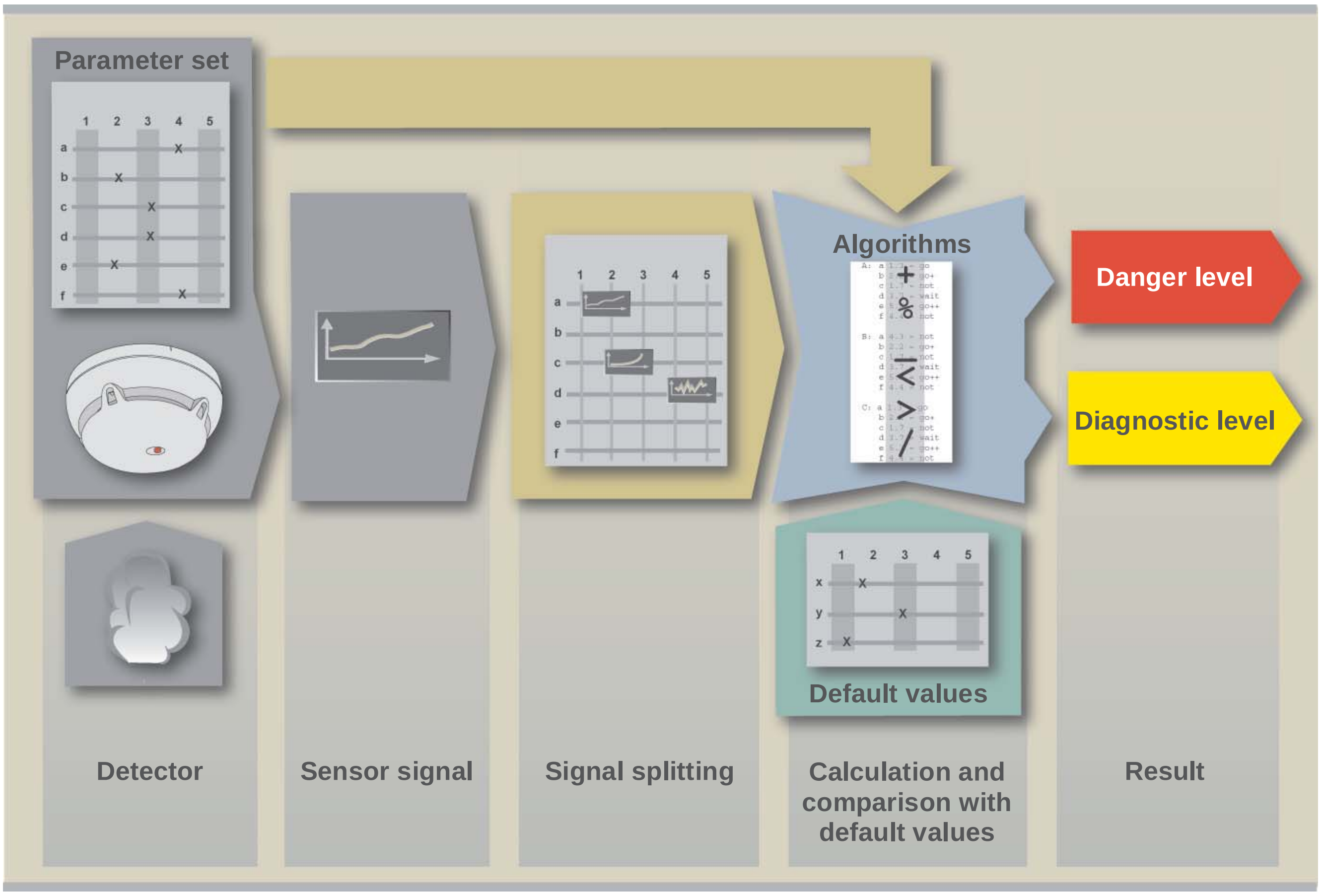


Figure 4.18: Signal processing in a smoke detector based on algorithm technology

ASAtechnology™ (Advanced Signal Analysis)

ASA*technology™* is the continued development of algorithm technology. The detection behavior can be adapted to the relevant application, owing to corresponding parameter sets. The major difference between this technology and algorithm technology is the real-time interpretation of the situation and, based on that, the dynamic impact of the selected parameter set. The individual parameters of the selected parameter set are no longer static; they are modified depending on the sensor signals. The application range of the detector is extended, which is the equivalent of larger detection dynamics. In the event of fire, a detector based on **ASA***technology™* responds in a more sensitive way. In case of deception, it is more robust than a detector using algorithm technology. The result is unparalleled fire detection, combined with an inimitable immunity to deception.

The figure shows the signal processing of a multisensor fire detector with smoke and heat as fire phenomena. Intelligent signal processing is based on the data provided by the smoke and heat sensors.

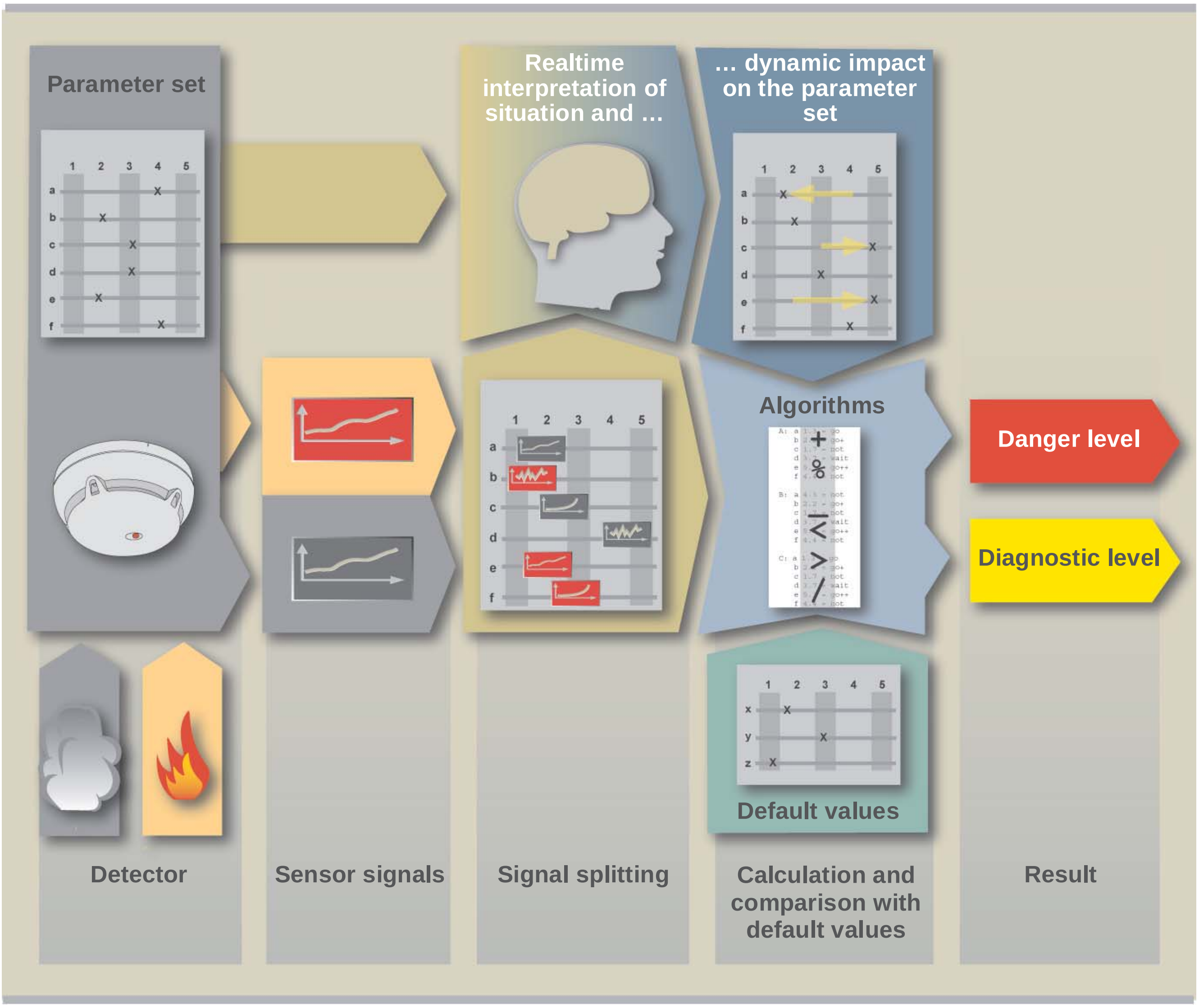


Figure 4.19: Signal processing in a multisensor fire detector based on ASA*technology*™

4.3.2.4 Multisensor Fire Detector

In a multisensor fire detector, the detection of an incipient fire and the decision on alarm are based on the evaluation of several sensor signals. In comparison with normal fire detectors, the detection reliability of such detectors is significantly higher.

Point-type fire detectors with the sensor combination smoke / heat or smoke / gas are typical examples of such multisensor fire detectors. They are designed to detect fires at an early stage and are at the same time highly immune to deceptive phenomena. However, there are multisensor detectors in which only one sensor is required for fire detection, as all other additional sensors merely have the task of detecting possible deceptive phenomena in order to increase the detection reliability.

A typical example is the modern flame detector with three sensors.

- A pyroelectric sensor measures the infrared radiation in the CO_2 spectral range between 4.0 to 4.8µm as it is typical for flames (Sensor A / flame detection).
- A second pyroelectric sensor measures the infrared radiation of sources of deception in a range of 5.1 to 6µm (Sensor B / deception by hot objects, for example).
- A silicon photo diode measures the solar irradiation in a range of 0.7 to 1.1µm (Sensor C / deception by sunlight)

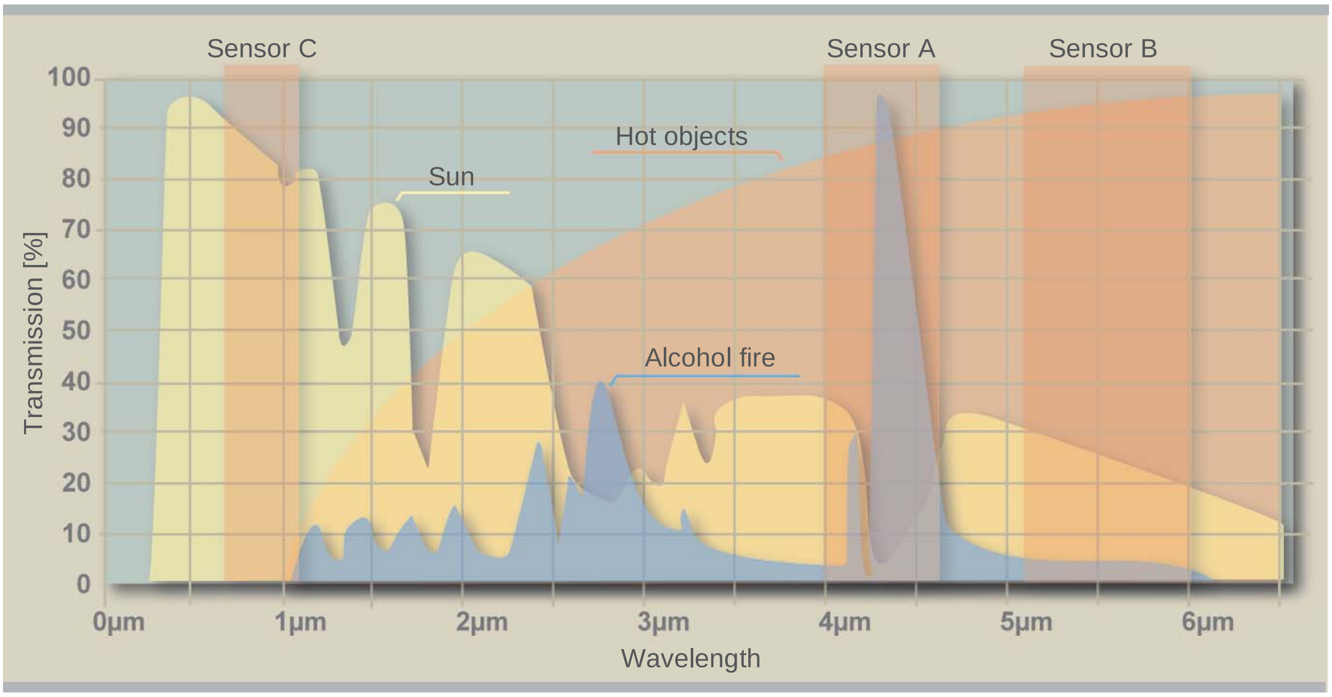


Figure 4.20: Infrared spectrum of sunlight, hot objects and alcohol fire

The IR radiation spectrum of the sun differs from that of hot objects and organic fires. Thanks to these different characteristics and the three sensors, the flame detector can distinguish between real fires and deceptive phenomena. If sensor signal A is stronger than sensor signal B, and if sensor signal A is significantly stronger than sensor signal C, a real fire has occurred. Otherwise it is a deceptive phenomenon. If sensor signal A more or less has the same intensity as sensor signal B, the signal is emitted by a radiator. If sensor signal C is simultaneously significantly stronger than the two other signals, solar irradiation is the cause.

In addition to merely assessing the signal intensity, intelligent signal processing also considers changes to the signals, thus increasing detection reliability. These types of flame detectors are capable of reliably detecting a flaming fire even when it occurs in the immediate vicinity of a deceptive phenomenon.

4.3.2.5 Summary

Apart from the mechanical design and the sensor electronics applied, it is the signal processing that determines the quality of fire detection. Early and absolutely foolproof fire detection is the goal. When fire detectors are placed in a clean environment, this is possible without any problems today. If, however, a detector shall be able to detect a fire as early and safely as possible, even in environments where different deceptive phenomena occur, we are still faced with a challenge. Very fast fire detection combined with 100% detection reliability cannot be guaranteed. Fire detectors with intelligent signal processing and an appropriate detector design, however, already come very close to this goal.

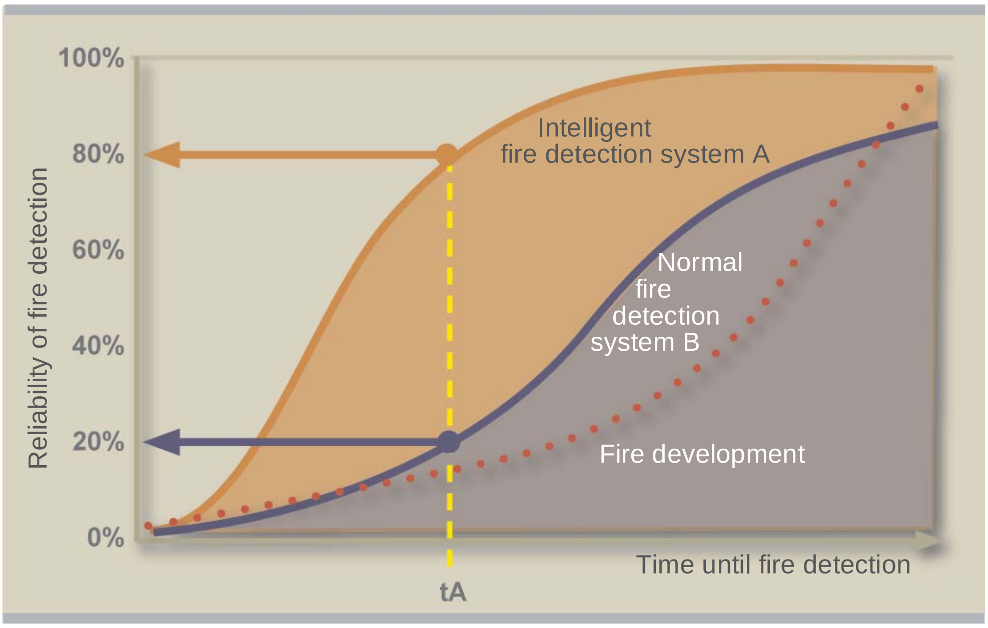


Figure 4.21: Detection behavior depending on signal processing

Earliest possible detection combined with false alarm prevention

4.3.3 Networking Technologies

The task of a fire detector is to prevent the development of fires. There is no use in a detector that identifies a fire but does not reliably transmit the information. For this reason, fire detectors must be connected to a control unit, either hard-wired or wireless. The two most important networking methods are discussed below.

4.3.3.1 Collective Addressing

This type of networking is the oldest technology still in use today. Alarms are transmitted to the control unit by the detector lines. The control unit merely sees which line has transmitted the alarm, but not which detector. This method is thus called “collective addressing” – referring to the collectivity of all detectors on a detector line.

To localize a hazard source in case of an alarm, the individual detector lines are arranged in such a way that they can be easily traced; i.e. one detector line per floor. In addition, external alarm indicators are often placed above the doors, so that the alarm triggering detector and thus the seat of fire can be found within a reasonable period of time.

4.3.3.2 Individual Addressing

Individual addressing was first introduced in the 1980s. Simpler systems still transmit their information sequentially. This means that the detectors transmit their information to the control unit one after the other, in accordance with their sequence on the detector line. Based on this sequence, the control unit “sees” which detector has sent the information and is capable of indicating the alarm triggering detector on the display. Systems with state-of-the-art networking technology, however, make use of addressing methods known from information technology.

When fire detectors with individual addressing are exclusively applied, external alarm indicators become superfluous as the alarm triggering detector is directly indicated on the fire detection control unit.

Modern fire detection systems in which the signal analysis is performed in the detector itself come to a preliminary alarm decision and thus only need to transmit the corresponding alarm level. Fire detectors without built-in signal analysis however depend on transmitting the measured values of the sensor signals to the control unit, which can then decide on alarm in real time.

4.4 Selecting the Appropriate Fire Detector

Fires can develop explosively, fast (within a few seconds), normally (within a few minutes) or slowly (within hours). This chapter only deals with classic fire detectors used to detect fires developing from fast to slow.

This document neither handles special detectors, such as pressure and spark detectors applied for explosion protection which must respond within a few milli-seconds, nor does it deal with gas sensors as they are used for the detection of smoldering fires in carbonization plant, or for the detection of combustion gases.

In selecting the best suited fire detectors, the following aspects must be taken into account:

- the type of fire to be expected
- the room height
- the ambient conditions
- possibly occurring deceptive phenomena

4.4.1 Consideration of the Type of Fire

Based on their suitability, their reliability and the costs for acquisition and mainte-nance, detectors are used as follows. Detection of:

- **smoke**: point-type and linear smoke detectors and aspirating smoke detectors.
- **heat**: point-type and linear heat detectors.
- **radiation**: IR and UV flame detectors.

The use of point-type multisensor fire detectors that are capable of detecting both smoke and heat increases constantly.

4.4.1.1 Sensitivity of Optical Smoke Detectors

In practice, the sensitivity of optical smoke detectors is often given as a certain smoke density in %/m. This value corresponds to the detector's response value, measured in a defined smoke channel with predefined test aerosol, defined air speed and temperature (EN54-7). This smoke density is more precisely referred to as the "light obscuration module".

The light obscuration module is calculated as follows:

$$D = \{ 1 - (I/I_0)^{1/d} \} \times 100 \qquad [\%/m]$$

D = light obscuration module

I_0 = received light intensity without smoke

I = received light intensity with smoke

d = distance between emitter and receiver

The measurements in the smoke channel are used for testing the detectors' stability and reproducibility and have little to do with the actual response behavior of the detectors on real fires. It is thus absolutely thinkable that a smoke detector with intelligent signal processing and a light obscuration module of 6%/m detects a real fire earlier than a detector with normal signal processing and a light obscuration module of 3%/m. The sensitivity required for approval conforming to EN 54 is checked by means of the test fires described below.

4.4.1.2 EN 54 Test Fire

The EN 54 test fires serve as proof that the detectors have sufficient sensitivity to certain fire phenomena. They are set up in such a way that each fire produces a different, typical aerosol spectrum. Such fires are mandatory to achieve approval of fire detectors. They are also quite often used for testing the response behavior of existing fire detection systems.

EN Test fire	TF1	TF2	TF3	TF4	TF5	TF6
Fire type	Open cellulose fire (wood)	Pyrolytic smoldering fire (wood)	Glowing / smoldering fire (cotton)	Open synthetic fire (polyurethane)	Liquid fire (n-heptane)	Liquid fire (ethyl alcohol)
Heat development	Strong	Negligible	Negligible	Strong	Strong	Strong
Upward air flow	Strong	Weak	Very weak	Strong	Strong	Strong
Smoke generation	Yes	Yes	Yes	Yes	Yes	No
Aerosol spectrum	Predominantly invisible	Predominantly visible	Predominantly invisible	Partly invisible	Predominantly invisible	None
Visible property	Dark	Light, strongly scattering	Light, strongly scattering	Very dark	Very dark	None

Table 4.4: Test fires according to EN 54 and their properties

4.4.1.3 Fire Detectors and EN 54 Test Fires

EN 54 test fires are artificially induced, "ideal" fires that will rarely occur in practice, as real fires usually produce a mix of smoke types. The advantage of the EN test fires is that they produce reproducible fire phenomena and thus enable exact comparisons between the response behavior of different detectors or sensors.

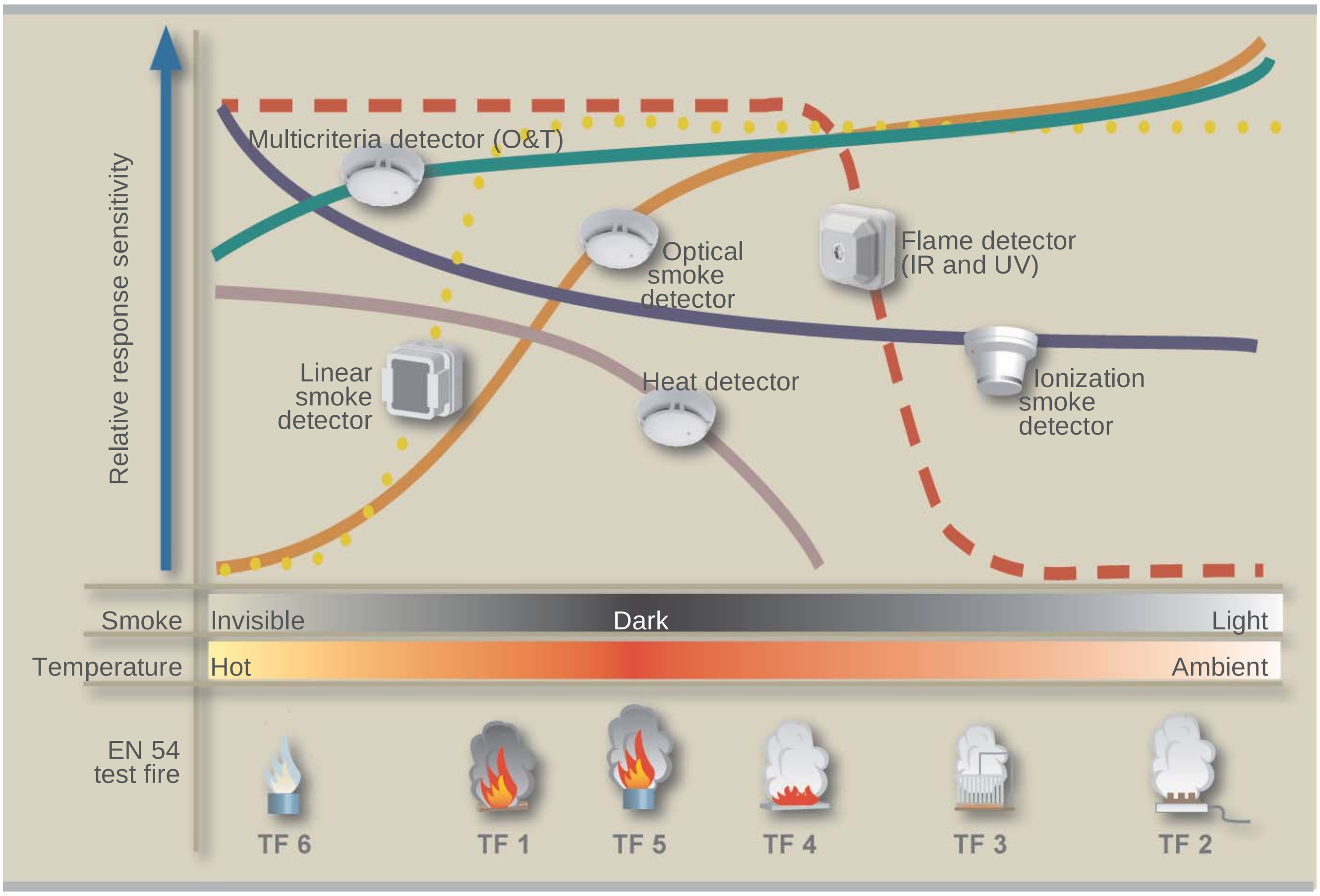


Figure 4.22: Response behavior of different fire detectors on EN 54 test fires

The figure above shows the qualitative, basic capability of the detectors to respond to EN test fires. A heat detector cannot respond when a fire does not produce heat (TF 2 and TF 3). The sensor design has an additional impact on the quantitative response behavior of the sensors. The response of optical smoke detectors to TF 1, for example, depends on the scattering angle.

4.4.1.4 Selecting the Right Fire Detector

The selection of the optimum fire detector is based on the expected fire phenomena, generated by the incipient fire. For an office building, smoke detectors will preferably be selected, as in this case fires will produce clearly visible smoke both in the incipient phase and later. In a storage area where combustible liquids are stored, flame detectors and / or heat detectors would be the right choice.

To be able to reliably detect all expected incipient fires, it may be necessary to combine different fire detector types.

4.4.2 Considering the Room Height

To make it possible for a fire detector to indeed detect a fire, the fire phenomenon (i.e., smoke, heat, radiation) must reach the detector. As most detectors are mounted on the ceiling, the room height limits the application range of the different detectors. The application limit for the different fire detector types is defined in the specifications. These values may vary from one country to another.

Typical limits for point-type detectors are:
– smoke detector max. 12.0m room height
– heat detector max. 7.5m room height
– flame detector max. 45.0m room height

If an incipient, smoke-generating fire shall be detected in the atrium of a shopping center, the large room height neither allows for the use of point-type smoke detectors nor heat detectors. Flame detectors can only detect such a fire after it has developed from a smoldering to an open fire and if the fire seat is within the visible range. Depending on the room geometry, an ASD is capable of detecting an incipient fire quite early, but the ideal solution in this situation is a linear smoke detector. These detectors are able to monitor distances up to 100m. They can be installed on walls at a height of 5m, for example, and can thus detect ascending aerosols which do not reach the ceiling due to the thermal conditions.

4.4.3 Considering Ambient Conditions

Fire detectors must only be applied within the temperature range specified by the manufacturer. Typical values for modern fire detectors are -25°C to +60°C. When fire detectors are applied at temperatures below zero, icing up of the detectors must be avoided, for example by installing heating elements.

When heat detectors are applied, it must be ensured that the minimum response temperature is at least 10°C higher than the possible maximum ambient temperature.

Air movements deserve special considerations when smoke detectors shall be installed. In the event of fire, major air circulations reduce the aerosol concentration, making a safe detection with normal fire detectors virtually impossible. For this reason, rooms with a high degree of air movement are preferably equipped with high-sensitive aspirating smoke detectors or with special smoke detectors installed in the ventilation duct.

Fire detectors are electric devices that can be damaged by water or by the impact of solid objects. In selecting fire detectors, it must be tested whether the detector type chosen has the IP protection category required for the respective environment (see section “IP Protection Categories”, page 315).

4.4.4 Considering Prevailing Deceptive Phenomena

Statistics worked out in different European countries have shown that more than 90% of all alarms triggered in fire detection systems are false alarms. A large part of these false alarms are deceptive alarms, i.e. alarms caused by external influence and not by an incipient fire. Possible deceptive phenomena may be:
– cigarette or cigar smoke
– vapor and heat produced during cooking or in the shower
– smoke produced by welding and soldering
– fog generated by fog generators used for show events
– exhaust gases from motor vehicles or emergency power units
– dust generated during grinding or filling work
– moisture condensation
– heat accumulated in case of insufficient ventilation

Due to their setup and the sophisticated signal processing, state-of-the-art fire detectors are largely capable of distinguishing between deceptive phenomena and genuine fires. If, however, massive deceptive phenomena are to be expected within the area to be monitored, the fire detectors' position deserves special consideration, in addition to the selection of modern fire detectors with intelligent signal processing.

When particular deceptive phenomena are to be expected, for example moisture condensation in the entrance area of cold storage rooms or dust in recycling facilities, aspirating smoke detectors are preferably installed. These systems can be equipped with appropriate additional components, such as air filters or condensate separators, so that the deceptive phenomena will not reach the detector and reliable fire detection can be guaranteed.

If deceptive alarms cannot be ruled out in spite of the optimum detector selection and position, most fire detection systems offer technical measures by which deceptive alarms can be reduced. Among these, the most important ones are:
– verification of the alarm status with intermediate alarm storage
– multidetector or multizone logic

4.4.5 Fire Detectors for Explosion-Hazard Areas

Electrical operating equipment used in explosion-hazard areas must meet certain safety requirements. Fire detectors used in explosion-hazard areas must comply with a particular type of ignition protection so that they can be ruled out as potential ignition source.

The term ignition protection sums up all measures taken in designing electrical operating equipment in order to prevent the ignition of an explosive atmosphere. Each type of ignition protection is advantageous for particular types of devices or applications. This is based on the principle of isolating ignition sources. The most important types of ignition protection for electrical operating equipment in explosion-hazard areas are described in detail in the annex “Ignition Protection Classes” on page 317.

4.4.6 Summary

A fire detector must be able to early and reliably detect at minimum one of the fire phenomena to be expected. Room height, environmental conditions and possible deceptive phenomena must be taken into account. The impact of deceptive phenomena on the detection behavior can be reduced by measures such as correct positioning, suitable detector settings or structural separation of fire sectors.

In selecting the best suited fire detector, risks and costs play an important role as well. If an area with high fire risk shall be monitored, an area in which strong deceptive phenomena may occur and operating interruptions must be avoided at any rate, fire detection must be as early, reliable and immune to deception as possible. This is the case with automatic welding facilities, for example. In such areas, different fire detector types are often combined, for example multisensor fire detectors and flame detectors. In an office building with smoking ban, the use of smoke detectors will completely suffice.

For use in dirty environments or explosion-hazard areas, fire detectors must meet special requirements set up for the respective area.

The following paragraphs describe some typical application areas for the different types of fire detectors.

Point-Type Smoke Detector

Point-type smoke detectors are used in areas where incipient, smoke-generating fires are to be expected and where little or no deceptive phenomena occur. As it has already been described in section 4.3.1.1, scattered light smoke detectors are particularly suited to detect light smoke particles, whereas the strength of ionization smoke detectors lies in the detection of small, dark smoke particles. As a radioactive radiation source is used, and due to the resulting disposal problems, ionization detectors are used less and less frequently.

Typical application areas for point-type smoke detectors are:
- rooms where smoking is prohibited such as
  - hospitals
  - nursing homes
  - offices
- museums and exhibition rooms
- storage halls for paper, consumer electronics, etc.
- production facilities for electronic products
- EDP rooms (in combination with an ASD system)
- communication facilities

Point-Type Heat Detectors

Point-type heat detectors are used in areas where incipient fires generate much heat. Heat detectors should principally be used only in areas where process-related deceptive phenomena such as intensive aerosol concentrations render the use of other detector types impossible.

Typical application areas for point-type heat detectors are:
- canteen kitchens with low ceilings
- interlocks in cooling facilities, where fog is produced by condensation
- storage halls for combustible liquids generating little smoke in case of fire (mostly in combination with flame detectors)

Point-Type Multisensor Detectors

The use of point-type multisensor fire detectors that simultaneously detect smoke and heat is increasing steadily. Due to the intelligent interlinking of the sensor signals, such detectors are characterized by early and highly reliable fire detection. They are thus applied in all areas where early detection and high resistance to deception are of equal importance.

Typical application areas for point-type multisensor fire detectors are:
- offices, conference rooms, hotel rooms, restaurants, etc., where smoking is allowed
- rooms with kitchenettes in nursing homes
- production halls where deceptive phenomena may occur
- parking facilities for motor vehicles or Diesel locomotives
- all types of storage buildings (food and animal feed industries, cooling facilities)
- canteen kitchens with ceilings higher than 3m
- discotheques and other event centers in which artificial aerosols may be re-leased

Linear Smoke Detectors

Linear smoke detectors are used in areas in which smoke-generating incipient fires are to be expected and where point-type smoke detectors cannot be used.

Typical application areas for linear smoke detectors are:
- very high rooms (atriums, hangars)
- large halls in which the maintenance of point-type detectors would be more difficult or more expensive than that of linear smoke detectors
- areas with strong operational danger of soiling of point-type detectors (sawmills, spinning works)
- historical buildings in which point detectors are unwanted for esthetical reasons

Aspirating Smoke Detectors

Aspirating smoke detectors are used wherever smoke-generating fires must be detected as early as possible and point-type detectors are too insensitive or not sufficiently robust against soiling.

Typical application areas for aspirating smoke detectors are:
- rooms with a high concentration of valuable property where even smallest aerosol concentrations must be detected (EDP rooms, chip production facilities)
- very high rooms where the smoke concentration below the ceiling is strongly diluted due to the large volume (atriums, hangars)
- large halls in which the maintenance of point-type detectors would be more difficult, or where point-type detectors would be essentially more expensive than aspirating smoke detectors
- areas where point-type detectors are prone to operational soiling (recycling facilities, heavy-duty industry)
- rooms where strong deceptive phenomena such as moisture condensation are to be expected (entrance areas of cooling facilities)
- historical buildings in which point detectors are unwanted for esthetical reasons
- areas with increased danger of vandalism (e.g. in prisons)

Flame Detectors

Flame detectors are used in areas where open fires may occur very rapidly and where large open areas must be monitored.

Typical application areas for flame detectors are:
- storage facilities for combustible liquids
- open storage halls or loading decks
- oil and fuel tank farms
- paint shops
- motor test stands
- recycling facilities

Example: Workshop

The following example shows some considerations on the selection of the optimum fire detector in a workshop.

A workshop with a room height of 7m shall be monitored with fire detectors. Welding work is frequently performed in this workshop. In addition, there are Diesel-driven forklift trucks. These deceptive phenomena might cause false alarms with smoke detectors. The use of heat detectors shall thus be discussed to reduce or avoid the risk of deceptive alarms.

The following prerequisites apply for heat detectors:
- In many countries, a category 1 heat detector with a response temperature of 62°C may be applied up to a maximum room height of 7.5m. The maximum admissible monitoring area is $20m^2$.
- Calculations show that such a heat detector is able to detect a wood fire of $0.5m^2$ with a power of approx. 110kW and a flame height of approx. 1.2m. These details are correct when the fire occurs directly underneath the detector and when there is no air circulation. Assuming that the fire would occur a few meters beside the detector and there would be slight air movements in the room, such a detector sees a fire only when it produces several hundred kW of heat.

For an objective-oriented protection setup of a fire detection system, it must thus be clarified whether the protection objective allows for such a fire. Otherwise, a different solution for an earlier detection of a possible fire must be found. Examples are:

- smoke detectors with high immunity to deceptive phenomena
- smoke detectors with multidetector zones, with the alarm only being transmitted when a predefined number of detectors (usually 2) are in alarm status
- flame detectors

This example shows how complex the selection of the optimum fire detector can be. In practice, of course, not each and every single fire detector can be planned in this way, which is why highly experienced specialists are required to set up a fire detection system.

Selecting the best suited detector type requires both profound technical knowledge and a grasp for the application itself, its risk, the combustible load, the possible fire progression and the probable and achievable fire size.

Selecting the optimum fire detector requires both knowledge and experience

In some cases, fire detection systems must be set up for objects in which one cannot accurately predict how a fire will develop or the smoke will spread. In such cases, the selection of the detector types, their settings and positioning must be found out by means of simulation tools or optimized on site.

Development

Taking a closer look at automatic fire detectors applied today, more than 90% are point-type fire detectors. Of these, approximately 75% are smoke detectors, 5% are heat detectors and 20% are multisensor fire detectors. In many applications, a clear shift from the “pure” smoke or heat detector to a multisensor fire detector can be observed. The reason is that multisensor fire detectors make a more reliable and nevertheless early detection of many different fire types possible. In addition, the price difference to conventional, point-type smoke detectors has decreased significantly over the past years. For special applications, ASD systems are applied increasingly, as they can detect fires at a very early stage and may as well be applied in rooms with strong deceptive phenomena, provided that additional measures are taken.

4.5 Number and Positioning of Fire Detectors

The fire phenomena generated by fire (smoke, heat, radiation, gas) propagate differently. This must be taken into account when planning and installing a fire detection system, which is why the number of required detectors (or the coverage area per detector) is largely determined by the propagation characteristics of the respective fire phenomenon.

The number and positioning of fire detectors is frequently laid down in country-specific directives, which always take priority.

4.5.1 Basics

The higher the room, the larger normally the distance between the seat of fire and the detectors on the ceiling. This is why the intensity of the fire phenomenon to be detected, i.e. smoke density, temperature increase or radiation intensity decreases with increasing ceiling height. It must be taken into consideration that with an increasing ceiling height an incipient fire may be larger due to the larger room volume without increasing the danger of rapid fire propagation or flashover.

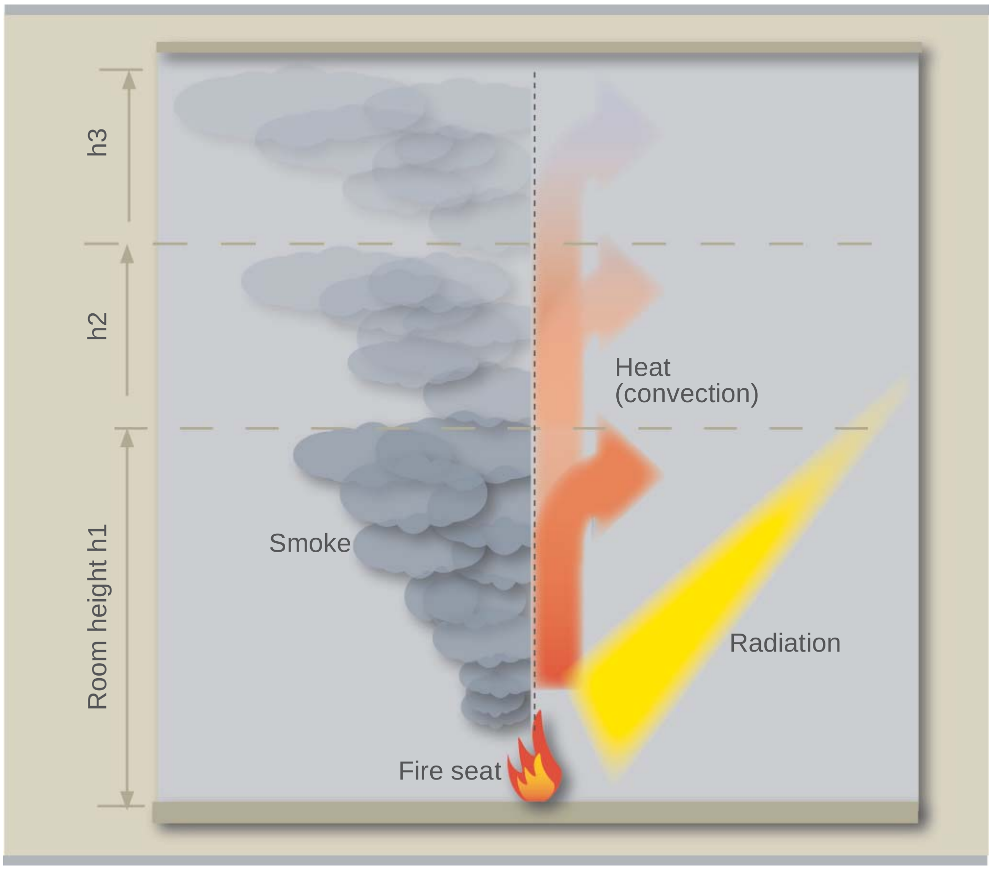


Figure 4.23: Propagation characteristics of fire phenomena

Smoke

The thermal characteristics of open fires transport the smoke particles, which become diluted in the larger air volume, even to very high ceilings. This smoke dilution must be accommodated by the use of smoke detectors with sensitive response behavior.

Smoldering fires largely lack the thermal conditions to transport smoke. Such fires are thus only recognized by detectors mounted on high ceilings after they have developed to open fires.

Heat

The warm air ascending from the fire cools down with increasing distance, which means that heat detectors are of limited use with increasing room heights.

Radiation

Although the radiation energy is reduced the larger the distance between fire seat and detector, flame detectors can be used in very high rooms thanks to their high response sensitivity.

Generally Applicable Facts

In arranging the fire detectors, it must be ensured that the fire phenomena reach the fire detectors, so that the detector can indeed recognize a fire.

Each room to be monitored must be equipped with at least one automatic fire detector.

Fire detectors must be principally arranged symmetrically and evenly throughout the room.

The detector placement must comply with the prevailing room conditions (e.g. the ceiling’s construction: ceiling with girders, special roof or ceiling shapes) or room divisions (alcoves, furniture, equipment, etc.).

Additional considerations in placing fire detectors include:

- In some countries, flame detectors may be applied up to room heights of 45m. It must be clarified, however, which fire size may still be detected with such an arrangement, and whether the defined protection objective can still be achieved.
- When monitoring a room where very strong deceptive phenomena may occur, the optimum arrangement of the fire detectors is crucial. Minor changes to the detector position may lead to massive improvements relating to the immunity to deception without impairing the detection reliability.
- In very special cases, experience alone does not suffice – tests on site become necessary to determine the optimum detector position.

4.5.2 Manual Call Points

Manual call points must be placed at a clearly visible location along escape routes, for example in corridors, staircases, entrance halls, besides extinguishing posts and in especially endangered areas at a distance of maximum 40m.

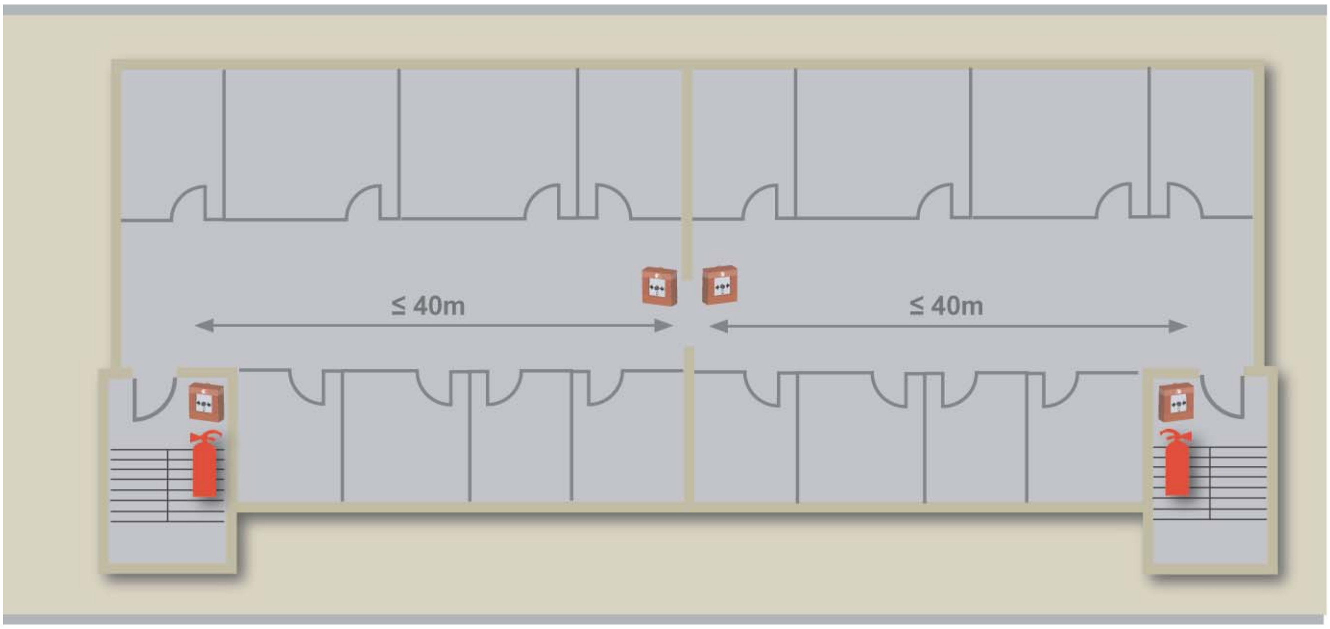


Figure 4.24: Positioning of manual call points along escape routes

Manual call points must be generally installed at a height of 1.5 to 1.7m above the floor, in order to avoid erroneous operation, for example by mistaking them for light switches in the dark).

4.5.3 Point-Type Smoke Detectors

Point-type smoke detectors are installed either on the ceiling or where the strongest propagation and accumulation of smoke is expected. Point-type multisensor fire detectors, which simultaneously detect smoke and heat, must be arranged in the same way as point-type smoke detectors.

4.5.3.1 Impact of the Room Height

Point-type smoke detectors may normally be installed at a room height up to 12 meters. With increasing room height, the smoke density on the ceiling decreases, as the total smoke volume spreads throughout a larger air volume. In addition, smoke cooling off can no longer break through the heat cushion accumulating on the ceiling of high rooms.

This results in the conclusion that at increasing room height:
- the response sensitivity of the fire detection system must be higher, or an increasingly larger incipient fire is required to trigger alarm
- the coverage area per smoke detector may be larger
- smoke from smoldering fires will hardly reach the ceiling and thus the detectors
- the smoke detectors must be placed at larger distances from the ceiling

These physical conditions must be taken into account in selecting the response sensitivity and determining the distance to the ceiling.

	Roof inclination (angle α)	
Room height [m]	< 30°	> 30°
< 6	3 - 30cm	20 - 50cm
6 - 7.5	7 - 40cm	25 - 60cm
7.5 - 9	10 - 50cm	30 - 70cm
9 - 12	20 - 80cm	50 - 100cm

Table 4.5: Distance between ceiling and detector

4.5.3.2 Coverage Area

The coverage area is defined depending on the room height and the fire risk.

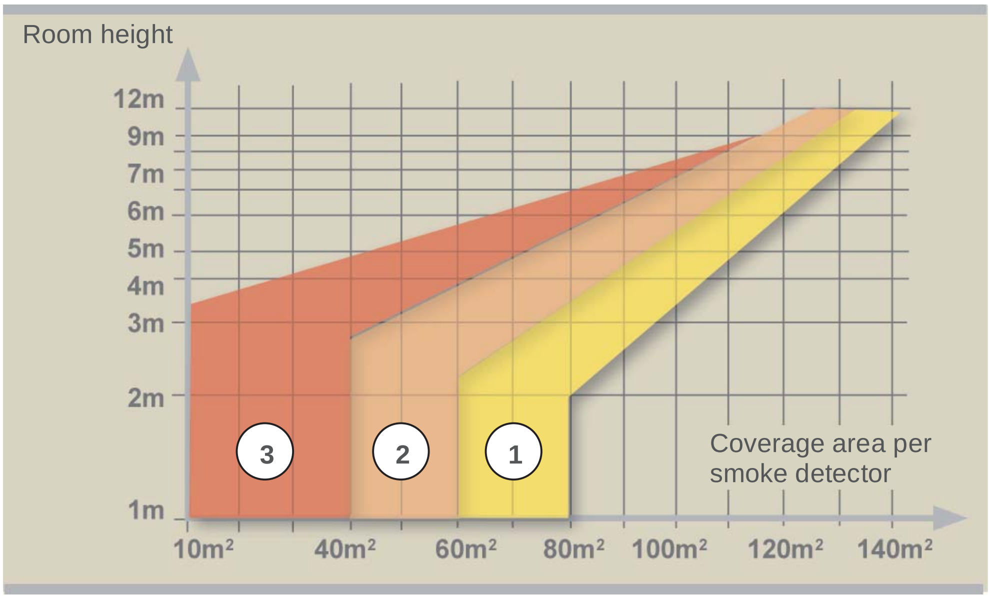


Figure 4.25: Coverage area per smoke detector depending on the room height and the hazard potential

Area 1 with minor hazard potential should only be selected when the following conditions are fulfilled:
- any danger to human life can be ruled out
- neither valuable property nor irreplaceable goods are stored in the area
- the fire risk is very low
- other fire protecting measures prevent possible fire propagation
- no hazard can be caused in adjacent areas, for example by corrosive decomposition products

Area 2 with medium hazard potential can be selected for most applications.

Area 3 with high hazard potential is recommended in the following cases:
- increased danger to life
- valuable property or irreplaceable goods are stored in the area
- the loss of goods or installations could endanger the economic existence of the owner
- the fire risk is classified as “high”

In artificially ventilated rooms, natural smoke propagation is impaired. The higher the air movements, the more the smoke particles are discharged without the possibility of a uniform smoke concentration building up. This reduced and locally different smoke distribution leads to a delayed response of the fire detection system, which may partially be compensated by reducing the coverage area and increasing the detector sensitivity.

4.5.4 Point-Type Heat Detectors

In contrast to smoke detectors, heat detectors must always be installed at the highest point on the ceiling. To avoid false alarms and at the same time guaranteeing an acceptable response behavior, the static response temperature of heat detectors must be between 10°C and 35°C higher than the highest temperature that can occur by natural or operational developments in the immediate vicinity of the detector.

4.5.4.1 Impact of the Room Height

Heat detectors of class A1 may normally be installed at room heights up to 7.5m. The temperature at the ceiling, directly above the fire seat, decreases by the power of two with increasing room height. This means that the response sensitivity of the detectors must be set higher with increasing room heights, or else, that a larger fire would be necessary to trigger alarm.

4.5.4.2 Coverage Area

The coverage area depends on the size of the room to be monitored and on the inclination of the ceiling. With inclined ceilings, the heat ascends along the ceiling inclination and up to the highest point, resulting in heat concentration in the ridge. For this reason, both the basic coverage area and the detector distances may be increased with inclined roofs. The maximum admissible distance between detectors (s), or between a detector and the wall (½s) depends on the coverage area and the roof inclination.

Basic surface area of the room to be monitored	Maximum coverage area (A_M) and maximum distance between detectors (s)					
	Roof inclination (angle α)					
	< 10°		10° - 20°		> 20°	
	A_M	s	A_M	s	A_M	s
≤ 30m²	30m²	7.8m	30m²	9.2m	30m²	10.6m
> 30m²	20m²	6.6m	30m²	9.2m	40m²	12.0m

Table 4.6: Coverage areas and distances between heat detectors

The distances between detectors and walls, equipment or stored goods must not fall below 0.5m, with the exception of corridors, channels, ducts or similar constructions with a width below 1m. If there are any girders, beams, etc., or air conditioning ducts closer than 0.15m under the roof, the lateral distance of at least 0.5m must be considered as well.

4.5.5 Linear Smoke Detectors

Direct and unhampered visibility between the detector and the reflector must be ensured. The monitoring ray must not be interrupted by moving objects such as overhead cranes, ladders, etc.

The detector must be secured in a way that it is fixed and inflexible. It must be taken into account that flexible wall constructions are unsuited, as a too large deviation of the monitoring ray makes reliable detection virtually impossible. Concrete and brick walls meet these prerequisites, whereas wood or steel constructions are mostly unsuited, as they may be affected by temperature or moisture changes, wind or snow pressure.

4.5.5.1 Impact of the Room Height

Heat cushions below the ceiling can prevent ascending smoke from reaching the ceiling. Linear smoke detectors must thus be installed below a heat cushion to be expected (see Table 4.5 on page 106). With room heights above 12m, the distance to the ceiling should be 60 to 120cm.

To make sure that smoldering fires or smaller fires with low fire thermals can be detected in high rooms, a second and possibly third detector must be installed at the assumed level of the smoke propagation of a smoldering fire. This differentiation in levels becomes important in rooms higher than 6m.

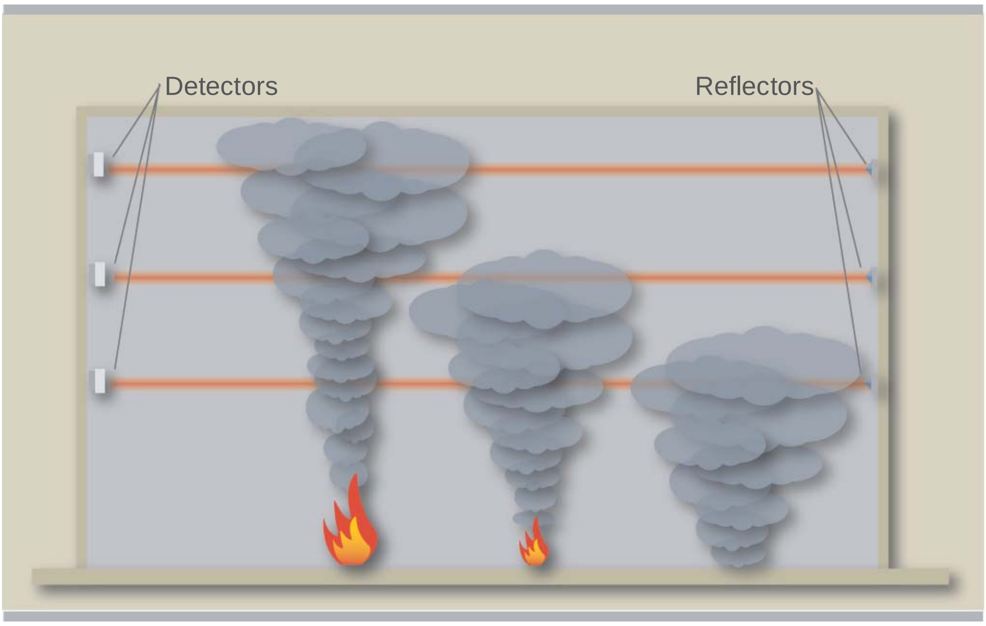


Figure 4.26: Detection of smoldering fires in high rooms

The table below exemplarily shows the detector mounting height for three different room heights.

Detection level / Room height	Upper	Medium	Lowest
6m	~ 6m	3 - 4m	–
12m	~ 11m	6 - 7m	–
20m	~ 19m	6 - 7m	~ 12m

Table 4.7: Mounting height depending on the room height

4.5.5.2 Coverage Area

The coverage area is determined by the distance between the detector and reflector and by the horizontal distance between the detectors. For linear smoke detectors, a maximum distance of 100m between the emitter / receiver unit and the reflector is admissible. The coverage width may be enlarged due to the smoke propagation with increasing room height.

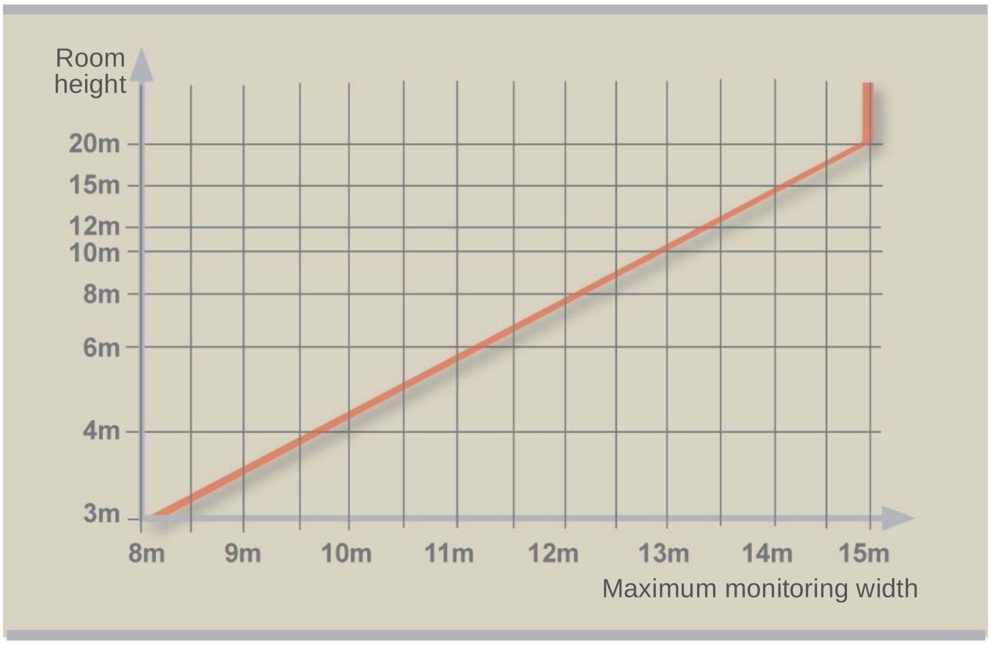


Figure 4.27: Monitoring width depending on the room height

The values given here apply for rooms with a low fire risk. To cover larger risks, the monitoring width should be half the value shown above.

4.5.6 Aspirating Smoke Detectors

ASD systems are applied for room monitoring (storage rooms, cooling facilities, hangars, etc.) and for object monitoring (control panels, IT and telephone facilities, radio stations, etc.).

4.5.6.1 Sensitivity

If a fire occurs in a room, the smoke ascending due to the thermal conditions is gathered by the suction openings and is guided to the smoke detector via the pipe system. The ASD triggers an alarm as soon as the average smoke concentration of all suction openings exceeds the alarm threshold. It does not matter whether this value is caused by very high smoke concentration at one suction opening or by a slightly higher smoke concentration at several suction openings.

The required ASD sensitivity can be calculated by means of the following formula:

$$S_{ASD} = \frac{S_{DP}}{N_{DP}} \times N_{DPS}$$

S_{ASD} = required sensitivity of the ASD sensor

S_{DP} = sensitivity at the point of suction as required by the fire protection concept

N_{DP} = selected number of suction points in the pipe system

N_{DPS} = accepted smoke propagation (number of suction points in the smoke)

As a general rule, ASD systems are classified in the following sensitivity categories:

– normal sensitivity with a smoke sensitivity of 1.0 to 0.1%/m
– high / highest sensitivity with a smoke sensitivity of 0.1 to 0.005%/m

If a fire shall be detected as early as possible, the ASD system must trigger an alarm as soon as there is smoke at one suction point. Such systems usually require a very high ASD sensitivity.

In room monitoring, an alarm is often accepted even if the smoke propagation is already so advanced that the smoke is aspirated by more than one suction point. If smoke reaches two or three suction points, twice or three times as much smoke is detected by the ASD. This is called accumulative effect or smoke accumulation. If an alarm is also accepted when larger smoke propagation has already taken place, an ASD system with lower sensitivity can be chosen.

Example: Recycling Hall

An ASD system shall be installed in a recycling hall to detect medium-sized fires. The following preconditions are specified:

- The response behavior shall be similar to a system with point-type smoke detectors (sensitivity at the suction point: 3%/m).
- The monitoring area of $800m^2$ shall be covered by a pipe network with 10 suction points.
- Alarm shall be triggered when the smoke on the ceiling reaches 3 suction points.

Therefore, for this example an ASD sensitivity of (3/10) x 3 = 0.9%/m is needed.

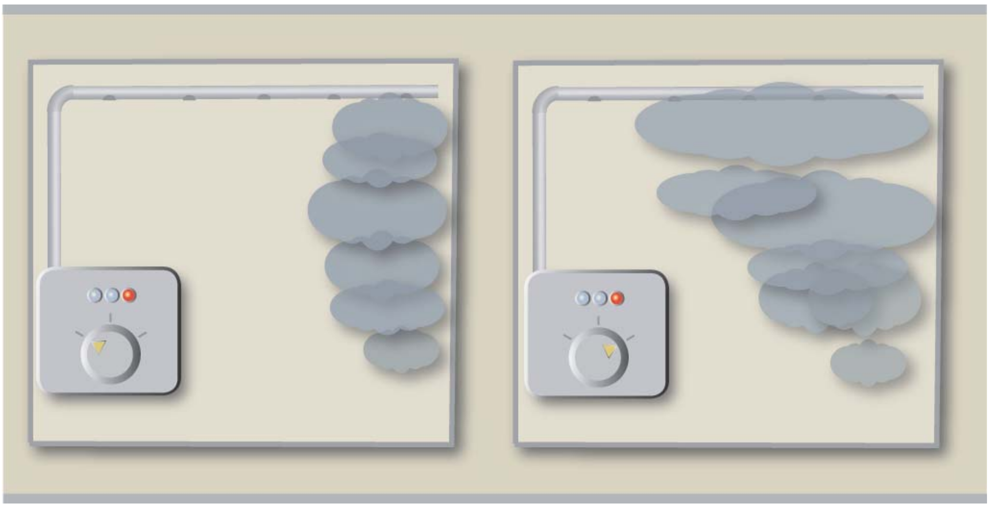


Figure 4.28: Detection with accumulative effect in a hall

4.5.6.2 Room Monitoring

With normal room monitoring, the pipe system and the suction points are selected in a way that each suction point has a coverage area of 40 to 80m^2, which is comparable to point-type smoke detectors. The pipe system is mounted below the ceiling. In false floors and suspended ceiling with a corresponding combustible load, the pipe system is mounted in such a way that the suction points are at the highest possible point.

Due to the large air volume, strong smoke dilution can be observed in large high rooms such as storage rooms, atriums or hangars. If a fire in such a room shall be detected at an early stage, a correspondingly sensitive system must be chosen. In addition, in high rooms, heat cushions often occur below ceilings, caused by strong solar radiation or by air warming due to fire. Such heat cushions partially or completely avoid that the smoke reaches the ceiling. This must be taken into account in placing the ASD suction pipes (see Table 4.5 on page 106).

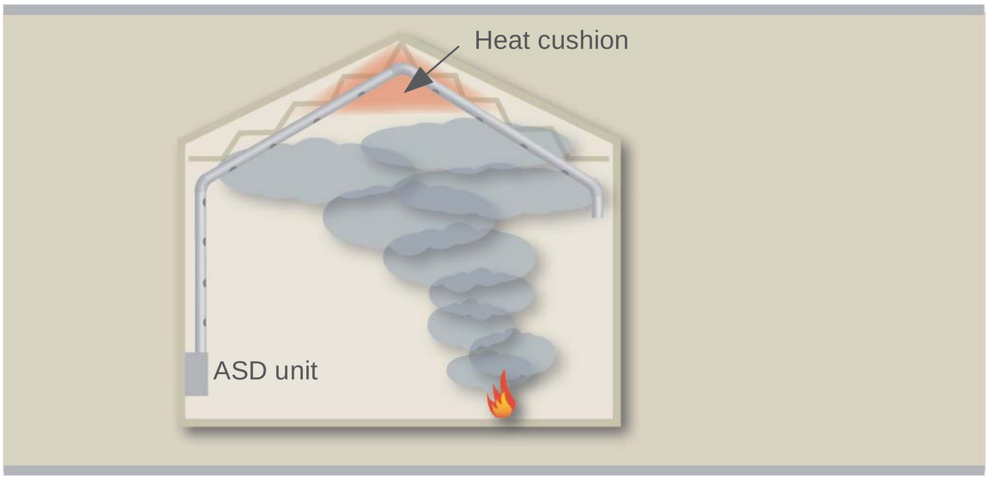


Figure 4.29: Pipe system below an inclined roof

In high storage rooms, the suction pipes are preferably mounted vertically. This way, the heat cushion effect can be largely neutralized and, in addition, smaller fires in the storage racks can be detected early thanks to this arrangement.

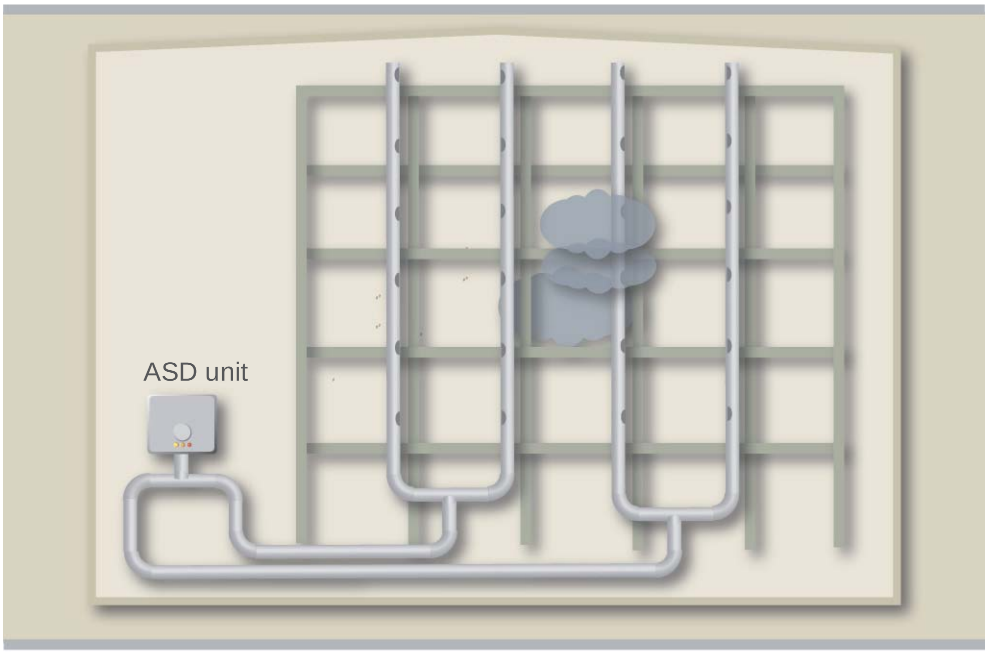


Figure 4.30: Pipe system in a high-rack storage building

When planning ASD systems in special areas, additional points briefly mentioned below must be taken into consideration.

Application in Strongly Soiled Environments

In addition to maintaining a reliable detection, ASD systems must also be resistant to soiling in rough environments. Smallest particles are deceptive elements for optical systems, leading to false alarms or, in the worst case, impairing the system in such a way that it can no longer work reliably. For this reason, filters are built in the pipe system in rough environments, filtering dirt particles before they can penetrate the measuring system. In strongly soiled environments, the suction pipes are additionally purged periodically to clean them from dirt or deposits. This guarantees a reliable transport of the aspirated air to the measuring system.

Application in Areas with High Air Circulation

Air conditioning equipment or air recycling systems can cause high air circulation, which in turn sometimes produces essential smoke dilution, as the smoke is mixed with fresh air before it reaches the detectors. In such conditions, it makes sense to use ASD systems with increased or very high sensitivity. It also makes sense to feed a sample of exhaust air to the ASD, in addition to the “pure” ambient air. The exhaust air is monitored directly before reaching the room ventilation system’s outlet opening.

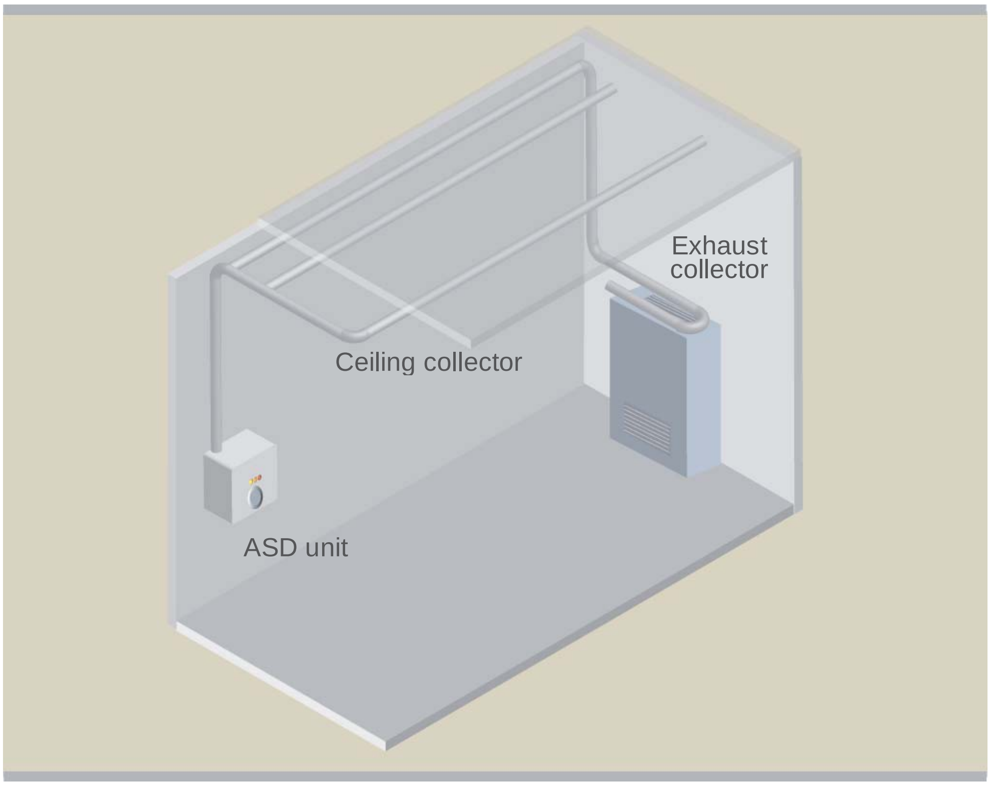


Figure 4.31: Pipe system with high air circulation

Application in Humid Environments

In humid environments, water traps with sluice valves are installed in the suction pipe.

Application in Refrigerating Warehouses

Due to the very dry air and the highly combustible isolating and packaging material, refrigerating warehouses constitute a high fire risk. A fire in such a facility may propagate quickly and cause a lot of damage, therefore early detection of a spreading fire is of utmost importance in this case. In refrigerating warehouses, ASD with high sensitivity are normally used. To prevent frost formation on the suction openings, the pipe systems are provided with a blow-out mechanism. This is of special importance in the entrance area where high relative air humidity prevails due to the air circulation, resulting in a high tendency of frost formation.

Application in Areas Prone to Vandalism

In areas prone to vandalism, the suction pipe is mounted in the ceiling. Only very small, almost invisible holes are present in the monitoring area. This type of installation can often be found in penal institutions.

Application in Culturally Significant Buildings

In culturally significant buildings, for example with historic ceilings, point-type fire detectors are often not wanted for aesthetic reasons. In buildings such as churches, cathedrals, museums, libraries or other historical buildings, ASD systems are increasingly applied, systems in which the pipe system is integrated in the ceiling and is thus invisible. The same applies to sophisticated modern buildings, such as concert halls, hotels and office buildings.

4.5.6.3 Object Monitoring

IT systems, server racks, telephone systems, radio stations and other electronic or electric facilities are potential fire risks due to their relatively high power consumption. A typical electric fire is usually preceded by a rather long smoldering phase, with the normally low smoke volume being additionally diluted by ventilation. If this low smoke volume can be detected early enough, it usually suffices to disconnect the endangered equipment from the power supply. This is exactly where ASD systems in object monitoring come into effect: An incipient electric fire must be detected as early as possible so that appropriate countermeasures can be initiated and possible damage can be minimized. ASD systems for object monitoring are designed in such a way that at least one suction opening is provided in each object, for example in a server rack or control panel.

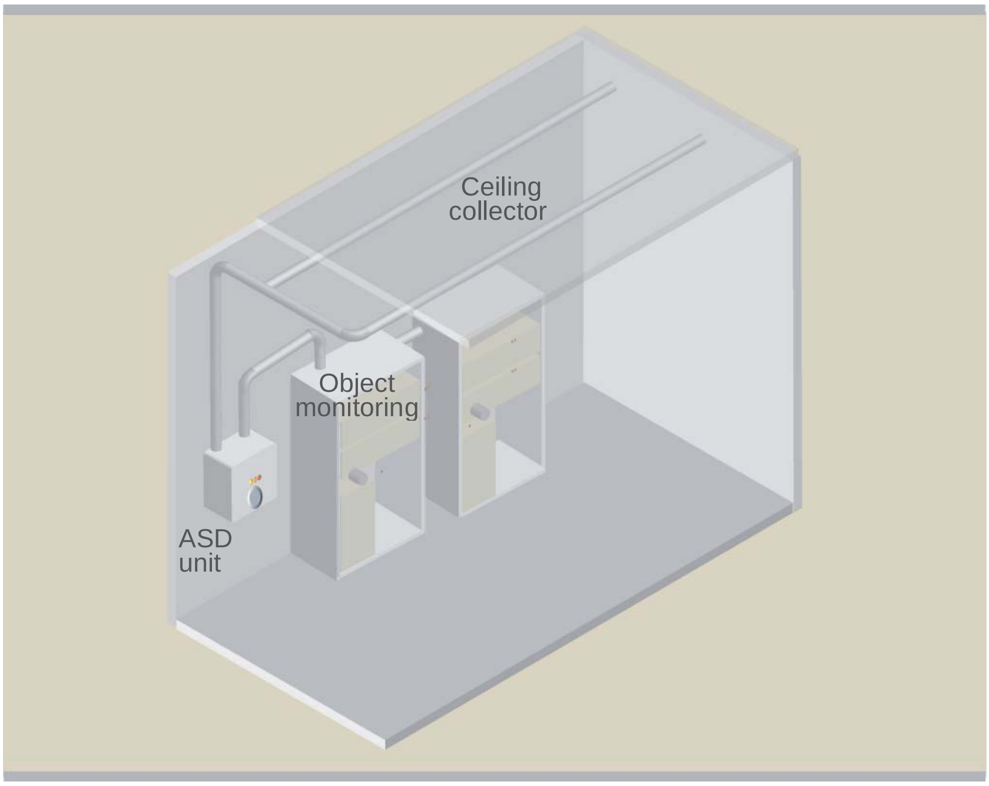


Figure 4.32: ASD for object monitoring

4.5.7 Flame Detectors

The electromagnetic radiation of possible fires must reach the flame detector. Within the range of sight, this is ensured by direct irradiation. If the direct view is blocked, IR flame detectors can still detect due to the reflection on the metal surfaces. UV flame detectors, however, are powerless in such cases, as UV is not, or only rarely, reflected. It must be taken into account that direct infrared radiation is always many times stronger than indirect infrared radiation. Flame detectors should thus always be installed within sight of the entire monitoring area and are thus preferably placed in a high corner of the room.

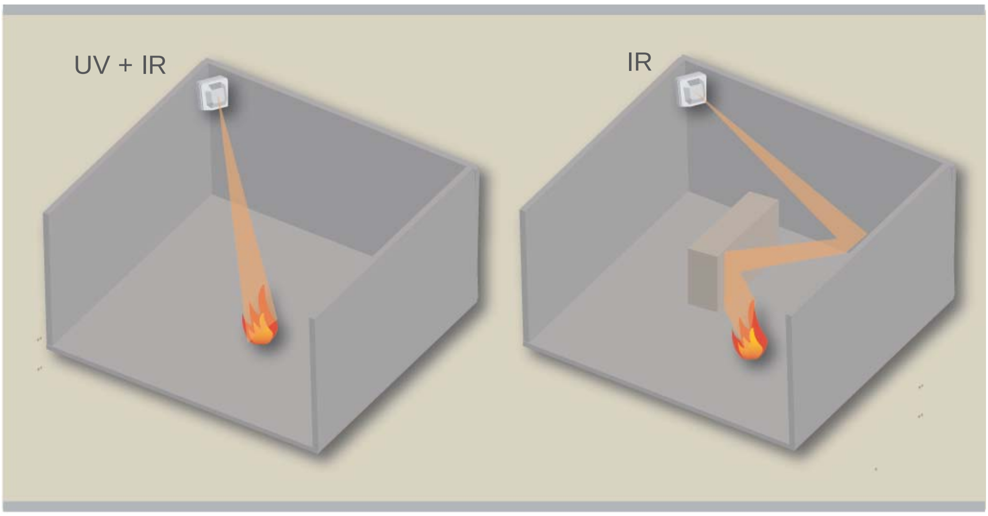


Figure 4.33: Flame detectors with direct and indirect visibility

When placing the flame detectors, equipment or obstacles such as wings must be taken into consideration. In a hangar, the area underneath the wings must be monitored by flame detectors as well.

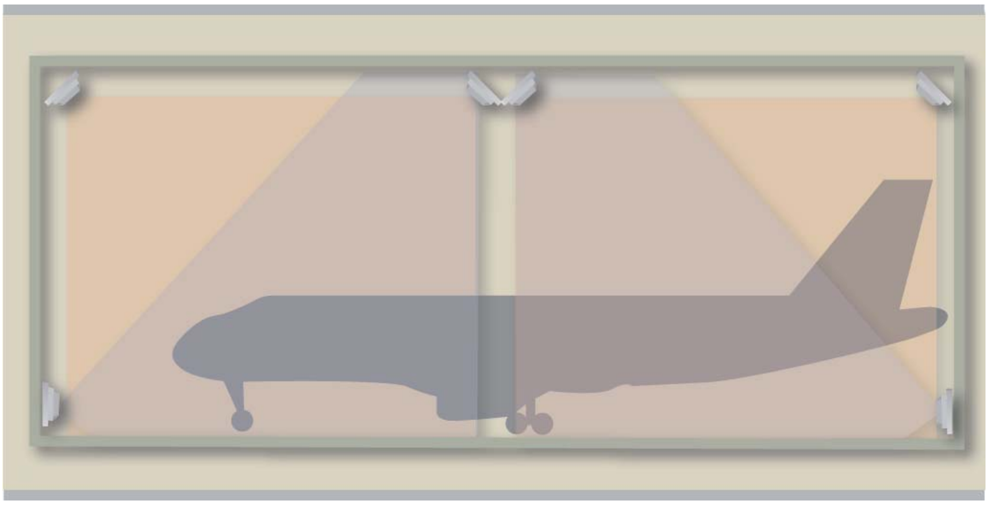


Figure 4.34: Positioning flame detectors in a hangar

If several flame detectors are required in one room, they should be arranged so that there is a high redundancy, that is, the monitoring areas of the individual flame detectors should overlap.

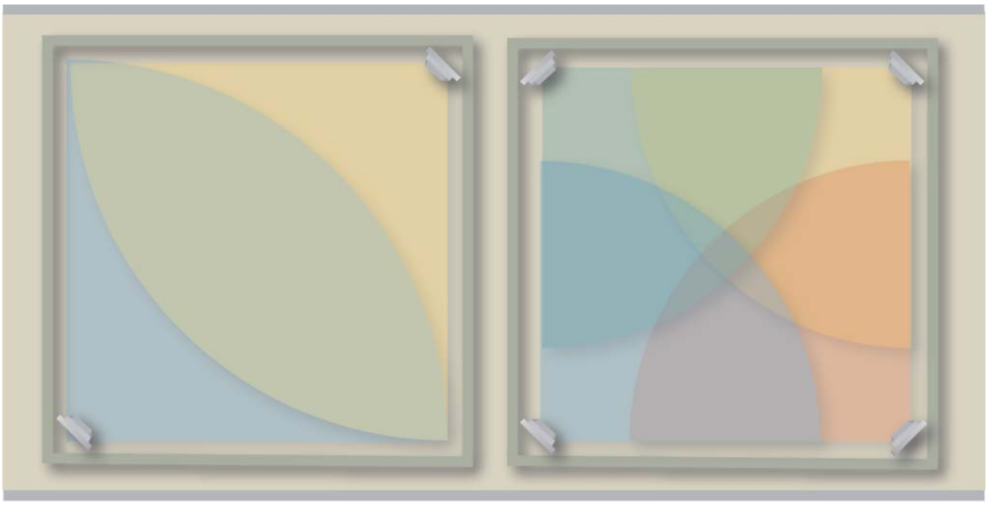


Figure 4.35: Arranging flame detectors in large rooms

4.5.7.1 Detection Distance

Of essentially greater significance than the maximum admissible room height is the detection distance in the project planning of flame detectors. The detection distance is the distance between the detector and the farthest point that still needs to be monitored. The response sensitivity decreases approximately to the second power with increasing distance. From this, it follows that the response sensitivity of the flame detector must be significantly higher or that a larger, open fire is necessary to trigger alarm.

This is clarified by the following examples:

- If the distance from the flame detector to the fire is 20m. For example, a flame detector is capable of detecting a fuel fire with a surface area of $0.025m^2$, a flame height of 0.6m and 18kW power.
- If the distance from the flame detector to the fire is 70m, a fuel fire with a surface area of $0.25m^2$, a flame height of 2.2m and 400kW power is required to ensure the detector triggers alarm.

4.5.7.2 Monitoring Area

Based on the maximum size of the fire to be detected and the response sensitivity of the detector, the maximum detection distance (d) is determined. As flame detectors with an angle of visibility of 90° are usually installed at an inclination angle of 45°, the maximum detection distance (d) of the room diagonal corresponds to a cube. As this is by $\sqrt{3}$ longer than the side (a) of the cube, the maximum fixation height is $a = d/\sqrt{3}$. This results in a monitoring area of $a^2 = ⅓d^2$.

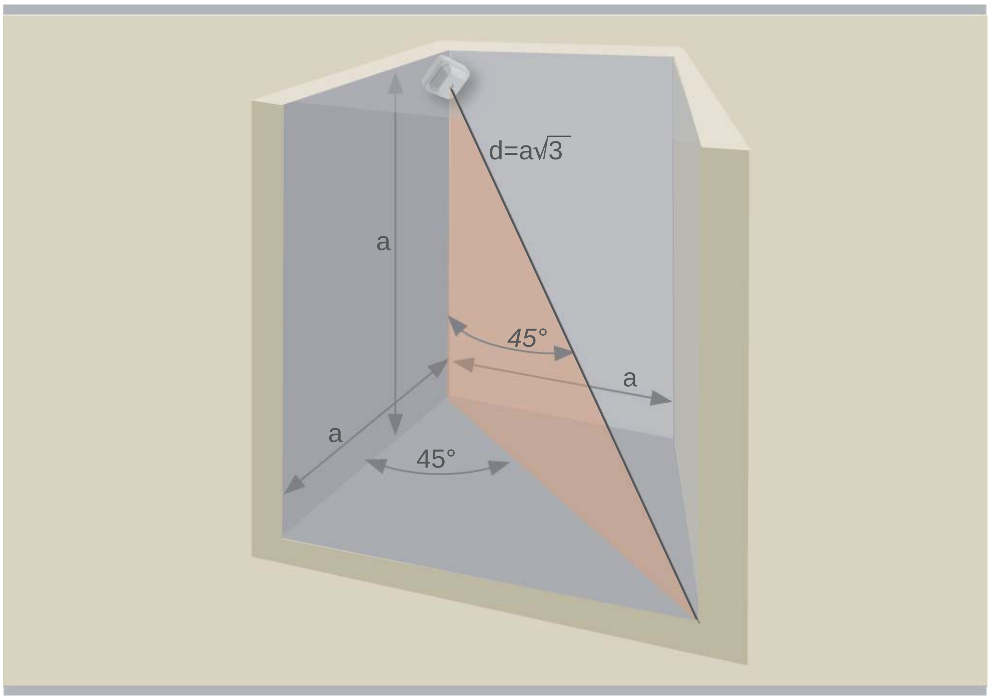


Figure 4.36: Monitored cube of a flame detector

Depending on the ratio of room surface and room height, it might make sense to choose an inclination angle smaller than 45°. If, however, an angle > 45° is chosen, the area directly underneath the detector with a visibility angle of 90° is no longer within the visible range and thus not monitored.

4.6 Fire Detection Control Unit and Peripheral System

The fire detection control unit evaluates the signals transmitted by the peripheral devices, it controls the fire alarm and control installations and is also the point of interaction between the operator and the system.

The term “peripheral system” summarizes the networking of the fire detection control unit with the peripheral devices, such as fire detectors, alarm devices and fire control installations.

Commissioning reveals how easily and flexibly a fire detection control unit can be parameterized according to customer needs. Some of these aspects should already be taken into account when evaluating the fire detection system.

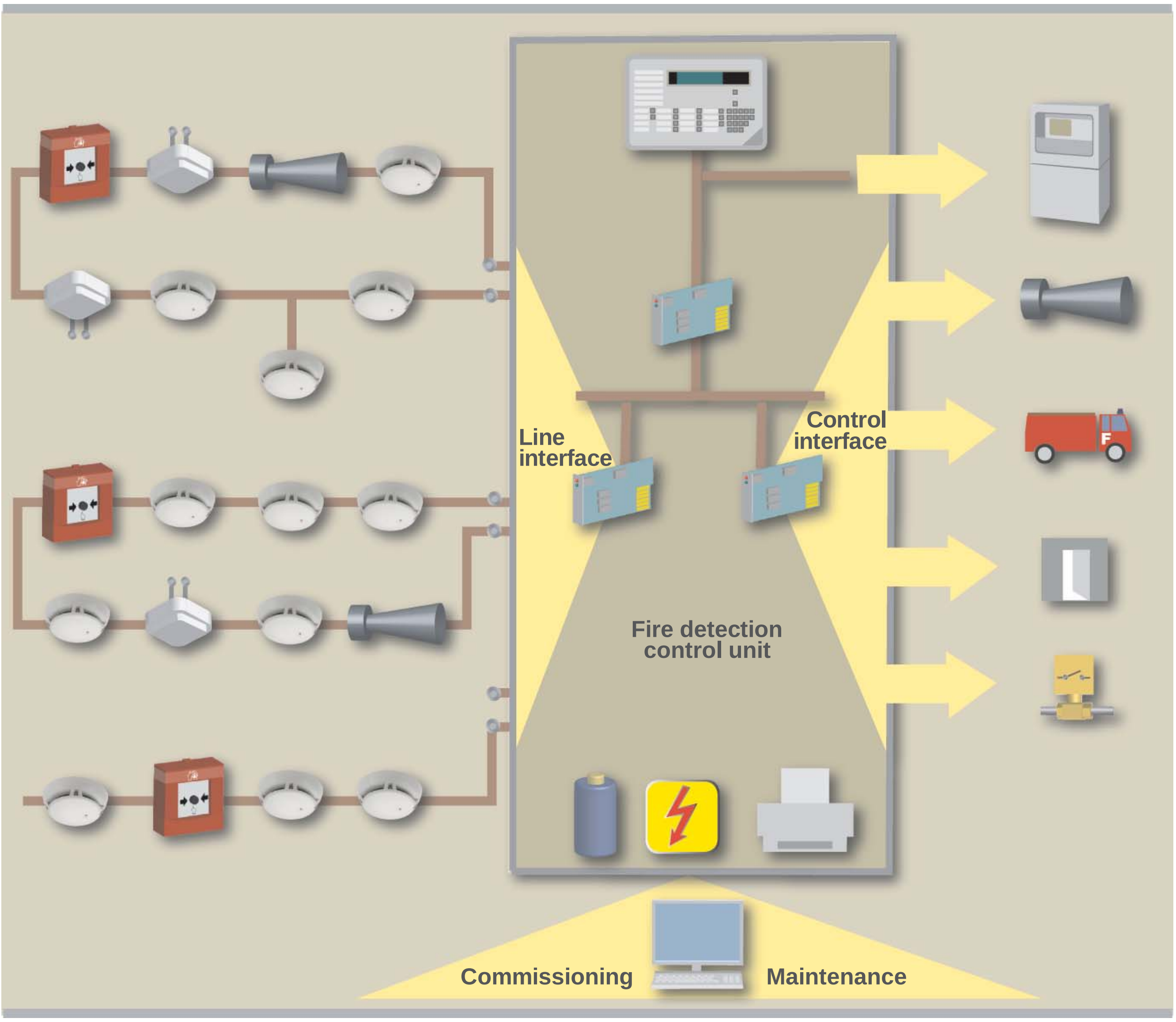


Figure 4.37: Fire detection control unit and peripheral system

4.6.1 Control Unit

The fire detection control unit is the core element of each fire detection system. Compact and medium-sized systems usually have only one control unit, whereas more complex systems often consist of several networked control units. This makes it possible to act upon all control units by one single procedure. In such a system, sensors and actuators can ideally be allocated to different control units, and control can be performed so that it acts on several control units. In addition, the transmission of fire alarms and faults to the receiving equipment can be effected centrally by a main control unit integrated into the network. This essentially reduces the connection fees and dedicated line fees. How comprehensive the functionality is in the specific case must be clarified in advance for each individual system.

4.6.1.1 Setup

Each fire detection control unit comprises a minimum of five components:

- **Main processor:** The main processor is the heart of every fire detection control unit. It coordinates and controls the entire fire detection system.
- **Operating panel:** This panel consists of indicating, acoustic and operating elements. The indicating and acoustic elements inform the operator on the system status (alarm, fault, operating mode, etc.). The operating elements make it possible to operate the system by acknowledging messages, or switching from unmanned to manned mode.
- **Line interface:** The line interface communicates with the peripherals and transmits information to the main processor.
- **Control interface:** The control interface transmits the information received (e.g. fire door open) to the main processor and activates the control outputs required by the main processor (alarm devices, fire control installations, etc.).
- **Power supply:** The power supply unit provides the energy required for the fire detection system.

Depending on the requirements and size of the fire detection system, the setup of the fire detection control unit can largely vary. For a small hotel with 30 rooms, for example, a control unit will suffice in which the main processor, operating unit, line interface and control interface are combined on one board. Complex systems are equipped with several line and control plug-in units. With such systems, remote operation and the possibility to operate the system from different locations is frequently required. Such operating terminals are connected to the control unit via a control unit bus designed in compliance with the highest safety standards.

Alternatively, there is the possibility of visualizing the control unit’s user interface by a mere software solution on a PC. The connection to the PC can be established by a LAN, for example (see Glossary, starting on page 297). This solution also makes it possible to indicate and operate several networked control units on the monitor of a danger management system (see chapters 7.2ff starting on page 240).

4.6.1.2 Power Supply

In compliance with EN 54, two independent energy sources must guarantee the power supply to the fire detection control unit. Both energy sources must be sized such that in case of failure of one source, the operation of the system and the alarm equipment can be maintained for a predefined period of time. The following aspects must be taken into account:

- One of the two energy sources must be a permanent mains supply, the second one a battery or equivalent.
- Parallel operation is mandatory, with the appropriately sized charging unit feeding the fire detection system and at the same time charging the batteries connected in parallel.
- The mains power supply of the fire detection system must be effected via a separate, safe supply line.
- Devices that do not constitute part of the fire detection system must not be connected to the system's power supply!
- The battery's capacity must be such that unimpaired operation of the fire detection system is possible during the required emergency operating time and that the alarm devices can still be fed for a minimum of 30 minutes after the emergency operating time has expired.
- The use of satellite power supply units is admissible. However, they must be monitored for permanent operability.
- Messages received from the satellite power supply units must be indicated on the control unit, just like fault signals.

Regarding the detection of fault signals and troubleshooting, the following emergency operating times are recommended:

Emergency operating criteria	Duration
Without fault signal transmission	72 hours
With fault signal transmission, unmonitored line	24 hours
With fault signal transmission, but with permanently manned signal receiving center at the installation location	12 hours
With fault signal and monitored line	12 hours
Secured mains connection (e.g. emergency power Diesel generator for 24h operation) and fault signal transmission	4 hours

Table 4.8: Emergency operating times as required by EN 54

4.6.1.3 Functions

A state-of-the-art fire detection control unit must feature the following:

- Easy and safe system operation.
- Free adaptation of the control unit organization to changing customer requirements.
- Free programmable control outputs to use fire control installations.
- Manufacturer-specific battery charging characteristics and periodic endurance testing of the batteries, in order to achieve optimum charging conditions and a longer service life of the emergency power batteries.
- Real-time clock with date and automatic summer- / wintertime changeover.
- Event memory storing hundreds of events, sorted by information category, and making them available on demand.
- Integrated emergency operating functions so that safe fire detection can still be ensured in case of failure to a signal processing unit.

4.6.1.4 Operation

The user interface of a fire detection control unit must be set up so that the basic functions such as alarm or reset alarm are easy to understand and to operate. This makes sure that such operations can also be performed by persons who rarely have to work on the system or who have received only elementary instructions.

Such a man-machine interface places high demands on an ergonomic arrangement of the operating elements, on the representation of messages and on a user-friendly operating structure. This is why state-of-the-art fire detection control units are provided with so-called “soft keys“ – function keys for the display of context-related commands used with the respective application. In case of fire, for example, the location of the fire is indicated, and on the operating elements only functions such as ”Acknowledging the alarm” or ”Resetting the alarm” are released and the corresponding countermeasures texts are displayed.

Operation of a fire detection control unit not only comprises alarm processing. Functions such as processing faults, switching from manned to unmanned, or switching off detectors are other functions of a fire detection control unit. Since functions like switching off detectors can impair safety, they must only be performed by authorized and accordingly trained staff. State-of-the-art fire detection control units thus offer the possibility of releasing commands in the menu structure for some authorization levels only. The table below shows an example with 4 authorization levels.

Level	Authorization	Authorized persons
1	- Acknowledging messages - Switching off acoustic elements on the operating panel - Switching to manned / unmanned	Competent person, e.g. janitor
2	- Commands from authorization level 1 - Resetting alarms - Switching off detectors	Trained person, e.g. company electrician
3	Switching detectors into revision mode, commands from authorization levels 1 and 2	Electrician or expert for danger management systems, e.g. maintenance engineer
4	Opening the fire detection control unit, exchanging modules, changing the system parameter settings, commands from authorization levels 1, 2 and 3	Electrician or expert for danger management systems, e.g. maintenance engineer acknowledged as installer

Table 4.9: Authorization levels for a fire detection control unit

4.6.1.5 Location

For the fire detection control unit, a location close to the main entrance or the fire brigade access of the building to be monitored should be chosen. This location must be agreed upon in advance with the organization (e.g. fire brigade) accepting the fire detection control unit. It often suffices to place the fire department control panel in the fire brigade’s main access, as in this case the fire detection control unit can be placed in any room easily accessible for the wiring arrangement.

In larger building complexes where networked fire detection control units are used, they are often installed in decentral locations, so that the lines to the detectors and other peripheral devices can be kept as short as possible.

To keep influencing factors which might lead to false alarms or faults as low as possible, only locations free from high electromagnetic interference (EMI) may be selected for the fire detection control unit.

4.6.2 Peripheral System

Devices that are not an integral part of the fire detection control unit are allocated to the peripheral system. In addition to the connected detector lines and the components on these lines, the peripheral system includes the complete supply network with alarm devices, fire detection control installations and fire department control panels.

4.6.2.1 Supply Network

With fire detection systems, the safety and reliability topic deserves top priority. This applies especially to selecting and installing the supply networks to the fire detectors, alarm devices, fire control installations, etc. When selecting and installing, the following aspects must be taken into account:

- The peripheral devices must be operated via a separate supply network.
- Although state-of-the-art detector systems are highly immune to electromagnetic interference, the detector lines should be separated from other lines and systems.
- To minimize electromagnetic interference acting on the system, always use twisted pair cables with new installations.

4.6.2.2 Detector Line

The detector line links the peripheral devices to the fire detection control unit. Over the last decades, information technology has led to major changes that are still relevant for essential differences between system types in use today.

Topologies

The peripheral devices or line components of a fire detection system are connected to the fire detection control unit via a stub or loop line. Additionally, modern fire detection systems make it possible to use T-tabs without additional elements, which increases the flexibility in wiring arrangement, at the same time reducing system costs.

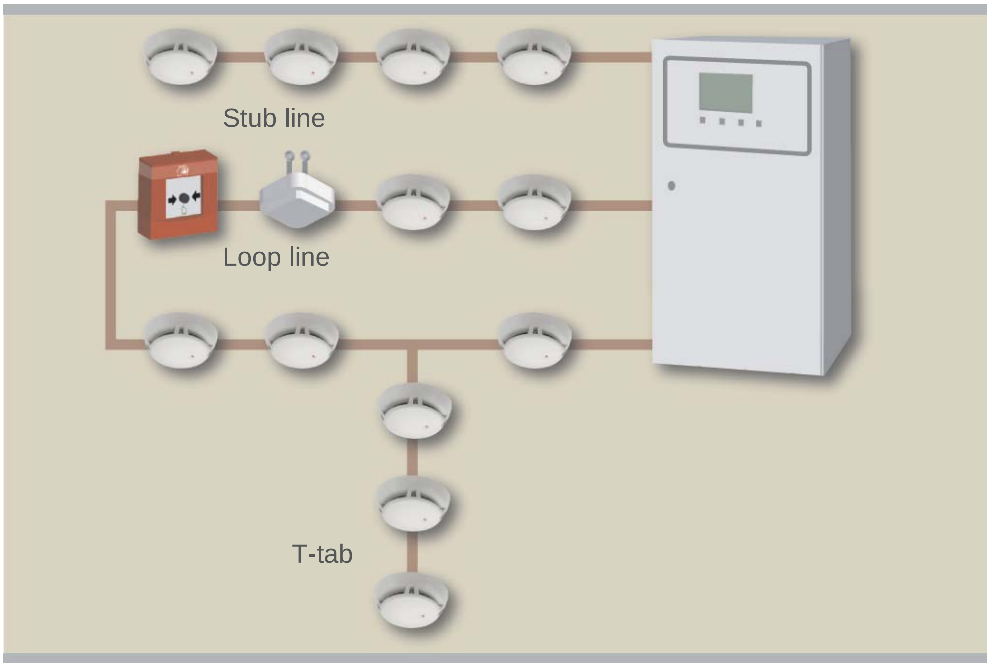


Figure 4.38: Fire detection control unit with different detector lines

For reasons of safety, stub lines today are only used in systems where fire detectors with conventional technology are applied or where existing lines are reused. Individually addressed elements on a loop line ensure a considerably higher fail safety of peripheral devices. In case of an open line, all elements remain fully operable, as the control unit may communicate with the elements from both sides of the loop. When all connected elements (fire detectors, input / output modules, alarm elements) use a separator function, the entire system remains fully operable even in case of a short-circuit, as the short-wired line segment is decoupled by the separators. Otherwise, at least every 32nd element must be equipped with a separator conforming to EN 54.

Collective Connection

With a collective connection, all detectors with conventional technology are connected in parallel to the same stub line (see section 4.3.3.1 on page 93). To indicate an alarm or a fault, a detector increases its power consumption. This change is evaluated correspondingly in the control unit.

With a collective connection, the following aspects must be taken into account:

- Only one alarm message or fault signal can be evaluated per stub line, as the detectors are not individually identifiable.
- Communication is unidirectional, from the detector to the control unit.
- In compliance with the EN 54 standard, a maximum of 32 devices may be connected to one line.
- A mixture of automatic and non-automatic fire detectors on a stub is not permitted.
- A line terminating element is installed at the end of a stub, with a monitoring current flowing through this element. Based on this principle, the fire detection control unit can monitor the line up to the line terminating element, but not the connection to each individual detector.

Collective addressing gradually disappears from the market and is offered today only as a standard connection for simple, compact fire detection control units. When replacing existing systems in collective technology, however, it may still be necessary to continue using the existing supply network. In this case, intelligent detectors with complex signal processing can be applied, which are operated on the stub line in collective mode. Due to the individual parameter setting possibilities, such modern fire detectors can be set to optimum detection behavior. If complete lines shall be retained in a modernization project due to cost reasons, the new control unit must be equipped with the corresponding line modules (see chapter 8.5 on page 275).

Addressable Connection

An addressable connection is a detector line system that can individually address each detector (see section 4.3.3.2 on page 93). This makes it possible to individually indicate each detector that triggers an alarm and to assign a text indicated in case of an event to this detector or detector zone. In addressable technology, the topology types stub, loop or T-tab are principally possible. In some bus systems, T-tabs can be implemented without additional modules, what considerably reduces the costs for installing the supply network.

With an addressable connection, the following aspects must be taken into account:

- If the line is wired as a stub, a maximum of 32 detectors are permitted per stub line, in compliance with the EN 54 standard.
- If the line is wired as a loop, a maximum of 128 detectors are permitted per loop line, in compliance with the EN 54 standard.
- It must be ensured that, in case of a short-circuit, the relevant line segment is isolated and that in case of an open line, access is possible from the opposite side of the loop. The smaller the number of elements that fail in case of a short-circuit, the better, which is why each bus element should contain separator elements.
- There must be a simple solution to localize detectors on the line. In this respect, well-proven solutions are the addressing based on the physical sequence, or the localization based on an unambiguous identification number.

Some features of state-of-the-art addressable bus systems are:

- Direct connection of input and output modules and of indicating and operating elements on the detector line.
- Direct connection of acoustic alarm devices without extra power supply.
- Control of external, additional response indicators by any detector. Assignment to the detector is made via the fire detection control unit. It is also possible that several detectors control the same response indicator (e.g. with multidetector zones).
- Automatic self-monitoring: The system periodically checks whether all devices are available and operate correctly.

Costs

The costs for installing a fire detection system are an integral part of the overall costs. To keep wiring costs as low as possible, it is important that a fire detection system allows for the connection of freely arranged detector lines, no matter whether these are stub lines, loop lines or T-tabs. In addition, it must be taken into account that as many elements as possible can be operated on the same bus and that no extra lines for external power supply are required.

4.6.2.3 Alarm Elements

Optic and acoustic alarm equipment is used to alert people in the danger zone as well as internal intervention forces. Alarm devices can be connected to the control unit either directly or via a monitored output. Some fire detection control units also offer the possibility of connecting addressable alarm devices to the detector line. This has the following advantages:

- The alarm can easily be limited to specific fire sectors (e.g. floors).
- Step-by-step alarm can be accomplished without problems. In case of an alarm, it is possible, for instance, to first locally act upon an acoustic alarm device, for example in a hotel room. After verifying the alarm, all alarm devices in the fire zone can then be activated.
- No additional lines are required for communicating with the control unit and for feeding the elements. This reduces installation costs.
- As the elements on the loop line remain fully operable even in case of open-circuit or short-circuit, no expensive wiring with cables for extended functional maintenance is necessary in most countries.

Alarm elements, such as flashing lights or horns, have limited information contents, which is why voice alarm systems are increasingly used in buildings (see chapters 5.4ff starting on page 166). These systems enable step-by-step alarm and evacuation depending on the situation.

Alarm of external intervention forces like the fire brigade, is accomplished by means of monitored dedicated telephone lines, dialup connection, radio connection, network connection or a combination of these transmission methods.

4.6.2.4 Fire Control Installations

Fire control installations are control functions activating structural and technical equipment with damage-limiting effects in case of fire. Fire control installations ensure that:

- the propagation of smoke and heat is limited
- smoke and heat can be extracted
- escape routes are unambiguously identified
- elevators can be moved to a defined position and can no longer be used
- automatic extinguishing systems are activated

The required systems are activated either decentralized via output modules on the detector line or centralized, directly with monitored outputs such as relay contacts or driver outputs in the fire detection control unit. Acknowledgement signals or the execution of the fire control installations are monitored by allocated inputs.

4.6.3 Commissioning

By commissioning the plant, the fire detection system is configured so that it responds in accordance with the messages received from fire detectors and other devices and acts on the relevant control systems. Short-circuits and open-circuits prevent fast and correct commissioning, which is why the fire detection control unit is commissioned only after a thorough check of the supply network.

4.6.3.1 System Structure

Indication of messages and system operation must be clear and simple for the operator. For this reason, the system structure of a fire detection system is set up according to geographical and organizational aspects. The indication of a fire alarm must precisely describe the fire location, for example “Alarm in main building, roof floor, room 807“.

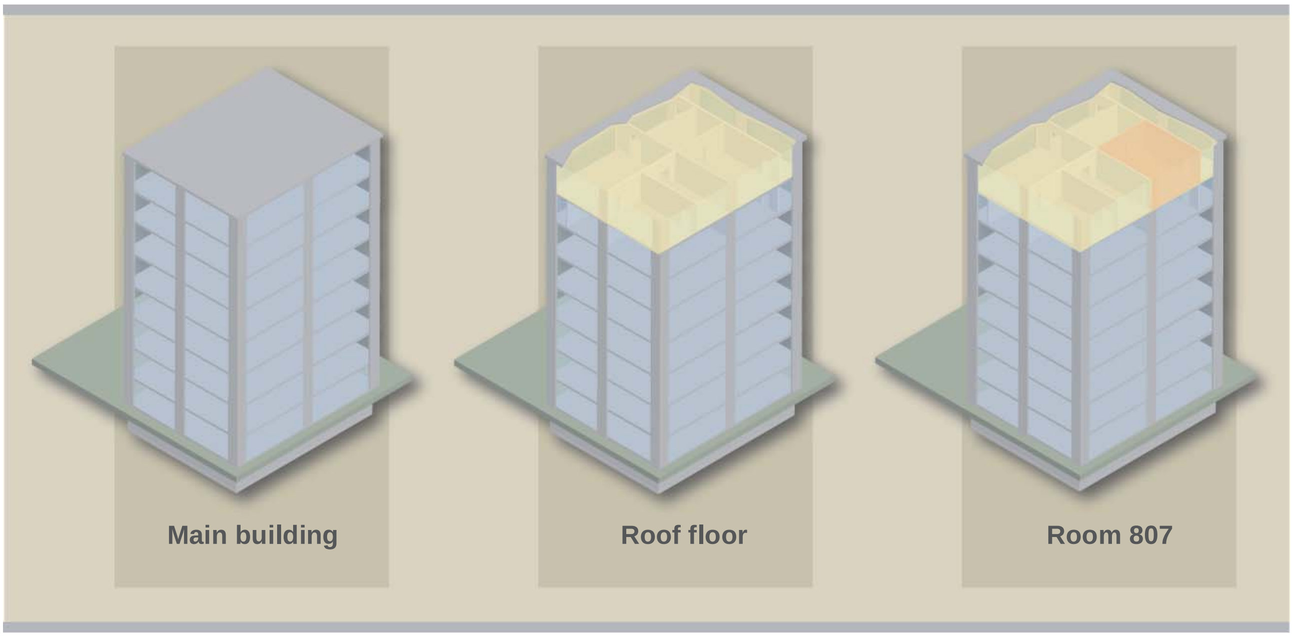


Figure 4.39: Geographic layout (building structure)

In practice, the subdivision of the system structure into a logical and a physical tree has proven worthwhile (see Figure 4.40). This allows for maximum flexibility, completely independent from the effective hardware installation of the detector network. For example, detectors connected to two different loop lines in the supply network can be assigned to the same detector zone.

The logic structure reflects the geographic layout in a system. It may be flexibly adapted to the room exploitation and is independent of the wiring arrangement in the detector network.

The physical structure reflects the hardware. It is defined by the hardware installation and can be read in by means of a commissioning tool with modern fire detection control units.

The commissioning process of a fire detection system links the logic and the physical structures. In doing so, it is defined which device is located where, for example "Smoke detector with ID 253A25 is in room 311".

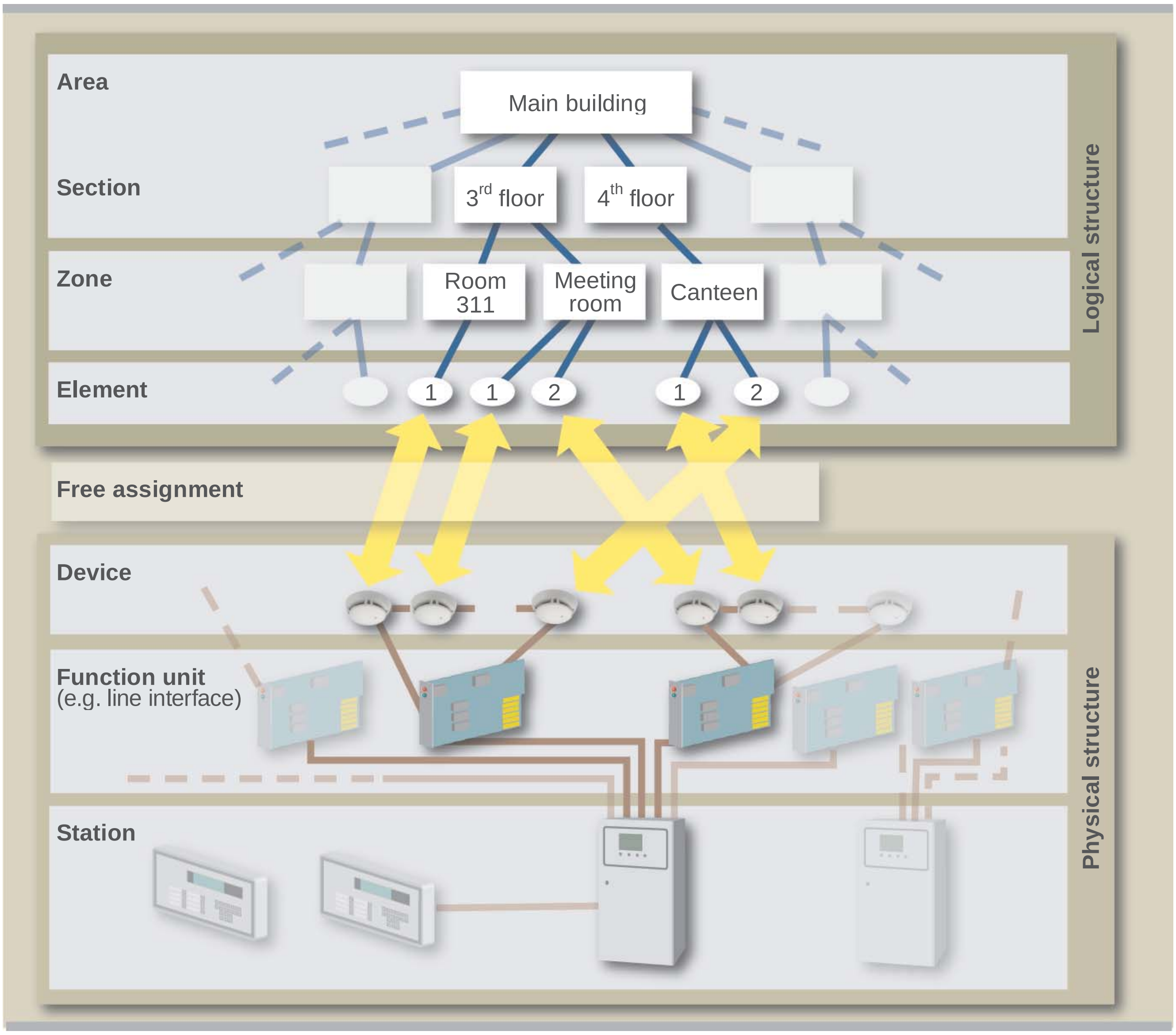


Figure 4.40: Interlinking the logical and physical structure

State-of-the-art fire detection control units make it possible to automatically read in all peripheral devices and modules connected to the control unit. This process is also called a "hardware read-in". The automatically generated data allow for quick and trouble-free commissioning of the fire detection system by means of the commissioning tool. Errors that may occur when the connected devices are acquired manually usually produce high costs and are eliminated by these types of systems.

PC-based commissioning tools make it possible to enter customer texts corresponding to the message and to concisely perform all parameter settings. In addition, it is possible to automatically draw up the complete system documentation thanks to such tools.

4.6.3.2 Detector Zones

To limit fire propagation in a large building, it is divided into different fire compartments by means of structural measures. The intention of such a division also plays a key role in the field of fire detection: Several fire detectors can be combined in a detector zone. By creating fire detector zones, it is possible to easily act upon complete areas, for example to switch off a detector zone or to create multidetector logic (see section 4.6.3.4).

In buildings with large rooms, such as production facilities or open-plan offices, all detectors in the room are combined in a detector zone. In a building consisting of several smaller rooms, such as an office building, the detectors in several neighboring rooms are combined in a detector zone. The detectors in a staircase are equally often combined in a detector zone.

The directives and limits in creating detector zones may differ from one country to the next, which must be taken into account in project planning.

For most countries, however, the following directives apply:

- Detector zones must be created only within the same fire sector.
- Automatic fire detectors and manual call points must be combined in different, separate zones.
- One detector zone may comprise a maximum of 10 manual call points or a maximum of 32 automatic fire detectors.

4.6.3.3 Setting the Parameters of Fire Detectors

Intelligent fire detectors can be ideally adapted to the ambient conditions by selecting the appropriate parameter set. Systems allowing for a time-dependent selection of parameter sets are coming onto the market. This also facilitates the use of optical smoke detectors in areas where conventional systems cause frequent false alarms, for example in discotheques. During operating hours, the fire detectors work with a parameter set that is specially set to the deceptive phenomena on fog from the fog machines used in discotheques. The detectors recognize the pattern of aerosol development created when fog machines are used, evaluate this event as a deceptive phenomenon – in spite of the very high aerosol concentration – and do not trigger alarm.

Outside normal operating hours, the detectors work with a parameter set that already detects lowest aerosol concentrations and is thus capable of detecting a smoldering fire. The parameters are set during commissioning by means of the relevant tool. If the terms of use are changed, for example when the discotheque is changed into a restaurant, the parameter sets of the respective detectors can be adapted directly from the fire detection control unit.

In state-of-the-art fire detection control units, the complete system configuration is stored in an internal memory, so that no manual reconfiguration or adaptation of switch positions is required after replacing a defective detector. The fire detection control unit recognizes that a detector has been replaced and reconfigures this detector with the same parameter settings.

4.6.3.4 Avoiding false Alarms

As already described in detail in chapter 4.3.2, false alarms may be largely avoided by appropriately selecting and positioning fire detectors. Multidetector logic and delayed alarm transmission are functions of a state-of-the-art fire detection control unit additionally supporting efforts for early and nevertheless safe alarms.

Multidetector Logic

Multidetector logic is created wherever considerable deceptive phenomena may occur, or where early fire detection is required for safety reasons, for example in a Diesel engine depot. When only one detector within a detector zone transmits an alarm message, only a prealarm is indicated on the fire detection control unit. Alarm is only indicated when a predefined number of fire detectors transmit an alarm message. In most cases, a two-detector logic is selected, meaning that two alarm messages are required. Multidetector logic is possible as well, meaning that three or four detectors must transmit alarm messages before an alarm is actually indicated. Only now does the control unit actuate the optic and acoustic alarm devices and / or a transmission unit and initiate the appropriate protective measures. As intelligent fire detectors are increasingly used, the significance of multidetector logic is continually decreasing.

Delayed Alarm Transmission

Delayed alarm transmission is also referred to as AVC (Alarm Verification Concept). This is an organizational measure for which the fire detection control unit must provide appropriate programming possibilities. The transmission of fire detection messages to an intervention center is delayed by the AVC until the alarm has been verified by an authorized person.

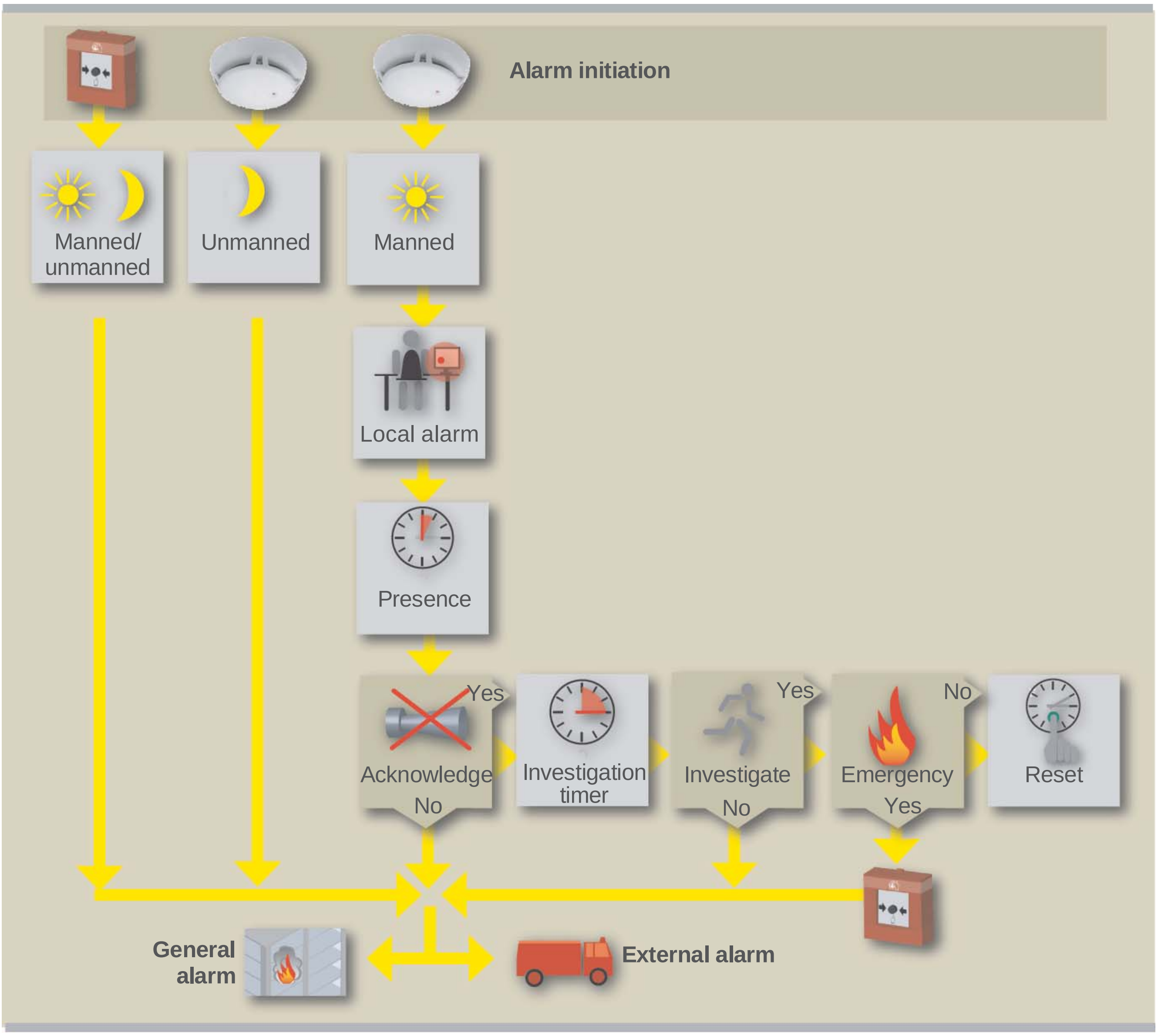


Figure 4.41: Delayed alarm transmission with AVC

When using delayed alarm transmission, the following aspects must be taken into account in most countries:

- Delayed alarm transmission must only be active in system state "Manned".
- An incoming alarm must be acknowledged within a maximum reaction time of 30 seconds. After that, the investigation delay begins.
- The maximum investigation delay must be 180 seconds.
- If another alarm is received during the acknowledging or investigation delay, an external alarm must be transmitted immediately.
- Switching over to delayed alarm transmission (Manned) must be possible only manually. Switching over to "Unmanned" must take place automatically, but manual switchover must be possible as well.
- Alarms transmitted by manual call points must not be delayed.

4.6.3.5 Alarm

After detecting a hazard, the fire detection control unit must trigger an alarm appropriate to the respective hazard and situation. Older or simpler control units merely act upon the acoustic and optical signal transmitters. State-of-the-art control units allow for programming specific, application-related alarms. Such systems make the following settings possible:

- Several alarm devices are combined in a zone.
- Each alarm device can be actuated individually or in a zone.
- Each alarm device or each zone can be actuated depending on the respective hazard (selection of the tonality, sound intensity or flashing frequency).
- Alarm activation and transmission to external intervention forces can be set up in a way that it is only effected after verification of the alarm (delayed alarm transmission).
- In larger building complexes, an acoustic evacuation alarm is initiated only for the relevant fire sector. In all other fire sectors, an acoustic warning signal for the fire alarm can be activated, alerting the people present in that sector without asking them to leave the building.

4.6.3.6 Fire Control Installations

During commissioning, the fire detection control unit must be programmed in a way that, based on the messages received from the fire detection system, it activates the control installations, retarding fire propagation and facilitating the evacuation of people. This includes, among others, closing fire doors and fire dampers, switching on smoke and heat extraction equipment and emergency lighting, or switching off machines and equipment.

To give consideration to this multitude of requirements, the fire detection control unit must include the following performance features:

- The possibility of programming complex controls (AND, OR, NOT functions).
- Flexible selection of control input criteria.
- Sufficient memory space for control zones to give consideration to growing requirements relating to the extent and complexity of control systems.
- Any communication failure between the control unit and a line component, such as an output module, must be recognized by the line component. In doing so, the line component autonomously switches the outputs to so-called “fail-safe position”. For example, fire doors and fire dampers must close autonomously in such a case.
- For fire control installations, the system makes it possible to automatically access the respective documentation – the correctness of the data must be ensured.

4.6.4 Selecting the Suitable Fire Detection Control Unit

When selecting the fire detection control unit, the following questions must be answered as a minimum requirement:

- What is the size of the area the control unit has to serve? How many peripheral devices must be connected?
- Which kind of alarm is expected – simple, target-oriented, or multilevel?
- What control systems shall be possible? How many control systems are required and how high is their complexity?
- Shall the control unit communicate with other control units or with a superordinated system? How easily can it be networked?
- Are any extensions planned during the next years?

Depending on system size and on the answers to the aforementioned questions, a compact or a modular control unit can be chosen. Compact control units are more economic, but rather limited with regard to flexibility concerning hardware extensions.

In smaller, clearly laid-out buildings, a simple alarm is often sufficient. In large complex buildings frequented by many people, a control unit with the corresponding alarm elements must be chosen, enabling a target-oriented alarm.

The number and complexity of the control systems to be served by the fire detection control unit is essential in selecting the right control unit. It must have sufficient memory capacity and processing speed for the number of control systems to be processed, and it must allow for the necessary links.

When several individual buildings shall be monitored, or when the control unit shall be operated by a superordinated system, a control unit must be chosen allowing for easy networking.

When it can be anticipated that the existing building structure will be extended, it is strongly recommended to opt for a modular control unit. These control units have the advantage of facilitating a flexible and cost-efficient adaptation to the system size due to their possible extension with additional control and line modules.

4.7 Linear Heat Detection Systems

Linear heat detection systems consist of a line-type sensor and an evaluation unit. The sensor is either a cable with electrical or optical conductors, a cable with a number of sensors or a pipe. These evaluation units are usually connected to a superordinated system, enabling the visualization of measured values and the control of extinguishing systems, ventilation systems, etc.

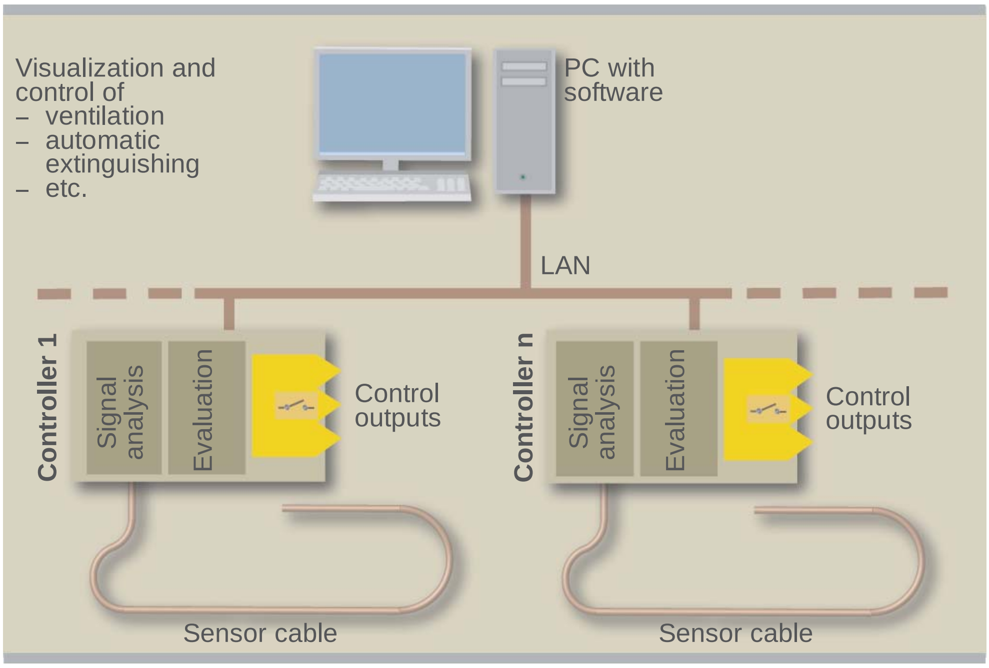


Figure 4.42: Topology of a linear heat detection system

Linear heat detection systems are capable of triggering an alarm in case of a defined temperature increase or when a maximum temperature is exceeded. They are applied in areas in which temperatures need to be monitored over long distances, but also where harsh environmental conditions prevail, for example in the case of corrosive gases, extreme temperatures, high humidity or soiling.

Typical application areas for linear heat detection are:
- road and railroad tunnels
- cable trays and ducts
- conveyor system and transport ducts
- escalators
- gas and long distance energy / heating lines
- process monitoring in the chemical industry
- mines and oil platforms
- tank farms
- paint shops

4.7.1 Detection Principles

The market offers a number of linear heat detection systems based on the most different detection principles and system characteristics. The most frequently used detection principles are described below.

4.7.1.1 Sensor Cable with Heat-sensitive Polymer

The sensor cable consists of two electrically conductive wires embedded in a heat-sensitive polymer. As soon as the temperature threshold is reached, this isolation starts to melt. The wires touch and generate a short-circuit, which in turn generates an alarm. To monitor different temperatures, cables with different polymers are used.

This measuring principle produces an alarm as soon as a temperature threshold is exceeded. With some systems, the approximate location of the short-circuit, i.e. the location of the fire seat, can be determined by measuring the residual resistance.

By default, cables with activation temperatures between 60°C and 200°C are available. The maximum sensor length is between 1 and 2km. By nature, the cable is destroyed by such an event, which is why the cable needs to be replaced after detection.

4.7.1.2 Sensor Cable with Temperature-sensitive Isolation

The sensor consists of a cable with electrically conductive wires and insulation with a negative temperature coefficient. This means that the insulation reduces its electric resistance as the temperature rises. This signal is evaluated for alarm.

Alarm is activated as soon as the measured value falls below a defined resistance value. The measured resistance, however, depends on the cable length and the ambient temperature. The measured value is assumed to be the average value over the complete cable length. One local hot spot has the same effect as a minor temperature increase over a longer distance.

The cable is not capable of locating the fire position. By default, cables with activation thresholds between 50°C and 250°C are available. The maximum sensor length is between 1 and 2km, depending on the system.

4.7.1.3 Sensor Tube

These systems make use of the law of nature according to which the pressure of a gas varies in function of the temperature changes if the volume of the gas remains constant. A fire heats up the copper sensor tube and thus the air contained therein. A pressure transducer at the end of the tube registers the pressure change and provides a signal that is proportional to the average temperature.

The alarm is activated as soon as a defined signal threshold is exceeded. The sensor tube is not capable of locating the fire position. Systems available today are designed in a way that activation temperatures up to 150°C are possible. The maximum sensor length is below 200m.

4.7.1.4 Cables with Integrated Temperature Sensors

With these systems, temperature sensors are mounted at equal intervals onto a screened flat cable serving as data and feed line. The values measured by the sensors are polled by an evaluation unit and serve for alarm activation.

The values measured by the different sensors can be evaluated by means of an appropriate software tool. Several sensors may be combined to groups, or multisensor logic can be created. These systems facilitate temperature measurements with differential and maximal characteristics. Localizing the heat sources is possible within the accuracy of the sensor intervals.

Systems available today support activation temperatures up to approx. 150°C. The maximum sensor length strongly depends on the interval between the sensors. The maximum number of sensors is limited by supply and data transmission. State-of-the-art systems make sensor lengths up to 2.5km possible, at sensor intervals of 8m.

4.7.1.5 Measuring Temperatures with Fiber-Optic Cables

This system is based on a laser beam being sent through a fiber-optic cable. As the fiber-optic cable reflects a small part of the laser radiation at any point, the backscatter can be measured by a receiver connected at the same end as the laser source.

The fiber-optic cable is a doted quartz glass, i.e. a form of silicon oxide (SiO_2). The infrared electromagnetic laser radiation emitted is reflected in different ways by the fiber-optic cable:
– Rayleigh scattering
– Stokes scattering
– Antistokes scattering

The Rayleigh scattering has the same wavelength as the laser beam, whereas the stokes scattering has a slightly higher and the anti-stokes scattering a slightly lower wavelength. The two stokes scattering types are also referred to as Raman scattering. While Stokes scattering is temperature-independent, Antistokes scattering is affected by the thermal energy of the fiber-optic cable’s local temperature. The intensity increases with the temperature. The temperature of the fiber-optic cable thus results from the intensity ratio between Stokes and Antistokes scattering.

By means of runtime measurements, it is possible to measure the associated Raman scattering for each cable spot. The local cable temperature is then determined by the ratio between stokes and anti-stokes scattering.

The following illustration shows the spectral position of Raman scattering.

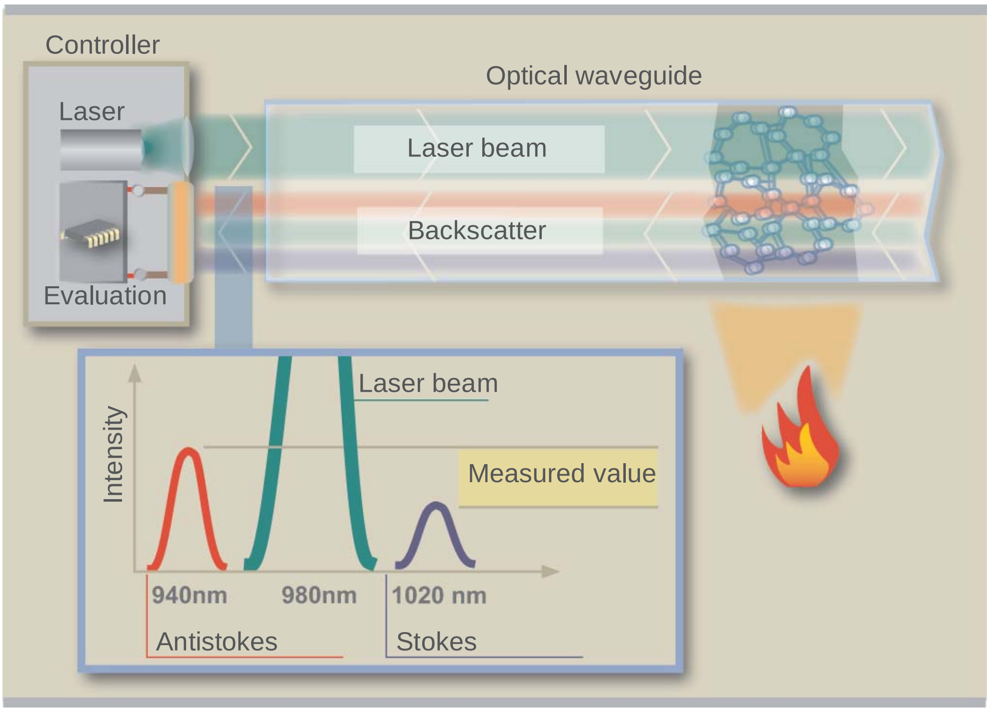


Figure 4.43: Principle of Raman scattering

The sensor cable can be divided into sensor sections from 1 to x meters by using appropriate electronic and software components. These sections are then handled as individual sensors. This means that several sensors can be combined in groups, or multisensor logic can be created. This measuring principle allows temperature measuring and alarm triggering according to the differential and / or maximal characteristics. Based on the accuracy of the sensor sections, it is possible to localize the heat sources.

Depending on the fiber-optic cable type, systems available today make activation temperatures up to 400°C possible. With a given sensor section length up to 4m, current systems allow sensor lengths up to 16km.

4.7.2 Selecting the Suitable System

The table below shows the properties of the different principles of linear heat detection systems.

Properties \ System	Heat-sensitive polymer	Temperature-sensitive isolation	Sensor tube	Tempera-ture sensors	Fiber-optic cable
Selectable temperature thresholds	No	Yes	Yes	Yes	Yes
Increase and fixed value evaluation	No	No	No	Yes	Yes
Possibility of creating zones	No	No	No	Yes	Yes
Pre-alarm possible	No	Yes	Yes	Yes	Yes
Temperature measurement	No	No	No	Yes	Yes
Ambient temperature compensation	No	No	No	Yes	Yes
Max. activation temperature	200°C	250°C	150°C	150°C	400°C
Automatic resetting	No	Yes	Yes	Yes	Yes
Localizing the heat spot	No / partially	No	No	Yes	Yes
Maximum sensor length	2'000m	2'000m	200m	2'500m	16'000m

Table 4.10: Properties of different linear heat detection systems

The most suitable system has to be chosen depending on the field of application, the risk and the price:

- If the operator wants to ensure with the simplest available means that a transformer will be switched off from the mains in case of overheating, it suffices to use a cable triggering alarm when a predefined temperature is exceeded. When such an event is expected rarely or not at all, no automatic resetting is required.
- To monitor the temperature of a reactor in the chemical industry, it is important that the system reliably produces a prealarm and an alarm message. The possibility of creating zones or localizing the heat spot is not normally necessary.
- To monitor a road tunnel with a linear heat detection system, it is mandatory to create zones, compensate the ambient temperature and localize the heat spot, i.e. the fire seat.

4.8 Planning

National standards and guidelines describe how fire detection systems must be planned, installed and operated. Adhering to these regulations is a prerequisite for the approval of an automatic fire detection system by the authorities, the fire brigade and insurance companies. Protection-objective oriented fire detection systems can only be designed if the prevailing risk is clarified, the protection objective is known and the resulting requirements on the fire detection system are specified. Such systems are complex and costly and must be executed by experts.

4.8.1 Object-Independent Planning

The planning process of a fire detection system must consider the following factors:
- extent of monitoring
- selection of the type of fire detectors
- coverage area and arrangement of the fire detectors
- design of the fire detection control unit, supply network and energy supply
- detector zones
- alarm and controls
- alarm organization

4.8.1.1 Monitoring Extent

The monitoring extent is defined as follows:

Monitoring extent	Description
Complete protection	Protection of all parts of the building
Selective protection	Protection of one or several fire sectors in the building
Escape route protection	Protection limited to measures serving the safeguarding of escape routes
Targeted monitoring	Protection of particular devices or function(s) in the building, which do not constitute a fire sector
Equipment protection	Protection of certain devices or pieces of equipment

Table 4.11: Variants of the monitoring extent

The local requirements define which areas must be provided with what monitoring extent. These requirements are limited to complete protection, selective protection and escape route protection. Targeted monitoring and equipment protection are not usually laid down in the specifications.

The threat plays a key role in the definition of the monitoring extent:

- If there is any threat to persons, as a general rule, all rooms frequented by people, whether permanently or temporarily, as well as the adjacent rooms must be included in the monitoring extent.
- If there is any threat to assets, as a general rule, all areas must be monitored. This does not include areas that only contain a limited combustible load or that do not facilitate fire spread.

For most buildings, the monitoring extent defined in the specification lists and tables is sufficient. With certain types of buildings, however, the monitoring extent must be determined for each area, based on the prevailing risks and the defined protection objective. The following examples illustrate which deliberations are required to define the monitoring extent of particular objects:

- A fire in a nuclear power station can have disastrous consequences. Therefore, everything is done to prevent fire. The probability of occurrence is thus very low. As the calculated risk is the product of the probability of occurrence and the effects, the effects of a fire must be minimized as well. In addition to a number of structural measures such as fire compartments or the reduction of the combustible load, a fire must be detected as early as possible wherever it occurs, and appropriate measures must be initiated. This means that complete protection is required in all critical buildings.
- In a hospital, the protection of patients has top priority. This means that complete protection is almost always required. All rooms, aisles and staircases must be monitored by a fire detection system.
- Considering a metal-processing factory, the focus is on the protection of the production facilities. A storage room with a low combustible load need not be monitored by a fire detection system if fire spread is limited and possible damage in this area is acceptable.

4.8.1.2 Selecting the Fire Detectors

To select the ideal fire detector, the type of fire to be expected and the associated fire phenomena are definitely in the center of all deliberations. Primarily, smoldering fires are detected with smoke detectors, while flame or heat detectors are most suitable for the detection of open liquid fires. In addition to the type of fire, however, the room height, the ambient conditions and the possible deceptive phenomena must be taken into account as well. More detailed information on selecting the ideal fire detectors can be found in chapter 4.4.

4.8.1.3 Monitoring Areas and Arrangement of Fire Detectors

Monitoring areas and arrangement of the fire detectors shall be in accordance with the type of fire detectors and the room geometry such as surface area, height, shape of the roof and ceiling. This topic is covered in detail in chapter 4.5.

4.8.1.4 Fire Detection Control Unit, Supply Network and Energy Supply

The fire detection control unit serves for operating the fire detection system. In addition, it evaluates the hazard messages received by the peripheral devices and the fire alarm and control installations.

The supply networks must guarantee the reliable communication between the control unit and the peripheral devices.

It is mandatory that fire detection systems be fed by two independent energy sources.

Detailed information on the topics of fire detection control unit, supply network and energy supply can be found in chapter 4.6.

4.8.1.5 Detector Zones

A detector zone is a combination of detectors for which an own indicator for messages and faults is provided on the indicating equipment. Detector zones must be defined in such a way that quick, unambiguous indication and location of the fire is possible.

Depending on the type of fire detectors, room size and special areas, such as false floors, particular restrictions apply for the creation of detector zones, referring to the number of detectors or the size of the monitoring area, for example. It is important that unambiguous identification of the fire location is always guaranteed.

4.8.1.6 Fire Alarm and Control Devices

One significant task of a fire detection system is to activate and control the fire control installations such as smoke extraction equipment or extinguishing systems.

The fire detection control unit must include at least one control device for an alarm system to alert people. Depending on the alarm organization, alarm areas may be defined, and additional acoustic and / or optical signal transmitters can be used for the purpose of alerting people. The signals from these alarm devices must differ from the usual operating signals.

4.8.1.7 Alarm Organization

The alarm organization is one of the focal points in setting up a fire detection system. This includes all measures serving for alarm, rescuing, avoiding fire spread, fire fighting and orientation in the event of fire.

To define the alarm organization and the measures in connection with it, the system operator, fire brigade, planner and installer of a fire detection system must work in close cooperation.

Especially the following measures must be ensured:
- warning endangered persons
- fire alarm signaling to public and internal intervention forces
- avoiding a quick fire spread by closing doors
- activating smoke and heat extraction ducts
- fire fighting

4.8.2 Object-Dependent Planning

Based on a few examples, this section shows what deliberations are necessary to plan and install a fire detection system, and which types of fire detectors are required for the different applications.

4.8.2.1 General

Authorities, insurance companies and fire brigades require automatic fire detection systems for many buildings such as hospitals, hotels, museums or industrial facilities. In most countries, there are also regulations specifying how such a system must be set up, and what products are approved.

As in many other fields, economy calls for selecting the system technology in accordance with the requirements and the risk situation:

- Collective systems are only used on the simplest application conditions, or for low-risk applications. This system technology is exclusively distinguished by its price.
- The addressable technology with threshold value technology is still very widely spread, but is rarely used in new systems. Such systems are used only for low or medium risk situations and with average degree of severity.
- Systems with individual addressing and algorithm technology are still characterized by their very good detection behavior. Their application is recommended with medium risks or average requirements.
- For high risks and requirements on the detection behavior, the use of advanced technology is indispensable. The savings resulting from early, reliable fire detection outbalance the high acquisition costs, as damage is minimized in the case of fire and false alarms can be virtually ruled out.

Early and safe fire detection due to object-dependent planning

4.8.2.2 Administrative Buildings

Risk

A modern administrative building largely consists of office rooms, meeting rooms and corridors. To minimize the combustible load and the risk of fire, only hardly combustible materials are used wherever possible. Electric installations, electronic devices and glowing cigarettes are possible ignition sources. Fire usually develops within a few minutes and remains locally limited in case of early detection combined with appropriate fire fighting.

The probability of a fire in such a building is rather low, due to the average combustible load and the existing ignition sources. Damage is mostly locally limited; the risk in such a building can be assessed as low to medium-sized.

If the administrative building has an EDP room, this area must be considered separately due to its high risk.

Protection Objective

In an administrative building, the protection of people clearly has first priority. In the event of fire, people must by no means be endangered and early alarm and evacuation must be guaranteed. Containing and extinguishing the fire has second priority, so that material damage can be limited. This means, for example, that damage must at any rate be limited to one floor only. Any possible operational interruption must be short-term and locally limited.

Fire Detection System

In addition to other protective measures, such as safeguarding escape routes or controlling fire sectors, the fire detection system must be set up in such a way that it detects a defined fire size, for example a burning stack of paper, and that it activates the alarm devices and fire control installations.

In a building of this type where smoking is prohibited, the operator has to expect very weak deceptive phenomena. Monitoring is possible with individually addressed fire detectors with threshold value technology. Also, no preliminary clarifications are required. If the system is set up in compliance with the regulations, i.e. the coverage area is taken into consideration and only approved fire detectors are used, the required protection objective can be achieved.

Optical point detectors are installed in the offices and corridors. In rooms higher than 3 meters and frequented by smokers, multisensor smoke detectors with algorithm technology are recommended.

4.8.2.3 Recycling Facility

Risk

In a recycling facility for paper and synthetic materials, the combustible load is extremely high. Electric installations, motors driving the production machines and many rotating parts are potential ignition sources. A fire can cause machine failure strongly impairing the production. Damage and resulting operational interruption can cause enormous costs or even bankruptcy.

The risk in such a recycling facility must thus be assessed as very high. Although damage is normally limited to property and operational interruption, it may be so high that the company cannot survive.

Protection Objective

Protecting material assets and the production clearly have top priority. In the event of a fire, the fire must be contained and extinguished as quickly as possible. The production interruption must by no means exceed a certain defined value. For example, a maximum of one production machine out of three may break down.

Danger to persons is rather low, as few people are present in such facilities, the fire does not spread explosively, and there are sufficient escape routes.

Fire Detection System

The fire detection system must guarantee quick and reliable alarm with a defined fire size, as well as the controlling of fire control installations. A defined fire size for this application would be a paper fire with a diameter of 30cm, for example. Such a fire burns approximately 4g of material per second, produces 50kW and reaches a flame height of approximately 1m.

Recycling halls are large, high rooms where rough environmental conditions prevail. In addition to a high temperature and humidity fluctuation, the air usually contains much dust depositing everywhere. Another aspect is solar radiation in such halls, which is why deceptive alarms and holding time deserve special consideration when it comes to selecting the fire detectors.

Intelligent flame detectors quickly respond to open fire and are completely immune to the prevailing deceptive phenomena. However, they have the disadvantage that they cannot detect smoldering fires. In addition, due to partitions, large machines, etc., it is very difficult to monitor all areas with an acceptable number of flame detectors.

The following combination has been tried and tested in practice:

- Monitoring the production machines with flame detectors.
- Additional monitoring of the entire production hall with an ASD system. To minimize detector soiling, the ASD system is equipped with a filter and a blow-out mechanism for cleaning the suction pipes. Long-term tests have shown that the cleaning interval in very rough environments is 3 months for the filter and 12 months for the built-in smoke detectors.

Early and reliable fire detection in a recycling facility can only be ensured by combining flame detectors and smoke detectors (e.g. aspirating smoke detectors or linear smoke detectors)!

4.8.2.4 Clean Room in the Semiconductor Industry

Risk

The semiconductor industry is one of the most advanced industrial sectors worldwide. Chips are produced in clean rooms in expensive and complex processes and with the finest microstructures. The processes must run in an extremely clean atmosphere, which is why the quality requirements on the air in these clean rooms are extremely high.

Typical fire hazards are the ignition of process solvents in electrically heated baths, short-circuits or overload in technical equipment and installations, or hazards by external fires.

Fires in clean rooms can have disastrous results. Even minor contamination by fire aerosols or corrosive gases damages the products and intermediate products. If the fire becomes larger, this may cause production to break down for many weeks. The figures below show that the damage to be expected in clean rooms by far extends the usual scope:

- In accordance with Factory Mutual, the average damage amount in the semiconductor industry exceeded the amount of USD 8'000'000 for each event in 1995.
- Also in 1995, one case of damage was registered for every tenth insured object.
- In comparison: In other industrial sectors, one damage case was registered for every hundredth insured object, with an average damage amount of less than USD 250'000 per event.

The semiconductor industry thus clearly reaches a new risk dimension!

Protection Objective

In a clean room, the financial damage that can be caused by operational interruption clearly takes top priority. Everything must be done to guarantee a possibly early, reliable detection of incipient fires. False alarms caused by environmental influence also lead to operational interruptions and must be ruled out at any rate. The protection of people is already ensured by early detection and alarm.

Fire Detection System

The production processes in the semiconductor industry are highly specialized and matched to the relevant products. Each production facility is different, with a different environment. Setting up a reliable fire detection system requires a lot of experience, and the detailed concept of the plant ventilation must be known at any rate.

By selecting appropriate ventilation concepts, the desired pureness of the air can be achieved. The ventilation delivers clean air to the room, supported by a more or less strong air flow. Basically, we distinguish between systems with low-turbulence displacement flow producing a laminar, i.e. uniform air flow, and systems with turbulent mixed ventilation.

In clean rooms, where low-turbulence displacement flow is used, a 600fold air change and air speeds up to 0.3 to 0.5m/s are to be expected. Early fire detection in such clean rooms can only be guaranteed by monitoring with high-sensitive ASD systems. In areas with low-turbulence displacement flow, ceiling detectors assume the function of additional civil protection.

In areas with turbulent mixed ventilation, for example in service rooms, the expected air change is 10- to 50-fold. Here, point-type, intelligent smoke detectors on the ceiling are suited for an early detection of incipient fire. A coverage area of $25m^2$ per detector and a maximum detector distance of 5m must be provided. In addition, any possible perforation of the ceiling around the detector must be avoided.

As clean rooms constitute a very high risk, the use of state-of-the-art technology is indispensable. Application and placement of the fire detection systems listed below are to be understood as a basic concept.

- High-sensitive ASD systems for early fire detection by monitoring the exhaust air from the clean room. The pipe system is usually placed in the false floor and must be planned depending on the ventilation systems. For maintenance reasons, the ASD must be placed in the servicing area and thus outside the clean room.
- By installing sensitive point detectors in the pipe system, a second alarm level is generated, with the purpose of automatically alerting the fire brigade.
- Intelligent, point-type detectors with a high sensitivity level are applied to monitor false ceilings and ventilation floors in large facilities.
- The servicing area is monitored by point-type smoke detectors; the coverage area should not exceed $25m^2$ per smoke detector.
- Manual call points are used for manually alerting intervention forces.

4.8.2.5 Fire Detection in Ex-Zones

If fire detection systems are installed in explosion-hazard areas, the devices used and the electric operating equipment must satisfy certain safety requirements. In addition, special aspects described below must be taken into consideration for the installation of fire detection systems in explosion-hazard areas.

Zone Allocation

In compliance with the IEC definition, explosion-hazard areas are classified in three danger zones 0, 1 and 2, with the temporal and local probability of the occurrence of an explosive atmosphere being relevant (see Annex: “Zone Division of Explosion Areas” on page 316).

Each industrial facility must be individually divided into such zones. In doing so, it must be taken into account that the authority in charge may as well divide one explosion-hazard room into different zones, for example up to 1.5m room height in zone 1, the part above 1.5m in zone 2.

Ex-zone 0 includes all areas where processes run. These hazards must thus be controlled by processing technology. Safety technology only handles ex-zones 1 and 2.

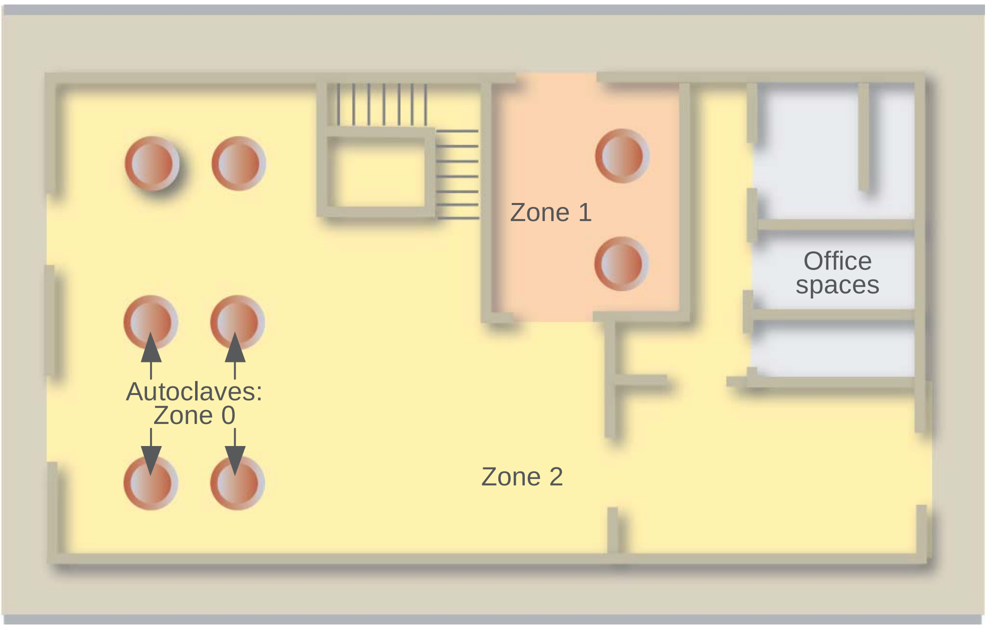


Figure 4.44: Zones in a factory building

Installation

While installing fire detection systems in explosion-hazard areas, it is important that country-specific regulations are always adhered to!

The following list reveals some points to be taken into account for the installation a fire detection system in explosion-hazard areas:

- Whether rooms are considered explosion-hazard areas and the degree of danger are defined by the local authorities in charge. Prior to implementation, a zone plan must be demanded from the relevant authorities, indicating zones 0, 1 and 2 as well as all zones that are not endangered.
- The passageways for detection lines and other lines from ex-rooms to non-ex-rooms must be gastight.
- Electric decoupling of the detection line is ensured with specially developed safety barriers that may not be mounted in the danger zone.
- In explosion-hazard rooms, only such products and installation materials may be used that comply with the national directives.
- In explosion-hazard zones, plants and pieces of equipment made of metal must be connected to the equipotential bonding rail.
- In explosion-hazard zones, only such wires may be placed that are used by the equipment in these rooms. Concealed wiring, completely embedded in concrete, may be run through the ex-zone.
- The protection distances of electrical equipment to door and ventilation openings in explosion-hazard rooms must be taken from the national regulations.

The above list only shows the most important aspects but is by no means exhaustive. In addition to products specially developed for such areas, the expert setup of a fire detection system in explosion-hazard areas requires a lot of knowledge and experience.

4.9 Installation, Commissioning and Acceptance

Installation and operation of a fire detection system are governed by standards and guidelines that must be adhered to by all parties involved, especially the system provider, planner, installer, operator and servicing company. This also applies to the installation, commissioning and acceptance of a fire detection system.

4.9.1 Installation

The following aspects must be taken into account for the installation of a fire detection system:

- Deviations from the system documentation can only be accepted after consulting the responsible parties and upon adhering to the protection objectives defined in the fire protection concept.
- Each deviation must be laid down and justified in the system documentation.
- When fitting the components of the fire detection system, the installation instructions provided by the manufacturer must be observed.
- All system parts must be secured to a solid, level surface. They must be mounted in such a way that the risk of mechanical damage is as low as possible.

When installing the fire detection control unit, the following aspects must be taken into account:

- The mounting location of the control unit must be close to the area where the fire brigade arrives in the event of fire. The control unit must be directly accessible.
- The control unit must be installed in a clean room with sufficient room illumination. It must be protected against damaging environmental influences, such as direct solar radiation, operational vibrations, dust or humidity.
- A separate electric circuit with a specially marked fuse must be used for the mains supply.

When setting up the supply network, the following aspects must be taken into account:

- The supply network must be installed according to approved rules and the local regulations.
- The lines must be routed in a way that they are sufficiently mechanically protected and fixed and must comply with the requirements for room usage.
- Only the cable types approved by the supplier for use with the respective fire detection system may be installed.
- Energy or signal cables must be laid in such a way that damaging influence on the system will be avoided. In so doing, electromagnetic influence impairing the correct function must be avoided as well.

4.9.2 Commissioning

The commissioning of a fire detection system is preceded by a detailed mounting check of all components. Commissioning itself is performed by an authorized installer.

The commissioning checklists handed over by the manufacturer must be observed item by item. After each successfully performed test part, the corresponding part of the acceptance protocol must be completed.

- If deviations from the planning documentation are revealed during the commissioning tests, the respective parts must be replaced and / or relocated.
- Defective devices or defective device components must be replaced by correctly working devices or components.
- During the course of the testing work, it must be ensured that erroneous activation of the transmission line to the fire brigade or the actuation of automatic fire protection equipment (e.g. extinguishing systems) is ruled out.

4.9.3 Acceptance

The prerequisite for acceptance is a successful commissioning test. During the acceptance test, the test positions listed in the acceptance testing list must be checked for their compliance with the system setup and the parameter settings.

- As with commissioning, it must be ensured during the acceptance test work that the transmission facility to the public intervention forces and the actuation of fire protection equipment are disabled, in order to avoid erroneous activation. The reactivation of these transmission facilities after the acceptance deserves special consideration.
- The operating panel indicators, and especially the customizable texts, must be checked during the test sequence for their compliance with the parameter setting documentation or the system documentation.
- After a successful acceptance test, the system must be handed over to the operator by the accepting party. The acceptance protocol must be completed, signed and also handed over to the operator / customer.

4.10 Profitability and System Evaluation

As with most investments, the overall costs play a key role for the decision-making process in evaluating a fire detection system. The classic approach for fire detection systems is to add ten times the amount of the expected maintenance costs to the acquisition costs. This corresponds to an expected service life of 10 years. The sum is then the basis for a cost comparison. Although this method makes possible a simple cost comparison between systems, it has the following deficiencies:

- Some important cost factors are not considered at all.
- The basic assumption that a fire detection system generally has a service life of 10 years is simply wrong.
- Costs incurring due to insufficient system quality are not taken into account, for example efforts of the fire brigade in case of false alarm.
- Costs for system extensions and modernization are additional aspects to be taken into account in the decision-finding process.

4.10.1 Cost Blocks

Setting up and operating a fire detection system can be broken down into the following cost blocks:

- Acquisition
  - system / hardware
  - installation and commissioning
  - integration into building automation
  - staff training and instruction
- Maintenance
  - preventive maintenance
  - intervention
  - personnel expenditure
  - false alarms
- Extension
  - adapting the system integration
  - improving the system features
  - extending / increasing the coverage
  - adapting the system to internal modifications / change of use
- Modernization
  - replacing the system by the next system generation

Ideally, these cost blocks should be recorded and compared for each system. However, usually this exceeds the scope by far, and most points are difficult to elicit. The following section covers some aspects that are of significance.

4.10.2 Service Life

Of course, the service life of a fire detection system cannot be exactly predicted, but it can be assessed on the basis of the company culture and self-conception of the manufacturer. The following aspects must be taken into account:

- How often does the manufacturer launch a new system generation?
  If a manufacturer launches a new fire detection system, the previous generation must be phased out within a few years. This is the only way maintenance costs for the prevision system(s) can be reduced to an acceptable level.
- Since when has the most recent fire detection system been marketed?
  Based on the service life of a generation and the year of the first system sales, it can be assessed after which period of time the most recent fire detection system will be replaced.
- How can the quality of the fire detection system modules be assessed?
  Assessing the quality not only means the actual product quality. The quality of fire detection is of equal importance, and what possibilities there are to adapt this quality to changing requirements.
- How much has been invested into the fire detection system regarding modernization?
  Manufacturers who have a good modernization concept for existing systems will probably continue to do so in the future. For these systems, possibilities for a step-by-step modernization will most probably continue to be available in the future.
- For how many years can the availability of the system modules be guaranteed?
  In former times, availability guarantees of 10 years after announcement of a system phase-out were often given. Due to the use of electronic standard modules with a service life of a few years only, such time spans can no longer be guaranteed today.

Based on two extremes, it shall be illustrated below that service lives between 6 and 15 years are possible.

Example A

- The manufacturer launches a new generation every 4 years.
- The current system was first sold 3 years ago.
- The quality of the products and detection behavior is fairly good, but it cannot be improved.
- The system is not designed for a seamless integration of modules of an older system.
- The manufacturer guarantees for the delivery of system parts up to 5 years after announcing the system's phase-out.

The system will thus probably be replaced in a year, and the guaranteed delivery of system parts will end in 6 years from now. Since an adaptation to changed requirements and a step-by-step modernization are not possible with this system, the realistic service life is 6 years.

Example B

- The manufacturer launches a new generation every 8 years.
- The current system was first sold 2 years ago.
- The quality of the products and detection behavior is sufficient and can be improved without problems, for example by compatible fire detectors with improved properties.
- The system is designed so that modules of an older system can be integrated, for example by means of an interface to older modules.
- The manufacturer guarantees for the delivery of system parts up to 5 years after announcing the system's phase-out.

The system will thus probably be replaced in 6 years, and the guaranteed delivery of system parts will end in 11 years from now. Since an adaptation to changed requirements and a step-by-step modernization are possible with this system, the realistic service life is 15 years for most system elements.

These two examples show that a fire detection system's service life strongly depends on the possibilities for system extension and modernization – features that have not been sufficiently taken into account in the scope of system evaluation.

4.10.3 Extensions and Modernization

Extensions are a topic rarely handled, and whose consequential costs for the evaluation are often not considered at all. In accordance with the principle "How am I to know what the future will bring?", this problem is set aside although it is indeed very explosive. Even with very static companies, the expenditures for extensions and adaptations accumulated over the system's service life amount to 20% to 200% of the acquisition value. These are absolutely relevant sums. Depending on the type of fire detection system, an extension may generate up to 50% extra costs if, for example, the flexibility for extensions is limited or has been exhausted. In the worst case, an extension is not possible at all, for example when new requirements on the detection capability simply exceed the system's capabilities.

Sooner or later, a fire detection system begins to age, and the question for replacement arises. As it rarely happens that the complete system requires the same degree of renovation, the system parts that are still operable should continue to be used for several years for economic reasons. By means of well thought-out modernization concepts, a step-by-step replacement is made possible, so that the system parts that most urgently require replacement can indeed be replaced first, while others that are in better condition can continue to be used. Smart modernization thus has a positive influence on the profitability of a fire detection system.

Simple, cost-efficient extensions and well conceived modernization concepts have a significant impact on overall costs and must thus be taken into account for the evaluation of a fire detection system. This topic is covered in detail in chapter 8 starting on page 261.

4.10.4 False Alarms

Early alarm in the event of fire and a high immunity to deceptive phenomena are opposite characteristics. Today, it is relatively easy to set a fire detection system so that it alerts as early as possible. It is not difficult either to install a system that is highly immune to deceptive phenomena. A state-of-the-art fire detection system, however, must be capable of alerting as early as possible in the event of fire and, at the same time, avoiding false alarms.

In large cities, it has been a rule for many years to partially pass on the cost of fire brigade expenditures in case of false alarms. If it happens repeatedly, it may exceed 1'000 € per case. Based on a conservative calculation of 1'000 € internal costs (due to the interruption of productive work), the internal and external costs of each false alarm amount to a total of 2'000 €. A fire detection system with a service life of 10 years and two false alarms per year generates extra costs of 40'000 €. This amount shows that an investment in a fire detection system with intelligent fire detectors that ensure reliable detection quickly pays for itself.

4.10.5 Conclusion

To evaluate a fire detection system, the required quality regarding the detection behavior and detection reliability must clearly take top priority. Only this way can the defined protection objective be achieved, defining the required degree of personal safety, damage mitigation regarding buildings and assets, as well as the limitation of operational interruptions and environmental damage.

User-friendliness, additional functions and integration into a superordinated system are additional aspects to be taken into account and to be assessed. With these points, the incurring additional costs must at best be compared with the higher productivity that can be achieved. This can be in the form of time savings, for example, better system overview or higher flexibility.

During the planning phase, it is virtually impossible to exactly determine the overall costs of a fire detection system. The result may be more or less accurate, depending on how thoroughly the different aspects are considered. It is important that the determination of the overall costs, in addition to the mere acquisition costs, takes into account maintenance, extendibility and extension costs as well as modernization possibilities. Longer service life has already led to an excellent profitability for many fire detection systems, although their acquisition costs were initially higher.

It is mandatory to give consideration to these factors so that a more or less correct evaluation can be made. Only this way can the overall costs be determined as accurately as possible, which is a prerequisite for the selection of the most cost-efficient system in the long term. Investing in a fire detection system with high detection reliability, high flexibility and well thought-out modernization concept pays for itself.

Intelligent investment pays for itself

5 Alarm and Evacuation

5.1 Summary

To save lives, hazard warning is indispensable. Conventional devices such as horns, sirens and bells may be economic, but people hardly follow such signals, ignoring them more and more often. Thanks to its plausibility, voice alarm is followed quickly and consistently, which is why it will spread rapidly in the future. The information of people in the building without delay by means of voice messages can be adapted to the current hazard situation and largely helps to prevent panic reactions.

To plan a voice alarm system, special knowledge of acoustics is absolutely necessary. This is the only way to achieve the necessary intelligibility with a cost-efficient system design. Voice alarm systems should be easy to integrate into the building infrastructure. In particular, automatic interfaces to the danger management systems are useful. The required control unit technology can be installed centrally or decentrally. The efficiency of the amplifiers is crucial for the size of the required emergency power supply unit.

Over the past decades, much experience with voice alarm systems has been gained. The quintessence of this experience is the quasi standard, aiming at first evacuating the endangered fire sectors, then the immediately adjacent ones. After that, all other areas are successively evacuated. This phased evacuation is definitely superior to the formerly habitual one-step evacuation and has many advantages. Panic prevention or the possibility of partial evacuation are only two of them. In addition, it makes fewer demands on escape routes. Advanced evacuation systems thus allow for phased evacuation matched to specific needs.

Alarm is initiated to make sure that the building users can leave the building in good time in case of hazard. And according to experience, hazards can only be handled smoothly if procedures have been rehearsed in advance. The emergency training sessions that are conducted regularly in Anglo-Saxon countries are thus indispensable and are of increasing significance in other countries as well. Automatic escape route guidance is increasingly paid attention to. It always guides people correctly and safely to the outside, independent of the seat of fire, so that nobody can accidentally get to the hazard zone.

Alarm devices not only save lives. In the case of voice alarm, they also have a valuable additional benefit, as they can be used to emit background music and voice messages. Digital technology makes possible simpler cabling, more flexible system programming and essentially more efficient amplification. Although cabling is the largest single post in the investment calculation, it lives as long as the building itself. Voice alarm is thus a worthwhile strategic investment.

Voice alarm systems are also the correct answer to the people's and especially the building users' increased demand for safety in view of an aggravated liability law.

5.2 Basics

The purpose of an alarm is to warn of hazards by means of alarm signals. Different target groups are addressed by an alarm. Especially two groups of people are of significance: The people for whom a hazardous situation has been detected, and the people who shall fight this situation. To alert the intervention forces has reached a generally high level in Europe, whereas threatened persons can still be considered the ones neglected by alarm systems.

In the past, the possibility of self-rescue of threatened persons has been considered only marginally. Today, however, people have become aware that priority must be given to successful self-rescue. This is even more important as the fire brigade do not begin extinguishing before the building has been evacuated. Hence, successful self-rescue is also a prerequisite for damage limitation.

While the first fire alarm bells were manually operated, the increasingly used sirens and alarm horns today are actuated automatically. However, regarding their information content, they must be considered inferior to fire bells. Because during the course of time, other types of hazards have emerged in addition to fire alarms. Beginning with flood alarm, intrusion alarm, environment alarm or bomb threats – a few new reasons for alarm that call for different kinds of behavior (e.g. closing the windows during environment alarm).

Doubts about the justification of an alarm (false alarm?) and ignorance concerning the appropriate reaction (what type of alarm?), however, are fatal for the response time. In the end, all the building operator wants to achieve is:

- Building users shall remain undisturbed as long as possible so that they are not impaired in their well-being and comfort.
- When a building requires evacuation, it shall be evacuated as soon as evacuation becomes indispensable. The fire might have been there for quite a while (even in consideration of the time passed before fire detection), so that fire resistance values of the building construction cannot be simply relied upon (T30, F60, etc.).
- Evacuation shall be performed as quickly and trouble-free as possible.

To achieve the two major goals, personal safety and damage limitation, self-rescue is of central significance and largely decisive for success. While a quick and panic-free self-rescue has a direct impact on personal safety, the conclusion of the self-rescue process is simply a prerequisite for the fire brigade to begin with damage mitigation.

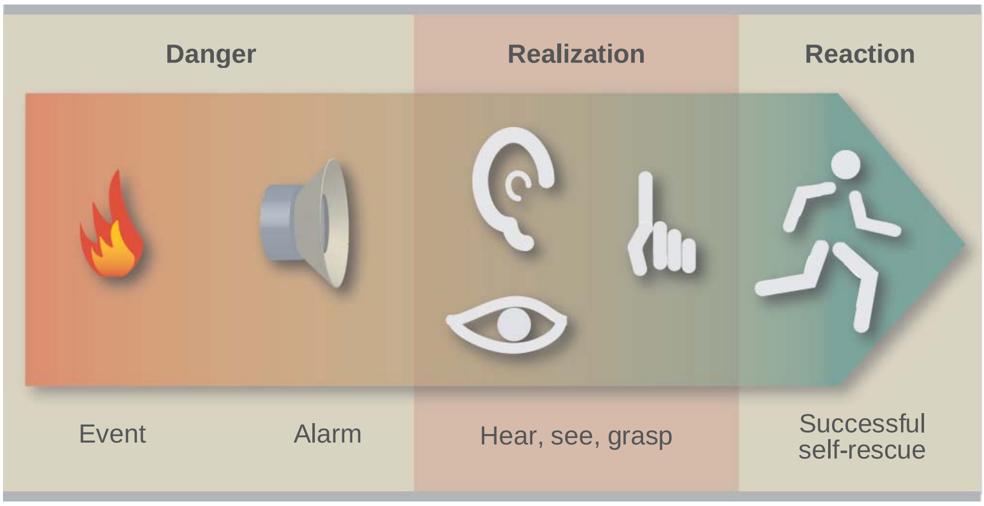


Figure 5.1: Steps of successful self-rescue

The real innovation of voice alarm is to provide the endangered persons on the optic and acoustic channel enough information to allow a quick grasp of the events taking place and to let them accept the fact that they must act.

To trigger this recognition process successfully in a very short time is the central concern of voice alarm. After this, successful self-rescue is only a small step, simple to take for non-handicapped persons.

Successful self-rescue = main objective of voice alarm

5.3 Information Transfer of the Alarm

Alarm systems shall alert people. This automatically leads to the question which of our five senses shall be addressed. Especially the sense of hearing and the sense of seeing are competing. On the other hand, the question arises how much information shall accompany the alarm.

The following paragraphs present the different solution concepts used today and briefly highlight their most important aspects.

5.3.1 Sound Alarm: Sirens and Alarm Horns

Of course, it has been tried to distinguish the different meanings of sound alarms, varying regionally and partly even from one building to the next, by sound patterns (permanent sound, intervals, etc.). In spite of everything, doubts remain about what kind of alarm has been triggered. In Sweden, for example, a continuous tone over 30 seconds is used as all-clear signal. In England, the continuous tone is the signal for evacuation. Besides this, EN standards are interpreted differently by each nation. Some countries may have up to three different sound patterns all of which are standardized. International providers of fire detection systems are usually capable of fulfilling the different national requirements by appropriate configuration. This is important when, for example, internationally active companies wish to have a largely identical infrastructure in their different countries.

Another problem of sound alarm is the social change, such as the society's turning away from a command-oriented behavior towards individualization, that is, to individuals that can best be motivated if explanations are given and if they may act out of conviction. Or changes in claim attitudes, such as taking comfort and safety for granted.

Tests with arbitrarily selected persons have resulted in the fact that alarm bells or sirens are not able to motivate building users to leave the building immediately. If there was any response at all, ten or more minutes passed until the test persons showed any interest in the alarm – this is precious time which can be decisive in an emergency case. Good and continuously repeated instruction of the staff or the building users is an absolute prerequisite for the use of sound alarm systems.

The cost factor of such periodic instructions should not be underestimated. The overall costs of the initially cheaper sound alarm system exceed the overall costs of voice alarm over the years. Voice alarm systems offer additional features, such as background music and the possibility of transmitting voice messages.

There is thus only one reason to restrict oneself to the classic sound alarm: The budget in the construction phase of the building. When, for financial reasons, sound alarm is the only alternative, multifrequency horns generating sounds consisting of various frequencies are advantageous for persons with impaired hearing.

The sound level to be reached must exceed the background noise by approximately 6dBA to make sure that people will hear the alarm. To generate any attention at all, a minimum sound level of 65dBA is necessary. In office buildings, usually a uniform level of 85dBA is provided to simplify matters.

Horns releasing intermitting signals must be synchronized, meaning that the quiescent and sound phases of neighboring horns must occur simultaneously. Today, this is usually ensured by the fire detection system. If two horns actuated by different control circuits or loops are placed next to one another, the synchronization deserves special attention.

State-of-the-art fire detection systems are capable of integrating horns into the fire detector lines, to directly feed and actuate them from the detector bus. This decreases significantly cabling costs for the horns. If financial reasons require considering only a sound alarm system, it must be ensured the horns will integrate into the fire detector line.

The sound alarm concept usually provides full acoustic coverage. Alternatively, only the escape routes are acoustically irradiated so that the alarm can still be heard in the individual rooms – accepting a higher sound level in the corridors, i.e. the escape routes as such.

5.3.2 Voice Alarm

An instruction to leave the building given by a voice alarm system is followed immediately. Especially when a preliminary warning signal has been given, the reaction periods confirmed in various tests are extremely short.

Over the past years, the costs of entertainment electronics have dramatically dropped, and this has also resulted in a cost decrease of voice alarm systems. The threshold to broad usage of voice alarm systems seems to have been passed:

- The market for voice alarm systems is served by an increasing number of system providers, which is a clear sign of a young, growing market.
- An increasing number of publications on voice alarm show that the topic becomes increasingly significant for the public.
- In most European countries, the “state of the art” is a benchmark to assess which safety measures are reasonable for a building owner. With respect to long-term investments in the building sector in particular, more and more building owners opt for future-proof solutions. With increasing spreading, voice alarm systems will become state of the art; in certain sectors, they already are today.
- The influence of the Anglo-Saxon jurisdiction as well as the aggravated EU liability law contributes to personal safety receiving more attention in a building.

For these reasons, we must assume that in a few years, voice alarm will be the rule rather than the exception. Therefore, and because the field is not commonly known yet, voice alarm systems will be described in detail starting on page 166.

5.3.3 Visual Alarm

People with an impaired hearing cannot respond to acoustic alarm devices. For these people, as well as for areas with especially high noise levels (ear protection), optical alarm devices which often flash stroboscopically are required.

To ensure the alarm is as correct as possible, all alarm devices, including optical ones, must be actuated by one alarm system. Advanced voice alarm systems feature special control outputs.

5.3.4 Escape Route Guidance

Fire catastrophes are extraordinarily critical situations in which optical escape route guidance is of utmost importance. Optic escape route guidance has the task of facilitating the safe leaving of the building in case of emergency, especially in case artificial lighting breaks down. Fires often produce short-circuits or are caused by them, and in case of fire, it is to be expected that the electric lighting will break down. Escape route guidance is thus of prime importance.

In most cases, escape routes are still indicated by green signs mounted above doors. This pictographic indication usually shows a fleeing person, similar to the one in the figure below.

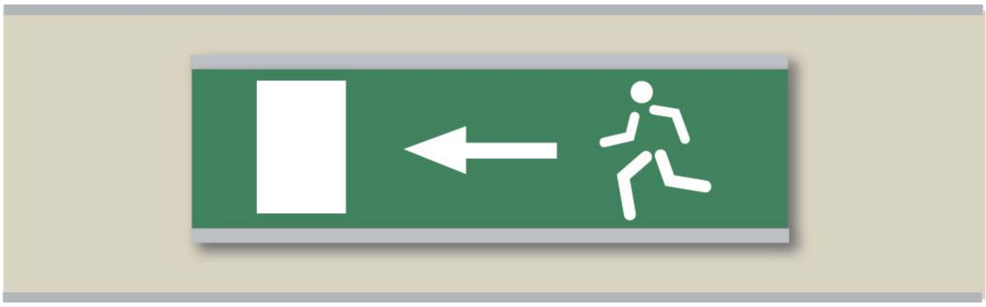


Figure 5.2: Example for an escape route sign

The problem with these signs is that they are practically no longer visible in smoky premises. This means that especially in the event of fire, they are of extremely limited use. For this reason, the concept of escape route guidance finds more and more acceptance.

Escape route guidance may consist of actively illuminated symbols (e.g. arrows) arranged at adequately short intervals, so that the next sign is clearly visible from each point, even in the case of smoke-filled rooms. This system must be supplemented by emergency lighting. Alternatively, it is possible to use phosphorescent signs integrated in equally phosphorescent, continuous guidance marks.

The advantages and disadvantages of each of these concepts are listed in the following table:

System	**Light-storing safety guidance system** (Safety marks and continuous guidance marks)	**Electric safety guidance system** (Backlit safety mark and escape route illumination)
+ Advantages +	– Continuous guidance function – Short distances between safety marks – Information close to floor level – Space dimensions are imparted – No scattered light – Independent of mains supply	– Higher environmental brightness – Higher absolute recognition distances of the safety marks – Higher lighting density – Static illumination parameters – Possibility of dynamic control
- Disadvantages -	– Low environmental brightness – Problems in recognizing people and obstacles – Decaying intensity – Low lighting density	– Missing continuous guidance function – Scattered light from additional illumination – Problems in recognizing people and obstacles – Distances between safety marks too long – Lack of information on floor level – Missing sense of space dimensions – Emergency power required – Maintenance required

Table 5.1: Comparison of different escape route guidance systems
(Source: see End Note 9)

5.4 Voice Alarm and Evacuation

A voice alarm system is an alarm system using electronically stored voice messages (and acoustic signals) for the purpose of alarm in case of emergency. Voice alarm systems can be activated manually or automatically, for example by an alarm of the fire detection system. The preprogrammed evacuation process can then be initiated. Typically, the system delivers an alarm signal, for example a gong or whistle, followed by a stored voice message.

Of the five human senses, especially the senses of hearing and seeing are suited for alarm, with sound being the preferred alarm medium as it penetrates walls and is thus better suited to wake people up. Thus, especially sound alarm systems and voice alarm systems are competing for the planners' favors today. Voice alarm is alarm by spoken, electro-acoustically transmitted language. It is basically simply a further development of the original sound alarm, which transmits only tones.

Voice alarm systems offer by far the best prerequisites for successful self-rescue. People react virtually immediately. Whoever triggers the alarm convinces the building users of the necessity of the desired reaction. Another major advantage of voice alarm systems is that the people concerned are immediately informed about the correct reaction instead of merely being alerted.

The system is normally operated in automatic mode during the first minutes after the alarm. In a later phase, for example after the fire brigade has arrived, they, or other authorized staff, can give individual instructions. Instructions adapted to the current hazard situation are spoken into a microphone. The system transmits these instructions directly to the selected loudspeaker zones in the building (live transmission).

5.4.1 Benefits of Voice Alarm

One of the major problems in case of fire is immediate information and safe evacuation of all people endangered by smoke and fire. Alarms by conventional signal transmitters such as sirens, alarm clocks or alarm horns are, unfortunately, increasingly ignored. Even when people realize that the signal announces a fire alarm, they tend to doubt the alarm signal and assume it to be a test or a false alarm – due to missing communication or insufficient information.

By the transmission of situation-adapted voice messages over loudspeakers, people are informed and instructed to leave the building area concerned – or to remain there, depending on the situation. Voice messages indicate escape routes that shall be used or avoided in case of evacuation and can be transmitted in any desired language or in a combination of different languages. Especially these directly transmitted messages make it possible for building users to successfully rescue themselves without panicking in any given hazardous situation.

For these reasons, timely and correct behavior can only be ensured when voice alarm systems are applied.

Quite often, voice alarm systems are used as normal public address systems (PA) for other communication purposes such as paging, advertising or for the transmission of background music. By this, the building operator has a high-quality transmission system at hand, with a high degree of fail safety. The prerequisite is, however, that the voice alarm is controlled by fully automatic priority switching, to make sure that the information transmitted by the voice alarm system is at any rate and automatically allocated priority in case of alarm.

5.4.2 Prerequisites for Building Evacuation

Evacuation of a building is a drastic measure. Therefore, it is to be ensured that it is appropriate. The requirements to be met for an evacuation vary from building to building. In any case, the authorities' regulations have priority. Unfortunately, these regulations differ from region to region and the locally organized fire brigades have usually very distinct and individual conviction of the proceedings required for an evacuation.

Since every evacuation starts with detection, it is of utmost importance that the fire detection system responds quickly and error-free. For this reason, the following considerations are helpful:

- The fire detection system operates with intelligent detectors. This avoids largely false alarms caused by deceptive phenomena. Also refer to section 4.10.4 on page 155.
- Deceptive phenomena must be recognized as such by the fire detection system. This is to be ensured by appropriate tests.

5.4.3 Methods of Building Evacuation

State-of-the-art voice alarm systems are able to handle the fully-automatic, step-by-step evacuation of a building. This results in the following advantages:

- Reduced capacity peaks of the escape routes and especially of staircases: When the complete building is evacuated at once, people flock to the staircases on all floors at the same time. This leads to considerable tailbacks.
- Low probability of panic reaction: The awareness of being subjected to danger without being able to do anything (blocked exits) easily leads to panic reactions, the consequences of which may be even worse than those of the actual fire.
- Restriction of evacuation to the minimum is absolutely necessary: The complete evacuation of an entire building is only recommendable when the fire can no longer be controlled. It is mostly sufficient to evacuate one or several fire compartment(s) .

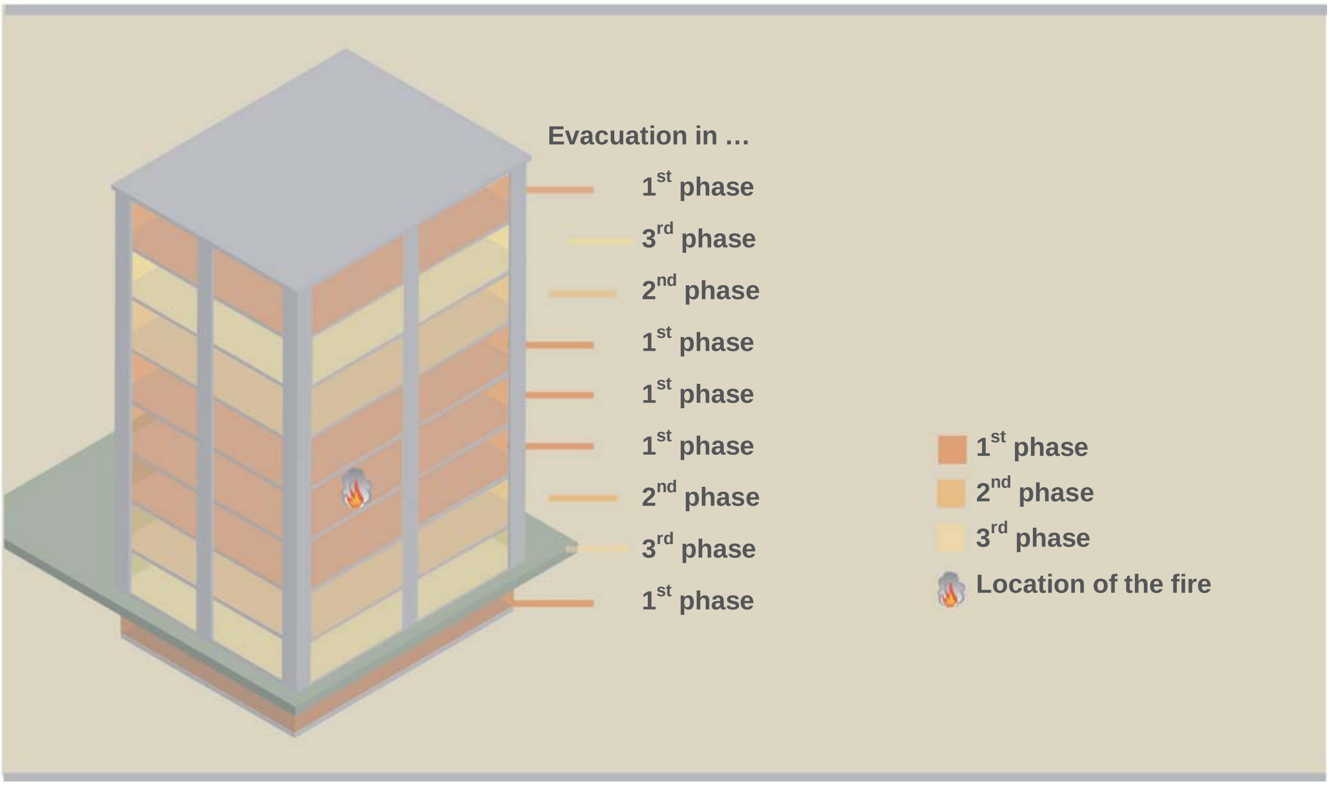


Figure 5.3: Phased building evacuation

The method established as a quasi-standard provides for the floor on which a fire occurs, as well as those immediately above and below, to be evacuated during the first phase. Depending on region and usage, the attic floor and all basement floors can also be evacuated during this first phase. As the fire spreads, all other floors are evacuated one after the other in subsequent evacuation phases. During the first phases, a warning message instructed people on these floors to wait.

Efficient building evacuation holds many benefits

5.4.4 System

Voice alarm systems consist of a control unit protected against power failure, with relatively few input channels and serving a whole network of loudspeakers on the output side.

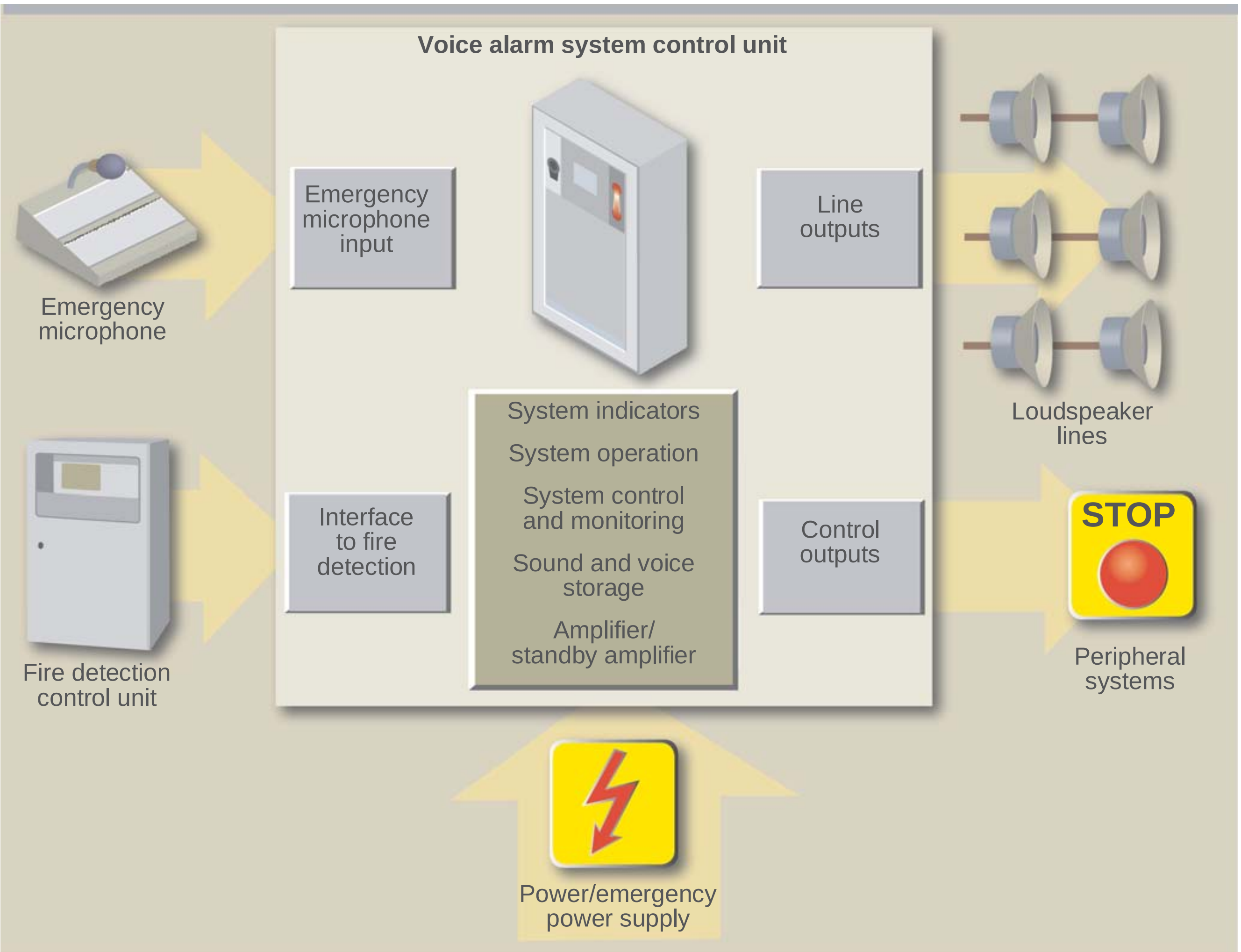


Figure 5.4: System overview of a voice alarm system

Voice alarm system control units are equipped with an emergency operation circuit covering all processing steps, which means that in case of failure of any of the modules, alarm capability is completely maintained. In cases where this emergency operation circuit is not (or only partially) available, it is most likely a public address system for background music and voice messages. To raise such systems to the safety standards of voice alarm systems normally requires unreasonably high labor and time expenditures.

5.4.5 System Configuration and Operation Concepts

With medium-sized and complex installations, voice alarm systems are increasingly designed as networks distributed all over the building, with different decentralized subsystems being responsible for the local loudspeaker periphery, for example grouped on floors. The subsystems are interconnected by means of a network, principally enabling a central parameter setting of the different system components. Whether these central parameter settings have indeed been made and how comprehensive the functionality of these settings is needs to be clarified in advance with each system.

Such a decentralized structure considerably reduces both the required cabling and the installation costs and guarantees optimum system flexibility in case of a change in building usage, for instance.

Relating to network technology, state-of-the-art systems even go so far as to combine several neighboring buildings. This means that each building has its own independent control unit, but can also be operated from some other remote control unit if required (campus structure), cutting staff costs significantly.

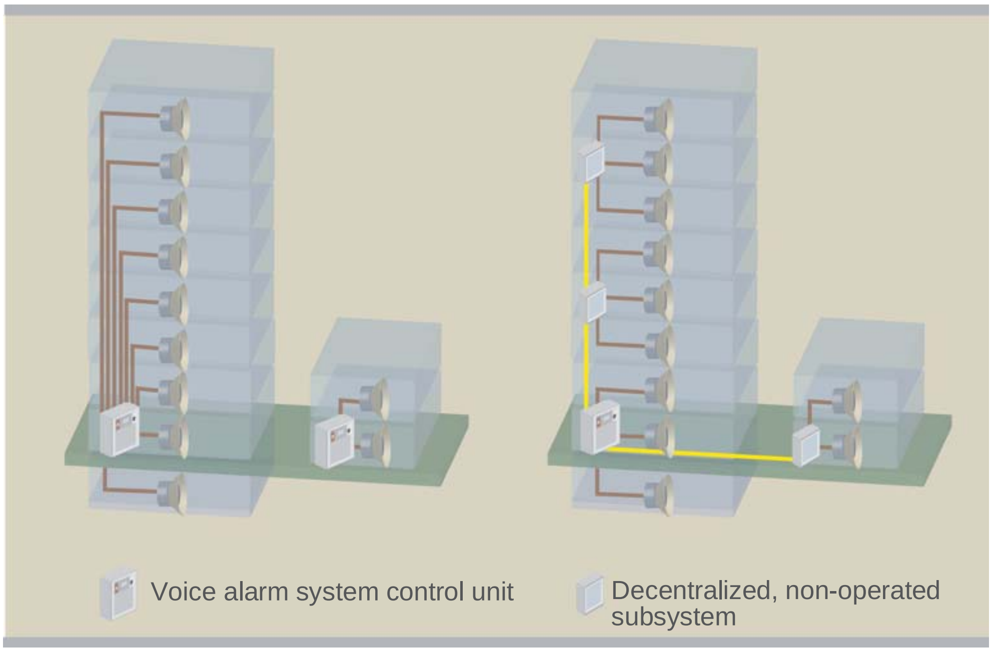


Figure 5.5: Central and decentralized system structure

Of course, the loudspeakers' cabling is made with copper cables of a diameter sufficient to transmit the required power, while the network cabling with digital transmission is made in the form of conventional bus cabling. The slightly higher material costs of a decentralized configuration are not only contrasted by the higher cabling costs of the central structure (length of the copper cables, cable diameters required for power transmission) but also by the transmission loss over the complete transmission distance, which also leads to additional costs on the part of emergency power supply. With longer distances, the use of fiber-optic cables has proven worthwhile, which is why more and more systems support this type of cabling.

Of course, several independent control units at one company location require considerably more staff, which is why decentralized, non-operated subsystems are generally preferred.

5.4.6 Fail Safety and Amplifier Technology

In contrast to public address systems for background music and voice messages, the functions provided by a voice alarm systems must be available at any time, requiring a high degree of fail safety. This is ensured by generally high reliability of the different components. On top of this, these systems have redundant amplifiers that are automatically put into operation in case of breakdown of an amplifier (automatic “hot swapping”). Like the amplifiers, most components should be redundant – from internal and external cabling and the input interfaces (microphones) to the stored voice messages, many system components are available twice or even more. This is one of the reasons why a public address system cannot simply be used as an emergency warning system – as safety systems must ensure a considerably higher fail-safe standard than conventional systems applied for everyday use.

Digital audio technology opens up new application possibilities for voice alarm systems. Thanks to digital signal processing, it has become possible to simultaneously transmit multiple audio channels with different audio signals on one and the same digital system bus. Furthermore, due to the introduction of digitally switched amplifiers (class D amplifiers), it has become possible to significantly increase the degree of efficiency of the amplifiers. This reduces power consumption by approximately one third, the capacity requirement of the emergency power supply is reduced by approximately 50%, and waste heat generation by approximately two thirds (in comparison to analog amplifiers, which often convert more than half of the supplied energy into heat).

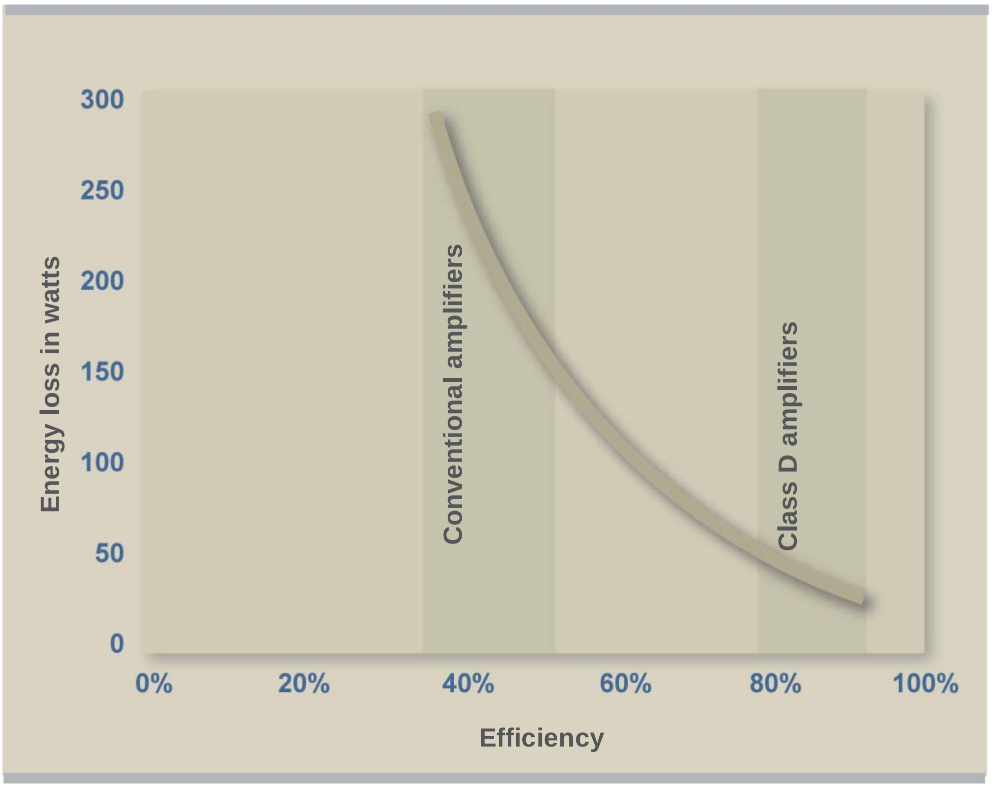


Figure 5.6: 180W amplifiers – efficiency and energy loss

Although the energy loss (in watts) indicated in the figure above is also relevant regarding the current consumption, the difference becomes obvious when sizing the emergency power supply. The decisive factor, however, is usually that systems with a low energy loss factor can also be applied for background music and public address (PA) purposes in unventilated and non-airconditioned rooms, whereas conventional systems generate much higher costs due to the necessity of air conditioning.

Tangible benefits due to digital technology

5.4.7 Amplifier Concepts

Bulk amplification is the “original recipe” of voice alarm: First, the correct sound source (e.g. music, message or evacuation) is selected, then the loudspeaker groups are determined to which the amplified input signal shall be connected. In most cases, one large amplifier is used which can support all loudspeaker groups if required. The advantage of this concept is ease of configuration. However, due to the required emergency amplifier size, this variant is not necessarily the most economic one. And, with this solution, the complete lengths of line for the loudspeaker cabling must also be considered, which has a negative effect on costs.

When two or more amplifiers and a relay-equipped distributor board are used, bulk amplification also provides for the simultaneous transmission of different channels.

Zone amplification benefits from modern, simple electronic channel allocation, enabling a cost-efficient, free allocation of the desired sound source to the zone amplifiers which in turn are connected to the respective loudspeaker zone. Zone amplification offers the following benefits:

- The backup amplifiers need not cover all loudspeaker groups and may thus be smaller. Frequently, several backup amplifiers are used, leading to a higher degree of fail safety.
- Different loudspeaker groups can transmit different messages simultaneously. This is a precondition for phased evacuation. The areas adjacent to the danger zone are acoustically alerted with the warning message, while the evacuation of the immediately endangered areas is already in progress.
- Decentralized concepts increase safety but can only be implemented with zone amplification.

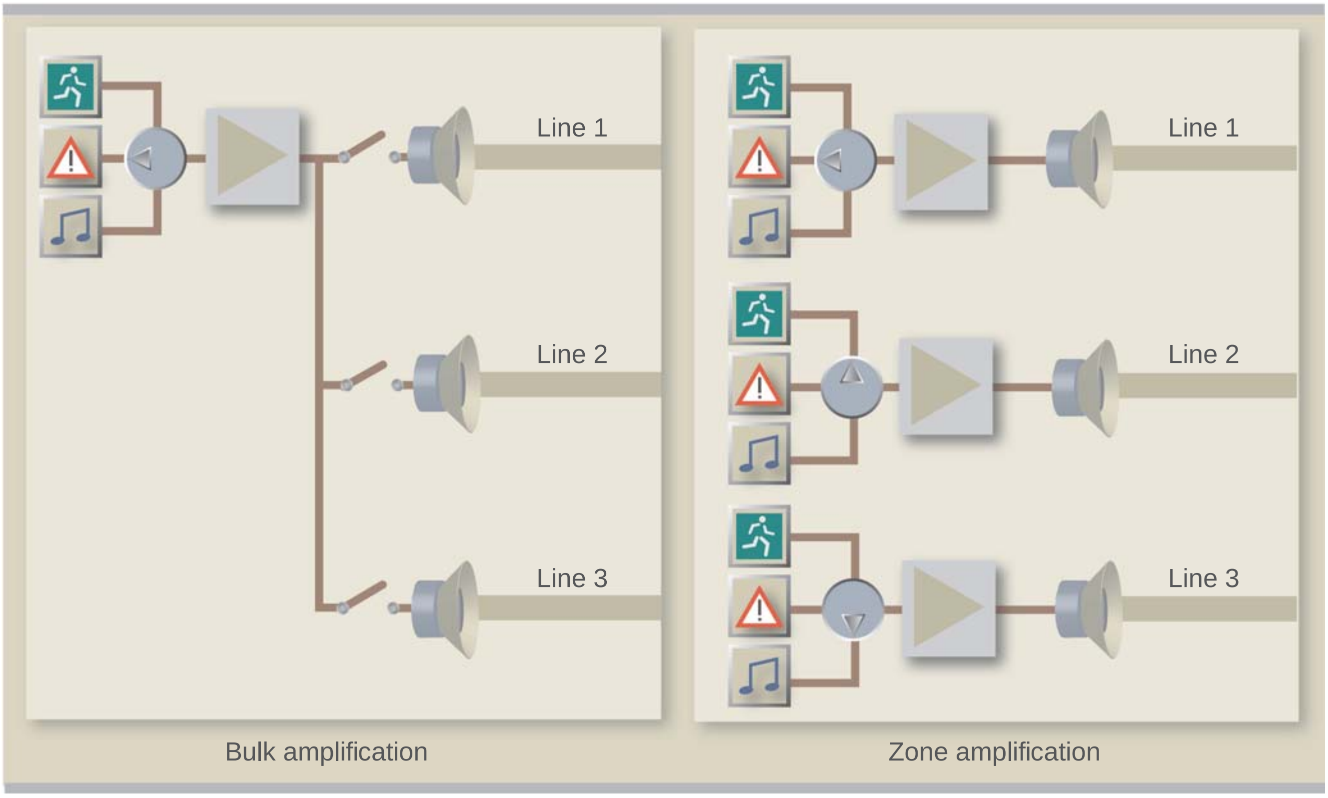


Figure 5.7: Comparison between bulk amplification and zone amplification

In practice, neither pure zone nor pure bulk amplification is used. Due to the specific building situation, it makes sense to choose a “mix” of both principles, covering individual requirements in the best possible way.

5.4.8 Loudspeaker Line Cabling

The easiest cabling type, class B cabling, shows no redundancy and no relevant fail safety. In case of an open-circuit or short-circuit on one line, the complete loudspeaker line will break down. With class A cabling, an open-circuit does not impair the functionality, while a short-circuit leads to a breakdown of the complete loudspeaker circuit. With mixed class A/B cabling, every second loudspeaker is connected to a different loudspeaker circuit. In case of an open-circuit or short-circuit, every second loudspeaker is still available, which of course leads to reduced sound intensity.

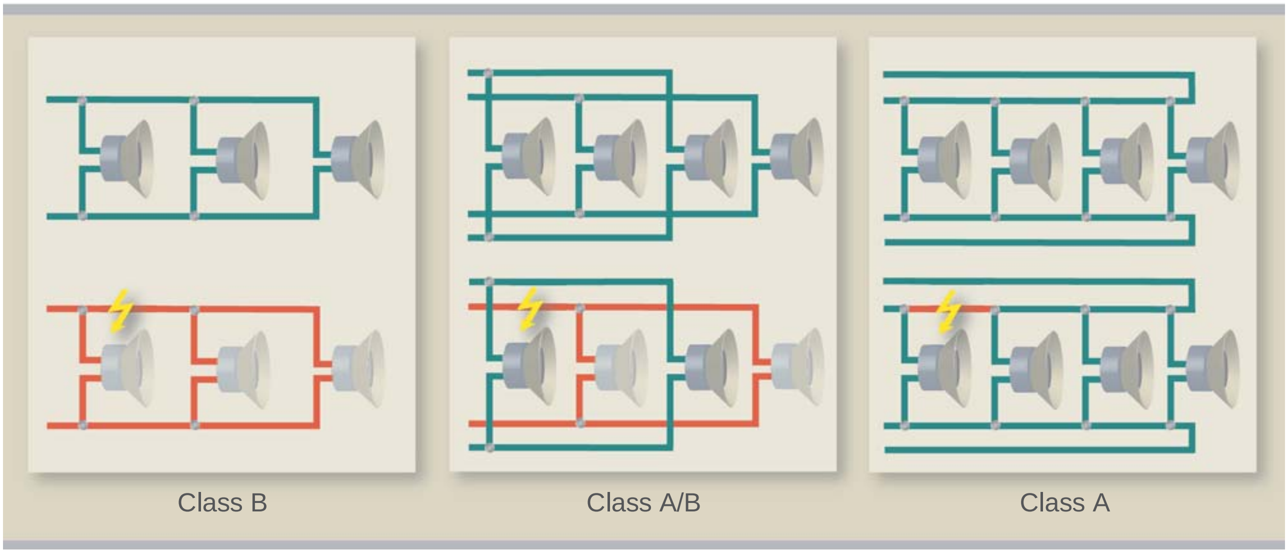


Figure 5.8: Cabling classes and their fail-safe behavior in case of open-circuit

5.4.9 System Embedding and Interfaces to Building Automation

The transmission of a fire alarm from the fire detection system control unit to the voice alarm system can, in the simplest case, take place by means of potential-free contacts. The signal can be transmitted as a collective alarm or as an alarm of a detection area or detector zone. In addition, the “Acoustics On/Off” or “Evacuation Alarm On/Off” signal should be transmitted to be able to interrupt the transmission of alarm messages if necessary. If the fire detection control unit has been reset successfully, the voice alarm system should be automatically reset as well. Any occurring faults in the voice alarm system must be transmitted to the fire detection control unit as a collective fault.

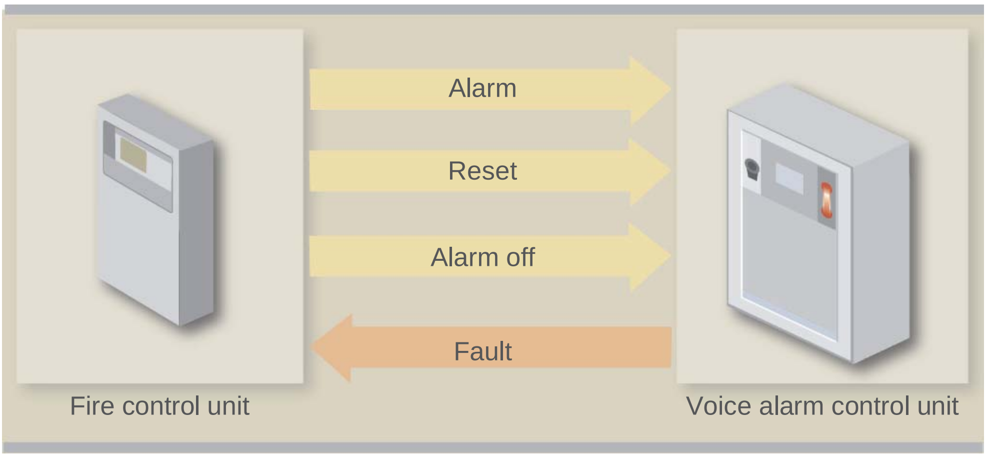


Figure 5.9: Interfaces to the fire detection system

5.4.10 Operating Concepts and Organization Principles

Voice alarm systems can be operated in different ways: With or without automatic connection to the fire detection system, by internal staff, or by the fire brigade, with recorded messages or live announcements, or with both message types – to mention only the most important influencing factors.

Decisive for the organization principle are usually the national and / or local directives. In France, for example, live announcements are forbidden. In Germany, some fire brigades do not accept automatic evacuation.

Such manifold requirements call for flexibility. The voice alarm system must thus be capable of taking into account all requirements resulting from the individual situation in such a way that the overall process is coherent and elaborate.

For the correct functioning of voice alarm, good implementation of the organizational fire protection is decisive. This means especially that the most important problem areas must be addressed:

- Make sure that the escape routes are adequately signaled so that they are easy to find, also in smoky premises.
- Make sure that the escape routes are and remain free. Employees must be constantly made aware of the fact that no material may be stored in escape routes.
- Organizational fire protection can only work when rehearsed and trained at regular intervals.
- All people in charge and their deputies are aware of who assumes which tasks and in which sequence in case of emergency.
- The information concept lays down who must be informed when, in which way and under which circumstances. The information flow is tested and permanently adapted to changing general conditions.

The weak points of organizational fire protection are virtually equivalent to the weak points of human beings. People work especially reliably when they have been able to rehearse situations they are not familiar with. This is another reason to take training extremely seriously (see “Emergency Training” starting on page 181).

5.5 Planning

The planning, execution and maintenance of voice alarm systems require special technical qualifications of planners, installers, operators and service staff. During the planning phase, intensive cooperation between planners, installers, operators, authorities and the fire brigade is required to define the alarm organization.

In doing so, especially the following topics have to be dealt with and tasks need to be resolved:

- Defining the alarm areas, in consideration of the fire sectors as well as the escape and rescue routes.
- Overlapping of fire detection and alarm areas.
- Determining the sound interference level and thus the required sound pressure levels.
- Calculation of the maximum acoustic irradiation area for each loudspeaker (see “Diagram of loudspeaker arrangement” on page 177 and Table 5.2 to Table 5.4).
- Consider the room-acoustic influencing factors such as reverberation time, echo and runtime delays, which may have an overall impact on the speech intelligibility.
- Determining the required number of loudspeakers and the required amplification power.

5.5.1 Loudspeaker Selection

Different loudspeaker types are available for project planning. Among others, these are:

– recessed loudspeakers
– wall-mounted loudspeakers
– horn loudspeakers
– spherical loudspeakers
– pressure-chamber loudspeakers

Some of these loudspeaker types are additionally available as both outdoor and indoor speakers, increasing the variety even more.

Added to this are different placement possibilities. Ceiling-mounted speakers are best suited to achieve a uniform, easily comprehensible sound irradiation. Wall-mounting requires fewer speakers and is consequently more economic, but wall-mounted loudspeakers generate high sound intensities in their immediate surroundings. Up to a mixed form of inclined loudspeakers, there is a variety of different types, helping to determine the optimum variant in consideration of the budget and the customer’s wishes.

Loudspeakers with a high degree of efficiency bring about a considerable reduction of the required amplifier performance. For good speech intelligibility, the effective sound level must be at least 10dBA higher than the noise level. Consequently, correct information on the noise exposure is required for proper planning of a voice alarm system.

5.5.2 System Layout / Decision on Full or Partial Sound Irradiation

Full sound coverage is of course the ideal case. But when it cannot be considered for cost reasons, partial sound irradiation is possible in such a way that – depending on the regulation – for example the aisles are irradiated and the sound intensity raised to a level where people in the adjacent offices become aware of the message. The sound absorption value of doors is in general between 29 and 40dBA. In such cases, it must be taken into account that the sound intensity in the aisles does not become unbearably high.

With partial sound irradiation, it must be taken into consideration that individual, soundproof rooms such as conference rooms, managers' offices, electronics control rooms or archives are directly irradiated.

5.5.3 Irradiation Areas

The so-called opening angle of the loudspeakers determines the loudspeaker's angle of irradiation. The larger this angle, the larger the area that can be covered. This is, however, at the expense of speech intelligibility, due to the equally increasing sound reflection.

Decisive for the irradiation area is the room height at a given opening angle.

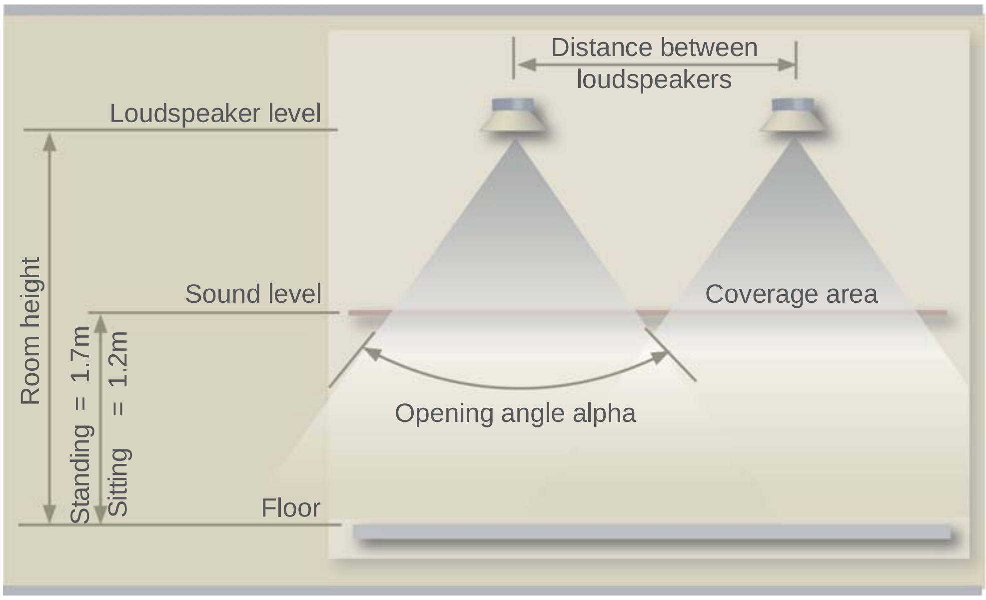


Figure 5.10: Diagram of loudspeaker arrangement

Based on this diagram, the coverage areas listed in the tables below result as a function of the opening angle and ceiling height:

Ceiling height	**[m]**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
Distance between loudspeakers	[m]	11.2	14.9	18.7	22.4	26.1	29.9	33.6
Coverage area per loudspeaker	[m^2]	125	223	348	501	682	891	1'128

Table 5.2: Coverage area with moderate intelligibility – alpha = 150°

Ceiling height	**[m]**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
Distance between loudspeakers	[m]	5.2	6.9	8.7	10.4	12.1	13.9	15.6
Coverage area per loudspeaker	[m^2]	27	48	75	108	147	192	243

Table 5.3: Coverage area with normal intelligibility – alpha = 120°

Ceiling height	**[m]**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
Distance between loudspeakers	[m]	3	4	5	6	7	8	9
Coverage area per loudspeaker	[m^2]	9	16	25	36	49	64	81

Table 5.4: Coverage area with good intelligibility – alpha = 90°

The above tables give the calculated, correct coverage area. In practice, these areas are usually considerably exceeded for cost reasons, or fewer loudspeakers are installed than should be required based on this formula – this is especially the case with low ceiling heights. The crux of the matter is to maintain the required speech intelligibility with possibly few loudspeakers.

The number of required loudspeakers thus decreases with the ceiling height. However, it must not be overlooked that with constant sound performance, the sound pressure on ear level decreases to the square of the distance. If the sound pressure shall remain constant, however, a square increase of the electric performance per loudspeaker is required.

As a rule of thumb, sound-absorbing surfaces such as carpets and curtains reduce both sound intensity and reflections, at the same time increasing the speech intelligibility. As on the one hand the standards require minimum speech intelligibility, while on the other hand the number of loudspeakers constitutes a massive cost factor, we are faced with an optimization problem. Planners specialized in acoustics are capable of calculating the speech intelligibility in advance and performing the required system optimization in advance, in compliance with individual conditions.

5.5.4 Emergency Power Supply

In case the voice alarm system is part of a fire detection system, the emergency operating time for the supply of the voice alarm system, ready for operation, must be ensured by the battery.

Emergency operating time	Prerequisite / precondition
4 hours	A standby mains system must be available for the voice alarm system, being able to maintain operation for at least 30 hours. A mains failure must be recognized at any time (permanently manned, responsible monitoring station).
30 hours	The fault is recognized in time (permanently manned, responsible monitoring station) and maintenance is ensured within 24 hours.
72 hours	If the conditions for the emergency operating time cannot be fulfilled, neither for 4 hours nor for 30 hours.

Table 5.5: Emergency operating time and prerequisites

In voice alarm systems integrated into a danger management system, the battery capacity must be calculated so that at the end of the emergency operating time, the battery is still capable of continuing alarm signaling for 30 minutes. This means that at the end of the emergency operating time, the batteries must be able to supply a multiple of their nominal discharge current without any admissible voltage drop (see section 4.6.1.2 on page 121).

5.6 Installation and Commissioning

The system components used must comply with the relevant standards and must bear the corresponding approvals (EN 54-16, BS 5839 part 8, UL 864, etc.).

During installation, a careful selection of the loudspeakers regarding their opening angle, nominal sensitivity and loading capacity must be taken into consideration:

- Ensure the correct placement and alignment of the loudspeakers, i.e. an even coverage of the areas to be irradiated. If in doubt, consult a specialized acoustics planning office.
- Calculation of the emergency power requirements and the required capacity of emergency power supply according to EN 54, Part Emergency Power Supply (EN 54-4).
- The cabling must comply with the relevant local regulations. This is especially important in terms of fail safety.
- Alarm signals must at any time be at least 10dBA above the noise level, based on the highest noise level to be expected.
- Speech intelligibility must be measured at a sufficient number of representative points and must be larger than or equal to 0.7 CIS throughout the complete coverage area (see Glossary on page 297).

In case of automatic actuation of the voice alarm system by the fire detection control unit, it must be ensured that no false alarms will occur in the fire detection system. Therefore, a possibly high performing and false alarm-free detection is to be ensured. Manufacturers, whose products are really able to distinguish between deceptive and real alarm are also in a position to give proof of this (e.g. in a fire test room for customers where fire and deception tests can be carried through).

5.7 Emergency Training

By emergency training we understand the simulation of emergency situations by building users and operators. This must be clearly distinguished from the fire brigade's emergency training sessions, which are not taken into account in this section.

While in the United States emergency training sessions are stipulated by the authorities and performed regularly, in Europe – with the exception of Great Britain – only few people really care about emergency training. Both the more complex and different building structures and the unfavorable fire statistics of the United States partly explain this discipline. The American fire damage statistics are decisively influenced by wood construction habitual for detached houses and by the disadvantageous mains voltage. The mains voltage, with 110V half of that in Europe, requires twice the amperage to ensure equal performance, at the same time producing four times as much heat on wires and bad contacts. However, it should not be overseen that the size of building structures is growing continually in Europe, due to an advancing concentration process.

Most countries oblige building operators to perform emergency training sessions. But these requirements are usually limited to companies subject to the statutory order on hazardous incidents or companies that store toxic or fire-promoting substances, such as gases, or that concentrate their activities on biotechnology, thus representing a considerable hazard potential. But emergency training sessions make sense in every building. This becomes obvious with the example of the administrative building in which the director remained in his sound-isolated office while the building was evacuated! Only by the aid of training sessions can such weak points of the protection concept be recognized without endangering people.

Experience continues to show that an evacuation is never complete because only a maximum of 95% of the building occupants are reached. Toilets, electronic rooms, cleaning rooms and other remote zones such as archives in the basement, etc., must be checked by the people in charge. Major problems are also caused by the evacuation of employees of external companies, for example electricians and cleaning personnel. Quite often, these people are literally left out of the evacuation process. In addition, there is the problem of foreign workers who often do not understand voice messages as they do not master the language. These reasons underline the importance of emergency training sessions: Good evacuation is only possible when people are trained accordingly and faults occurred in the past can be corrected.

By means of previous instructions, checks in parallel with the training and subsequent evaluation, emergency training sessions therefore aim at ensuring the following:

- If possible, all people in the building are evacuated, including the employees of foreign companies, guests, etc.
- The behavior of people correctly considers the type of danger.
- Evacuation is quick and smooth.

As soon as the people have reached the meeting point, presence checks must follow immediately so that any missing persons can be informed in good time.

To perform emergency training sessions, it is recommended to call upon the help of experts. This is the only way to guarantee that the best possible results can be achieved within the shortest possible time.

5.8 Profitability and System Evaluation

Profitability assessments should encompass the following aspects:

- The costs of a voice alarm system are contrasted by even higher benefits when the system is also used as a public address system. This becomes possible when the system overrides the public address system in case of alarm by means of an automatic priority switching function. However, some voice alarm systems have a frequency range that is insufficient for music; this can easily be clarified.
- The cost of the emergency power supply is substantial if the required run times for emergency operation are adhered to. Not all suppliers observe such regulations, but adherence to them can be decisive in case of emergency.
- Digital amplifiers of class D have a degree of efficiency of 80% minimum. A simple extrapolation shows that such amplifiers quickly amortize their additional costs. Their advantage lies not only in their low power consumption but especially in emergency power supply as well as building air conditioning that needs to carry off the dissipated heat. Furthermore, the use of a control unit room is not only limited by the heat released by the control units (room temperature) but also by the noise generation when a large number of fans are used.
- Voice alarm is part of safety technology and, as part of the building automation and control system, must by no means be confused with entertainment electronics. The performance of modern entertainment electronics systems is still unparalleled, but what is much more important than the final pinch in performance is the long-term availability of spare parts and an efficient maintenance department. For this reason, provider and maintenance organization are often more decisive than technology itself.
- More than ever, voice alarm has become a standard. Setting the course for voice alarm today means bringing the right infrastructure to a building that may well have a service life of 50 years or more. The largest cost pool of voice alarm is the loudspeaker cabling – this is an investment into the entire life of a building.
- Voice alarm is more than a simple trend. Its continuous spread is favored by such different factors as technological progress, decreasing price levels, the development in liability law and social changes. Last but not least, we must ask ourselves whether long term, we can really afford doing without something that may save people’s lives.

6 Automatic Extinguishing

6.1 Summary

Automatic extinguishing systems shall either extinguish or prevent incipient fires in order to protect objects, rooms or entire buildings from fires and their consequences.

The extinguishing agents used for this purpose are liquid (water), two-phase (foam), solid (powder) or gaseous (gases). Depending on the extinguishing agent, heat and/or oxygen is displaced from the fire, which means separated from the fuel. The extinguishing or suppressive effect begins with the flooding time and ends after expiry of the holding time. Intervention and automatic extinguishing must be harmonized accordingly.

Water as the most frequently used and most widely distributed extinguishing agent is used in different sprinkler systems as well as in water spray and water fog extinguishing systems. While the activation of sprinkler systems is mostly temperature-sensitive, other extinguishing systems generally require the activation by automatic fire detectors.

By means of various foam generators and by adding compressed air in different concentrations, a wide array of extinguishing foams can be generated, applied in different areas and situations. In contrast, powder extinguishing systems are rarely used, as they are only advantageous in specific situations.

Gas extinguishing systems use either natural gases or chemical extinguishing gases. While natural gases mainly displace oxygen, chemical extinguishing gases actively intervene in the combustion process. The best-known chemical extinguishing gases are halons, which have been banned for reasons of environmental protection. However, the environmental compatibility of advanced chemical extinguishing gases applied today is beyond controversy.

Extinguishing gases are stored in pressurized containers. The system layout and especially the correct discharge of the extinguishing agent under sufficient pressure is decisive for the correct functioning of the extinguishing system – even today, this can still not be taken for granted.

Extinguishing is a crucial part of an integral protection concept

To select the best suited extinguishing method, the correct system layout and the optimum integration of the extinguishing system into the building management system requires experience and knowledge. If these prerequisites are matched, the system's fire protection effect will be very high and in compliance with the objectives.

6.2 Basics

The industrial development, which took place particularly during the second half of the 19th century, promoted the concentration of production processes. Instead of the small handicrafts enterprises, industrial companies now produced goods mechanically, with the aid of large-scale facilities in accordingly voluminous production halls. This process automatically lead to a massive increase of fire risk, which due to their size, could no longer be contained with conventional, manual methods.

This environment was the beginning of the first technical extinguishing installations. The pioneers of these extinguishing systems were mills, usually built in wooden constructions that were several stories high. In these mills, widely ramified piping systems leading to every room and provided with simple bore holes were installed. In case of fire, water could be fed through these bore holes.

The first automatic extinguishing systems based on this concept were so-called “sprinkler systems” in which the bore holes were replaced by sealed heads with heat-sensitive activation elements. Today, these sprinkler systems are still the most widely distributed extinguishing systems worldwide. Later, other solutions with foam, powder or different gases were developed, especially for fire risks for which water was not the optimum solution.

Today, a variety of possible solutions is available, distinguished according to their extinguishing agents, protection concept and protection objective. Due to scientifically based research, efficient systems are available today, providing rapid extinguishing when used appropriately.

6.2.1 Extinguishing Agents

The following extinguishing agents are internationally known and available today:
- water
- gases
- powder
- foam

Water continues to be the most widely spread and best-known extinguishing agent. The most commonly used automatic system using water is the sprinkler system. These systems are employed in almost all fields of industry, larger business enterprises, department stores, garages, meeting places, schools, hospitals, hotels, airports, etc. In addition to the sprinklers, automatically activated water spray extinguishing systems are available as well. Since the late 1990s, water is also used in systems operating with higher pressures, thus generating smaller droplets. These so-called water fog systems or water spray systems provide the extinguishing effect of “classic” water extinguishing systems and are consuming considerably less water while working equally reliably. In the course of this section, this system type will be described in detail.

During decades, carbon dioxide (CO_2) and halons were virtually the only known extinguishing gases. As a consequence of the Montreal Protocol of 1987, halons were outlawed as extinguishing gas, and industry reacted by developing alternative solutions. This led to the use of other natural gases as extinguishing agents: To-day, nitrogen (N_2) and argon (Ar) are the most important natural extinguishing gases apart from CO_2. Furthermore, compounds of these three natural gases are available as well. Other chemical alternatives to halons have been developed. The most significant group of chemical extinguishing gases not harmful to the ozone layer are the chlorofluorocarbons (CFC), their best-known representative being HFC227ea, marketed among others by Great Lakes under the name of HFC227ea. Lately, the chemical extinguishing agent Novec™ 1230 has been commercially available, an agent that neither destroys the ozone layer nor essentially contributes to the greenhouse effect.

While powder extinguishing systems are scarcely used due to considerable conse-quential damage (corrosion!), foam extinguishing systems for the protection of chemical and tank storage facilities are widely spread.

In Germany, for example, 60% of all automatic extinguishing systems are sprinkler systems, 35% are gas extinguishing systems and the remaining 5% account for other system types.

6.2.2 Protection Categories

Here, we have to distinguish between building protection, room protection and object protection. Building protection is the complete protection of an entire build-ing, while room protection deals with individual rooms separated by structural fire protection measures. These rooms usually contain highly valuable objects. Object protection separately protects individual equipment, such as industrial machines erected in large halls or outdoors.

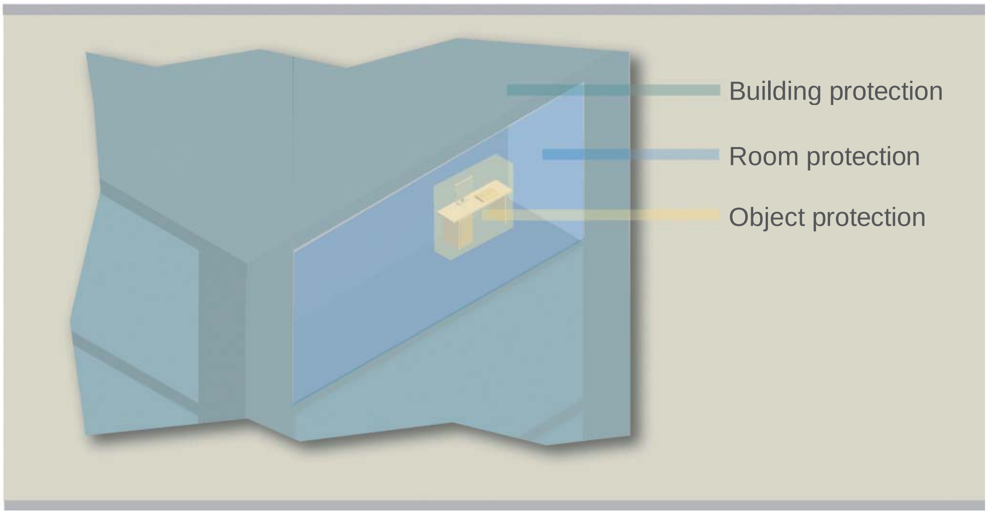


Figure 6.1: Protection categories

Building protection is almost always achieved by water (usually with sprinkler systems), while extinguishing gases are specially suited for room protection purposes. In object protection, only one gas – carbon dioxide – can currently be used as an alternative to water or foam. Carbon dioxide is heavier than air and can be locally contained.

6.2.3 Protection Objective

In general, the following protection objectives can be distinguished:
- fire extinguishing
- fire suppression

Like most water extinguishing systems, sprinkler systems aim at suppressing a fire. This means that they are not able to extinguish a fire in any case, but they can fight and contain it until the fire brigade arrives to extinguish the fire completely.

On the other hand, gas extinguishing systems aim at actually extinguishing any fire in the protection area.

6.3 Fire Physics

The objective of this section is to provide an in-depth overview of the physical and chemical processes, specifically looking at the different possibilities of fire extinguishing.

6.3.1 The Three Elements of Fire

In general, a fire requires the presence of each of the three following components:
- heat (or in more general terms, energy)
- oxygen
- fuel

These three components are familiar from the so-called fire triangle (see chapter 4.2 starting on page 65). Only one or two of these components do not suffice to produce a fire – only all three of them together do, causing a chemical reaction known as combustion. In terms of chemistry, fuel and oxygen are the raw materials which only react under the influence of heat and are converted into combustion products, releasing energy. A fire is simply the consequence of this exothermic (= heat generation) process. These components can be described as follows:

- Heat = energy from ignition sparks, hot surfaces or already burning materials (fuel).
- Oxygen = an integral part of our ambient air, in a concentration of approx. 21% per volume of the atmosphere.
- Fuel =
  - solid fuels, such as wood, paper, synthetic materials, i.e. all materials containing carbon
  - liquid fuels, such as alcohol, propellants, particularly all liquid hydrocarbons
  - gaseous fuels, such as hydrogen, butane, propane, i.e. all gaseous hydrocarbons and a number of other gases, such as carbon disulphide (CS2) or ammoniac (NH3)

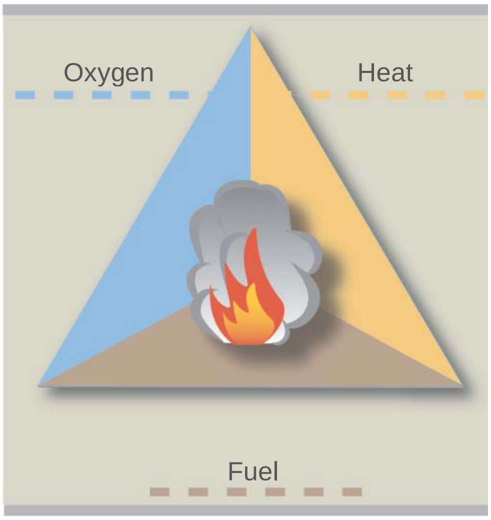


Figure 6.2: Fire triangle

The specific reaction steps of decomposition occur sequentially but partly also in parallel to the reaction steps of the synthesis (the combination of individual atoms to new molecules). This so-called chain reaction is the core of the combustion process, which is triggered by the three components heat, oxygen and fuel and is maintained as long as all three components are present. A combustion process is always exothermic, thus producing heat – this is one of the reasons for the dynamics of fire: It grows continuously as oxygen and fuel are available in almost unlimited volumes at the beginning of the process.

6.3.2 Combustion Process

Combustion is simply a chemical oxidation process of fuel with the ambient air. The oxidation process can be divided into three different subprocesses.

Depending on the type and nature of the oxidation, these different processes can be distinguished as follows:
– smoldering fire, the decomposition of substances under the influence of heat
– glowing fire, with the fuel burning weakly without flames
– flaming fire or open fire

Depending on the physical state (cf. Figure 6.3) of the burning material, different types of fire may result. The graphic below shows these correlations in a more detailed way:

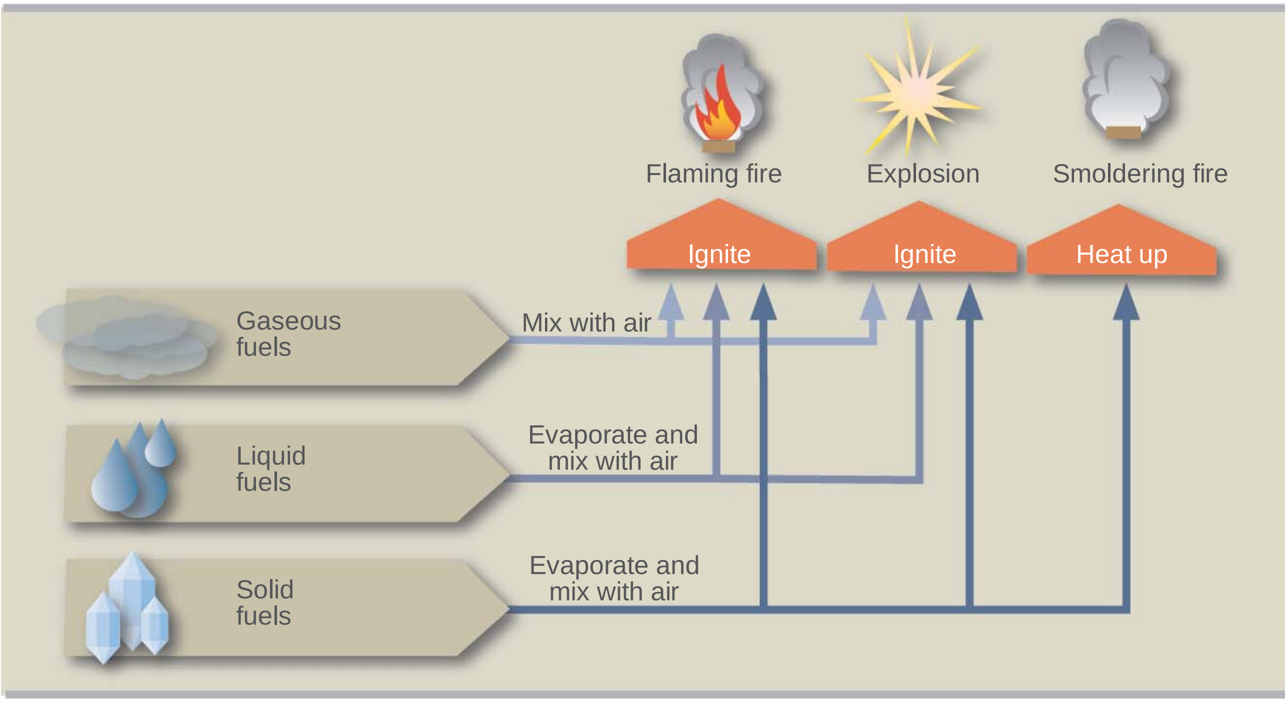


Figure 6.3: Type of fire depending on the physical state

6.3.3 Principles of Fire Extinguishing

In accordance with the three components of fire, there are three fundamentally different principles how a fire can be extinguished. Each of these three principles aims at one of the three fire components.

6.3.3.1 Removing the Fuel

The fire goes out when all the fuel not yet burnt is separated from the heat source, the fire. As the fuel cannot be eliminated automatically in most cases, this method is generally useless with automatic extinguishing systems. Even manual removal of the fuel from the fire is impossible in most cases.

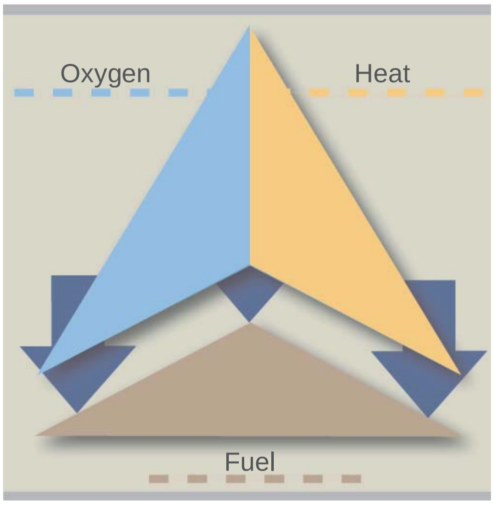


Figure 6.4: Removing the fuel

6.3.3.2 Removing the Heat

Reduction of the temperature at the seat of fire stops the combustion process, thus extinguishes the fire. This is classically done with water. When the water is brought to the seat of fire, it evaporates due to the heat. However, since the vaporization process absorbs a lot of heat (energy), the heat is withdrawn from the fire. The resulting cooling effect leads to the breakdown of the combustion process if sufficient water is available.

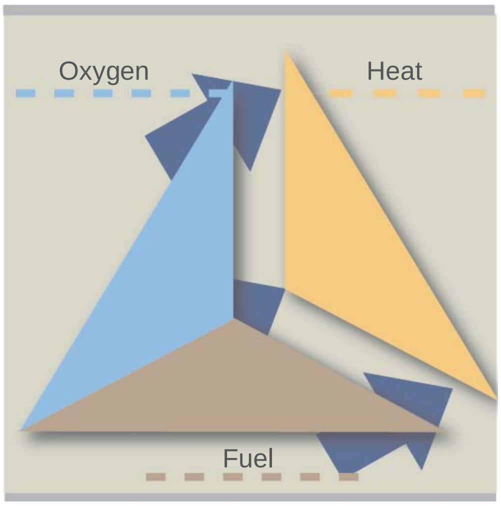


Figure 6.5: Removing the heat

6.3.3.3 Removing the Oxygen

The reduction of the oxygen concentration near the seat of fire stops the combustion process due to lack of oxygen. The concentration of oxygen in the air is 20.8vol %. If this concentration drops below 13vol %, the combustion process will be stopped with most fuels.

Automatic extinguishing systems operating with the natural gases CO_2, N_2, argon or mixtures of these gases make use of this extinguishing principle. The air – and thus also the oxygen – is partly displaced by the extinguishing gas; this process is known as “blanketing”. Good to know that these gases cannot react with the fuel.

It is important that the residual oxygen concentration (normally between 10 and 13vol %) normally does not entail danger to life. Breathing in such an atmosphere is comparable to breathing at an altitude of 4'000 to 5'000 meters above sea level, as the number of oxygen molecules available for breathing is approximately the same in both cases.

In spite of this method being largely harmless, an evacuation of the extinguishing area is necessary. This is due to the fact that the actuation of the extinguishing process is very noisy and unfamiliar to people, which may cause panic reactions. In addition, the fire to be extinguished has already generated flue gases, which might be dangerous. Loose objects in the room may be catapulted by the blowing in of the gases and may also cause harm.

The above mentioned details on the harmlessness are not valid for CO_2. This gas is already harmful to people at concentrations of approximately 5vol %. This effect has nothing to do with the reduced oxygen share in the air but with the toxicity of CO_2. As concentrations up to 50% are used for extinguishing purposes, it would be fatal to remain within the extinguishing area.

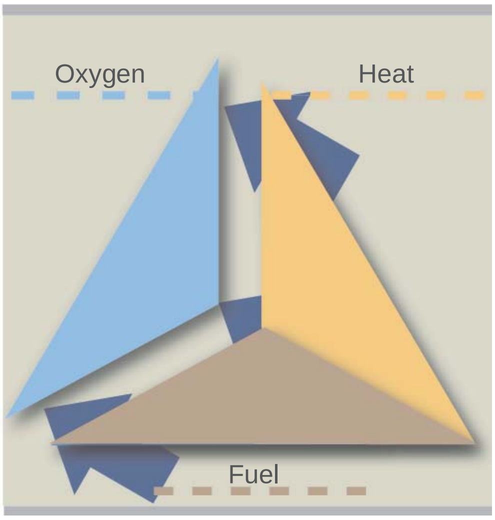


Figure 6.6: Removing the oxygen

Foam extinguishing is based on removing the oxygen as well. The foam forms a separation layer between the burning material and the oxygen in the air.

Chemical extinguishing agents such as HFC227ea or Novec™ 1230 are usually applied in concentrations below 10vol %. They are long-chained molecules consisting of many atoms. When such an extinguishing agent molecule penetrates the reaction zone, it is decomposed in smaller parts, ideally in its atoms. This decomposition leads – in accordance with the gas law – to an expansion of the extinguishing gas on the one hand and thus to a local reduction of the oxygen concentration. On the other hand, the decomposition of the molecule and the subsequent recombination also leads to heat absorption, which in turn lowers the temperature. Chemical extinguishing agents thus withdraw heat from the fire, simultaneously reducing the oxygen concentration, which is a combination of the two latter effects described. Which of the effects will dominate depends on the extinguishing agent applied.

6.3.4 Flooding Time and Holding Time

The flooding time is the time between the activation of the extinguishing process and the moment the required extinguishing concentration is reached. The holding time is the period of time during which the extinguishing system maintains the required concentration by continuous supply of extinguishing agent.

In accordance with the exact conditions prevailing at the seat of fire, a successful extinguishing process must prevent re-ignition. This can only be ensured when the required flooding and holding times are adhered to.

As the cooling takes longer when the fire seat is larger, the required holding time depends on the fire size. It is thus important to detect fires at a possibly early stage when they are still relatively small. A consistently high response velocity, independent of the cause of the fire, is thus very advantageous in fire detection and subsequent extinguishing. The quality of fire detection is a decisive factor, even when an automatic extinguishing system is installed.

6.4 Water Extinguishing Systems

Without doubt, water is by far the most important element on earth. Approximately 71% of the earth's surface is covered by water. Fauna and flora consist by 60 to 90% of water, and the atmosphere contains an equally significant amount of water in the form of humidity. Water is a fundamental prerequisite for life. For this reason, in mythology, water has been a symbol of life for thousands of years.

Water has played the main part in fire extinguishing since ancient times, and it is for sure the oldest and most common extinguishing agent. As approximately 90% of all fires are solid fuel fires (= class A) which can be easily extinguished with water, it is still the most widespread extinguishing agent today.

6.4.1 Water as an Extinguishing Agent

The extinguishing principle of water (H_2O) has already been discussed in section 6.3.3. Its main effect is cooling. Water has a high specific heat capacity and an especially high evaporation heat:

- To heat up 1 liter of water from 10 to 100°C, 375KJ or 90kcal are required.
- To evaporate 1 liter of water from 100°C to water vapor, 2260KJ or 540kcal are required.

This cooling effect destroys the thermal base of the chain reaction. Moreover, unburnt combustible material is covered with water and hence separated from the oxygen. In addition, water constitutes a heat sink (= absorption of heat). These effects reduce both the rate of fire propagation and – after extinguishing – the risk of re-ignition.

A side effect of extinguishing with water is the generation of water vapor (steam). On complete evaporation, 1 liter of water is converted into approximately 1,690 liters of water vapor, which may lead to further blanketing. This side effect is unimportant with sprinkler systems, but it plays a role with water fog systems, which is described in detail in the sections 6.4.4 and 6.7.4.

How the water is applied to the fire is crucial for its extinguishing capability. A great number of small droplets have a much better cooling effect than a concentrated water jet.

6.4.2 Sprinkler Systems

The first patent for a sprinkler system was issued in 1723 to a chemist named Ambrose Godfrey. This system consisted of a tank containing water and the water was distributed by a gun powder load which was in turn ignited by the fire to be extinguished.

The first installation using a pipe system was invented in 1806 by an Englishman named John Carey: A master valve was kept closed by a system of ropes and counterweights. When the ropes caught fire, the valve was opened due to the counterweights, and water was released from a water tank positioned at a higher level.

The first systems with perforated sprinkler pipes were installed in the United States in 1852. Major A. Stewart Harrison from London invented the first automatic sprinkler head which, however, was never used or patented.

The first usable sprinkler head was patented in the United States in 1874 by Henry S. Parmelee. This sprinkler was already equipped with a fusible link the design of which has been revised many times until today. Around the same time, the so-called “wet sprinkler systems” were introduced. This design finally became established as it facilitated faster extinguishing.

Dry-pipe systems made it possible to protect unheated buildings where a wet-pipe sprinkler system would freeze in winter. The first widely accepted valve for dry-pipe systems was patented by Frederick Grinnell in 1885. In 1924, the Grinnell quartz bulb was introduced, followed by the “Save all” sprinkler head in 1931, which was already activated by a melting, organic compound.

The spray technique was largely neglected until the middle of the twentieth century. However, from 1947 to 1950, the Factory Mutual Laboratories conducted experimental studies on this topic, resulting in the development of a spray sprinkler head which became the standard for automatic sprinkler heads in 1955.

6.4.2.1 Protection Objectives of Sprinkler Systems

As already mentioned, sprinkler systems primarily serve the purpose of building protection. Although the protection of valuables or people in the building must by no means be neglected, it is basically a consequence of the first protection objective.

Sprinklers are automatically activated individually when the temperature measured on the sprinkler head exceeds a critical value. As the activation automatically triggers the water supply, sprinkler systems also serve as fire detection systems and are normally directly connected to the intervention forces on site or to the fire brigade.

6.4.2.2 Setup

Automatic sprinkler systems consist of a pipe system enabling a homogenous distribution of the sprinkler heads. The sprinkler network is separated from the main water supply by a main alarm valve.

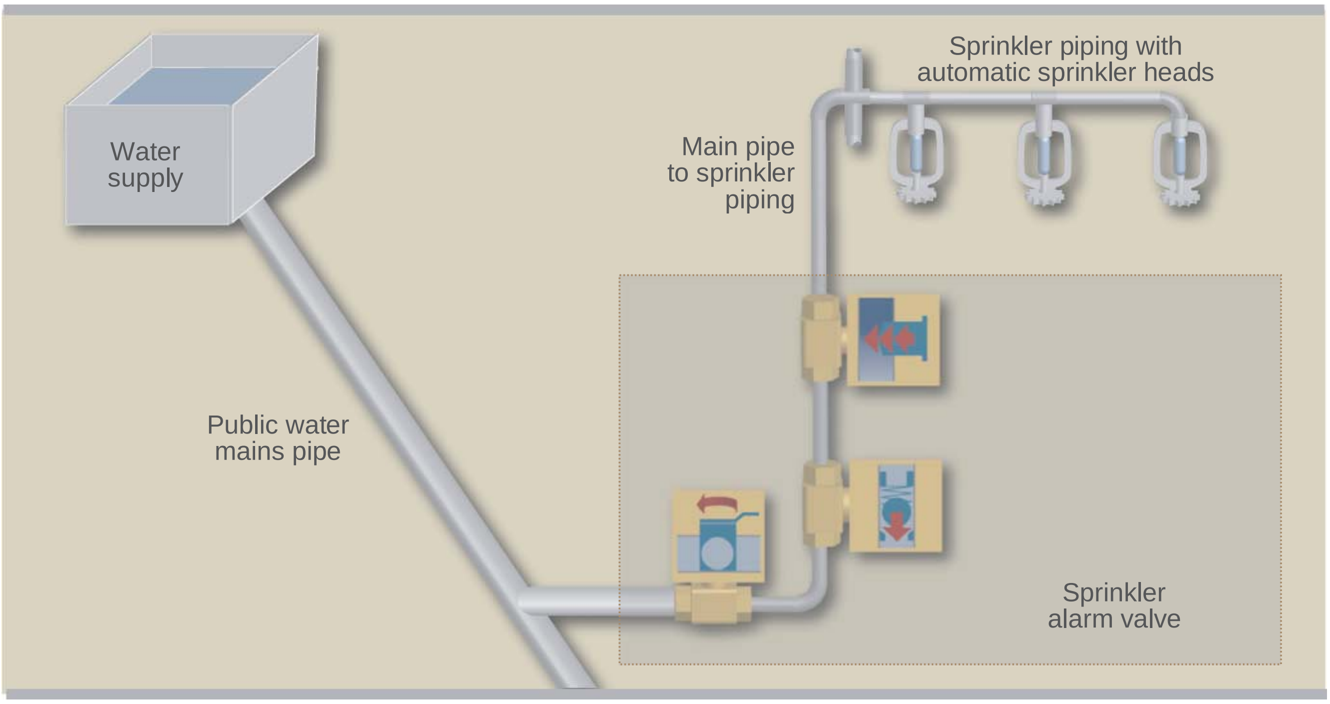


Figure 6.7: Basic diagram of an automatic sprinkler system

The alarm valve between the main water supply and the sprinkler network serves different purposes:

- separating the sprinkler network from the water supply (usually a reservoir or, rarely, the public water main), as the water pressure in the sprinkler network differs from that in the public water main
- enabling system maintenance
- activating alarm bells and sirens
- activating alarm transmission via the control unit to the fire brigade

Basically, three types of sprinkler systems can be distinguished:

- wet-pipe systems
- dry-pipe systems
- pre-action systems

The water supply must be sized such that a holding time (function time) of at least 30 minutes can be obtained.

Automatic Wet-Pipe Sprinkler Systems

Automatic wet-pipe sprinkler systems are the oldest, most widely distributed and most reliable sprinkler systems.

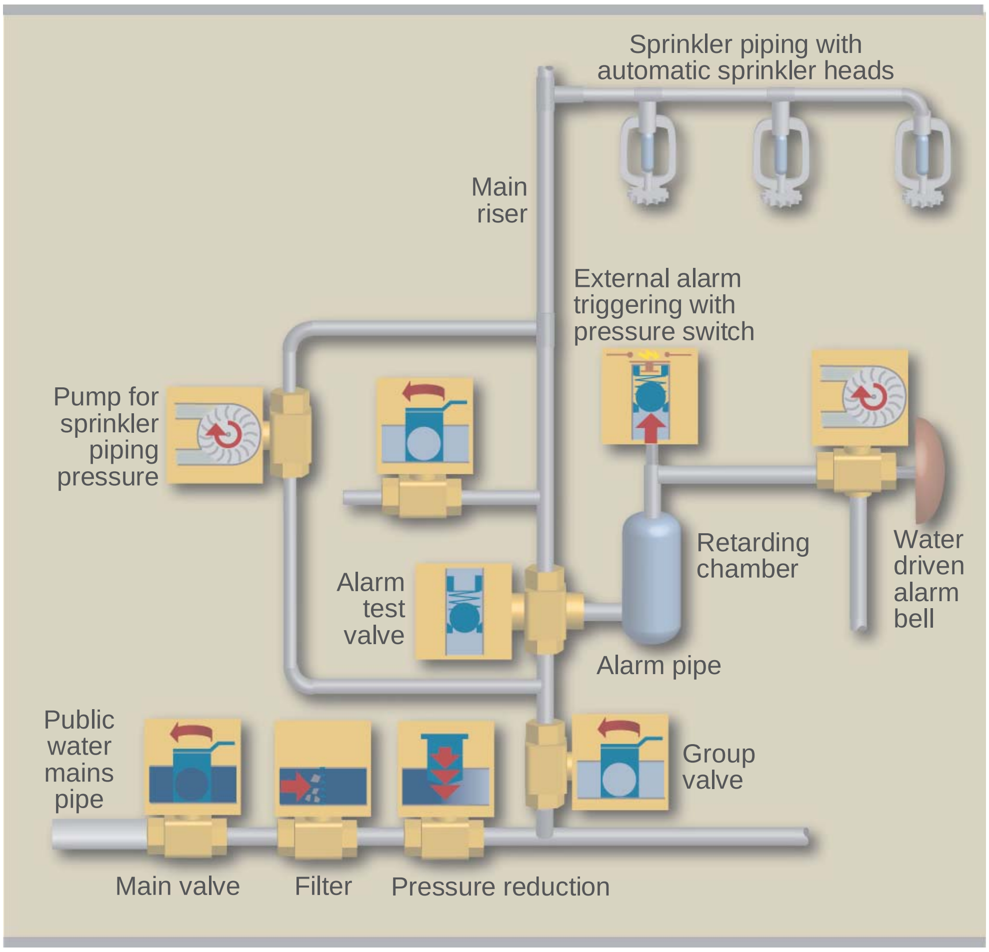


Figure 6.8: Basic diagram of a wet-pipe sprinkler system

A wet-pipe sprinkler system consists of the main riser, beginning at the sprinkler station and connecting the attached branch pipes on which the closed sprinkler heads are mounted.

Normally, the main component of the sprinkler station, the alarm valve, is closed and the complete pipe volume is filled with water.

The water may contain an anti-freeze agent. The pressure is usually slightly higher (approx. 2 to 3 bar) than in the water supply pipe, in order to keep the alarm valve closed.

The alarm valve serves different purposes, the most important being the opening of the water supply pipe in case of a pressure drop in the sprinkler pipe network. This is the case as soon as a sprinkler head has been activated. Opening the alarm valve enables the influx of the complete water volume through the riser into the sprinkler pipe network and shows that one or more sprinkler heads have re-sponded.

The same valve serves as a test valve and prevents contaminated water from flowing back from the sprinkler pipes to the water supply pipe.

Automatic Dry-Pipe Sprinkler Systems

Dry-pipe sprinkler systems are a derivate of wet-pipe sprinkler systems to ensure protection of unheated rooms.

Dry-pipe sprinkler systems require a pipe network similar to that of wet-pipe sprinkler systems. This pipe network is under air overpressure instead of water pressure, with the air taking on the task of keeping the alarm valve closed. As dry-pipe sprinkler systems are particularly used for unheated buildings, the water-containing part, i.e. the alarm valve, must be heated.

As the blowing-out of the air results in a delay compared with wet-pipe sprinkler systems, the fire has more time to develop. For this reason, neighboring sprinkler heads are usually activated simultaneously. In comparison with wet-pipe sprinkler systems, more sprinkler heads are activated, resulting in correspondingly higher water discharge.

Pre-Action Systems

These systems are installed in rooms where the activation of sprinklers would entail considerable damage, for example in EDP rooms. For this reason any unwanted activation, for example by mechanical damage, must be avoided at any rate. Like with dry-pipe systems, the pipe network is filled with pressurized air. The alarm valve station, however, is designed in such a way that it can only open when a fire detection system has additionally responded. This means that mechanical damage alone cannot lead to a water discharge.

6.4.2.3 Sprinkler Heads

Sprinklers have two functions:
- selective fire detection
- generation of water droplets in a predefined size and their distribution over the coverage area

All sprinklers are of the same design, consisting of the sprinkler head with nozzle, sealing element, activation element and spray plate.

With the glass bulb sprinkler, the activation element is a glass bulb filled with a liquid. The water bulb bursts when it is heated up, due to the strongly rising pressure of the filling material. With the fusible element sprinkler, the activation element is made up of the soldering joint of two plates. The soldering metal used melts at a defined temperature.

With both sprinkler types, the sealing element is catapulted from the nozzle by the water or air pressure in the sprinkler pipe network. The water flowing out is divided up into droplets by the spray plate and sprayed over the coverage area. With standing sprinklers, the water flow must be additionally turned downwards.

Sprinkler Types

The sprinkler types are determined by the nature of water distribution and their application area:
– normal sprinklers
– spray sprinklers
– flat spray sprinklers
– sidewall sprinklers
– ESFR sprinklers
– wide-range wall sprinklers

Normal sprinklers direct more water to the ceiling than spray sprinklers. This effect was consciously used to cool the wooden construction, which was the most common building construction type in the past. Fire tests have revealed that even with spray sprinklers, the temperatures below the ceiling remain within limits that imply no risk of an ignition of the wooden construction. For this reason, spray sprinklers are most widely used in Germany, for example.

Flat spray sprinklers are installed when there is not enough free space between the sprinkler and the equipment or stored goods.

Sidewall sprinklers are used with limited ceiling heights and when there is risk of mechanical damage to the sprinklers.

ESFR sprinklers (Early Suppression Fast Response) have been developed for use in risky storage facilities with high storage heights, without sprinklers on intermediate levels. In addition to a quicker activation element, they have a different water distribution spectrum with a very high water charge of more than 40 l/m^2 per minute. Due to the large nozzle bore and the high minimum pressure, larger drops are ejected at higher speed, being more likely to penetrate the flames and directly extinguish the seat of fire. The installation of ESFR sprinklers requires full adherence to many building construction specifications, such as the inclination angle of the roof, and is therefore not always possible.

Wide-range wall sprinklers have been developed for the use in small rooms of limited heights, to be mounted on one wall. Hotels and offices are typical application areas for this sprinkler type.

Activation Temperature

The nominal activation temperature of sprinklers should be approximately 30°C higher than the maximum ambient temperature. The standardized temperature levels of the different sprinklers are listed in the table below:

Fusible element sprinklers		Glass bulb sprinklers	
Nominal activation temperature [°C]	Color code	Nominal activation temperature [°C]	Color code
57 - 77	Uncolored	57	Orange
80 - 107	White	68	Red
121 - 149	Blue	79	Yellow
163 - 191	Red	93 - 100	Green
204 - 246	Green	121 - 141	Blue
260 - 302	Orange	163 - 182	Violet
320 - 343	Black	204 - 260	Black

Table 6.1: Color codes of the sprinkler heads

Response Sensitivity

In the course of further development, the response sensitivities have been improved. By modifying the fusible elements with heat conductive plates and smaller sizes, the time until opening could be reduced. Over the past few years, smaller glass bulbs with the same characteristics have been developed.

Sprinklers are divided into three response sensitivity classes. These classes and the application limits at the installation are listed in both the VdS and NFPA guidelines.

Response sensitivity	RTI [sec] (Response Time Index)	Intermediate level sprinklers	Ceiling sprinklers over intermediate sprinklers[1)]	Dry-pipe systems	All other systems
"Standard"	80 - 200	Not admissible	Not admissible	Admissible	Admissible
"Special"	50 - 80	Admissible	Admissible	Admissible	Admissible
"Fast"	< 50	Admissible	Admissible	Not admissible	Admissible

1) The ceiling sprinklers must have the same or a slower response sensitivity class as the intermediate level sprinklers.

Table 6.2: Response sensitivity classes of different sprinkler types

6.4.3 Water Spray Extinguishing Systems

Water spray (also called “deluge”) extinguishing systems are stationary water extinguishing systems. In terms of setup, they are similar to sprinkler systems.

The two most significant differences to sprinkler systems are:

- The system is provided with **open** sprinkler heads or nozzles; the water spray heads have no heat-sensitive elements.
- To activate the water spray range valves, a separate fire detection system is required.

What is most characteristic for water spray extinguishing systems is their large-area water spraying through many spray heads. The deluge system has been developed for areas with a particularly high combustible load, such as fuel storage facilities where a quick fire spread has to be expected. In such cases, neither wet nor dry extinguishing systems with their individually opening sprinkler heads could control the quickly spreading fire, especially because a limited number of sprinkler heads distribute the water only locally and too late.

Due to the very high water volumes discharged in case of activation, water spray systems require an extremely high capacity of water supply.

A deluge system consists of the following indispensable components:

- reliable water supply
- main valve
- deluge system range valves
- fire detection system with interface to the deluge system
- pipe system
- open deluge system heads

The water supply must have a very high capacity and is therefore normally equipped with stationary extinguishing pumps, as the water supply usually does not generate a sufficiently high pressure which would in turn not generate a sufficient water flow for all simultaneously opened spray heads. The main valve requires a position indicator to switch off the deluge system and the deluge system range valves require an electric, hydraulic, or pneumatic drive and allow manual activation.

6.4.4 Water Fog Extinguishing Systems

Over the past few years, the water fog extinguishing technology has gained in importance both for room and object protection. Different products have been developed by various suppliers for a wide range of applications. All these solutions have one thing in common: In contrast to the conventional sprinkler technology, they try to achieve a droplet spectrum with the smallest possible diameters by applying higher pressures (up to 100bar) and specially designed nozzles, in order to achieve better cooling, or evaporation respectively, by the larger droplet surface.

However, on the market and especially among customers, there is considerable uncertainty about extinguishing principles, flooding times or application limits. This is aggravated by the fact that there is no directive giving a definite answer to such questions. The planned European standard (CEN TC 191 WG 5) has not been published yet.

In comparison to sprinkler systems, the water fog technology aims at applying considerably lower water volumes, as tests and approvals have shown. The European standard on water fog systems, currently being developed by CEN, will consider these systems as a sprinkler system replacement. Every extinguishing system must successfully pass fire tests for each application, proving that it is at least as efficient as a sprinkler system. The flooding time of all water fog extinguishing systems is up to 30 minutes according to this planned standard. The tank must thus be sized accordingly.

Often, however, more advanced objectives are propagated for water fog systems, such as:

- For room protection, water fog supposedly is able to “reach around corners”, i.e. the nozzle jet need not necessarily be directed to the fire seat.
- Instead of fire suppression, as it is the case with sprinklers, safe fire extinguishing can supposedly be achieved as with gas extinguishing systems. It should thus also be possible to considerably reduce the flooding time.

These objectives, however, are not only contradictory to all previously published guideline drafts. They are also in contrast to physical laws. This is discussed in detail in section 6.7.4 “Water Fog Systems as a Replacement for Gas Extinguishing Systems?“ starting on page 222.

6.5 Foam Extinguishing Systems

Foam as an extinguishing agent was invented as early as 1880. At that time, the search for crude oil had virtually caused a sudden increase in the number of drilling derricks, frequently causing oil fires. As it is impossible to fight such fires with water, soap was added to the water, with the expected effect of reducing the water's surface tension. These conditions were the origin of the use of extinguishing foams in fire protection: A mixture of water and foam-generating additives.

6.5.1 Foam as an Extinguishing Agent

Foam is usually generated in two steps:
1. mixture: water + foam-generating agent → foam solution
2. generation: foam solution + compressed air → foam

Many different types of foams have been developed until today, all of which have the same effect on fire: By covering the burning surface, the fuel (solid or liquid) is separated from the ambient air and thus from oxygen. Added to this is a cooling effect dependent on the foam type.

6.5.2 Foam Types

The ideal foam for fire protection purposes must have the following characteristics:
- it retains its water share as long as possible to build a vapor barrier layer over the burning surface
- it flows quickly and easily over a burning fuel surface
- it protects from flashover until the burning material has cooled below the inflammation temperature

In addition, foam should have a number of other properties, for example it should be non-toxic, economic, easy to clean, adhere to vertical surfaces, etc.

Unfortunately, in reality there is no foam having all these aforementioned characteristics. This is the reason for the large number of foam generators developed worldwide. This variety is divided into three classes:
- low-expansion foam
- medium-expansion foam
- high-expansion foam

These classes are distinguished on the basis of the air volume to be added.

Aqueous Film-Forming Foam Agents

AFFF is a remarkable type of foam. The abbreviation stands for "Aqueous Film Forming Foam agents". The main component of these foam agents is synthetic and capable of generating aqueous films on combustible liquids.

All AFFFs contain fluorinated, long-chained hydrocarbons, providing them with particular surface-active properties. Different water-soluble, high-molecular synthetic polymers are added to reinforce the foam bubble walls and to delay the collapse of the bubbles.

AFFF generates air foam combining low viscosity with fast propagation and level compensation. AFFF thus behaves similar to other foams, acting as an air barrier and cutting off the fuel evaporation. The main difference is that AFFF is capable of generating a dense aqueous film on the fuel. Combined with water, AFFF can be discharged by conventional water extinguishing systems, without the necessity of using specially designed pipe nozzles.

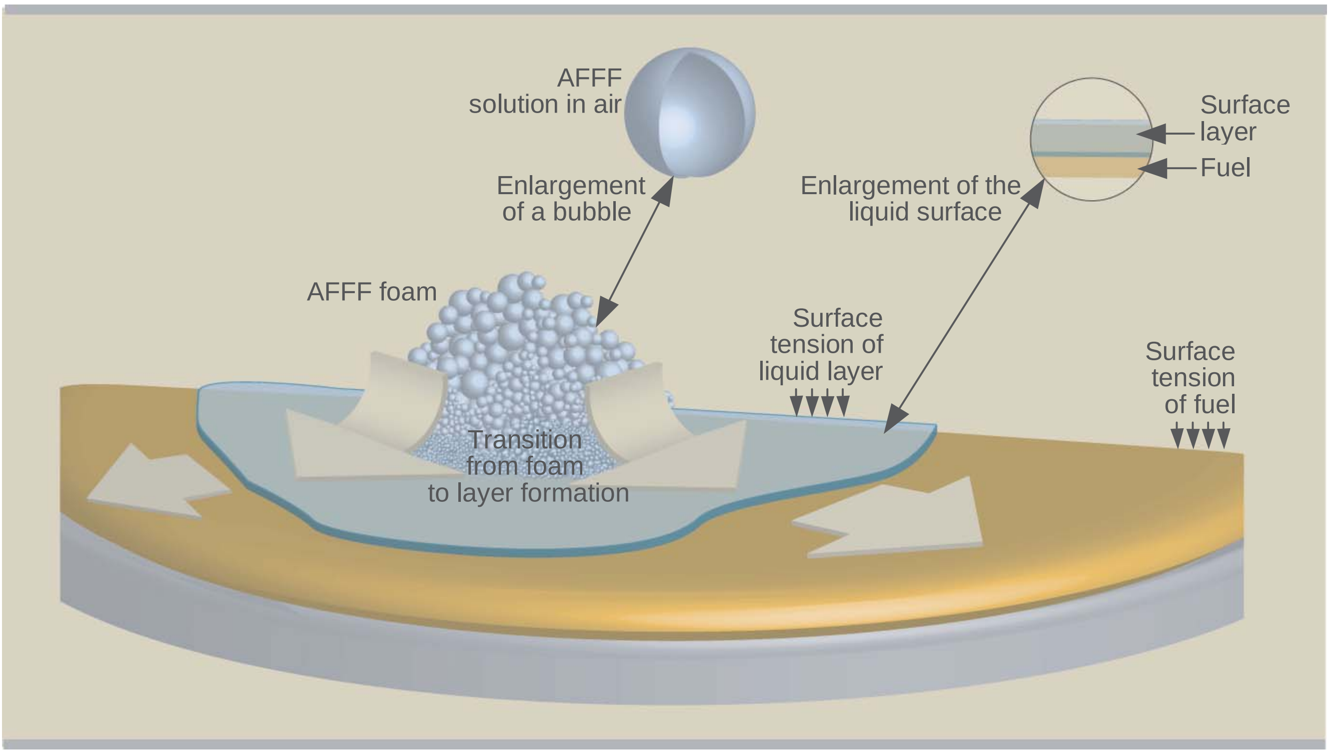


Figure 6.9: Surface effects of AFFF

6.5.3 System Setup and Function

Foam extinguishing systems are used for combustible liquid fires.

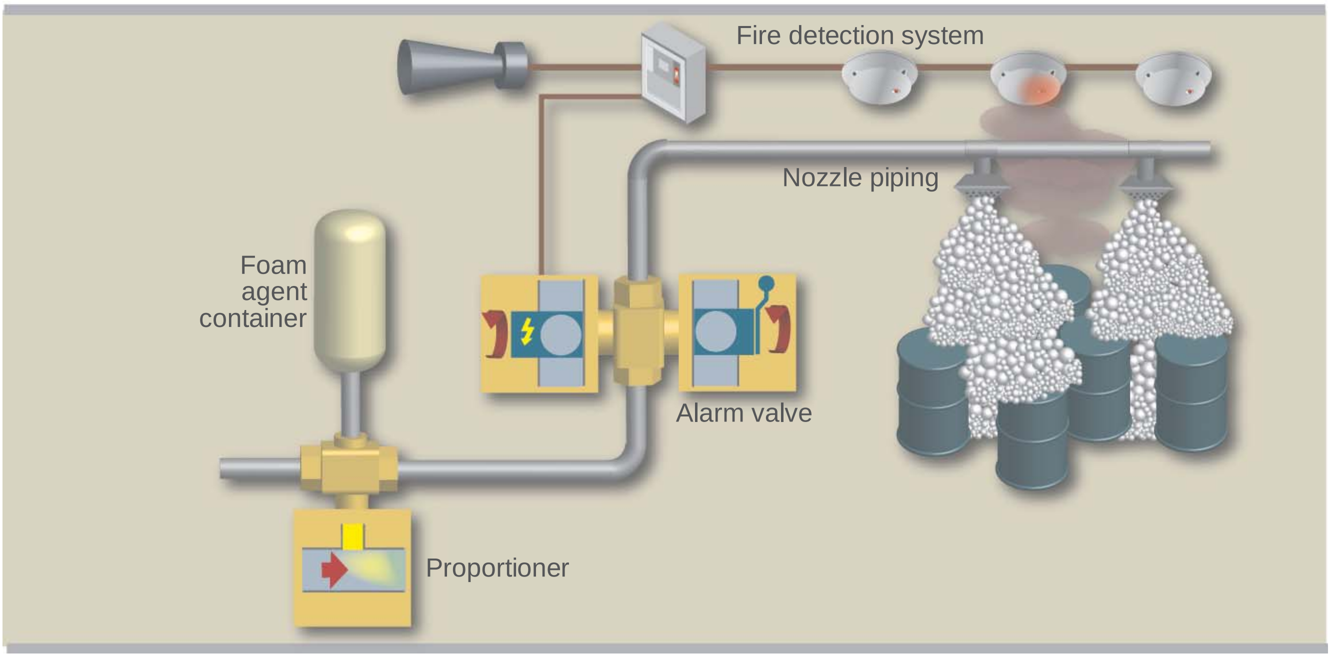


Figure 6.10: Setup of a foam extinguishing system

A foam extinguishing system consists of the following major parts:
– fire detection system with alarm and extinguishing activation
– water supply network
– foam proportioning
– foam generation and distribution

The first part comprises the fire detection, which must be selected in accordance with the type of risk. The detectors are preferably set up in multidetector logic, as it is common practice with automatic extinguishing systems. In case of alarm, the fire detection control unit activates all alarm devices and switches off the power supply, air conditioning and other devices in the alarm zone. It simultaneously activates the automatic main water valve of the foam extinguishing system.

The second part consists of the manual foam inlet valve, which serves for separating the foam system from the water supply. The manual foam inlet valve is normally open. The water pressure and the available water volume of the water supply must correspond to the volume and speed of foam required for the respective risk. If this is not guaranteed, pumps with adequate water storage containers are required.

The automatic main valve is normally activated electrically and / or manually. This valve is usually a so-called butterfly valve, which is opened by an electric motor or hydraulically.

The third part is the heart of the system, where the foam is proportioned. Three different proportioning principles can be distinguished:

- proportioning by the Venturi principle, based on the subpressure generated by the flow velocity
- pressure proportioning; the foaming agent is subjected to the water pressure
- proportioning pump driven by a motor

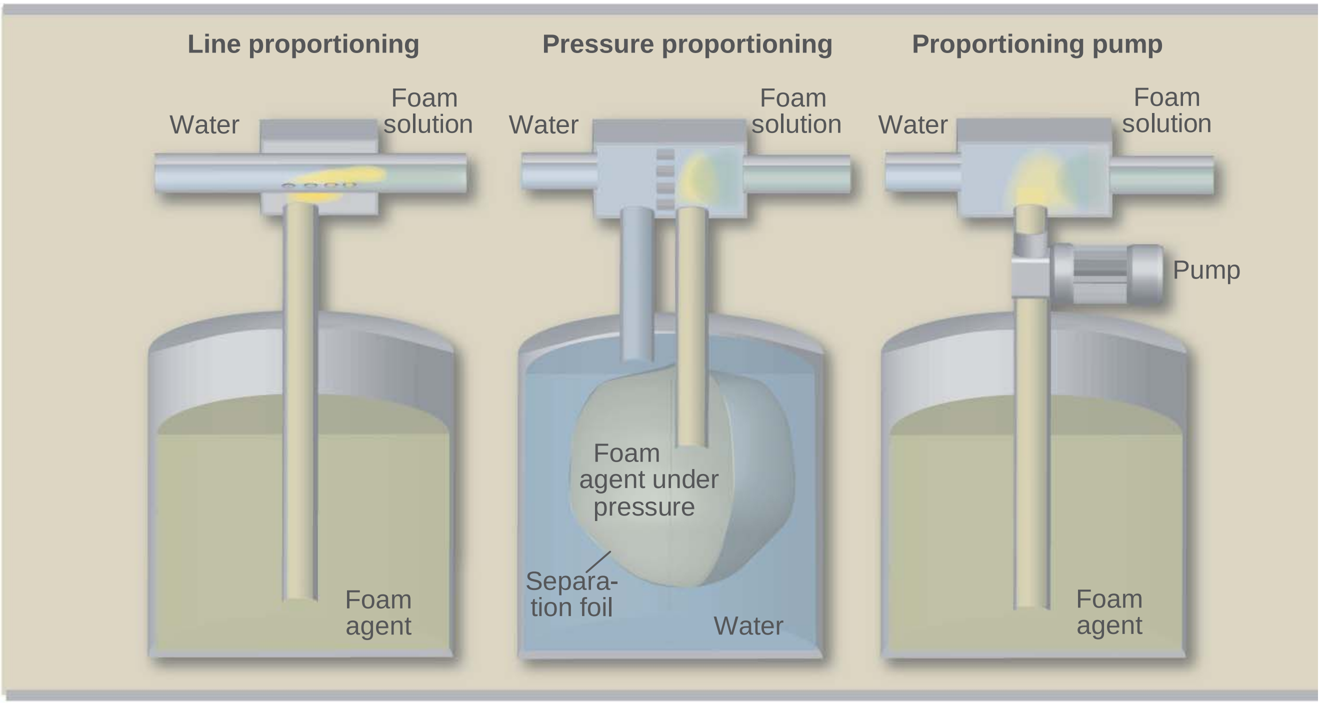


Figure 6.11: Mixing principles

In the fourth and final part, the foam is generated and distributed. The foam generators distribute the foam mass flowing through the pipe system to the surfaces to be protected.

6.5.3.1 Devices for Foam Generation

Low-expansion foam is usually distributed over the burning surface through large pipes or foam cannons, for example with burning liquids (see Figure 6.12). Low-expansion foam is particularly suited for the protection of large storage areas and buildings.

Medium-expansion foam may be distributed through in-line foam agent inducer (automatic foam generators), which have no built-in blowers. The outpouring mix of water and foam agent blends with the ambient air, generating the medium-expansion foam.

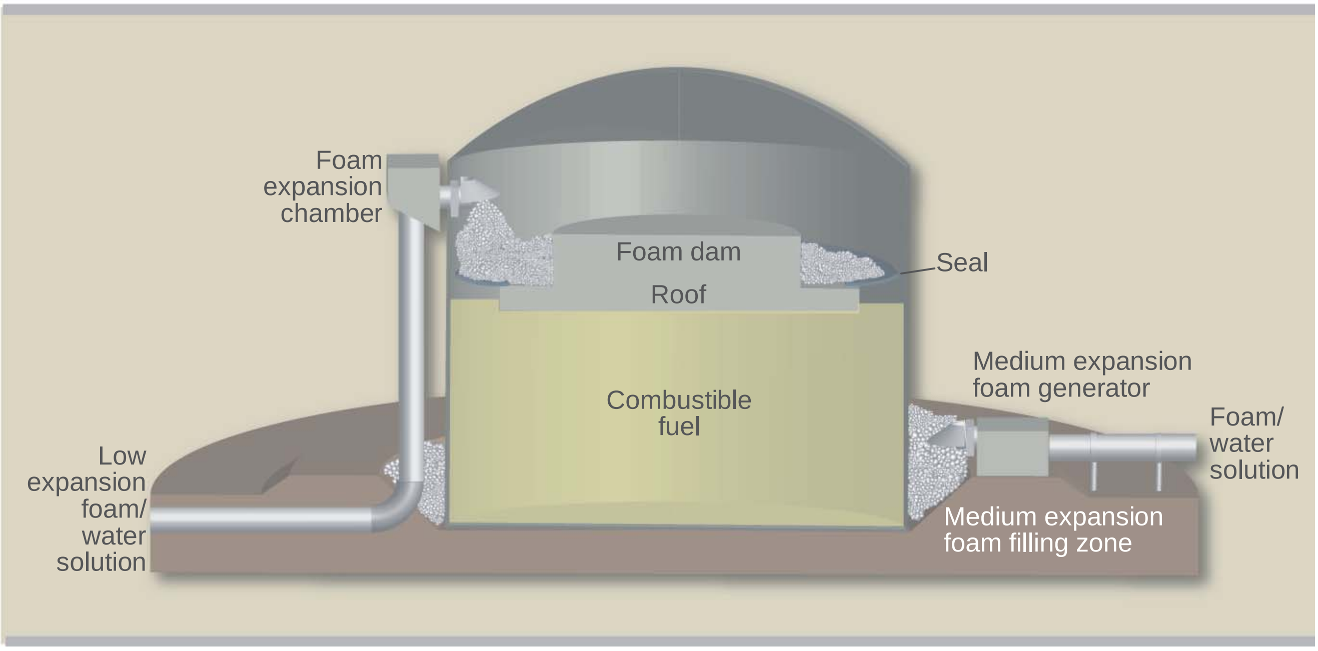


Figure 6.12: Typical application of low-expansion foam (tank) and medium-expansion foam (collecting basin)

High-expansion foam is usually produced by foam generators using either rotating sprinkler nozzles or nozzles with blowers. High-expansion foam is normally used to protect rooms or covered facilities, such as vehicle fueling facilities. These systems can be operated either automatically or manually. The system setup largely corresponds to that of sprinkler systems or deluge systems.

The expansion ratio (ER) is the proportion of foam volume to volume of the liquid (water and foam agent). The ER indicates by what factor the volume of the liquid was expanded through the foaming process. For example, if 1 liter of liquid and 7 liters of air generate 8 liters of foam, the ER is 1:8.

The ER of the various foams lie in the range of around 4 to 1'000. Foams are classified according to their ER:

Foam types	Expansion ratio from	to
Low expansion	~ 4	20
Medium expansion	21	200
High expansion	201	1'000

Table 6.3: Foam types classified according to their expansion ratio (ER)

6.6 Powder Extinguishing Systems

Powder extinguishing systems are used when there is a risk of liquid or gas fires. For fighting metal fires, special extinguishing powders are available as well. The extinguishing principle is based on the interruption of the combustion process by intervening in the chemical reaction and the associated energy deprivation.

This system type is used rather rarely since the very finely distributed powder forms residues that are difficult to remove and highly corrosive. In addition, the powder cannot be used with electric or electronic facilities.

The powder is usually stored without pressure and discharged by means of a propellant. The required powder volume is then sprayed through the nozzles.

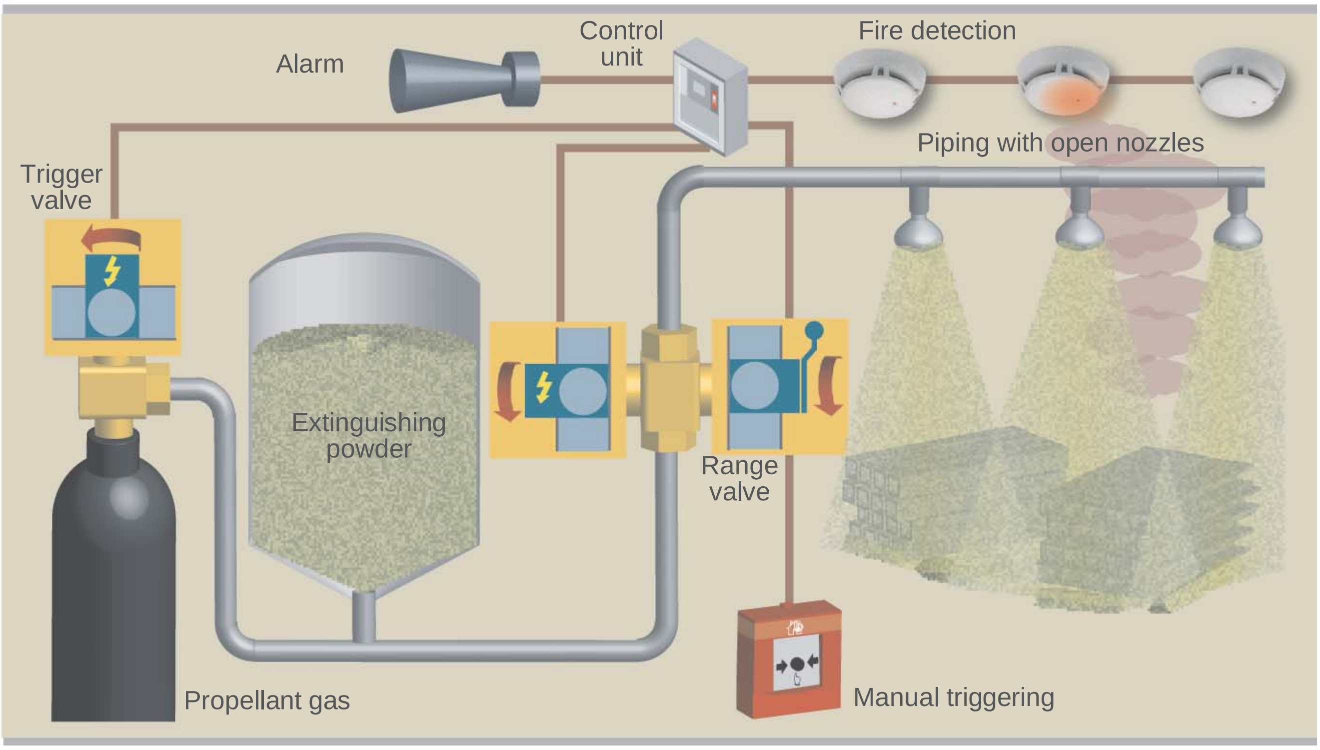


Figure 6.13: Setup of a powder extinguishing system

6.7 Gas Extinguishing Systems

Currently, blanketing natural gases and chemically acting extinguishing gases are available as gaseous extinguishing agents. These gases are discussed in detail in the following sections.

6.7.1 Natural Gases

Natural gases are distinguished by two characteristics:

- they can be found in nature
- the extinguishing effect is achieved by oxygen displacement throughout the complete volume of the coverage area

The following natural gases are suited for extinguishing purposes, as they are gaseous at ambient conditions and can be extracted without significant expenditures:

- carbon dioxide (CO_2)
- nitrogen (N_2)
- argon (Ar)

In addition, mixtures of these gases are commercially available, for example Inergen (52% N_2, 40% Ar, 8% CO_2) or Argonite (50% N_2, 50% Ar).

All these gases are colorless and odorless. They are extracted from the atmosphere by air fractionation. The first extinguishing gas ever used was carbon dioxide, which has been in use for this purpose since the 1930s. The other natural gases have only been used since the late 1980s.

As already discussed in section “Removing the Oxygen” on page 194, the extinguishing effect is based on the displacement of air and thus of oxygen in the coverage zone by the natural gas. Most fires are extinguished when the oxygen concentration drops below 13vol %. Figure 6.14 illustrates this using the example of CO_2.

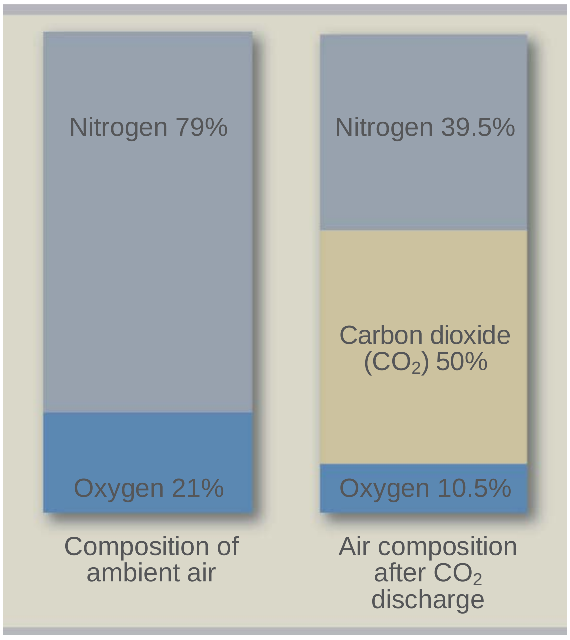


Figure 6.14: Air composition in the protected area after CO_2 flooding

The residual oxygen concentration aimed at in systems today is usually between 10vol % and 13vol %, corresponding to an extinguishing gas concentration between 36vol % and 52vol %. A displacement of such high gas volumes always requires overpressure release in the coverage area.

The residual oxygen concentration should not fall below 10vol %, since below this level adverse health effects on people remaining in the protection zone cannot be ruled out. The LOAEL value (lower observed adverse effect level) is then exceeded. In some countries, like for instance Germany, the installation of a special time delay unit is required in this case, providing for additional safety in adhering to the evacuation period. As carbon dioxide is always toxic, increased requirements on the protection of people are essential with this gas. A certain evacuation time, depending on the size of the protection zone, must always be taken into account.

The extinguishing agent concentration to be actually used depends on the type of fuel. To extinguish a methanol fire, for example, considerably more gas is required than for wood. The concentrations are determined in experiments, either in standardized room tests or in standardized tests of reduced scale (cup burner test). A safety margin (generally 30%) is then added to these theoretical concentrations, resulting in the application concentration.

The methods for determining the concentration as well as the effectively required concentrations for each risk can be taken from the following guidelines: VdS 2093 and NFPA 12 for CO_2, and VdS 2380, ISO 14520 or NFPA 2001 for all other gases.

Studying these guidelines, it becomes obvious that the different types of natural gases require different concentrations, even when the protection objective and risk remain the same. This seems surprising at first, as it is not to be expected if oxygen displacement is the only extinguishing effect. However, in addition to oxygen displacement, the heat absorption by the extinguishing gas plays a role, although a rather subordinate one. The only independent comparative study in which all gases have been compared in the same test setup has been conducted by the VdS in Germany (Report CEA GEI 7 – N 125). This study revealed that carbon dioxide has the best extinguishing properties, followed by nitrogen, while argon performs worst. This is hardly surprising, as carbon dioxide molecules consist of three atoms, nitrogen consists of two, and argon molecules of only one. The more atoms a molecule has, the more bonds there are which may absorb energy. The efficiencies of gas mixtures range between nitrogen and argon. There is thus no reason to revert to these gases.

For this reason, the use of pure natural gases is advantageous: For reasons of danger to life, carbon dioxide is only used for object protection and for rooms that are not frequented by people (e.g. generator rooms). Nitrogen is used for standard applications such as EDP rooms whereas argon is applied for special cases such as metal fires, where metals like magnesium would react with nitrogen.

The different weights, or the different densities of the gases respectively, play no role in room protection, as the gases do not decompose after flooding in a gas-tight room. This has been shown in experiments, but the atmosphere also shows that there is no gas decomposition. A gas-tight room is an ultimate prerequisite for the proper functioning of gas extinguishing systems, as the concentration must be retained during a holding time of at least 10 minutes in order to prevent re-ignition.

In object protection, however – meaning the protection of open equipment – the gas weight is crucial. Carbon dioxide is the only suitable gas here, as it is heavier than air and can thus be retained close to the object.

Natural gases can be used for the following fuels or materials:
- combustible gases, provided that no ignitable mixture can be generated after extinguishing
- combustible liquids or matters reacting like combustible liquids in case of fire
- solid matters possibly requiring a higher concentration and longer holding time
- electric and electronic equipment

6.7.2 Chemical Extinguishing Gases

Halon 1211 (CF_2ClBr) and Halon 1301 (CF_3Br) were the first chemical extinguishing gases used worldwide. In the stratosphere, however, these gases lead to the decomposition of ozone. In the scope of the efforts taken to protect the ozone layer, their replacement was decided in the Montreal Protocol of 1987 and consequential international agreements. With the exception of strategic special applications (aviation, military, nuclear energy technology), the use of halogenated hydrocarbons is prohibited for the purpose of fire protection. Refilling of existing halogenated hydrocarbons extinguishing systems is equally illegal in most countries. In the European Union, halogenated hydrocarbons extinguishing systems had to be withdrawn by December 31, 2003. In Germany, this decommissioning was already completed by January 1, 1994.

To replace the halons, halogenated carbohydrates were introduced on the market in the mid-1990s. These substances have no ozone-depleting effect and have an ODP value (ozone depletion potential) of 0. Especially the two groups of fluorinated carbohydrates and perfluorinated carbohydrates must be mentioned here. Well-known extinguishing gases from the group of fluorinated carbohydrates (HFCs) are HFC227ea (C_3F_7H, which is marketed by Great Lakes under the name of FM 200™) and HFC125 (C_2F_5H), for example. This group has found wider distribution than that of the perfluorinated carbohydrates (PFCs). From the group of halogenated carbohydrates, only HFC227ea and Trigon are today approved as extinguishing agents in Germany. These gases, however, strongly contribute to the greenhouse effect. They all have a GWP value (global warming potential) of more than 2'000, meaning that their contribution to the greenhouse effect is more than 2'000 times that of carbon dioxide. The actions regarding the protection against global warming, agreed upon in the Kyoto Protocol, decisively limit the use of halogenated carbohydrates. Although an international ban or restriction of their use in fire protection is not foreseeable at present, some countries such as Austria have issued more restrictive conditions for their use. In Switzerland, the use of HFCs is forbidden.

In 2003, 3M™ launched a new chemical extinguishing gas under the trade name 3M™ Novec™ 1230 Fire Protection Fluid. This gas belongs to none of the aforementioned groups; it is a fluorinated ketone with the chemical formula $CF_3CF_2C(O)CF(CF_3)_2$, which has already given proof of its extinguishing efficiency for room protection purposes in different extinguishing tests. In a corresponding draft of the ISO 14520 guideline, it is listed under the name of FK-5-1-12. It not only has an ODP value of 0 but also a GWP value of 1, meaning that its contribution to the greenhouse effect is not stronger than that of CO_2.

This property makes it possible to categorize chemical extinguishing gases in the following generations:

	1st generation	2nd generation	3rd generation
Environment parameters	ODP > 0 GWP >> 0	ODP = 0 GWP >> 0	ODP = 0 GWP ≈ 1
Gases (selection)	Halon 1211 Halon 1301 NAF S III	HFC227ea HFC125 HFC23 CEA410	FK-5-1-12 (Novec™ 1230)

Table 6.4: Generations of chemical extinguishing gases

6.7.2.1 Material Properties

The most important physical data of the two extinguishing agents HFC227ea and Novec™ 1230 are summarized in the table below.

Trade name		HFC227ea	Novec™ 1230
Chemical formula		C_3F_7H	$CF_3CF_2C(O)CF(CF_3)_2$
Physical state		Gaseous	Liquid
Molecular weight		170	316.04
Boiling point	[°C]	-16.4	49.2
Vapor pressure at 25°C	[bar]	4.05	0.4
Gas density at 25°C	[kg/m^3]	7.3	13.6
Liquid density at 25°C	[kg/m^3]	1'480	1'600
Liquid viscosity at 25°C	[mPa·s]	0.184	0.52

Table 6.5: Significant material properties of the most important chemical extinguishing gases

One essential difference between Novec™ 1230 and all other previously used extinguishing gases is the fact that Novec™ 1230 is liquid at ambient conditions (pressure: 1.013bar, temperature: 25°C). Novec™ 1230 reaches its boiling point at 49.2°C.

The high boiling point has many advantages, making pressure-free transport of Novec™ 1230 in appropriate plastic containers possible without any problem. However, Novec™ 1230 must be brought in the protection zone in gaseous state in case of flooding. The evaporation of the "gas", which is liquid at ambient conditions, must be ensured. To understand why an inherently "liquid gas" may evaporate, it is of help to compare it to water at approx. 80°C. When this water is sprayed into an equally heated room, it will soon evaporate completely, as it is close to its boiling point and due to the large specific droplet surface with fine spraying.

It is thus significant for the evaporation of Novec™ 1230 to bring the liquid gas into the extinguishing zone in the form of extremely fine spray. Internal tests have shown that at nozzle pressures of more than 10bar, a sufficient spraying effect can be achieved. The observed jet lengths, i.e. the distance between the nozzle outlet and the point where the droplets have completely evaporated, were up to 2 to 3 meters.

The lower nozzle pressures that are frequently used today for HFCs (and that may be as low as 4bar) do not suffice. To ensure a minimal nozzle pressure of 10bar, even with more complex distribution piping systems, Siemens has decided on a system pressure (storage pressure in the extinguishing agent containers) of 42bar.

6.7.2.2 Environmental Parameters

The table below shows the environmental parameters of HFC227ea and Novec™ 1230. The short service life in the atmosphere (ALT = atmospheric lifetime) of some days only and the GWP value of 1 characterize Novec™ 1230 as a third-generation chemical extinguishing agent. The ODP value of 0 is a typical feature of both gases.

Environmental parameter	HFC227ea	Novec™ 1230
ODP value	0	0
GWP value	2'900	1
ALT	36 years	5 days

Table 6.6: Environmental parameters of Novec™ 1230 and HFC227ea

6.7.2.3 Extinguishing Characteristics

As with all chemical extinguishing agents, the extinguishing effect of HFC227ea and Novec™ 1230 is a combination of several processes.

On the one hand, the extinguishing agent molecule is decomposed into its constituents, i.e. atoms, in the hot flame zone. In accordance with physical laws, this is accompanied by x-fold volume expansion (“x” standing for the number of atoms) and thus by a reduction of the local oxygen concentration in the flame zone. Therefore, the molecule decomposition leads to local blanketing. Furthermore, the molecule takes energy away from the fire, causing a cooling effect.

This shows that the extinguishing effect of the so-called chemical extinguishing agents is largely physical. As the Novec™ 1230 molecule is very heavy, consisting of 19 atoms, its contribution to the first effect is high. HFC227ea still consists of eleven atoms after all. This leads to relatively low extinguishing concentrations of chemical extinguishing gases, which is between 7 and 9 percent by volume for HFC227ea and between 5 and 7 per cent by volume for Novec™ 1230. More detailed specifications can be found in the guidelines VdS 2381, ISO 14520 or NFPA 2001. The required extinguishing concentrations are determined analogous to the methods for natural gases (see section “Material Properties”, page 215).

As with all chemical extinguishing agents containing fluoride atoms, hydrofluoric acid molecules (HF molecules) are generated when extinguishing with Novec™ 1230 or HFC227ea, due to recombination in the flaming zone. Hydrofluoric acid is strongly caustic and corrosive and causes damage to the respiratory organs after a while when concentrations in the ambient air exceed a certain level. For HF, the LC50 value is 50ppm. The LC50 value (“Lethal Concentration”) indicates the concentration which is after an exposition of 30 minutes lethal for 50% of the individuals.

An independent institute has conducted comparative measurements of the HF generation during extinguishing with Novec™ 1230. The results show that the HF generation is not higher as with HFCs such as HFC227ea or HFC125; however, considering the measuring accuracy, it is not lower, either.

The use of chemical extinguishing agents in protected sectors frequented by people should at any rate be reduced to such risks where large flames are to be expected at the beginning of the flooding procedure. A fast-reacting fire detection system immune to deception is indispensable to keep the HF generation as low as possible. Furthermore, it is generally recommended to contain the risk of rapidly growing fires, such as liquid fires, with natural gases instead of chemical extinguishing agents. In contrast, electronic risks can be met extremely well with chemical extinguishing agents, as such fires grow slowly. Some examples are:

– EDP rooms
– telecommunication systems
– control rooms
– distributor rooms
– false floors containing cabling

The prescribed flooding time of 10 seconds (in comparison to 60 to 120 seconds with natural gases) makes possible the required quick extinguishing.

6.7.2.4 Toxicity

The NOAEL (No Observed Adverse Effect Level) value of both HFC227ea and Novec™ 1230 is above the application concentration, which means that the extinguishing agent does not constitute any risk to people in the coverage area. However, the coverage area should always be evacuated prior to flooding.

6.7.3 System Technology

The gases are stored in pressure tanks:

- The non-liquefiable inert gases Ar, N_2 and gas mixtures in gas cylinders at pressures of 200 to 300bar.
- CO_2, liquefying under pressure, in high-pressure systems in gas cylinders at 56bar or, with low-pressure systems, in large cooled containers.
- Chemical gases are stored in gas cylinders, pressurized with nitrogen, acting as propellant. The storage pressure is either 25 or 42bar.

Extinguishing is controlled either manually or, preferably, automatically by means of a fire detection system. Only a quick, faultless actuation prevents consequential damage, as a fire shall be extinguished during its formation phase.

When the system is actuated, the cylinder valves of high-pressure systems, or the container valves of low-pressure systems respectively, are opened. Alarm is triggered to warn people in the protected area, and flooding is released after a predefined delay period, so that the room can be evacuated. Doors and other openings are closed automatically. Further operating equipment, such as ventilation systems and fire dampers are activated. The overpressure relief mechanisms are only opened in case of overpressure in the coverage area, otherwise they remain closed.

The extinguishing gas is guided through a piping network to the nozzles evenly distributed on the ceiling. The gas quickly fills the room and a homogenous concentration is built up throughout the room. The following figure shows the process diagram.

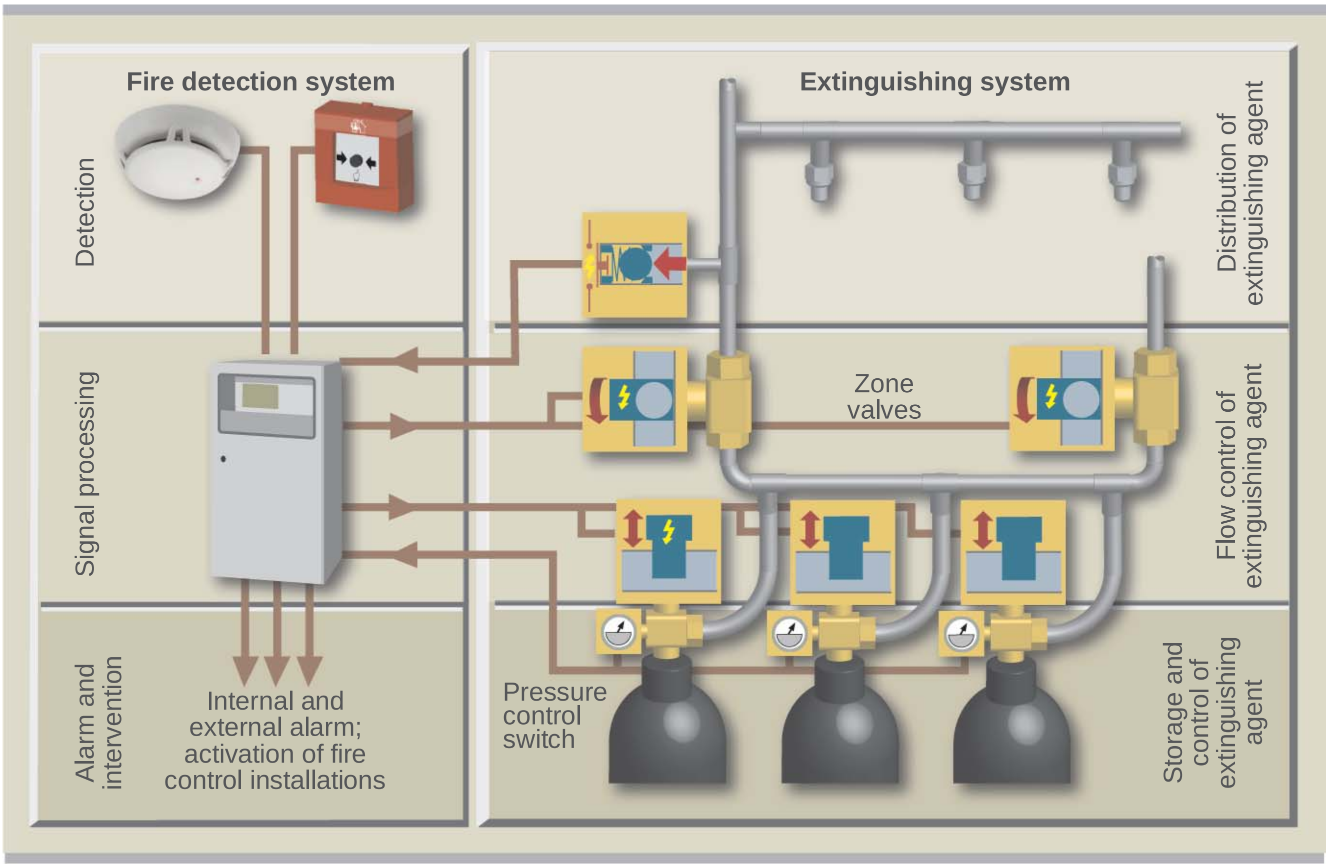


Figure 6.15: Operating principle of a gas extinguishing system

Inert gas systems for nitrogen, argon or gas mixtures are equipped with a pressure reduction system located behind the collector to which all cylinders are connected. This pressure reducing system usually consists of a membrane with an orifice reducing the pressure from storage pressure to approximately 60bar, so that no high-pressure material needs to be applied for the piping network.

6.7.3.1 Room Protection

The principal field of application of gas extinguishing systems is room protection, i.e. the protection of closed rooms. Two different system technologies are used, which are described below.

Centralized and Modular Systems

By definition, centralized systems use a central extinguishing agent battery. This battery should be placed in a special storage room outside the protected zone. The main advantage of this arrangement is that the storage room remains accessible in case of fire. In addition, the system is easier to service and maintain.

Centralized systems always require an individual design. This means that all pipe diameters and nozzles must be calculated individually for the relevant system. For this purpose, tried and tested calculation methods and programs are available.

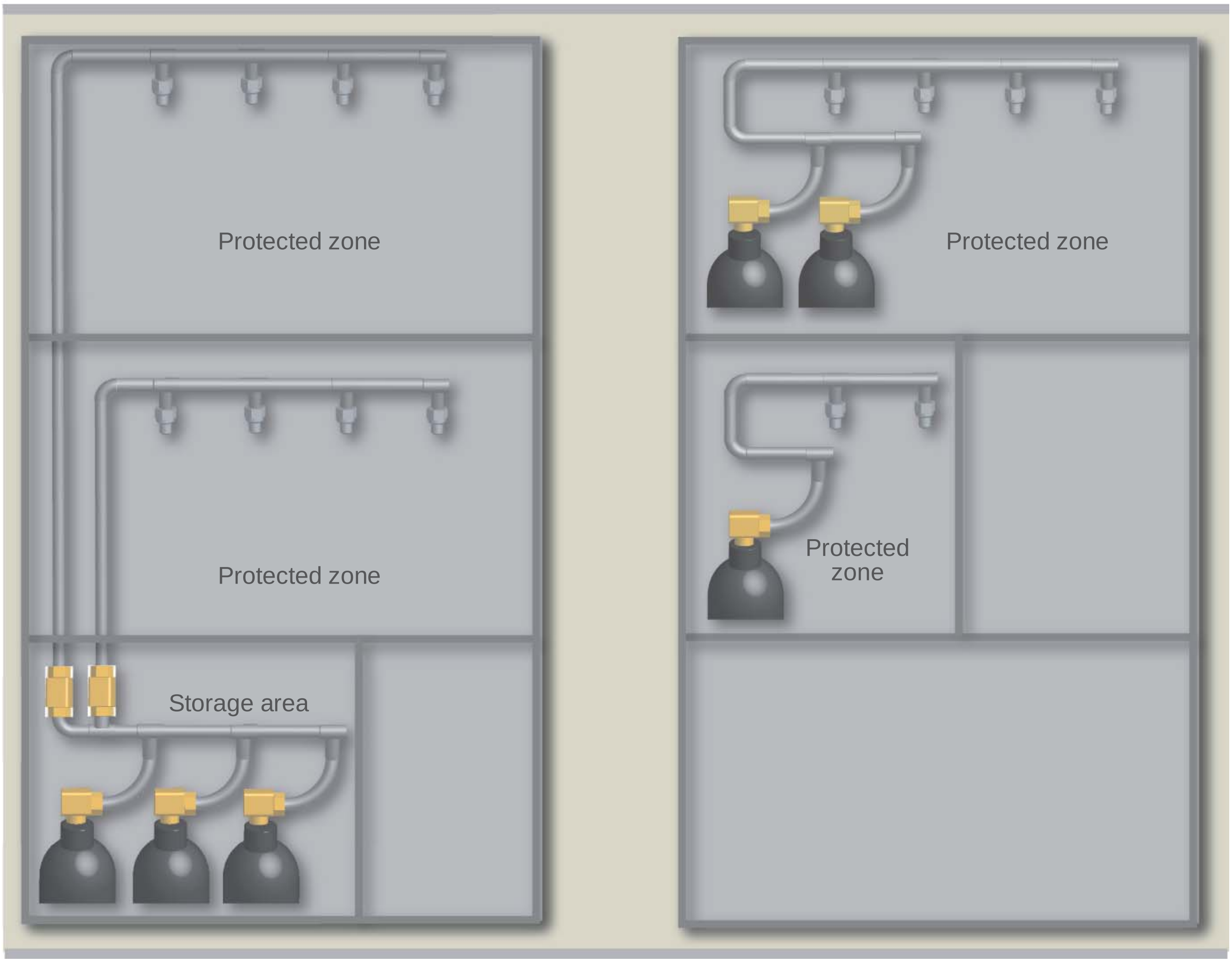


Figure 6.16: Operating principle of a centralized system and a modular system

In contrast to centralized systems, modular systems consist of individual storage containers arranged in the protection zone, with directly connected nozzles.

Single Zone and Multizone Systems

Single zone extinguishing systems completely discharge their extinguishing agent supply in one protection zone. This zone may consist of one or several rooms, with all rooms being flooded completely and simultaneously.

Multizone extinguishing systems are capable of protecting several zones. It is often necessary and reasonable to subdivide the protected volume by a single extinguishing system into two or more zones, with one zone comprising one room or several rooms that are usually located close to each other and are flooded simultaneously. To reduce the total amount of extinguishing agent, only one zone is flooded at a time. It must be taken into account that the other zones can no longer be flooded, thus remaining unprotected.

Should protection of these adjacent zones be required as well, additional extinguishing agent can be provided as reserve for the system. After flooding the first zone, the system will automatically revert to this reserve.

Dividing extinguishing systems into zones is independent of fire detection sectors. Zones are created preferably when a larger number of similar rooms (or groups of rooms) must be protected while the fire risk is not extremely high. In this case, cost savings concerning extinguishing agent and storage containers are possible.

The basic setup consists of a battery of extinguishing agent master containers. To this battery, a piping network is connected for every extinguishing zone by means of zone valves. By opening the relevant zone valve, the extinguishing agent is guided to the desired zone; the other zone valves remain closed.

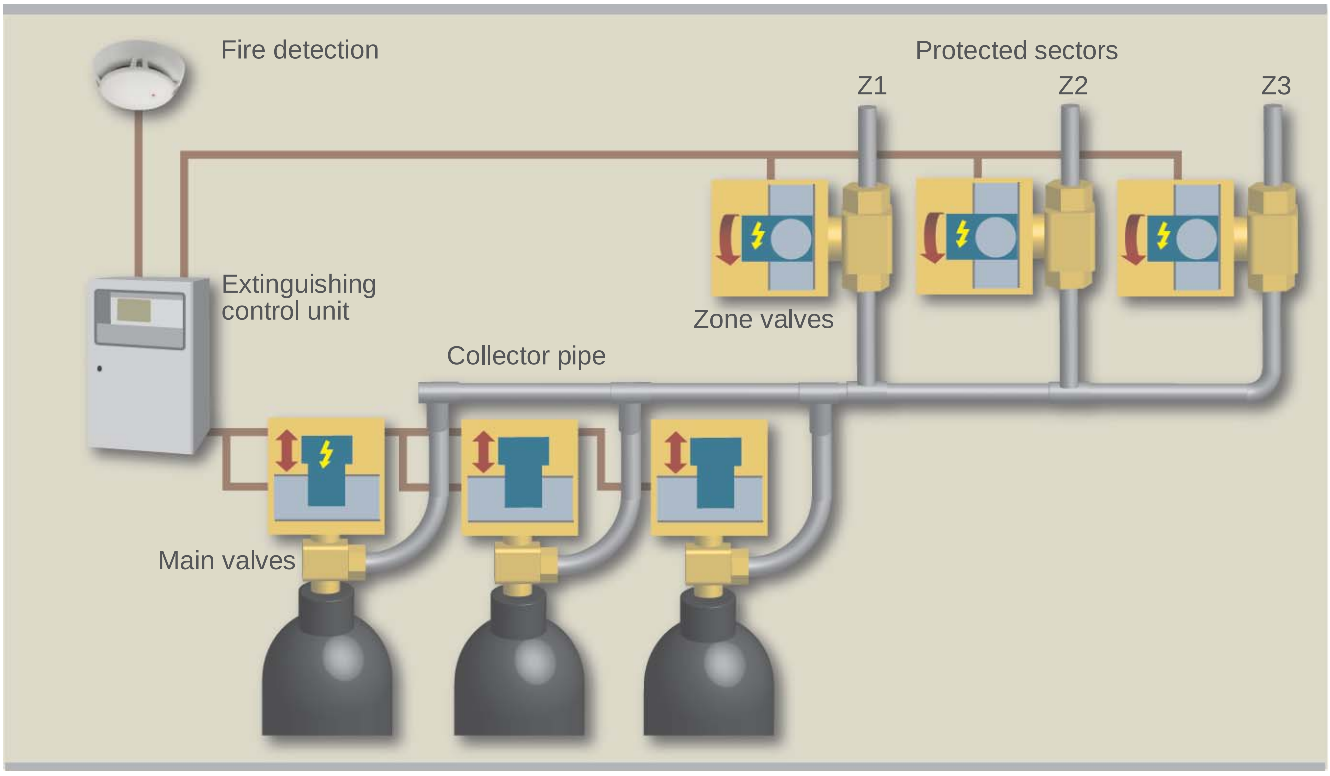


Figure 6.17: Operating principle of a multizone extinguishing system

The right zone valve can be opened either simultaneously with the cylinder valves or beforehand, but it has proven to be of advantage to open it prior to the cylinder valves. When the zone valve is opened first, it is not yet under pressure as the cylinder valves are still closed. This decreases the risk of malfunction, as it is easier to open a valve without pressure, and the complete procedure is more fail-safe.

The extinguishing control unit must be capable of subsequently and automatically actuating both the zone valve and the cylinder valve.

6.7.3.2 Object Protection

Detached objects can be protected with carbon dioxide. This protection method is also known as “equipment protection”. Examples for equipment protection systems are:
- immersion baths, quenching baths, paint spraying facilities, printing facilities
- air extraction hoods in kitchens, oil-filled transformers, etc.

The scope of protection for an equipment protection system comprises the object(s) to be protected as well as additional volume surrounding the objects. This is called the virtual protection volume, which is to be flooded by the best suited extinguishing agent in the appropriate concentration.

For outdoor applications, it must be ensured that neither wind nor other climatic influences have a negative effect on protection.

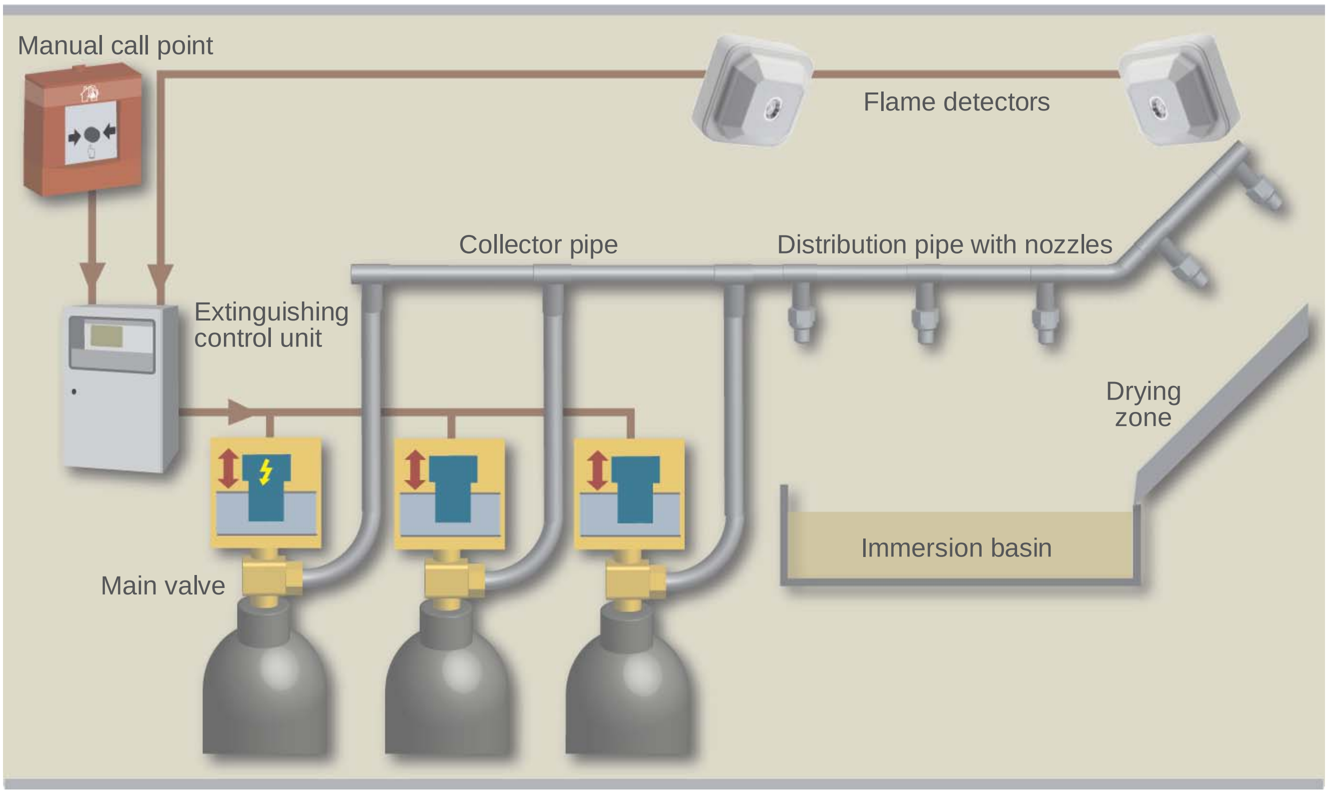


Figure 6.18: Operating principle of an object extinguishing system

6.7.4 Water Fog Systems as a Replacement for Gas Extinguishing Systems?

As mentioned in section 6.4.4, some market participants would like to replace sprinkler systems and also gas extinguishing systems used in room and object protection with water fog systems. This would mean, however, that the following goals would have to be fulfilled:

- For the purpose of room protection, water fog would have to be able to extinguish “around corners“. This means that the seat of fire would have to be extinguished successfully even when it is not directly located in the range of the nozzle jet.
- Safe fire extinguishing must be guaranteed at any rate. This is the case with gas extinguishing systems (in contrast to the mere fire suppression effect of sprinklers). Hence, the flooding time must be significantly reduced in comparison to sprinkler systems.

6.7.4.1 Room Protection

By spraying water to water fog, two effects contribute to a possible fire extinguishing:

– the cooling effect (heat absorption by vaporization)
– the displacement of oxygen (blanketing)

Both effects are emphasized by the suppliers of water fog extinguishing systems.

In room protection, however – and in contrast to object protection – only the contribution of blanketing may be taken into account. With room protection, the seat of fire may emerge at a spot which cannot be reached by the nozzle jet, for example in a covered machine part or a computer housing. This means that the seat of fire would not be charged directly.

When the seat of fire is not directly reached by the water fog, only the part of the water droplets transported by air movements can still reach the fire seat. As this water volume is rather moderate, however, the water already vaporizes before it reaches the reaction zone and the fog cannot generate the desired cooling effect in the reaction zone. In addition, the low water volume does not bring about sufficient oxygen displacement. This fact will be handled in detail in the section on blanketing.

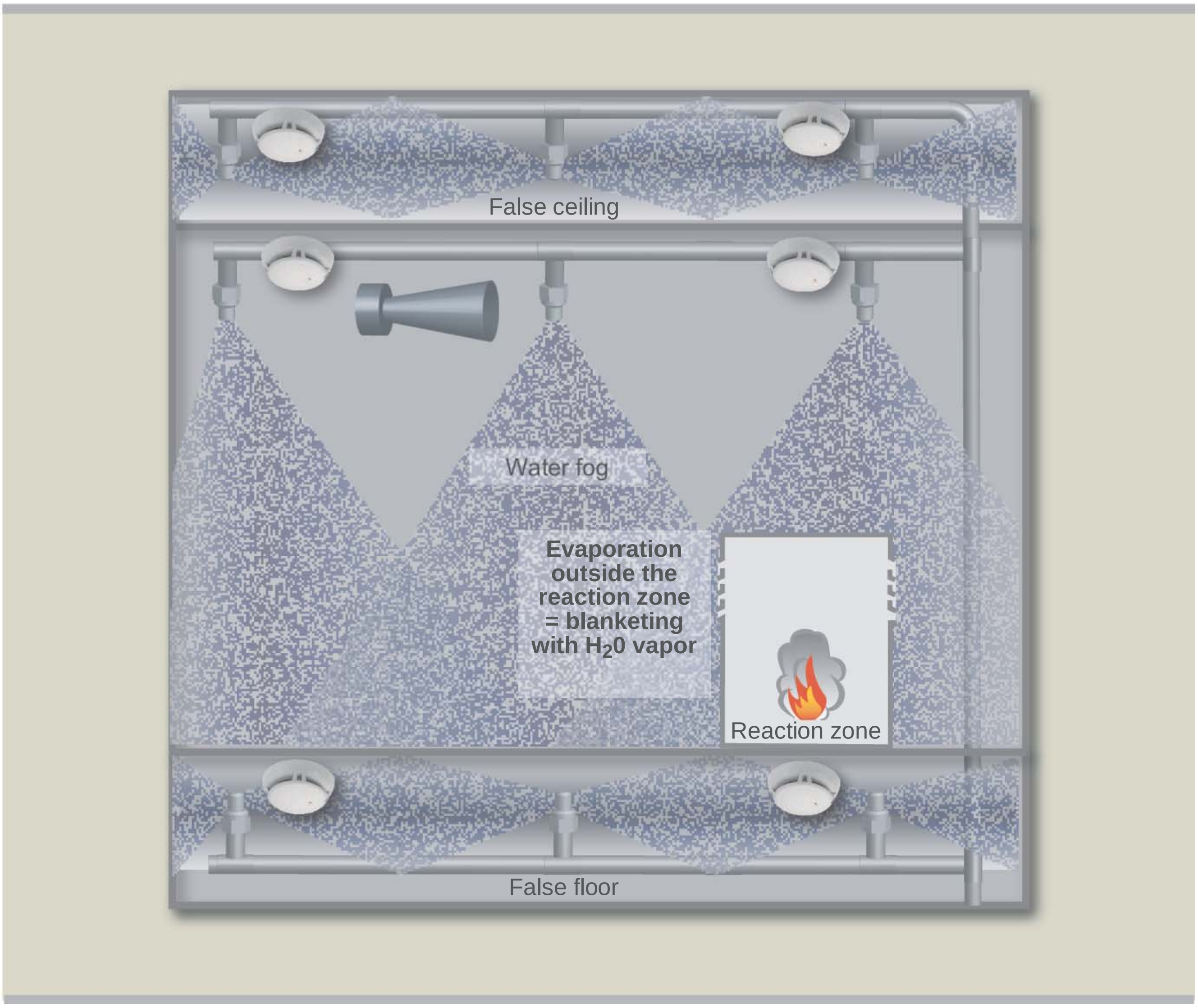


Figure 6.19: Extinguishing effect of water fog in room protection

Blanketing

From fire extinguishing with natural gases we have learned that concentrations between 35 and 50vol % are required to create a blanketing effect. For blanketing with water vapor, i.e. with H_2O in gaseous form, similar water fog concentrations are required.

In the extinguishing zone, the water vapor volume must be generated by evaporation or vaporization of the droplets. The water vapor then locally displaces a large part of the air in the seat of fire. At 100°C – that is when all droplets have completely vaporized – an air-vapor mixture contains a minimum of 300g water vapor per m^3 and absorbs approximately 675KJ of heat.

Stable water fog, as it occurs in the form of clouds in nature, has a droplet concentration of approximately 3g/m^3. With higher droplet densities, the air-borne droplets combine to larger drops and the cloud releases the water in the form of rain (this process is known as "coalescence"). Nuclear security research has shown that water fog with the commercially habitual droplet diameters may retain at maximum 115g/m^3 water at a dwell time of one minute. Higher water charges create an unstable situation, and as a consequence the droplets start to fall out (or to sediment) and can no longer be transported by the air current.

Water that has already evaporated and is now available in the form of gaseous water vapor does indeed contribute to the maximum possible water charge of air, but the maximum water vapor concentration in the air is limited by the dew point line. It defines the maximum possible water vapor concentration of an atmosphere as a function of the temperature.

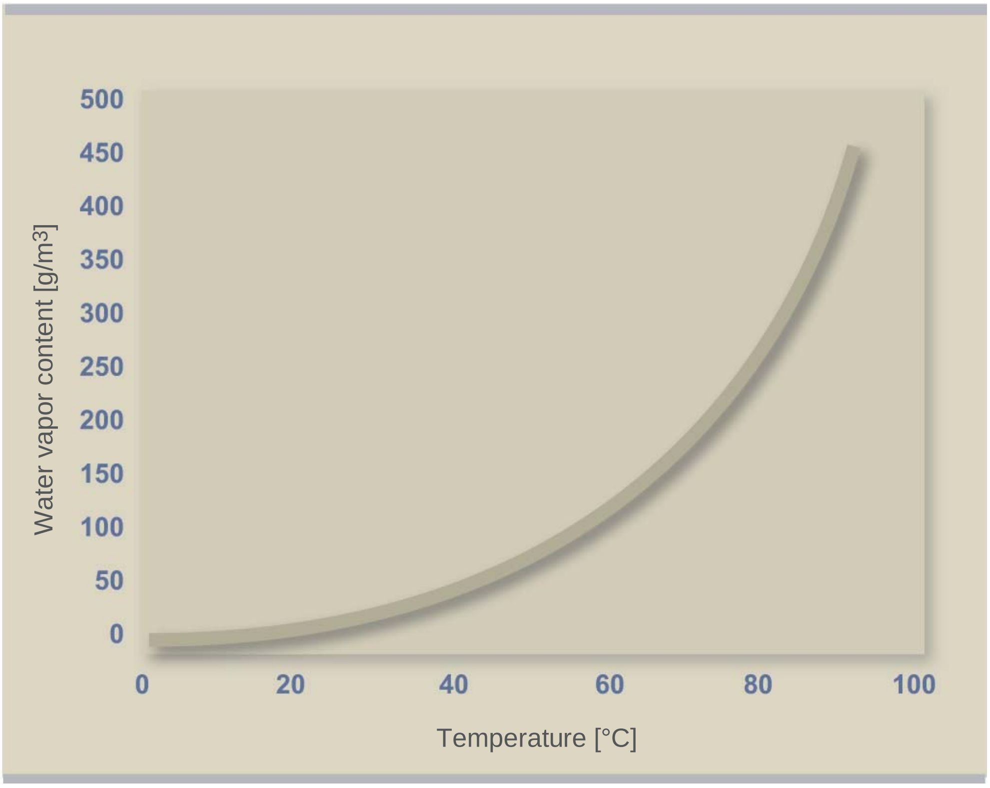


Figure 6.20: Dew point line for water vapor-air mixtures

The maximum vapor concentration at 20°C is thus only 20g/m^3 water.

This leads to the following conclusions:

- At 20°C, the necessary water charge of 300g/m^3 definitely cannot be reached with a combination of droplets and water vapor.
- When the droplets of a quasi-static water fog are transported to the fire by convection only, a fire definitely cannot be extinguished. Such conditions – that do not even constitute the worst case scenario – must be expected with room protection.
- Therefore, the extinguishing effect of water fog systems is not ensured for room protection. Water fog systems cannot be considered extinguishing systems but merely fire-fighting systems. – in contrast to gas extinguishing systems of which the extinguishing effect has been proven even when the seat of fire is not directly accessible for water.

For the sake of completeness, it should be mentioned that at higher temperatures, water vapor densities allow safe extinguishing. To reach the safety level of gas extinguishing systems, i.e. to be able to extinguish any fire at any location, a concentration of approximately 300g of water per m^3 is required. The combination of water droplets and vapor can only reliably build up this amount at room temperatures above 80°C. This temperature, however, would not only bring about severe damage to the building structure, combined with the destruction of largely all normal equipment. It would also mean immediate danger to life for any person in the area, as the water condensing on the body surface would lead to severe scalding.

The Sinorix™ GasSpray Solution from Siemens

To avoid the disadvantages of the water fog systems in room protection, a combination of water fog and nitrogen proved to be advantageous, in order to ensure that blanketing is sufficiently high even at inaccessible locations. The two agents are combined in the Sinorix™ GasSpray system, leading to the following benefits:

- safe extinguishing due to nitrogen
- cooling effect of the water vapor

The water vapor is thereby calculated on the basis of the risk situation. The lower limit is determined by the goal of reducing the fire seat's surface temperature from the reaction temperature (T_R) below the flaming point (T_F) and thus preventing spontaneous re-ignition.

Figure 6.21 schematically illustrates the principle of the Sinorix™ GasSpray system. The water is stored unpressurized in separate containers. Due to the nitrogen, serving as a propellant and simultaneously flowing into the pipe network under pressure, the water is discharged. Both extinguishing agents flow through the same piping system with the same outlet nozzles.

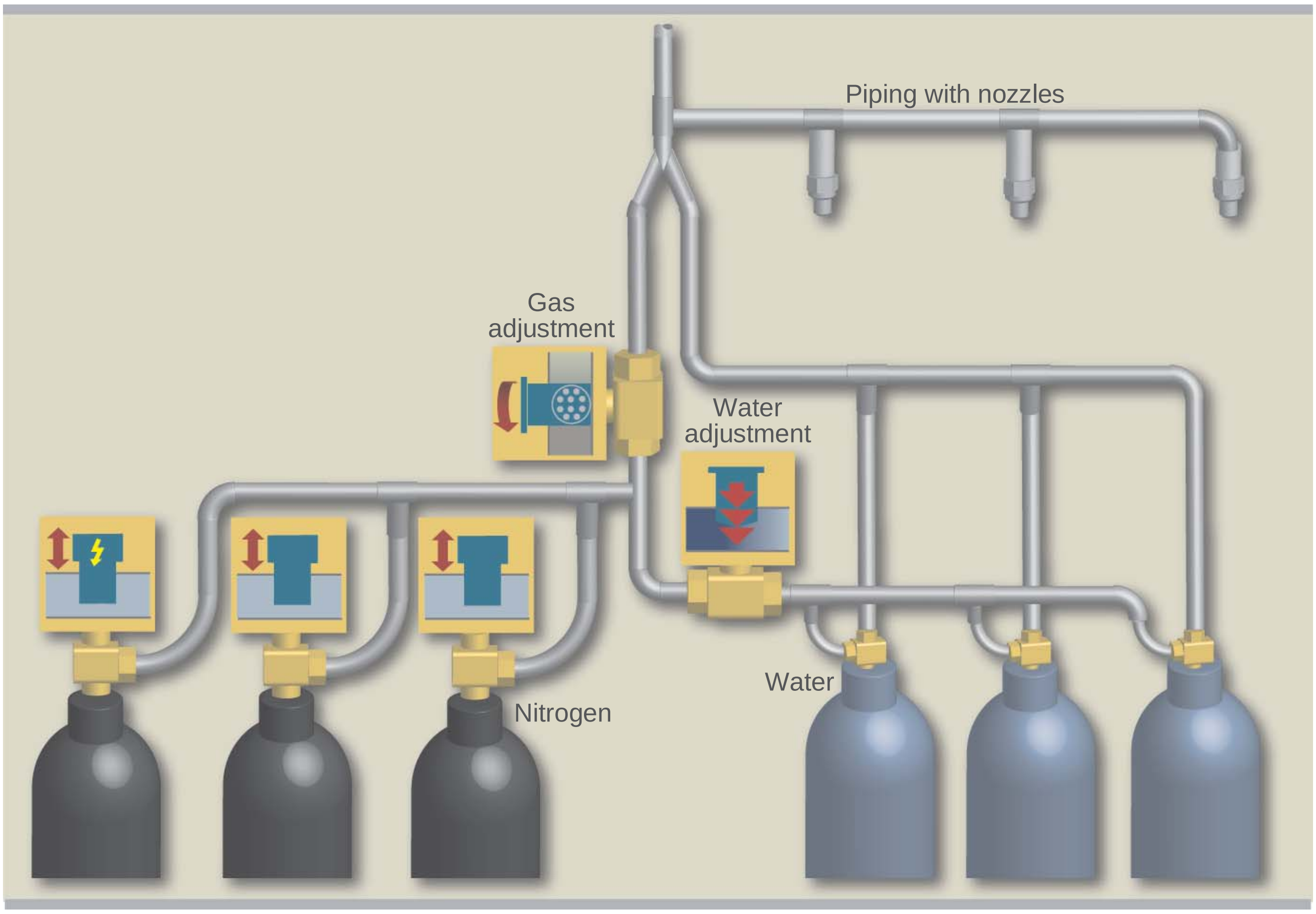


Figure 6.21: Operating principle of the Sinorix™ GasSpray system

The discharge of the two-phase extinguishing agent mix consisting of water and nitrogen has the additional advantage that low-pressure nozzles and standard piping components at 60bar are sufficient to generate water fog. Expensive high-pressure components can thus be largely avoided. The water fog, or the homogenization thereof, respectively, with a droplet size of less than 50µm in diameter, is generated automatically due to the turbulences and the two-phase discharge of the mixture from the system.

6.7.4.2 Object Protection

As it has been demonstrated in the previous section, water fog extinguishing systems cannot be used for the purpose of object protection due to the insufficient blanketing effect. If the nozzles, however, can be directly aimed to the object, quick extinguishing can be ensured, with no extinguishing “around the corner” and no blanketing required. In object protection, the water can be transported to the seat of fire in liquid form, where it can then withdraw the reaction heat from the fire by vaporization.

The Sinorix™ CerSpray system developed by Siemens exclusively serves for object protection, with the goal of extinguishing a fire within one minute, with the same reliability as with CO_2.

Droplet Diameter

The droplet diameter is decisive for the success of water-based extinguishing systems. Too small droplets evaporate before they can reach the seat of fire and thus have no notable extinguishing effect. Too large droplets have a lower specific surface and may thus traverse the seat of fire without evaporating completely.

As a typical low-pressure water extinguishing system, the Sinorix™ CerSpray system has a nozzle pressure of 5 to 15bar. Figure 6.22 shows the extinguishing capacity of a water jet as a function of the droplet size for different distances from the seat of fire. The extinguishing capacity in kW corresponds to the cooling effect of the water jet. The nozzle in this figure has a discharge capacity of 0.25kg/s, corresponding to a maximum possible extinguishing capacity of 564kW.

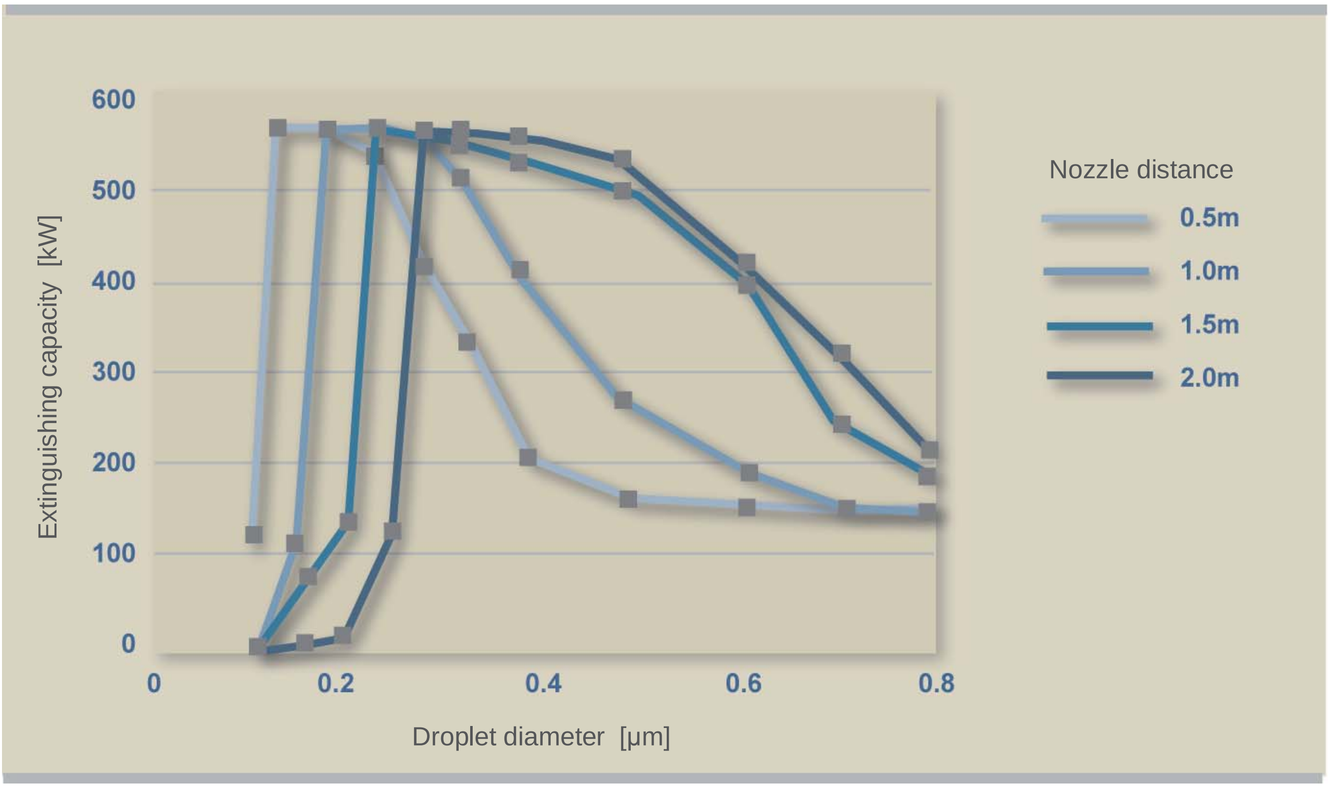


Figure 6.22: Extinguishing capacity as a function of the droplet diameter at 10 bar nozzle pressure

As can be expected, the optimum droplet diameter correlates with the distance between the nozzle and the seat of fire.

The Sinorix™ CerSpray Solution from Siemens

The Sinorix™ CerSpray system can be planned like any conventional water spray system, using a water storage mechanism with a pump, or, as illustrated in 6.23, the water can be discharged by pressurized nitrogen. It should be taken into account that, in contrast to the Sinorix™ GasSpray system, N_2 merely serves as a propellant and is not discharged itself. The required amount of N_2 is thus lower as with the Sinorix™ GasSpray system.

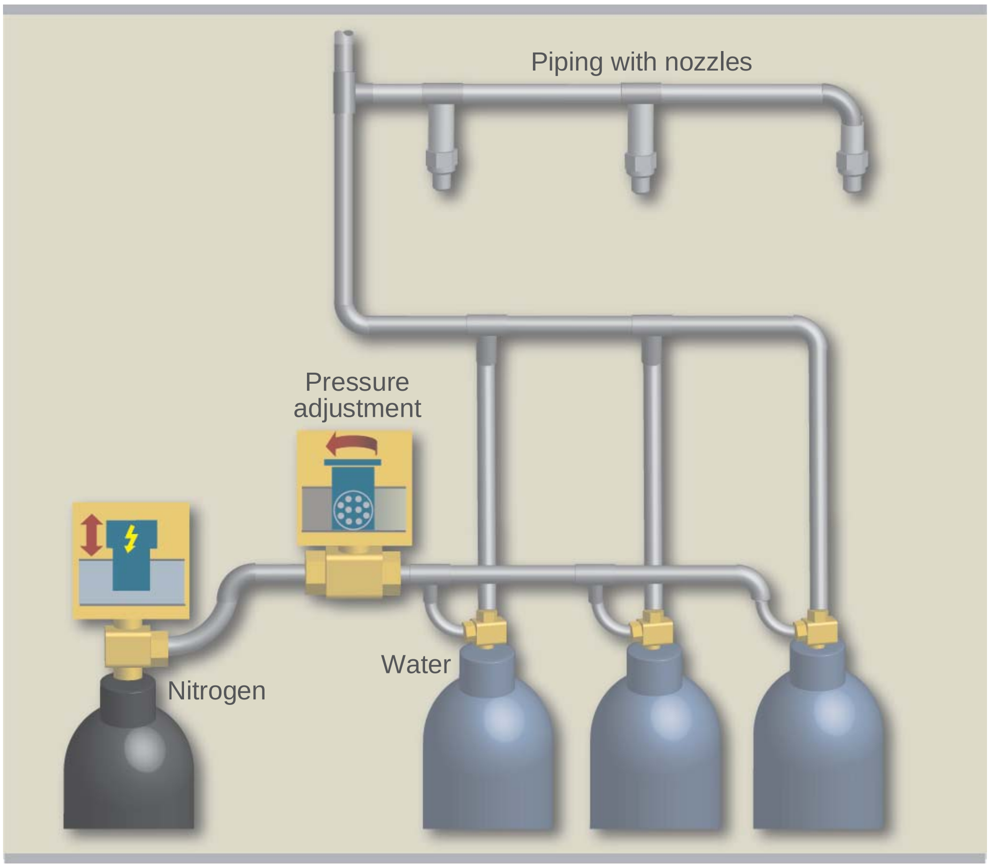


Figure 6.23: Operating principle of the Sinorix™ CerSpray system

The most important step in planning a Sinorix™ CerSpray system is to exactly determine the required water volume as a function of the risk, as well as determining the correct relation of the following three factors:

- nozzle distance (usually determined by local conditions)
- droplet size
- nozzle pressure

Sinorix™ CerSpray has successfully passed the VdS extinguishing tests for motors and generators and is a good alternative to CO_2 in object protection.

6.8 System Integration

This section describes how the fire detection system, coupled to the extinguishing system via the extinguishing control, cooperates with the extinguishing system.

The extinguishing control unit makes different variants of extinguishing control possible. Its alarm organization must be optimally adaptable to each individual situation. Extinguishing control units are preferably autonomous, independent units capable of performing the adequate controlling and actuation of the extinguishing process, on the basis of the alarm signal transmitted by the fire detection control unit.

Another possibility is the extension of the fire detection control unit with a plug-in module (interface) for the purpose of extinguishing control and actuation. In this case, it is the extinguishing module, which then has the complete control over the extinguishing system.

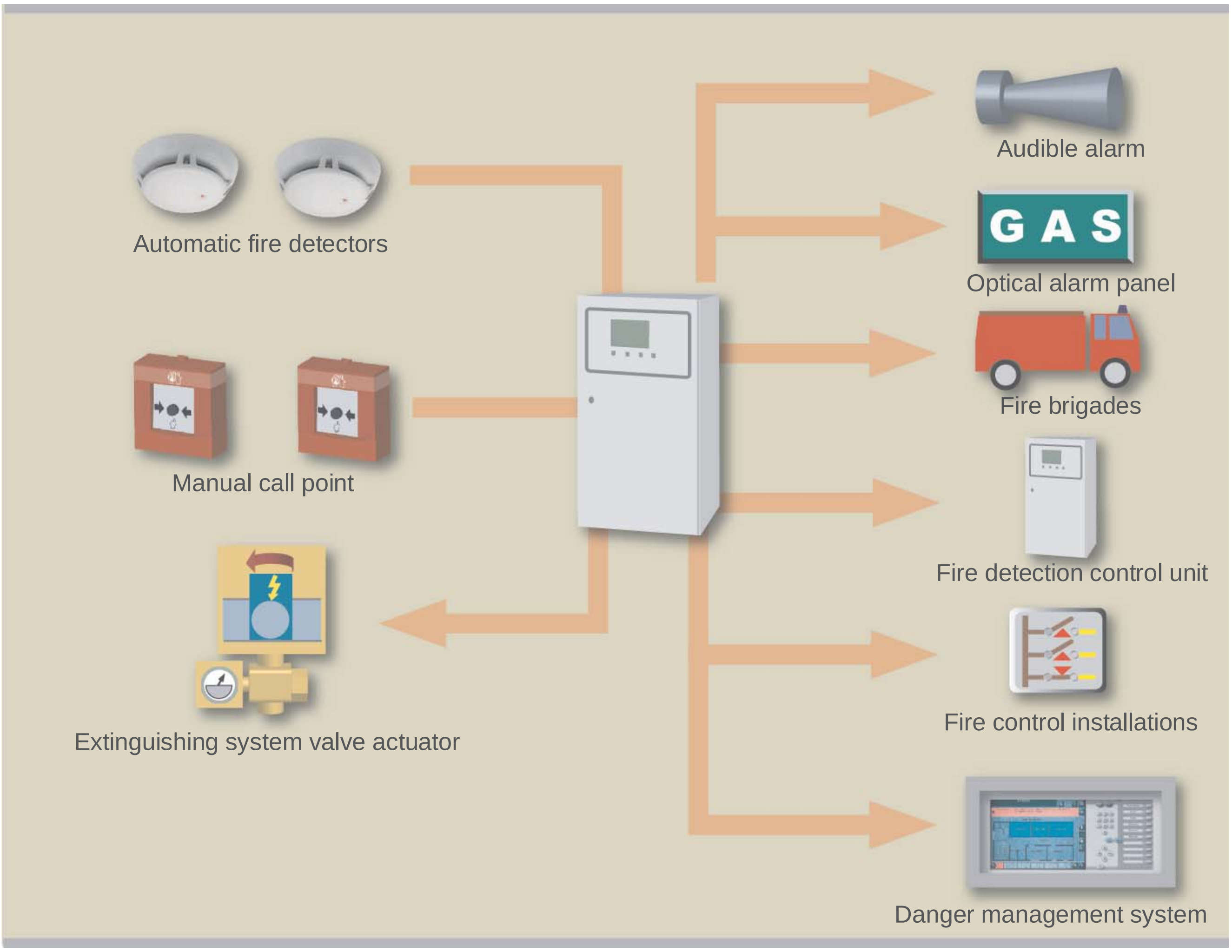


Figure 6.24: Networking diagram of an autonomous extinguishing control unit

An extinguishing control unit shall provide the following functions:

- Electric actuation of fixed fire extinguishing systems, such as:
  - gas extinguishing systems
  - water spray extinguishing systems
  - water fog extinguishing systems
  - foam extinguishing systems
- Applicable for extinguishing systems of all sizes, with the option of multidetector logic; i.e. actuation is only performed when two or more detectors deliver an alarm (see Figure 6.25).
- Applicable for the actuation of extinguishing systems with central extinguishing agent storage (including the possibility of switching over to the reserve storage), and applicable for modular extinguishing systems with individual storage containers distributed over the complete protection area.
- Adaptability of the extinguishing actuation command to all commercially available valve actuator mechanisms.
- If possible, capable to actuate multizone extinguishing systems fed by one single extinguishing agent battery. In this case, several identical control units are networked, with each control unit in charge of its own extinguishing zone (see Figure 6.27).

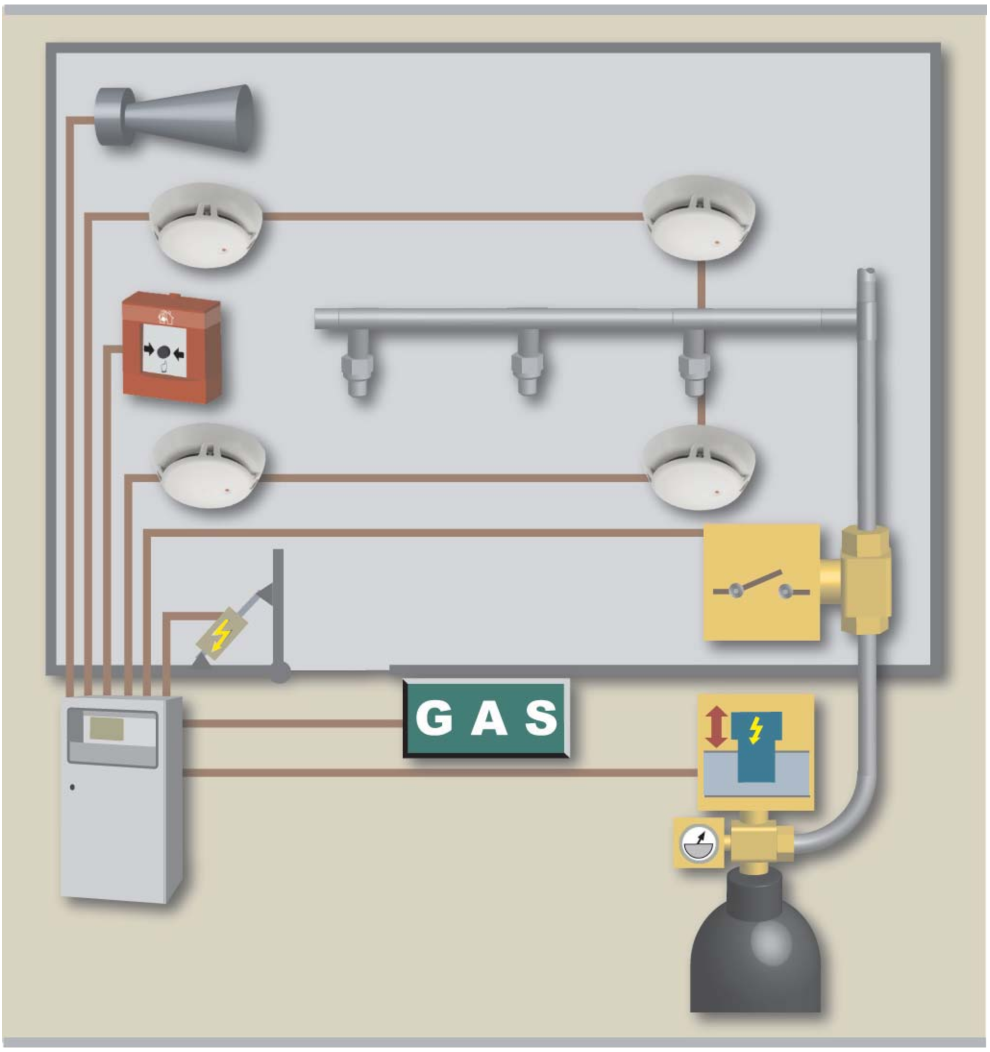


Figure 6.25: Fire extinguishing control unit with multidetector logic

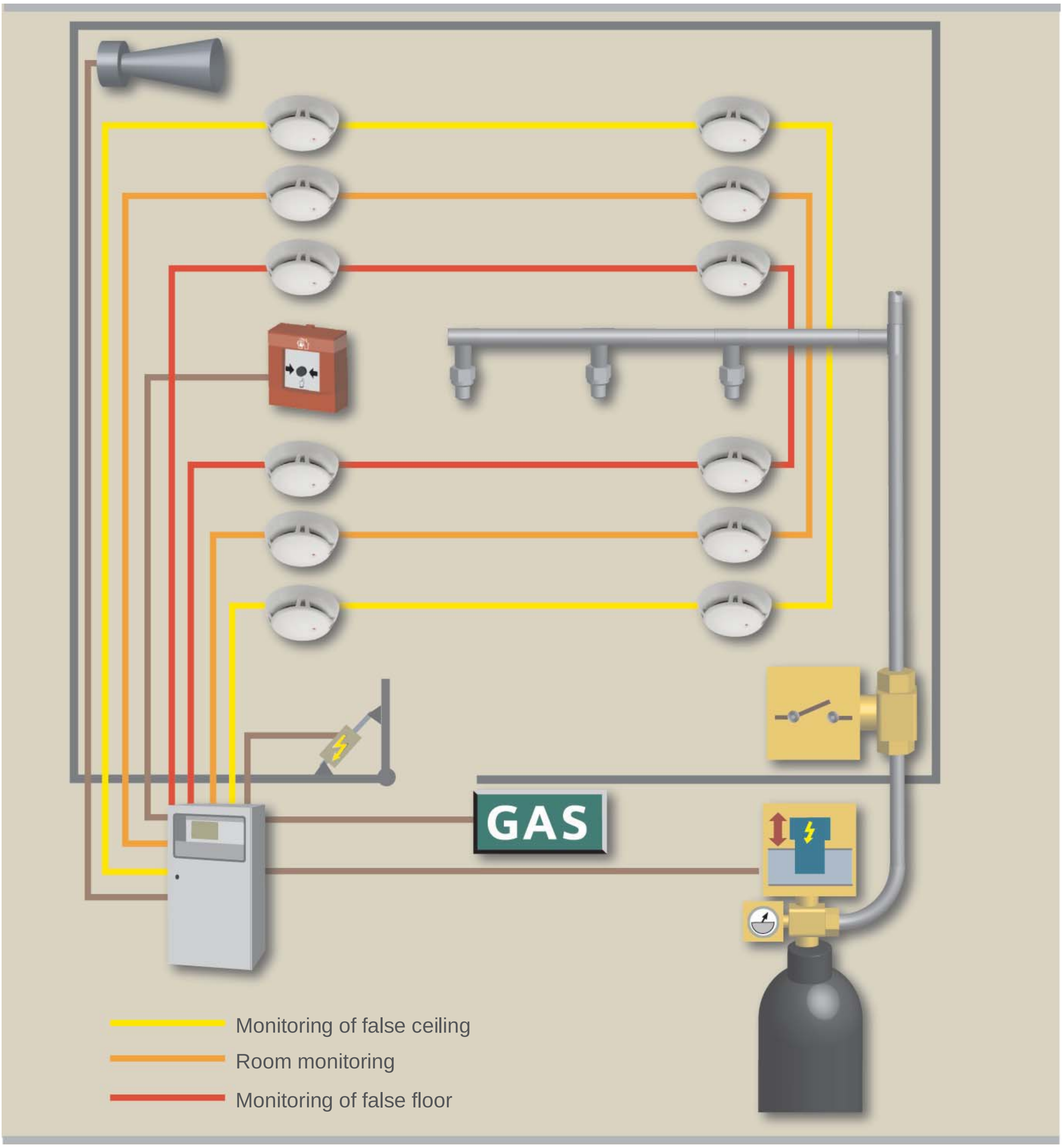


Figure 6.26: Extinguishing sector with additional detection lines monitoring false floor and false ceiling

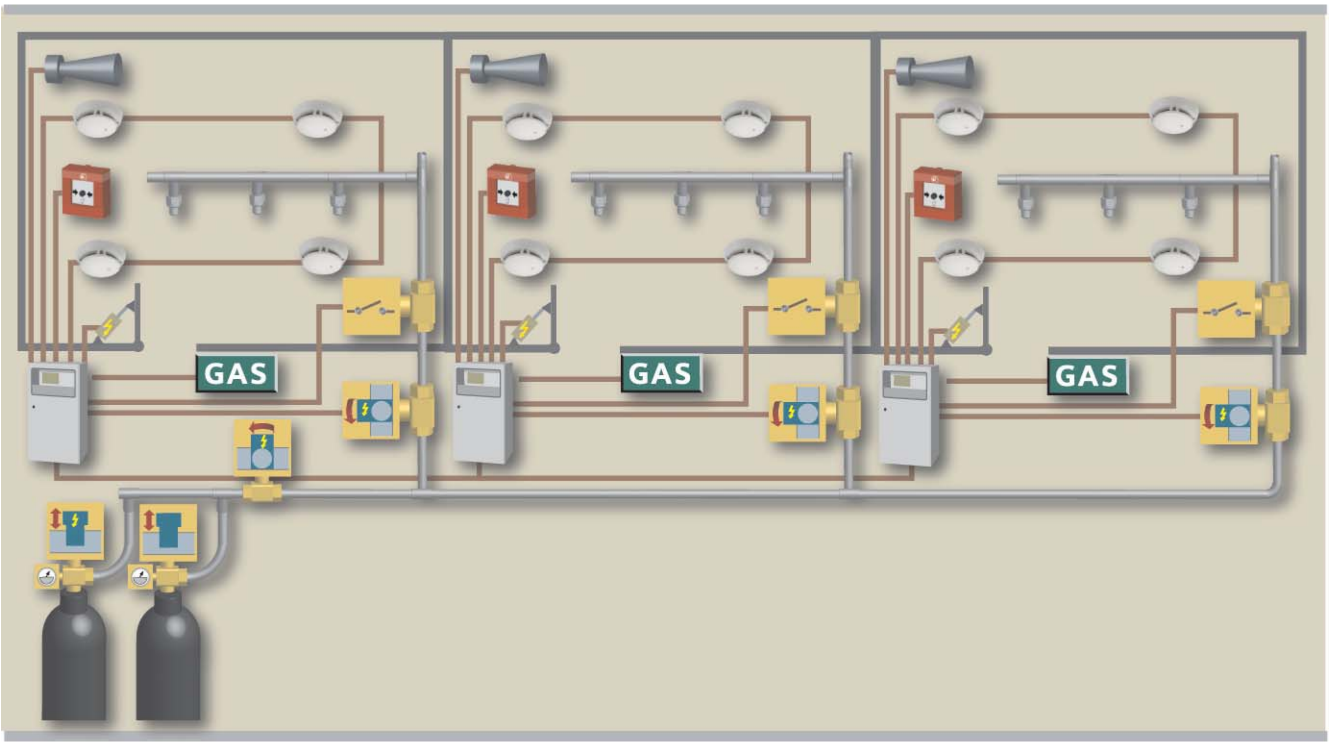


Figure 6.27: Multizone extinguishing system with slave control units

The slave control units depicted in Figure 6.27 must be networked in such a way that a simultaneous actuation of two sector extinguishing processes is impossible.

6.8.1 Location of the Fire Extinguishing Control Unit

The control unit must be located in a room immediately near the main entrance to the protected area; if possible also near the fire brigade access. If this does not make sense for any reason, satellite control panels must be provided.

Should the system size require different control units, each extinguishing zone must be provided with its own, specially assigned control unit.

6.8.2 Power Supply

As in fire detection, fire extinguishing control units must equally be equipped with two independent power supply sources. Both energy sources must be sized in such a way that one source alone is capable of ensuring the full functionality of the system over a predefined period of time. At least one of the energy sources must be permanent, while the other should preferably be a battery with buffer function.

The emergency power supply unit in the extinguishing control unit must be capable of reliably actuating the extinguishing process at the end of the predefined standby period. This standby period consists of the autonomy period (e.g. 72 hours) and the alarm time (e.g. 30 minutes).

6.8.3 Alarm Triggering

Extinguishing and fire detection are usually linked in such a way that the first automatic fire detector that reacts triggers an advance warning. As soon as a second fire detector triggers alarm, the extinguishing process is actuated. In case a manual call point is triggered, the extinguishing system is actuated directly – even when no automatic fire detector has responded yet.

Depending on the system and the conditions, the logic can be integrated into the fire detection control unit or in the fire extinguishing control unit. Of course, the complete electronic surveillance of the valves is the task of the extinguishing control unit.

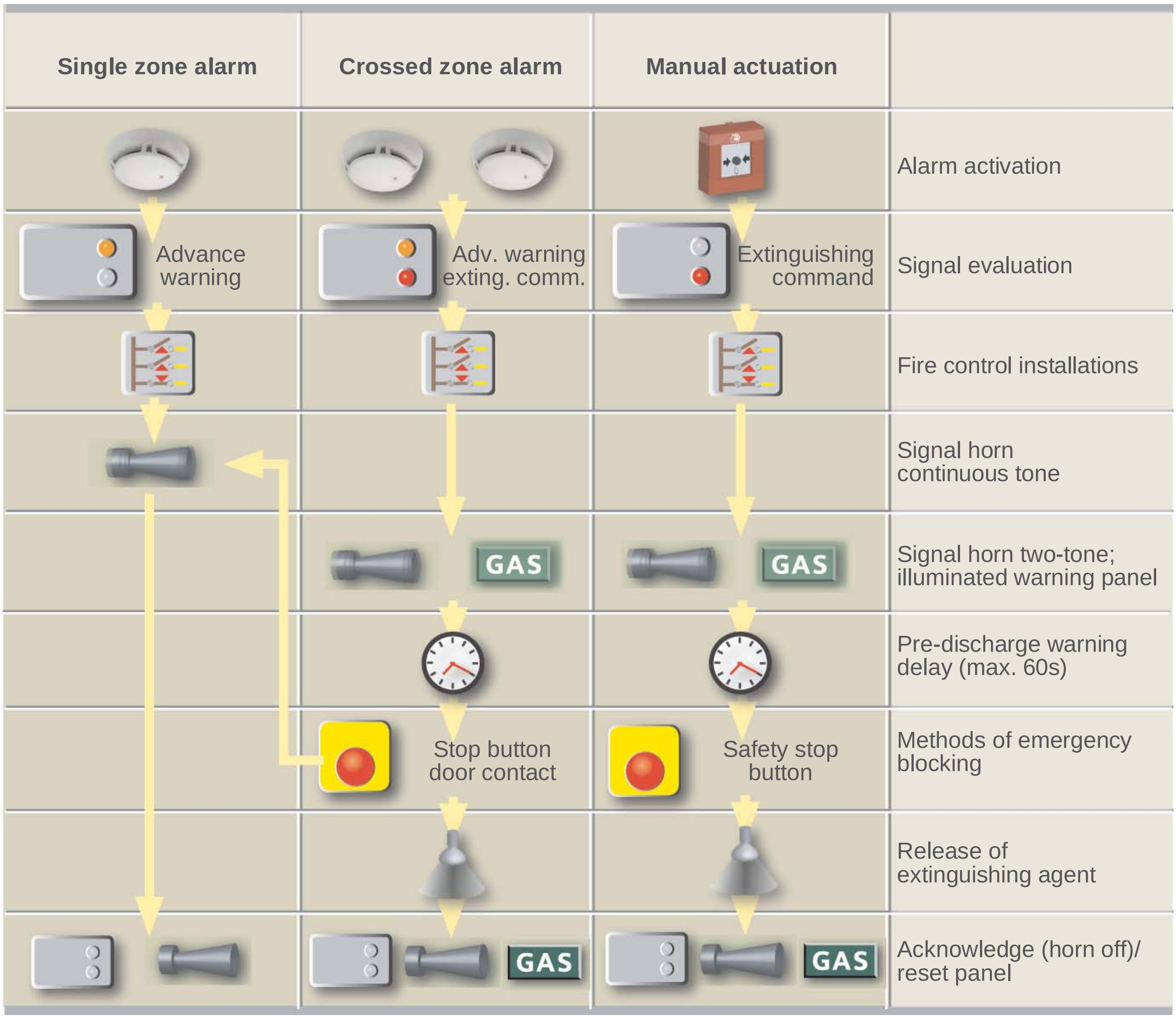


Figure 6.28: Alarm organization of automatic extinguishing systems

6.9 Maintenance and Servicing

To preserve the functional reliability of extinguishing systems, regular maintenance and revisions are indispensable. This is the only way to ensure undisturbed operational reliability.

Maintenance comprises actions for maintaining the nominal state of the extinguishing system, especially to ensure its operability. It is recommended to have extinguishing systems serviced at least once a year. Maintenance and revisions should be performed by the system installer or the respective authority. The type and scope of maintenance work strongly depends on the system type.

The customer should name a person responsible for the extinguishing system's servicing, preferably an employee who regularly performs the checks specified in the instructions. Of course, these checks must be performed more frequently than the maintenance work and revisions. Furthermore, the person in charge shall initiate the necessary repair work and record all actions and events.

When the complete extinguishing system, or parts thereof, shall be temporarily put out of operation, special fire protection actions have to be taken. These measures must ensure that a fire can be detected as early as possible and can be effectively fought with the extinguishing devices to be provided.

6.10 Profitability and System Evaluation

Automatic extinguishing systems constitute an essential and generally indispensable part of fire protection concepts.

The extinguishing method applied must be determined by an expert, as there are no universal solutions: Too many influencing factors are involved in the decision-making process.

Nevertheless, some experiences have been made that can be easily imparted:

- The use of gas mixtures has no advantage over extinguishing with natural gases.
- The correct design and sizing of the system cannot generally be controlled by the customer and is nevertheless a decisive factor. Competence and experience of the system supplier are thus of utmost importance, i.e. the correct nozzle pressure, for example, can significantly improve the extinguishing result of certain extinguishing systems.
- A system supplier with a comprehensive product portfolio is hardly tempted to provide any available system instead of choosing the best suited system that is unfortunately not available at the moment.

An extinguishing system is an investment in the building's entire life cycle and even in the case of object protection, it is not limited to a few years. For this reason, the investment should take into account that correspondingly long system serviceability is provided.

7 Danger Management System

7.1 Summary

Buildings require a multitude of administrative measures of which danger management as part of technical building management constitutes an extremely significant part thereof. The danger management system (DMS) is responsible for managing time-critical, hazardous situations. Data must be concentrated to give consideration to human receptiveness.

This data concentration is achieved by the hierarchical structure and classification at the field level, automation level and management level, each of them having its proper network. In addition, the DMS merges the various specialized subsystems, from gas warning and fire detection to intrusion detection and access control, in order to make a complete and consistent representation of the current hazard situation possible on one user interface.

To live up to all expectations, a DMS requires a flexible and scalable system structure. Only this way is it possible to easily integrate the requirements of different industries, company sizes and growth steps into the system.

Event handling is the core functionality of a DMS, with the top priority being on the fast and complete recognition of the hazardous situation, which is followed by the guided handling of the problem. To achieve this goal, the subsystems are integrated into the system and operated by the DMS. To be able to retrace what has happened, the DMS includes different extensive reporting choices.

User-friendliness is by far the most important feature of a DMS. Only an intuitively operable, informatively designed user interface adapted to the specific situation facilitates quick and stress-free problem handling.

Flexibility and open system architecture are prerequisites for the integration of the different subsystems with as little expenditure as possible. Apart from that, a DMS must take fail-safety into account and must make a simple, individual system setup possible by means of software tools.

The use of a DMS already makes sense with compact systems. The user benefits from considerably enhanced building safety and from significantly reduced time expenditure required for building safety issues.

Danger management systems reduce complexity

7.2 Basics

Today, terrorists and criminals develop increasingly more imagination, and the number of combined attacks is steadily increasing. Attackers deliberately try to outsmart security equipment, and what would be easier than setting fire in one place in order to break in at another, unnoticed in the general chaos?

Concise, sophisticated system structures are of central significance for the extendibility, flexibility and maintenance of DMS. As investments can only be as good as the way in which they fulfill future requirements, some important aspects of the system setup will be described in detail in the following sections.

7.2.1 Tasks in Buildings

To be able to structure the variety of technical systems in a better way, it is worthwhile to take a closer look at the different building management tasks. Three fields of functions are typically distinguished:

- Commercial administration is ensured by more specialized systems supporting the company's business processes and comprising many different subareas from procurement and logistics to sales and maintenance. Depending on the solution, these systems are more or less integrated and can be summarized under the name ERP (Enterprise Resource Planning). The best-known companies in this field are SAP and Oracle.
- Infrastructural building management comprises, among other things, systems for building maintenance such as facility management systems (FMS), which provide for maintaining the technical facilities.
- Technical building management consists on the one hand of building automation such as heating, ventilation, air conditioning (HVAC), lighting and elevator control and, on the other hand, of safety management (fire, intrusion, access control, video surveillance, etc.).

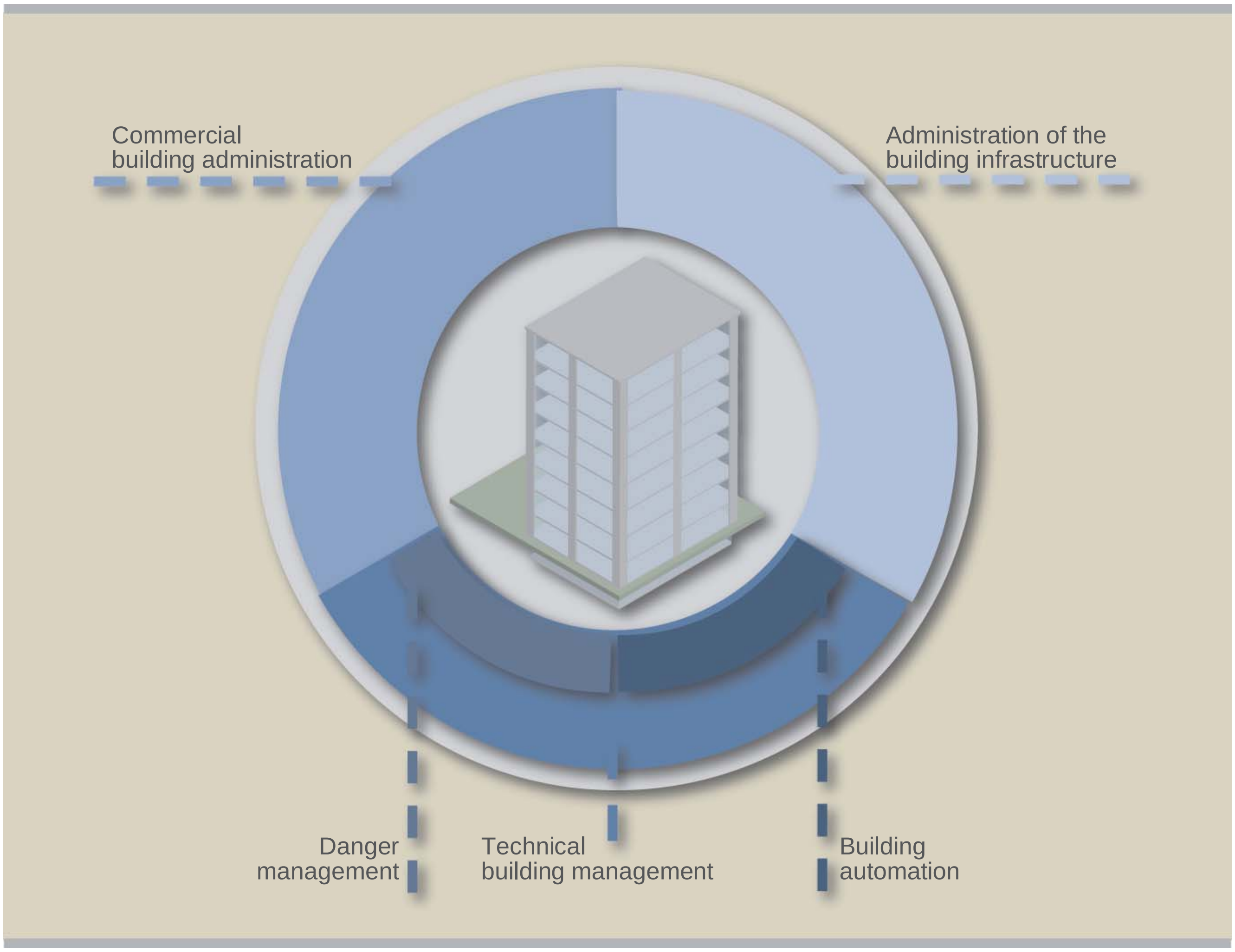


Figure 7.1: Fields of building management functionality

As safety is an integral part of the technical building management, the following chapter presents a brief overview of technical building management and will then focus on safety engineering.

In the sense of a data concentration, building management can be represented as a hierarchical pyramid.

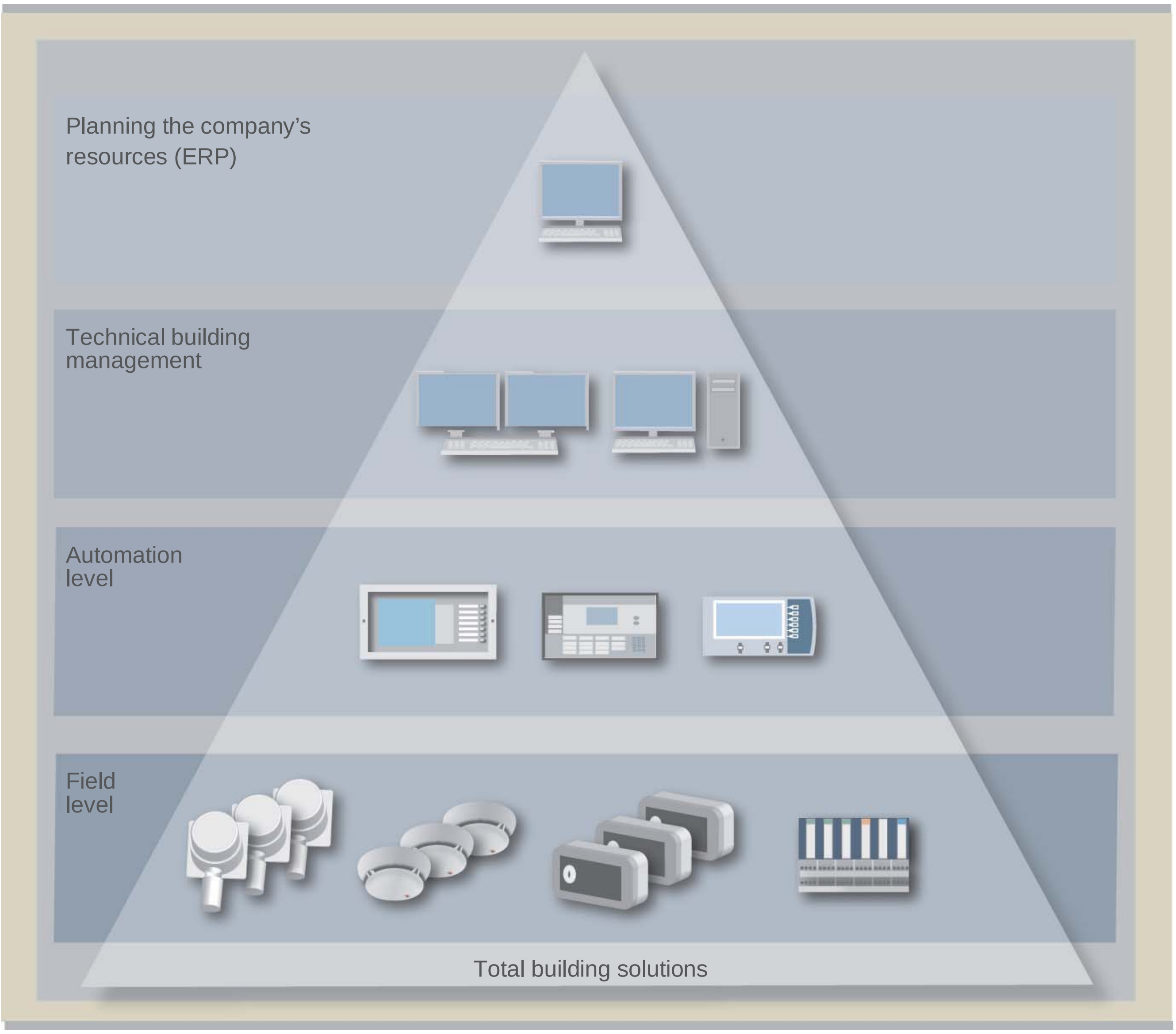


Figure 7.2: Structure of technical building management

It must be taken into account that the different levels work autonomously and are interlinked by means of high-performance communication networks.

The pyramid shown in Figure 7.2 reflects the data concentration from one level to the next. The field level acquires an enormous amount of information, but only a small part thereof is passed on. Intelligent fire detectors continuously record parameters, such as smoke density and temperature, but they normally transmit the danger level to the control unit only periodically. However, in case of an alarm, they immediately report the event to the control unit. Medium-sized systems already encompass thousands of data points on the field level.

The centrally managed subsystems transfer data to the building management system in exceptional cases only, and only a small part of these data is required for the ERP (e.g. energy consumption data).

7.2.2 Distributed Intelligence and Hierarchy

Twenty years ago, microprocessor-based devices were large, expensive, slow, energy-consuming and rather inflexible. Building up a system with such components necessarily led to highly centralized systems with low functionality. The technical progress that can be seen in daily life – systems that are smaller, faster, more intelligent and more economic – also led to completely new possibilities in device and system engineering. The resulting benefits for the user are not only reflected by lower purchasing and operating costs but also by the following aspects:

– increased reliability and improved self-surveillance
– quick hazard recognition, immune to deception
– actuation of immediate and automated, interdisciplinary interactions for danger management
– clearly arranged, graphic-oriented reporting of hazards to the safety staff
– the possibility of geographically distributed systems to be monitored and controlled from one or several workstations

In the following, we will focus on the field of safety engineering and take a closer look at the management, automation and field levels:

- **Management level:** DMS with the functionalities required to control the subsystems, particularly including central observation and operation of the subsystems but also the possibility of visualizing, archiving, logging and evaluating.
- **Automation level:** Automation controllers that are usually denominated control units, with the functionalities required for decision-making, distribution and controlling the processes.
- **Field level:** Sensors and actuators with the functionalities required for detecting, activating and transmitting hazard messages, or appropriate countermeasures respectively.

Each of the three aforementioned levels is provided with a high-performance network in order to link the decentralized components of the own level, or to integrate the subordinate level's networks.

Information flowing from a subordinate level to a higher level is condensed and filtered according to predefined criteria. Information flowing top-down may be multiplied according to predefined criteria, for example to open several smoke extraction dampers with one single command.

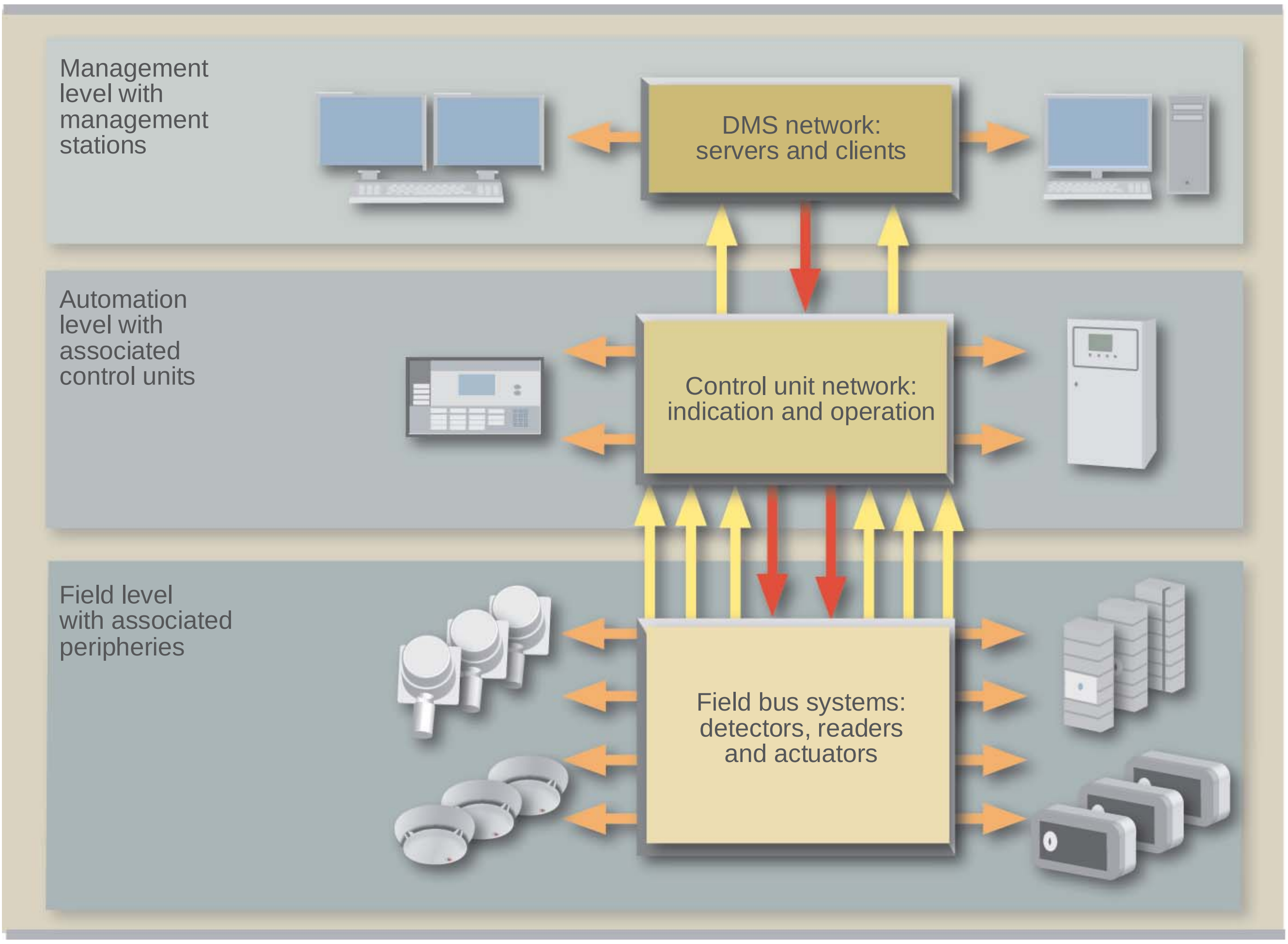


Figure 7.3: Hierarchy of the safety system technology

7.2.3 Scalable System Structure

When selecting a safety management system, it is important to know whether the system supports possible future extensions and modifications. The step-by-step extensibility of a system and the correspondingly easy and efficient system extension are central quality features of a DMS.

Flexible, scalable structures allow setting up different configurations with one system technology, including, for example.:

- compact systems
- LAN systems
- WAN systems

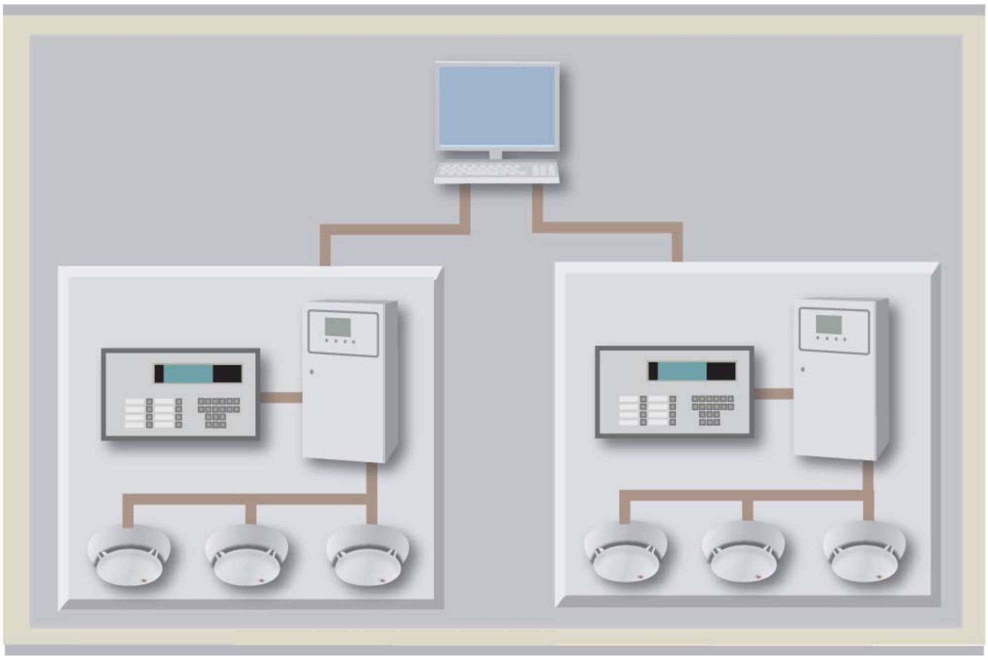


Figure 7.4: Example of a compact system

With compact systems, the complete DMS software is installed on one workstation. The system usually communicates with one or more subsystems via a serial connection.

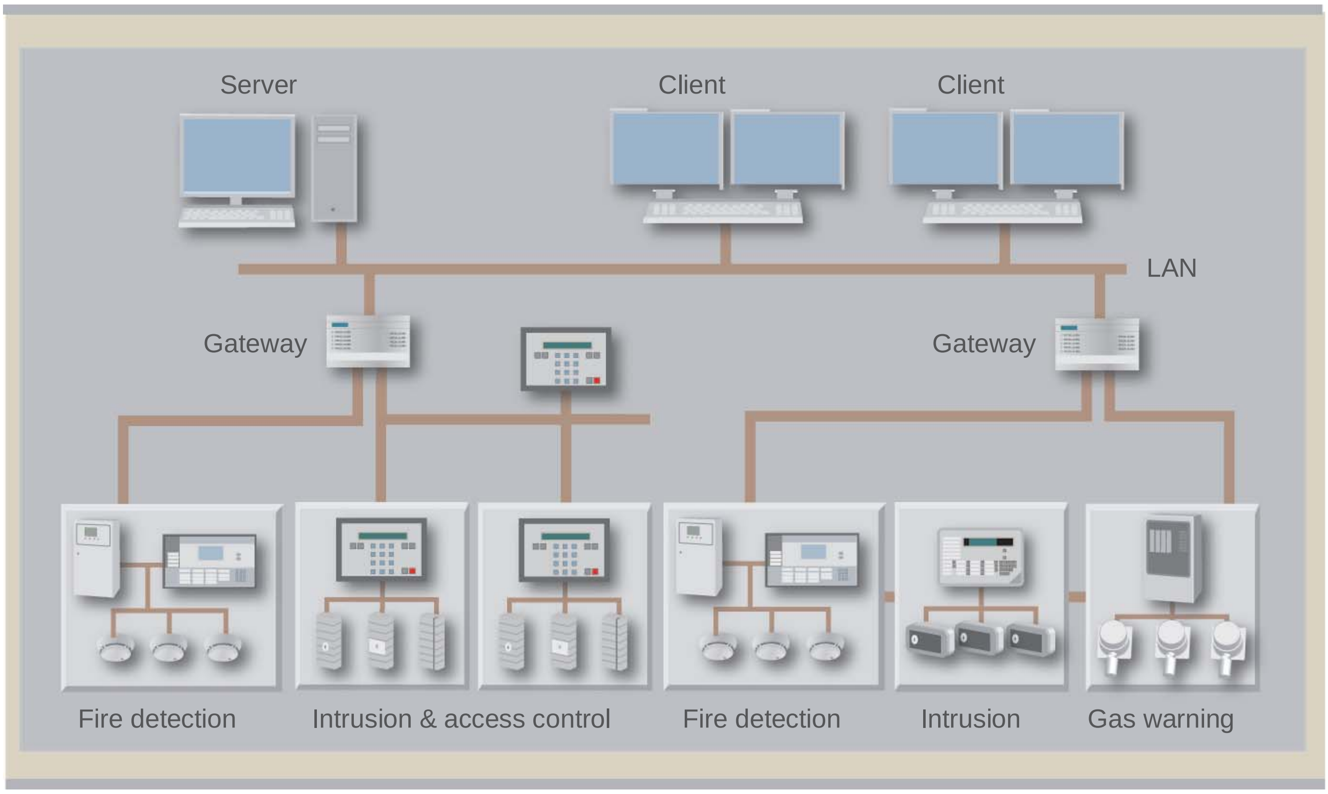


Figure 7.5: Setup of a DMS with LAN

LAN is the abbreviation for Local Area Network (see Glossary starting on page 297). A LAN system comprises several DMS operating stations (clients) by means of which the building can be simultaneously monitored from different workstations. The operating stations are connected to one or several servers via the LAN. Such a server is also called a client station, as they serve other clients while they can still be used as clients themselves.

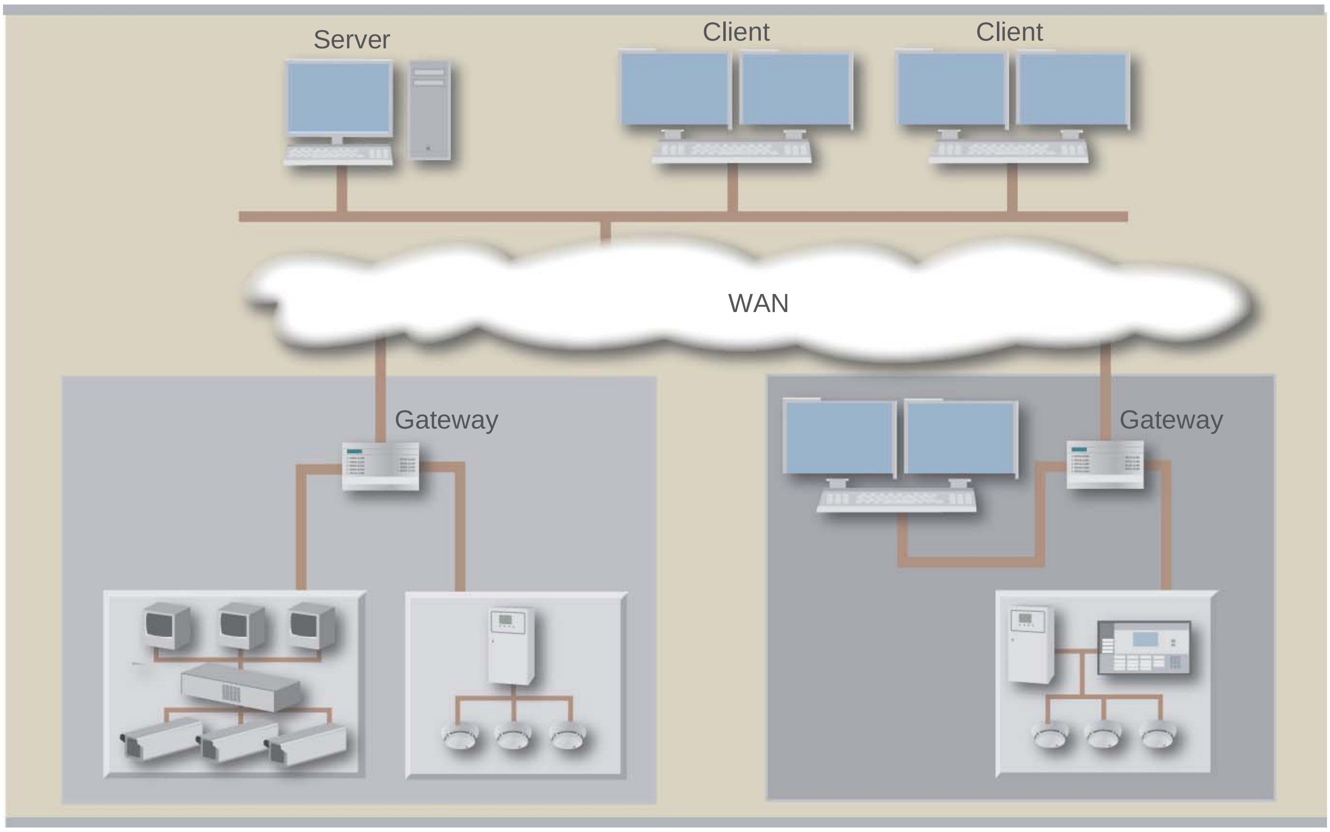


Figure 7.6: Setup of a supraregional DMS network with WAN

With a WAN (see Glossary starting on page 297) solution, geographically distributed systems can be monitored and operated either locally or centrally. This facilitates monitoring and control of many small bank subsidiaries by one or more central DMS, for example.

7.3 Main Functionality

The key tasks of a DMS are the handling of events, the operation of subsystems and reporting.

To make these main functions possible, a whole range of additional functions is required which, to some extent, constitute the infrastructure of the DMS. To name only the most important additional functions: Access rights concept, user administration, password administration, object administration in tree structures and graphic structures, graphic level administration.

The three following subsections describe the main functionality of a DMS.

7.3.1 Event Handling

The handling of actual events, sometimes simply referred to as alarm handling, is the core function of a DMS. Hence, its central elements are
– hazard recognition,
– hazard reporting,
– adequate intervention.

When a detector recognizes a hazard source, the operator at the workstation must immediately be alerted. Appropriate means to call the operator's attention are acoustic signals transmitted by loudspeakers, flashing elements on monitors or, in case of the operator's absence, mobile signaling via SMS or pager. The operator usually has a set of questions that need to be answered as quickly as possible:
– what kind of problem is reported?
– where has this problem occurred?
– what must be done next?

Event handling includes therefore:
- Indication of all pending events, both in clear-text and as dynamic symbols on the building's ground plan.
- Acknowledging the receipt of the event signal (acknowledgement).
- Resetting the event message.
- User guidance by providing individual handling steps, depending on the type and importance of the event, in accordance with the general conditions and requirements of the system.

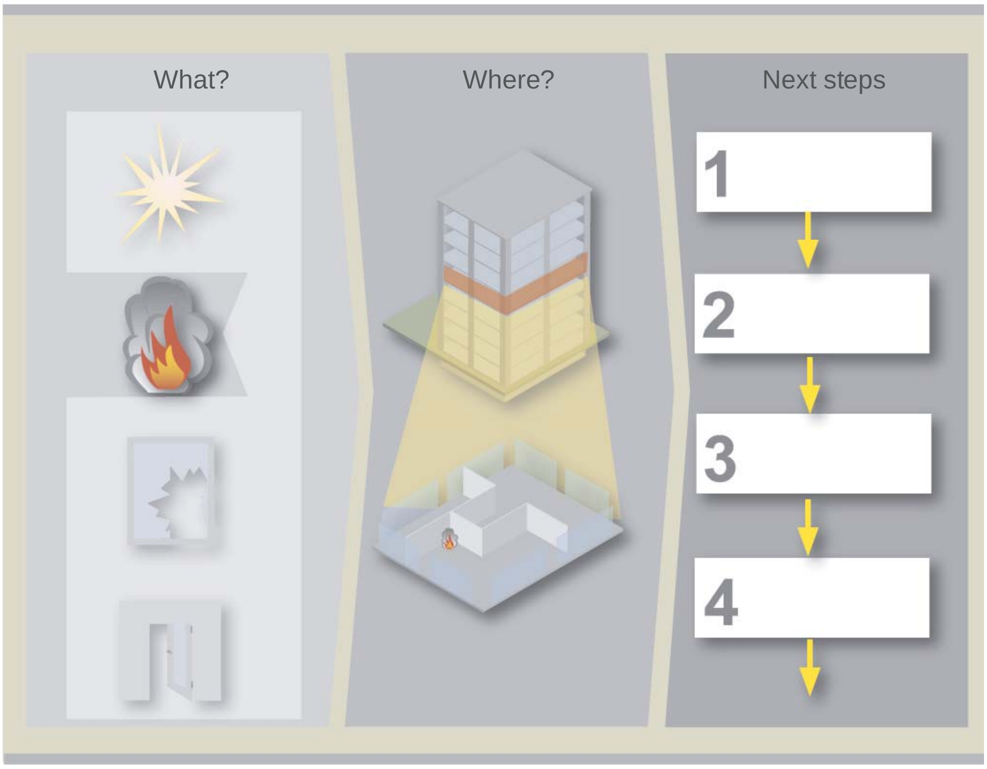


Figure 7.7: Event list and event on the building overview

The typical procedure is the following:

- The DMS recognizes an event and reports it to the operator in charge. The system simultaneously triggers a countdown.
- The operator localizes the alarm and reports to the DMS that he / she has noted the alarm (acknowledging the alarm). The countdown is canceled.
- When the system notices that no reaction (acknowledgement) has occurred within the countdown period, an external alarm receiving center is informed automatically.
- After acknowledging, the operator makes sure which tools are currently available to verify the event and takes care that the alarm is investigated. With compact systems, it is usually the operator who is responsible for this.
- Depending on the results, the intervention forces are alerted (police, fire brigade or other intervention forces), or the alarm has turned out to be irrelevant and is canceled (reset).

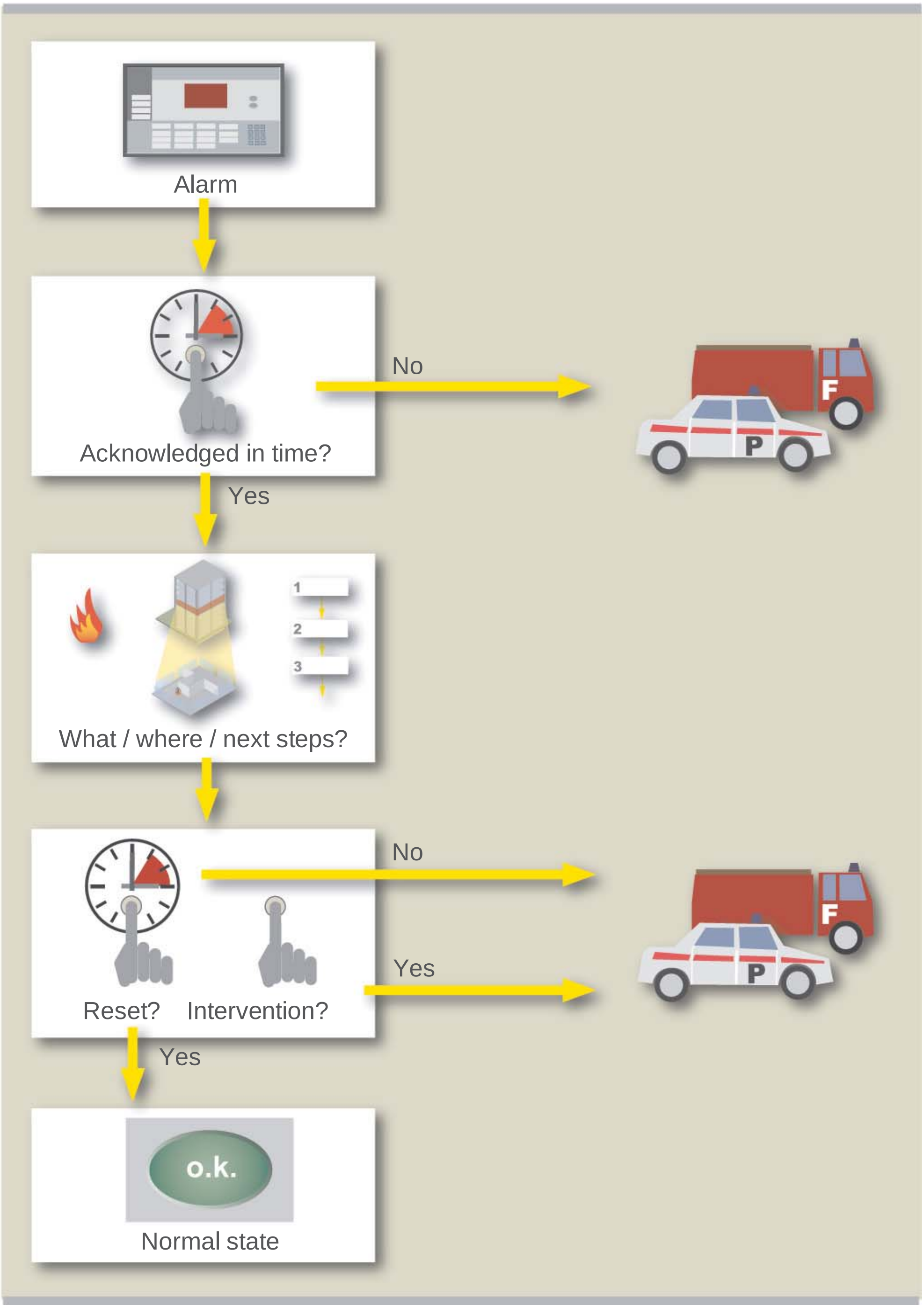


Figure 7.8: Event handling with DMS

7.3.2 Integrating and Operating the Subsystems

State-of-the-art DMS support all important types of subsystems such as fire detection, gas warning, intrusion detection, access control or video surveillance. In addition, a DMS must be able to integrate other subsystems, such as safety-related sections of HVAC systems or other technical installations.

As far as possible, and for all subsystems connected, the DMS shall
- indicate events and facilitate their handling (see section “Event Handling” starting on page 247)
- enable the activation of subsystem-specific functions
- enable the activation of preprogrammed control sequences (macros)

Usually, the subsystem-specific functions of a fire detection system comprise the following processes:
- switching individual detectors or groups of detectors (zones) on and off in order to perform maintenance work on the fire detection system
- changing the alarm organization (e.g. day / night mode)
- activating fire control installations, for example.:
  - closing the fire dampers in the event of fire
  - initiating smoke extraction
  - positioning elevators in emergency position

Examples of other, subsystem-specific functions are:
- positioning camera
- activating video recording
- opening doors

Subsystem-specific functions can be operated both via a text-oriented tree structure and via graphics. A uniform operation of different subsystem types with different operating concepts is only possible when the conceptual setup of the DMS takes the particularities of the different subsystems into account and flexibly integrates individual, subsystem-specific functions.

7.3.3 Reporting Functions

State-of-the-art DMS today work with integrated database applications, making it possible to store an almost unlimited number of past events together with their handling steps recorded. These system-specific recordings and the corresponding polling possibilities may help to answer questions such as:
- what has happened during the past 24 hours?
- how many faults occurred last year?
- who did what and when following yesterday’s intruder alarm?

Such reporting possibilities support the optimization of building operations and the technical facilities.

7.4 Operation

DMS are typically operated via a graphic-based user interface on which the ground plan of the floor concerned is indicated in case of alarm, including the room in which the alarm occurred. Today's DMS cannot be imagined without features like graphic navigation and operation via photos, ground plan and other images. As ground plans may be very large, the DMS must support vector graphics. Functions such as automatic scaling, zooming, small overview windows (bird's eye view), etc., are only possible with vector graphics. Since ground plans today are normally available as CAD files provided by the architect, advanced DMS make it possible to directly read in ground plans in AutoCAD format, for example. This makes time-consuming copying and editing processes a thing of the past.

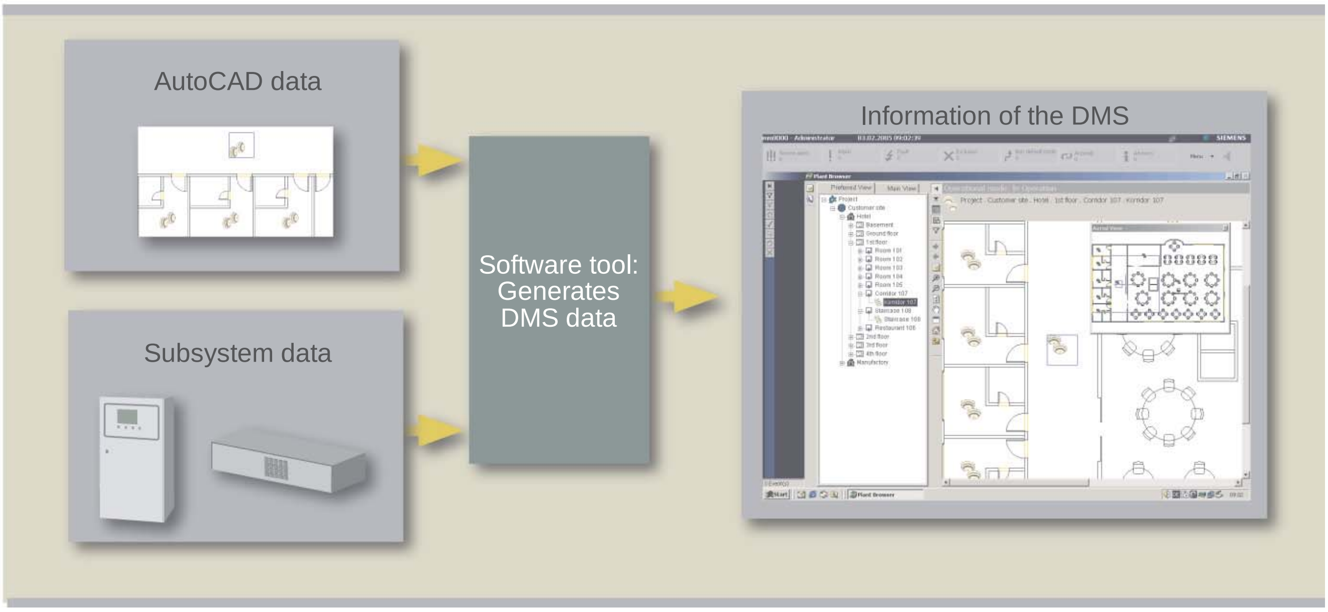


Figure 7.9: Excellent efficiency thanks to tool-based data transfer

State-of-the-art DMS also support multiple graphic layers, allowing to show more details on the lower levels. The visibility of different levels can depend on the operator's access rights, which in turn results in a better overview (focus on what is essential for the operator).

The user-friendliness of a DMS is probably one of the most important criteria to opt for a system. Not only experienced security and safety experts shall be able to accomplish their tasks quickly and easily with the DMS. Untrained staff with little PC experience must also be able to respond safely and quickly in case of emergency with the help of a DMS. This is aggravated by the fact that these systems are generally rarely operated, as no hazards are reported in normal operation. An emergency situation is a stress situation for most operators.

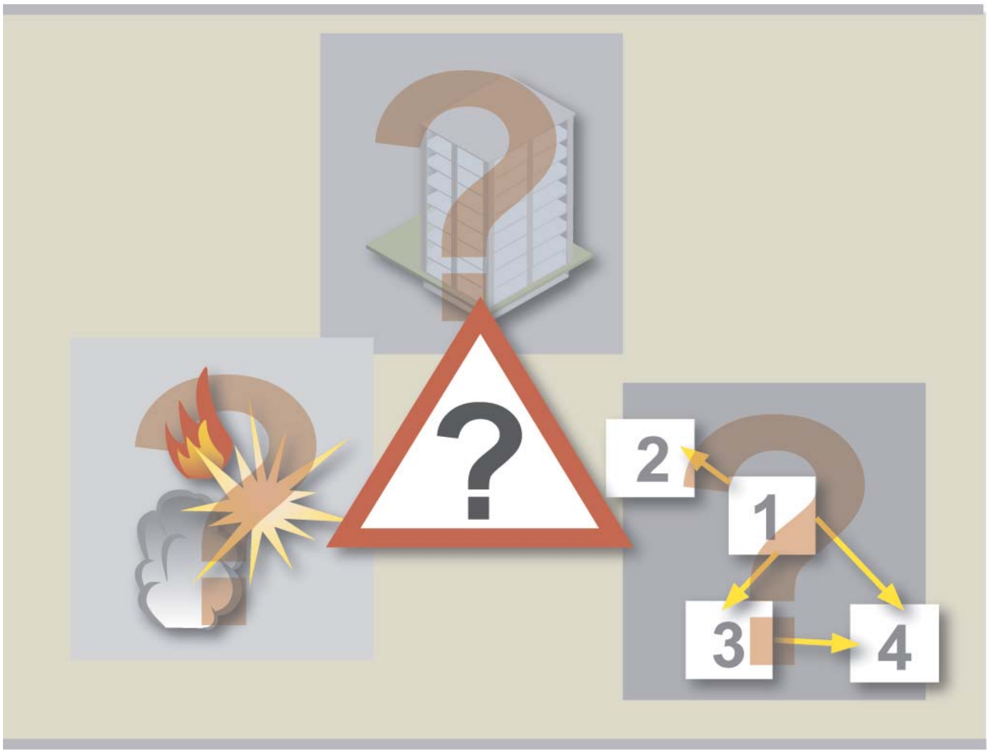


Figure 7.10: Ambiguous situations and unstructured processes under pressure create stress

Getting a correct overview of what is going on and reacting correctly in a stress situation is only possible if the system informs the operator in a possibly simple way, at the same time supporting the operators so that they can initiate the correct measures in the right sequence.

Clearly structured, logic processes that are easy to control are a prerequisite for successful hazard prevention.

It is thus essential for the operator to rely on a few simple and intuitive rules. These rules must remain constant, independent of the current state of the system, the instant at which the event occurs, or who is handling it.

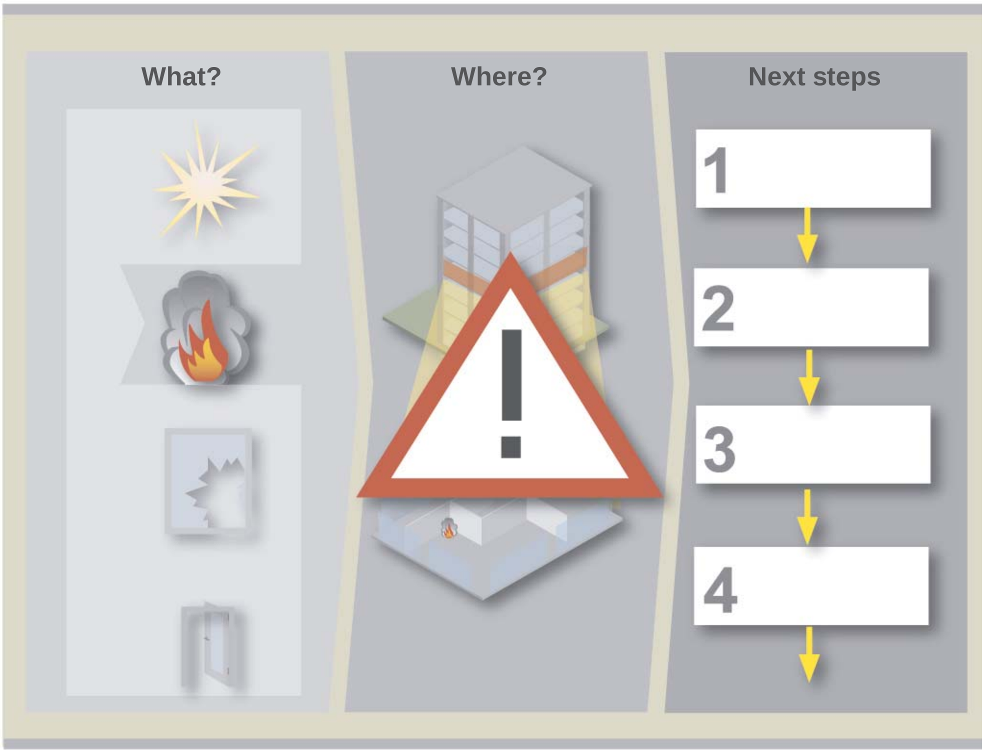


Figure 7.11: Hazards under control due to overview and structured processes

A DMS should make it possible to configure some workstations as exclusive DMS workstations, meaning that only the DMS application can run on these PCs, while all other applications or operating system functions can neither be seen nor used. But also for workstations that are not exclusively configured for DMS, monitor regions exclusively reserved for DMS with a clearly defined functionality in stress situation are a crucial advantage.

In addition, it must be ensured that the DMS allows for step-by-step, guided event handling in case of important events. Of course, this kind of event handling must be project- or customer-specific and adapted to company-internal security and safety processes and conditions. Whether a DMS allows such adaptations and how complex and costly this would be must be clarified in advance.

The state of subsystems, such as the number of currently deactivated detectors, etc., must be constantly visible. This is the only way to make sure that the operator has a correct overview of the actual situation at any time.

Easy operation prevents excessive demands on the operator and human error

7.5 Integrated Systems

The concentration of all safety--related information in one DMS has the following advantages:
- improved overview and thus increased safety
- reduced costs in comparison to several independent management systems with regard to purchase, configuration and maintenance
- consistent operation concept requiring less training and bearing no risk of confusion in case of emergency
- only one safety system to be integrated into the company's IT infrastructure
- easier interactions between subsystems

The goal is thus to integrate the subsystem into the DMS as completely as possible. Perhaps a complete integration may rarely be possible, but the aforementioned advantages are obvious.

The disadvantages of system integration are focused in two areas:
- The higher complexity renders operation more complicated for the user. Excessive demands and an inappropriately long adjustment period must be avoided for the operators and their deputies. To avoid these disadvantages, leading system suppliers have introduced access and visibility levels which can be allocated to the different user types. Each operator sees only what is relevant for him or her.
- Complex systems are more susceptible to errors than systems using a simpler structure. To eliminate error sources from the beginning, development and support tools are used which detect existing errors and avoid the generation of new errors by means of continuous testing of data consistency.

Provided that the aforementioned measures are adhered to, the safe operation of DMS with integrated subsystems is possible.

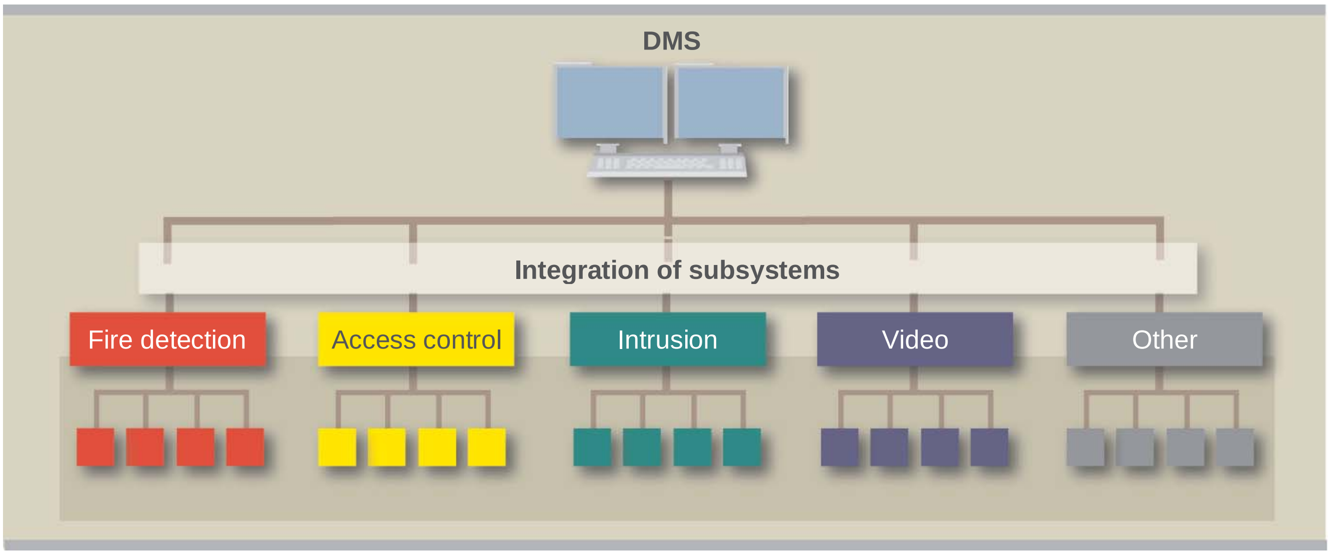


Figure 7.12: Versatile integration of different disciplines into DMS thanks to open system technology

Advanced DMS offer different possibilities to integrate subsystems. Some examples are manufacturer-specific protocols, open gateways for integration or open protocols, such as:

- OPC standard for an easy but frequently functionally limited, direct integration into the PC.
- BACnet for a more sophisticated, functionally more detailed integration into the PC. This protocol is equally suited for the communication without a PC, i.e. directly between the automation controllers for so-called peer-to-peer communication. This type of communication is suited for quick, safe interactions avoiding the error-proneness of PCs and PC networks.
- LON, EIB, PROFIBUS, Modbus and other protocols which may as well be used on the automation or field level.

7.6 Fail-Safe Operation

Fail-safe operation must be accommodated by different measures. Two different aspects shall be mentioned in brief below.

7.6.1 Standby Solutions

A possibility to improve the fail-safe operation of PC-based solutions is the use of standby servers. In a DMS set up as a typical client-server solution, the server is the weak point of the system. If it fails, the clients connected are no longer functional. When an emergency server or standby server is used, the system automatically switches to that standby server in case of a main server failure. Thanks to constant data mirroring, the standby server may continue exactly where the main server stopped. Typically, there is a separate high-speed communication link between the main server and the standby server, allowing for quick and trouble-free data mirroring.

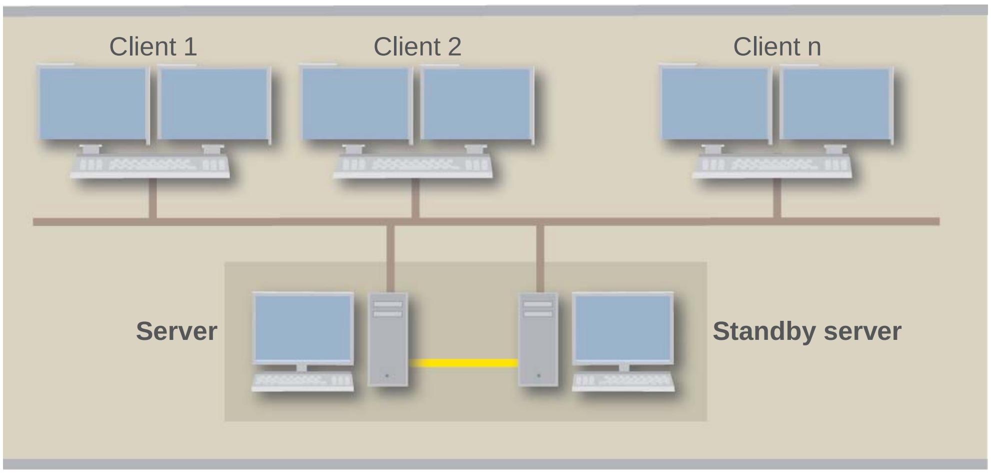


Figure 7.13: Increased network safety on account of a standby server

7.6.2 Power Supply

In safety technology, emergency power supply for the subsystems is usually ensured. It is also recommended to provide the emergency power supply for the network modules and the DMS itself. Generally, a power failure of 4 hours should be bridged by an uninterruptible power supply unit, for example.

7.7 Planning

In the era of digital image processing, digital photography, 3D-CAD systems and GUI (Graphic User Interface), the provision of photos and diagrams is no longer a problem. Consequently, it becomes more important that they are thoroughly selected:

- identical graphic representation formats for the entire building
- same degree of detailing and information contents
- same viewing angles, brightness, etc.

To be able to make the best possible selection, the following decisions should be made in advance:

- scale of the complete overview
- scale of the smallest details to be viewed
- number of intermediate steps
- zoom factor for each step (constant)
- navigation structure
- access rights concept

To answer the aforementioned questions, the DMS provider’s experts can provide valuable input depending on the situation.

7.8 Installation, Commissioning and Acceptance

Although it is possible to set up the safety management networks simultaneously with the rest of the building's cabling, commissioning calls for functioning subsystems that are usually only available after the building has been set up completely.

System integration implies that system acceptance includes integration tests. The correct configuration of each data point must be ensured, i.e. the management station indicates this data point with the correct designation, at the right location and allocates the correct data type to it.

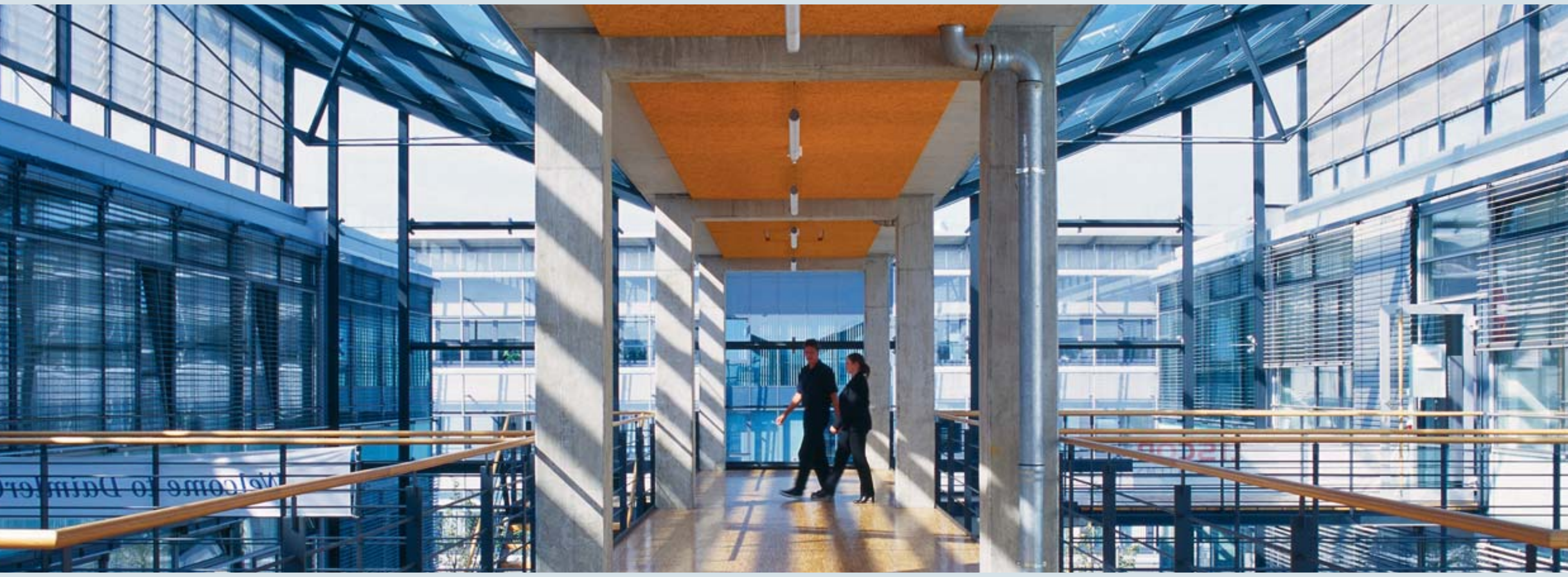
7.9 Profitability and System Evaluation

DMS are already profitable with compact systems, i.e. systems with more than 150 data points (detectors or sensors). This has the following advantages:

- **Fast reaction:** In contrast to the subsystem's operating panels mounted close to the exits, the DMS is located at the working place of the staff responsible for safety. Therefore, in case of an alarm, the time to get from the working place to the subsystem's panel is omitted. A fact that increases reaction speed while reducing stress of the responsible persons.
- **Increased productivity:** To operate the subsystems, the persons responsible not only spend unnecessarily time to walk from their working places to the operating panels, but they need to permanently recall the different handling modes of the various subsystems because the handling procedures of an intrusion detection system are not identical to those of a fire detection system, for example. By using a DMS, time will no longer be spent for walks to the operating panels and to recall handling procedures. In addition, reliability of operation is increased since event handling on a DMS is quite the same for the different detection systems.
- **Cost reduction:** Due to the centralized DMS, safety monitoring can also be centralized, resulting in minimum numbers of local safety staff.
- **Better system overview:** Considering a building as a system or as an entity is only possible with a central management system. And combined threats will increase in the future. The burglar making use of a fire alarm is only one classical example.
- **Better decision basis:** Due to the abundant information they provide, combined systems allow for the correct assessment of a situation. Video surveillance, for example, makes it possible to correctly assess an emerging fire in real time. Access control informs on the number of persons present in the fire section, or makes it possible to accurately locate a burglar. Only a central management system makes this information available on a network.
- **Targeted reaction:** If an operator makes decisions based on graphic, spatial representations, then this is for sure a better decision basis than a simple subsystem display. Is the supply shaft located in the immediate vicinity of the fire location, or does currently the gas cylinder store represent a much higher risk? Thanks to precise geographic information, such questions can be answered in case of alarm.

Concerning system selection, the optimum representation of the own organization in the management system is decisive. The flexibility of selecting new organization forms on short notice, or, of adapting the responsibility to the new staff organization, or of quickly and correctly integrating a new subsystem will prove worthwhile during the course of time. The functionality should thus always ensure optimum operation – even if it has not been provided for two safety officers sharing tasks, for example.

The economic efficiency of a DMS is guaranteed time and again



8 Maintenance and Services

8.1 Summary

Safety systems must be serviced and maintained to ensure proper operation. Furthermore, such systems represent considerable investments that should be protected.

To accomplish this task, preventive maintenance and corrective maintenance are applied. Up-to-date system functionality also facilitates the application of remote maintenance aimed at cutting unproductive expenditure, such as travel time.

Maintenance is the art of keeping the infrastructure up-to-date and adapting the safety systems to new environments and change of use. Especially the latter aspect is often disregarded, which can lead to dramatic effects. They range from rather harmless false alarms to the system's inability to respond in due time. One example would be structural changes that are made without subsequent adaptation of the detection system.

For most persons, "maintenance" is identical to improving the system's state. But before being able to tune, to fix or exchange the system and its components, thorough diagnostics is required. Regardless of whether it is a preventive or corrective maintenance task, diagnostics always precedes the intervention. Furthermore, supporting tasks are also included in maintenance. This may cover training, hotline, assistance or other infrastructural preconditions to operate a safety system, such as a central monitoring station (CMS).

The maintainability of systems of different manufacturers varies considerably. Ideally, a system should allow cost-efficient maintenance that leads to a long life expectancy. Furthermore, flexible modernization concepts allow at the end of the system's life cycle to replace the parts with the lowest reliability first, resulting in extended life of the remaining system sections.

It pays off to select the right company to service a safety system. There are many benefits gained from competence and seriousness of the company, from the beginning until the last part of the system is replaced by the new system. Stepwise modernization is much more advantageous than a one-time, total system replacement.

Although maintenance is required by regulation in many countries, most system owners do it because of conviction. It is worthwhile and protects life and valuables.

8.2 Basics

Electronic building safety systems represent a special kind of challenge: While it is commonly agreed that mechanical systems require maintenance because parts can rust or lubrication is needed, the majority of people think that an electronic system lasts forever without requiring maintenance. However, this idea is wrong: Consumer electronics devices rarely fail in the first years of operation and are then often replaced because of the progress made in between with newer models.

Also, a single fire detector hardly ever fails. But a safety system is confronted with the following important factors that completely differ from consumer electronics:

- A safety system cannot be compared with consumer electronic products. Such a system consists of many devices that are geographically distributed and networked by a LAN or even a WAN in some cases. This results in much higher complexity and in different aging processes of the various devices. It is obvious that the detector in the cold storage room is confronted with other problems than the detector in the parking garage, for example.
- Networking problems can range from simple earthing (potential differences) to fully grown problems concerning handling of information in networks, etc.
- While consumer electronics is granted a life expectancy of four to eight years, building safety equipment is required to last much longer:
  - A TV operates from 3 to 12 hours a day. But a safety installation is required to operate 24 hours a day.
  - Since a large part of the investment consists of installation and commissioning, a longer life expectancy has a dramatic impact in the investment quality and results in lower overall system cost.
- Building safety is regarded to be part of the building and therefore its life span is compared to that of the building's renovation cycles.
- Safety systems need to possess a particularly high level of reliability. Not only because of the risk of loss of life and valuables, but also because building administration should be burdened as little as possible by the management of these systems.
- Safety systems normally work in the background without any human interaction and proper operation is a matter of course. Therefore, these systems are equipped with comprehensive self-test functionality. Nevertheless, supervision of the system is required even if it is limited to the detection of malfunctions to initiate appropriate action.

Hence, safety systems require maintenance, a fact that is also underlined by the regulations of many countries, where regular maintenance is a mandatory requirement. But consciously executed maintenance covers more than just mandatory issues: For example, to define in advance the correct way to behave in case of a certain event, or the right mix between preventive maintenance and availability of on-call service.

Ensure the reliability of safety systems through proper maintenance

8.3 Objectives, Structure and Impact

The quality of a safety system is largely influenced by the four following parameters:

- **Effectiveness:** Capability to detect and react as requested.
- **Stability:** Capability to withstand irritating and interfering effects, like for example electromagnetic interference.
- **Reliability:** Probability to be free from breakdowns or malfunctions.
- **Maintainability:** Ease of maintenance and service.

Maintainability is usually determined by system design in which methods and means for maintenance are defined. The remaining three parameters for the system's quality, i.e. efficiency, stability and reliability, are largely also dependent on the system's maintenance, because it is the objective of maintenance to safeguard them. Hence, system design influences maintainability while maintenance influences system performance. This interdependency of system design, its maintenance and quality should not be underestimated. Frequently, one considers the capabilities of service and maintenance only after the system is installed, disregarding the great importance of maintenance and additional services. Therefore, it is preferable to examine maintenance of the various systems during the system selection process. Of course, a dense service network of the supplier is a must.

After sales service is defined as "all services offered by the vendor or the manufacturer after the purchase". It consists of services and maintenance. While maintenance covers all activities directed towards safeguarding the proper functioning of the system, service deals with all sorts of changes and amendments. Services cover virtually every new aspect starting from change of the building's use or alterations of the building's outfit to the system's extension or modernization.

Often, preventive maintenance is offered at a fixed price with fixed content. Contrarily, demand for services is usually unforeseeable and dependent on individual circumstances.

Maintenance is sometimes considered to be costly. But this needs to be put into perspective: A significant increase in reliability and a prolongation of life expectancy do normally more than outweigh its cost.

The reasons for maintenance are manifold:

- Proper functioning of safety installations is a prerequisite to fulfill the installation's task: Protect people and value.
- Safety installations are requested by law. For legal reasons, building owners and operators need to ensure that systems work as intended. By signing a maintenance contract with a reputable maintenance company, they may pass on, or at least diminish legal liability in case of a disaster. The chances for success in litigations are greatly enhanced.
- By means of maintenance, the safety installation's value is conserved since properly maintained equipment ages less rapidly than equipment that has not been maintained.
- Safeguarding the protection level by an annual check of the external service technician. Only a system specialist is able to judge whether, for example, changes of building use require an adaptation of the safety system.

Service and maintenance are components of the normal system's life cycle as follows:

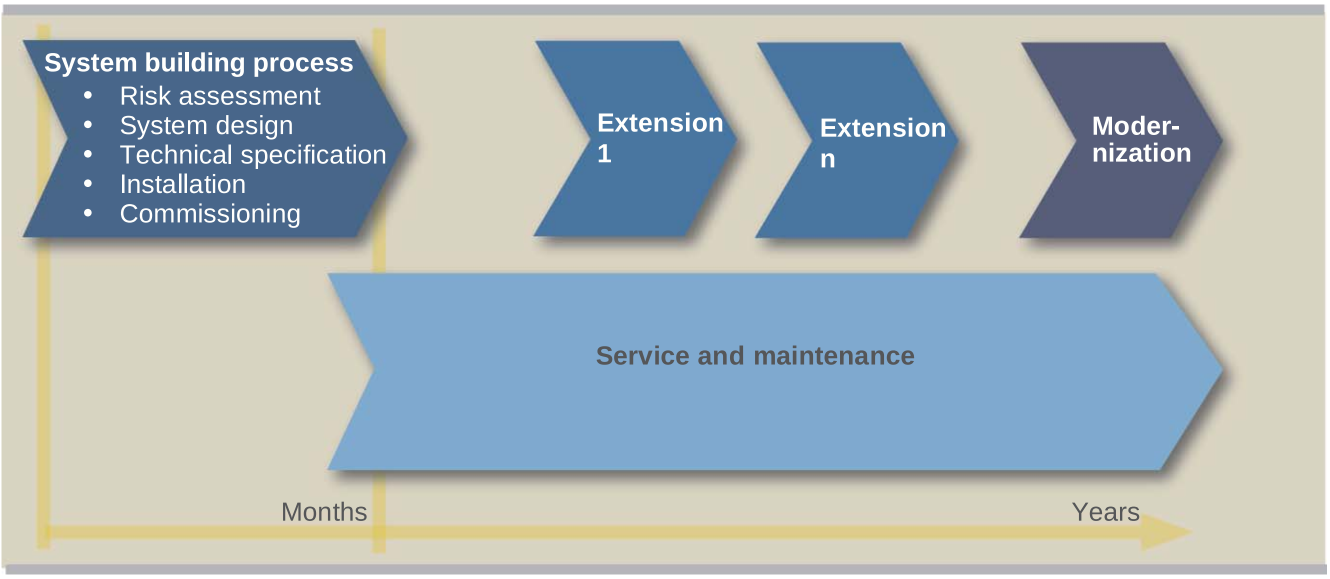


Figure 8.1: Service and maintenance in the context of the system's lifecycle

This graph shows that the rather complex system building process is followed by long periods of unspectacular system life in which the various safety systems frequently sink into oblivion. To ensure nevertheless proper system operation, the system must be maintained on a periodical basis. During maintenance work, the safety of the building is to be ensured. This means that in case a system needs to be switched off, guards must be posted or other measures are to be taken for the protection of the building. The measures shall ensure a fire is detected timely and can be controlled efficiently.

According to the standards IEC 60050(191) and EN 13306:2001, maintenance subdivides into the areas of preventive and corrective maintenance.

Maintenance tasks are classified in three different types:

- **Support:** A system requires attention. For this, various tasks like management, monitoring, training, assistance, etc., are required.
- **Diagnostics / Inspection:** In case of trouble, the first thing to do is the proper diagnostics of the system's state, that is, to identify the real problem by performing various tests.
- **Servicing:** If the exact state of the various system components is known, it is possible to repair, replace, calibrate, tune or upgrade the system.

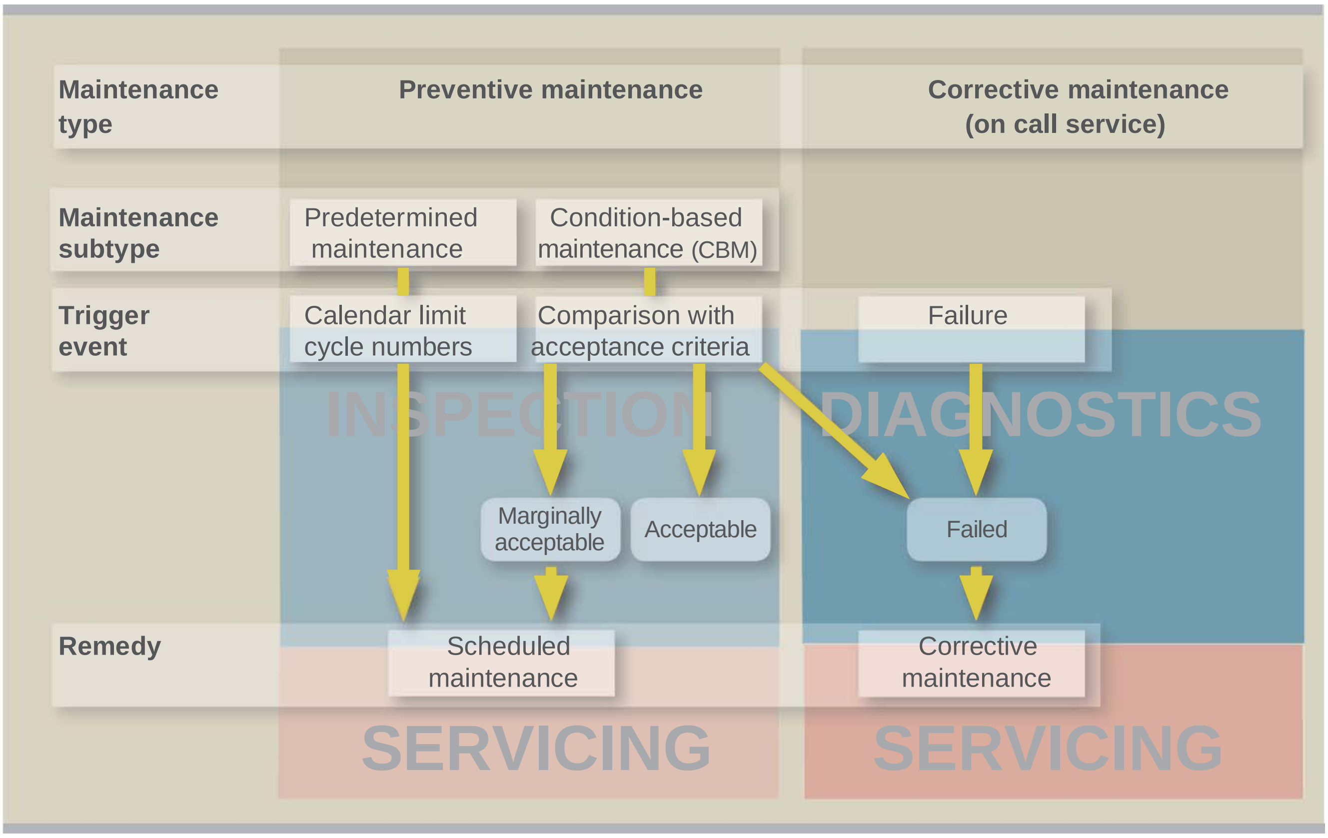


Figure 8.2: Structure of the maintenance process

By the means of preventive and corrective maintenance, it is ensured that system reliability is continuously kept at a high level. For most systems, one inspection per year is required. However, some types of systems require a more frequent check-up.

Preventive maintenance in the above diagram subdivides into the two following groups:

- **Predetermined maintenance**: Maintenance is executed once a year, for example, or once every X cycles.
- **Condition-based maintenance:** The comparison of the system's performance with acceptance criteria shows either acceptable results with no subsequent maintenance or marginally acceptable results that will result in the arrangement of a scheduled maintenance. In case results are not acceptable, an immediate corrective maintenance task is required.

An employee of the customer shall be responsible for each system. His or her task is to carry out the checks required. These checks obviously need to take place more often than maintenance by the technician of the service company. Besides the checks, the employee is responsible for documenting the checks and the decisions taken. More and more service companies provide remote monitoring services around the clock to support regular system checks. Such services often allow much shorter response times than manual checks.

The benefit of maintenance is higher efficiency, reliability and stability of the system. Furthermore, a maintained system lasts longer than a system that is not maintained. Thus, the investment into the safety system is not only protected but improved.

Figure 8.3 compares two maintenance strategies: System 1 is maintained normally, for example by annual maintenance, while system 2A is not maintained. Therefore, it needs to be replaced earlier by an equally non-maintained system 2B.

Due to aging, the performance of system components deteriorates in the course of time. Without intervention, the critical reliability of the system is reached quite early. Periodic maintenance readjusts the system constantly to ensure highest reliability. The difference in reliability corresponds to the functional value of maintenance, i.e. one gets more performance for the money spent. Based on proper maintenance, system life is considerably longer than without. The additional lifetime corresponds to the financial value of maintenance, i.e. through maintenance the investment made lasts longer. Hence, we need to distinguish between functional and financial value of the maintenance, maintenance's two different benefits to the system.

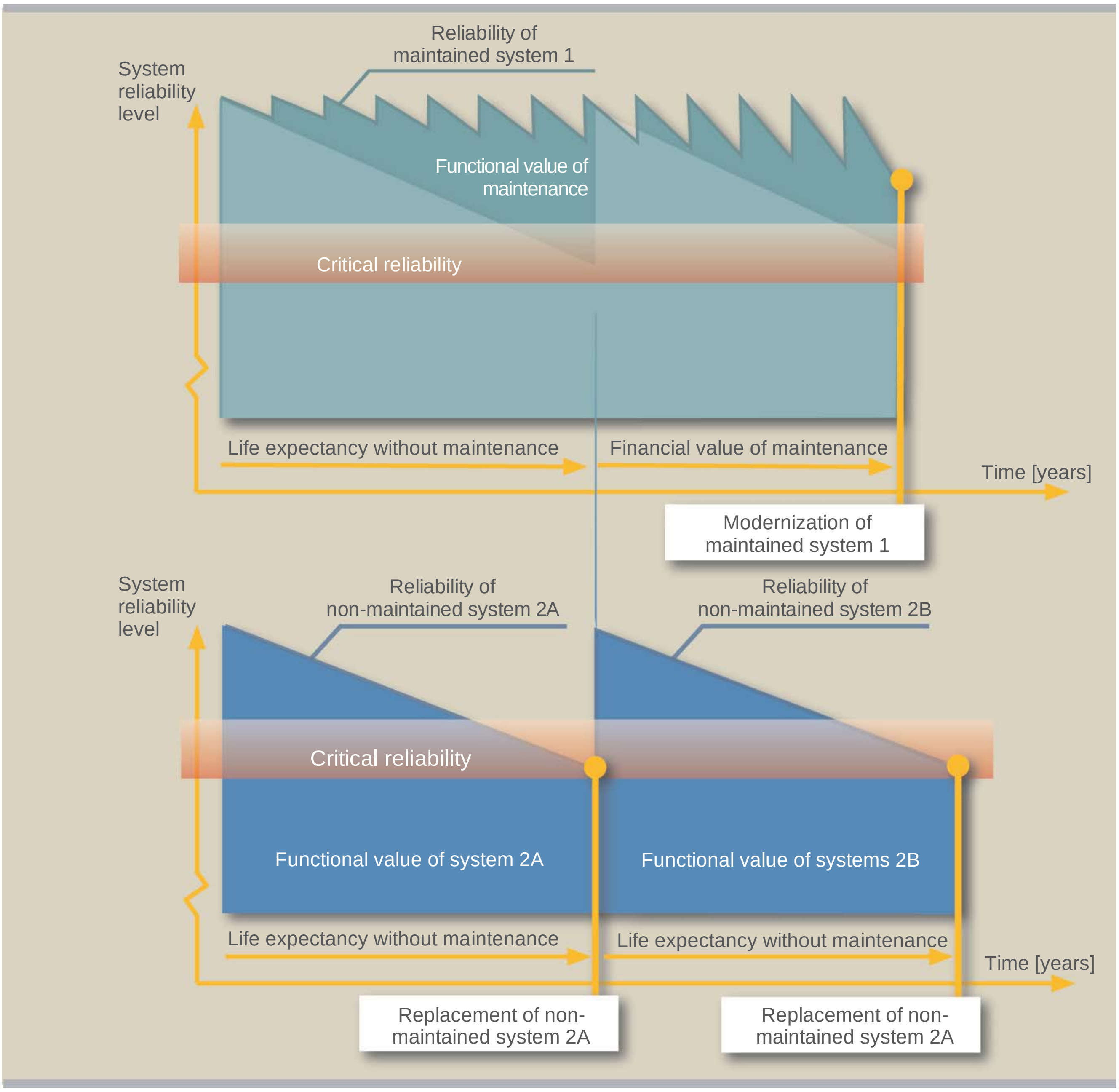


Figure 8.3: Impact of system maintenance

Therefore, the two components of additional value provided by maintenance are the functional value and the financial value:

- **Financial value**: The longer system life of 12 years, for example, compared to 8 years results in a longer depreciation period. Therefore, the annual costs of system 1 are in this case lower by one third. But a well maintained system does only have a life expectancy of, for example, 12 years if its supplier is able to provide the required spare parts that long – a prerequisite fulfilled only by companies that consciously foster maintenance.
- **Functional value**: The higher system reliability level saves among others the following costs: Cost of corrective intervention, system down times with reduced protection (risk!) and employees absorbed by administrative work.

Furthermore, the basic orientation of the manufacturer is also decisive for the options one has when the system will come to the end of its normal lifecycle: Either it will require a complete new system or it will allow a smooth modernization concept. In this case, the better preserved components of the system will last longer and improve the quality of the investment made years ago.

The value of maintenance: Longer system life and less trouble

8.4 Types of Maintenance

In conversation with people, one finds out quickly that everybody seems to understand something else under the term “maintenance”. The underlying problem is that maintenance is a collective noun that contains a great many issues. For this reason, correct use of the terms is a must. In the following, we provide an overview of the various issues of maintenance.

Service type	Service modules				
Operational services	Alarm handling	System monitoring	System operation	System operational assistance	System performance analysis
Specific services	Detector overhauling	Extinguishing maintenance	Gas detection		
Maintenance services	Inspection	Functionality check	Preventive maintenance	Corrective maintenance	Emergency intervention
	Emergency service (7/24)	Guaranteed response time	Replacement parts included	Consumable supplies	
Software services	Software back-up	Software update	Software upgrade		
Management services	Technology counsel	Technology assurance	Documentation management	Customer service view	Training
Financial services	Pre-financing plan	Leasing			

Table 8.1: Great variety of maintenance tasks

On-site services are largely standardized. Hence, only few standard contracts cover the various customer requests with specific optional services availability.

8.4.1 Preventive Maintenance

Preventive maintenance covers all planned service items agreed upon between system owner and servicing company in the service contract. The contract specifies the technical and administrative conditions and covers all management conditions. Preventive maintenance is aiming at preventing from system breakdowns to secure a high performance level for the customer and increase productivity and efficiency.

By systematic planning, dispatching and reporting, continuous performance analysis and benchmarking is ensured. This is a prerequisite to establish well performing processes for preventive maintenance.

The goal of planned inspections is to keep the system in perfect working order and to prevent downtimes. Normally, it consists of a visual inspection and periodic re-assessment, annual testing and servicing of the control unit, detector testing, testing of the alarm equipment, checking the installation and updating of the system's documentation. Compliance with local and national codes, standards and regulations is a must. A maintenance report informs about the control and equipment testing and suggests any improvement to maintain the system availability or to modernize the system in case of obsolete equipment.

Preventive maintenance may largely be tailored to the customer's desires. Its most important components can be classified as follows:

- **Diagnostics (system inspection and various system tests)** deals with determining the state of the various system components. According to the possibilities of the system tools and the politics of the maintenance company, various tests can be included, covering detectors, manual call points, valves, door fans, smoke exhaust, alarm path, optical and acoustical alarm means (microphones, loudspeakers, horns) etc.
- **Correct (tune / fix / exchange)**: Detected problems can be fixed, settings adjusted (with digital technology a task of decreasing importance), sensors calibrated (e.g. gas detectors) or parts exchanged to prevent future malfunctions or performance decrease of the system.
- **Overhaul**: To keep the detection functionality up, some suppliers offer periodical overhaul of certain components. Most important devices needing overhaul are fire detectors. A real overhaul takes place in the factory – to simply blow out the detectors has got nothing to do with overhaul. By including overhaul into the maintenance contract, peaks in maintenance cost can be avoided.
- **Remote monitoring**: Modern systems allow constant monitoring. According to the options provided, system state and performance, as well as soiling of detectors and many other parameters can be monitored remotely. For systems in unmanned locations, such as small or medium telecommunication stations, this is a must. And it becomes increasingly common to have all kinds of systems remotely monitored.
- **Software service**: Modern systems make use of information technology, which automatically involves software. A huge advantage of software is that it can be exchanged against improved versions. While in earlier days the behavior of a system could not be changed, state-of-the-art systems allow adaptations at different levels. Most important levels are the changing of parameters (this function was in earlier days partly provided by DIP switches) and exchange of software. Flexible systems are enabled by this to be adapted to new findings. Of course, also training and documentation should be included in a software upgrading option. A disadvantage of software is that it is volatile and might be deleted. But a backup service can avoid this unfavorable situation.
- **Customer training**: While initial training of the customer's employees is normally part of the system handover, periodical retraining ensures that the employees' competencies do not decrease in the course of time: Successors are trained as well as their predecessors and rarely used knowledge does not simply disappear.
- **Consumable supplies**: According to the contract, consumption of spare parts and other supplies needs to be paid separately or can also be included in the contract. In the latter case, an agreed list of additional materials and services such as periodical battery exchange, printer paper replenishment, etc., are included in the maintenance contract.

8.4.2 On-Call Service and Corrective Maintenance

The primary objective of on-call service is to maintain the availability of the system and to fix any trouble in the shortest time in line with the targeted service level. On call service is an unplanned intervention and may be requested by customers with or without service agreement. Intervention activities on customer sites are frequently initiated by equipment or system failure. But it may also be a planned maintenance visit on which the need for an unplanned, corrective intervention is discovered. The activities of an on call service intervention are directed towards the restoration of an item or system functionality to a specified level of performance.

The options in tailoring corrective maintenance are somewhat more limited, compared with preventive maintenance. Besides restoration of the system's functionality, unplanned maintenance can also cover the support of the customer's infrastructure. The following modules are common:

- **On-call intervention**: Restoration of system functionality in the shortest possible time. On-call intervention consists of a diagnostic part, in which the exact system state is determined, and of the servicing part, to get the system fully operational again.
- **Emergency service (7/24)**: Unfortunately system faults have no regard for our normal working times. In case immediate reaction is to be ensured regardless of the daytime or weekday, the servicing company needs to ensure the availability of its staff.
- **Central Monitoring Station (CMS)**: Central monitoring stations are designed to receive any alarm or fault status message from safety (and security) installations and to handle all alarms according to an agreed response and escalation plan. They therefore can substitute an organization of the customer. Obviously, the experts in handling alarms are performing better than the customer's own, less trained staff. Thanks to economies of scale, CMS service costs less than an own organization. A CMS connection relieves companies from the need to establish a proper safety / security organization on their own.
- **Hotline / remote assistance**: The specialist's advice is often the key for the individual responsible for the system to react in the best way. Therefore, hotlines have been established to assist and to give advice. Modern systems allow remote access. By this, the manufacturer or servicing company can log in remotely to analyze the system's state. Intervention can also take place remotely or by the customer's employees who act on the instructions of the maintenance company. Obviously, the findings may also result in an on-site intervention.
  Increasing interest is directed towards hotline support and remote assistance. Often, the only thing missing to the customer's staff is expertise. The issue is resolved with a simple phone call (hotline support) or an online assessment (remote assistance) of the system by the supplier. Hence, this may be a very cost-effective maintenance option.
- **Guaranteed response time**: Remaining unprotected is not acceptable for crucial installations. Hence, intervention must take place quickly. This is to be agreed upon by the servicing company which must guarantee not only the beginning of the intervention within a certain response time, but also that intervention takes place with skilled technicians.
  Unsurprisingly, companies with a dense network of subsidiaries and service points have a head start on competition.
- **Consumable supplies**: If included in the service contract, the system will be maintained at the agreed rate – regardless of what happens.

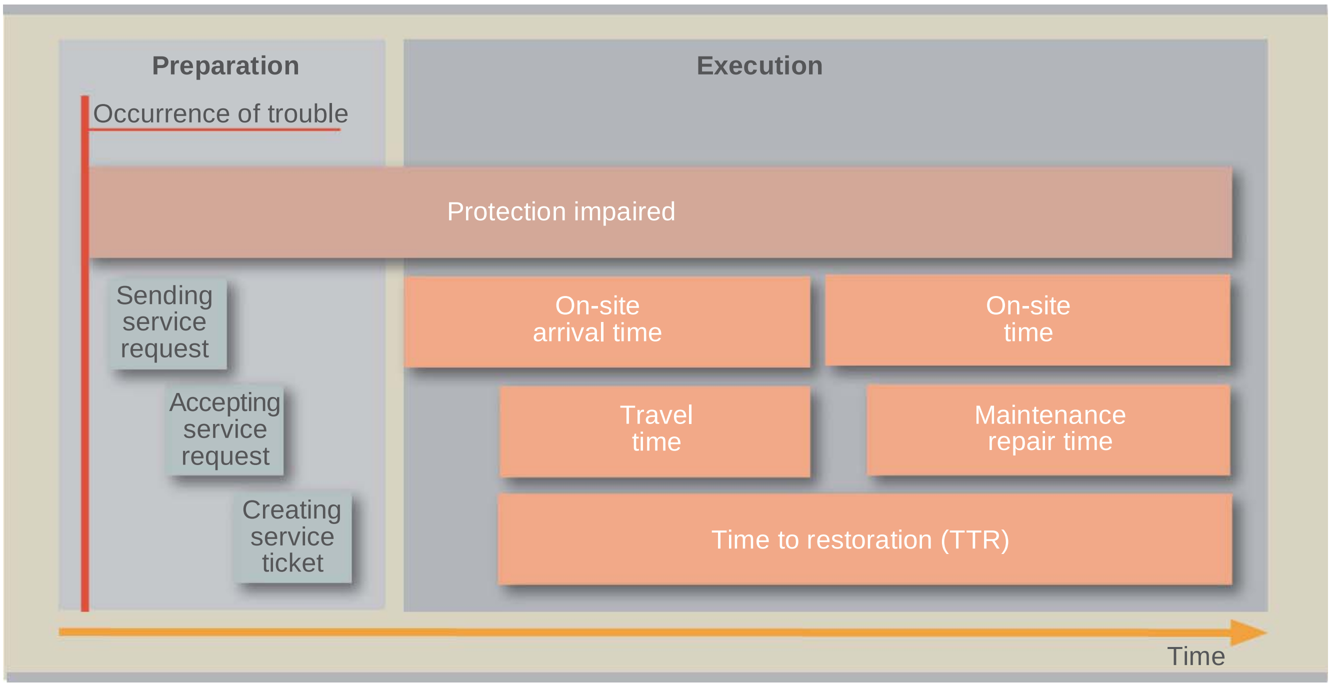


Figure 8.4: Events and actions in case of an on-call intervention

An on-call intervention always starts with preparation, i.e. the qualification of the call, which is a precondition for an efficient intervention. Also, travel time starts only after the technician prepared himself accordingly. And, after arriving on site, the technician first needs to report to the customer's individual responsible for the job to get the complete picture of the situation before starting with the works.

The servicing companies are the experts in maintaining safety systems. And some companies also spent thoughts on the question how to improve the overall value for the customer. Result of this is the management of the system's lifecycles – an interesting service provided by only few suppliers. Its goal is to define which component of the system should be replaced at what moment in time to achieve optimal maintenance cost while considering the risk situation and preserving the targeted protection level.

8.5 Service Projects

In case an existing system needs to be changed to a substantial degree, a separate, so-called service project is required. The two main reasons for service projects are the extension or the modernization of a system. To perform such service projects, separate service contracts are signed.

System extensions may be required to adapt the system to new detection demands or to include newly constructed building extensions in the protection. There are almost as many reasons for service projects as there are buildings.

Replacing parts of the system using up-to-date products allows decreasing the technological gap of an old system. For instance, this could enable an old system to perform new services like remote servicing, thereby achieving a payback in a very short time.

Every system reaches ultimately the end of its lifecycle. That is where, for the modernization of the system, a service project is required. Normally, modernizations involve partial upgrades on the existing system without dismantling the cabling while ensuring backwards compliance / compatibility between old and new components. This is the ground preparation for a smooth transition to the new system generation. A flexible modernization approach creates additional value since the most degraded components of the old system are exchanged first, allowing a longer life span of the other, better preserved system components. Furthermore, less trouble and less interference of the normal building utilization may be expected compared with normal system exchange.

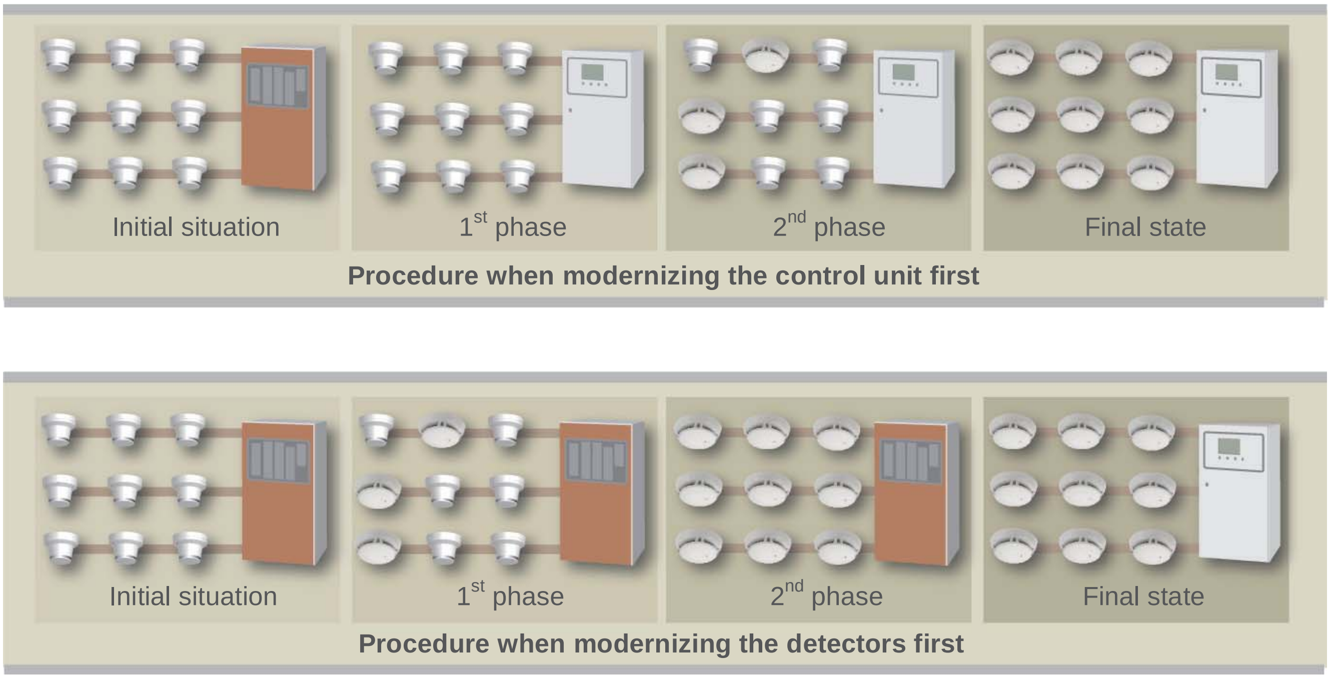


Figure 8.5: Modernization is tailored to the customers' individual needs

The illustration shows exemplarily how flexible concepts for modernization can increase the value of the existing system by extending the life span of the better preserved system parts. Obviously, an individual assessment of the actual situation is a prerequisite, which is no problem for a competent service organization.

8.6 Selection of Services to Be Used

Planned on-site maintenance allows limiting the non-planned intervention on site. Additionally, remote maintenance increases and supports the system operator's flexibility. But which maintenance contract should be taken, and which service suits your company best?

It is obviously not possible to treat this topic exhaustively. Nevertheless, the following considerations provide some hints:

- Most countries require the system operator to sign a basic maintenance contract to ensure proper system operation. Such regulations are often the consequence of bad experience. With or without regulation: A basic maintenance contract should be the natural consequence of safety consciousness and common sense. Only a maintained system will fulfill the task it is designed to.
- Moreover, a well maintained system will last longer, thereby improving the quality of the investment made. One should take into account that the investment does not only consist of the out of pocket money (external cost), but also of the absorption of own staff by the planning and management of the system replacement.
- Does our company intentionally cultivate a very high standard in its products and services? In this case, only full maintenance service should be considered. A high standard leads to high expectations that need to be met.
- Does our company have a high value added per employee? In this case, outsourcing of the required services will cost less than own staff.
- Obviously, companies with high risks are obliged to guarantee utmost availability of their safety systems. In case of a system breakdown, fire-watchmen need to be posted – a costly measure.
- Companies with strong deceptive phenomena or high risks benefit from software upgrades: Future updates of software and functionality increase the system's value.
- Are our own resources capable of dealing with the various issues of safety systems? Is competence and availability of our own staff ensured in every respect? For example, in case one has no dedicated security / safety manager, a CMS contract is helpful.
- It is possible to use own staff resources to assist the service technician in regular alarm testing and first level maintenance.

Well-organized servicing companies will let you choose among different standard maintenance contracts. This allows you to adapt the scope of maintenance to your individual requirements.

A system and its maintenance are interlinked. By selecting a system, the companies able to service it are largely defined. Therefore, maintenance needs to be considered already during the system evaluation process. The following questions help rating the offer:
– is the company able to service my equipment with the indicated service team?
– how far is the local branch office?
– which certificates does the company hold?
– what is the level of performance guaranteed?
– how is the equipment's lifecycle managed?

Select the maintenance provider and the maintenance modules carefully

8.7 Performance Criteria and Qualification

The selection of the right company to service and maintain an installation is often perceived as difficult. Which aspects should be rated? Where do differences exist among the different service providers? The following questions might help in rating the companies better:

- Has the company a strong reputation?
- What acknowledgements / certificates guarantee for the seriousness of the work and the company?
- What qualification level / certificates do the company's employees have?
- How is the capability of the company to resolve also large-scale problems in a short time? It hopefully never happens, but it is relaxing to know that it will be fixed rapidly.
- Where is the next branch?
- What is the distance of the service technician's journey to maintain your installation? A dense service network reduces travel time.
- Does the company have a branch network to fix capacity bottlenecks of the responsible branch quickly or to service the customers' subsidiary networks?
- What is the mean time to restoration (MTTR) specified by the company? A service technician dropping in three or more times to fix one thing is annoying.
- Is the company in a position to partly also service the installation remotely? Effectiveness has many appearances.
- Will the company still exist and honor the contract some years from now? If servicing of safety installations is e.g. not belonging to the core business of the company it might change its strategy and turn away from service business.
- What is the company's capability for prolonging the life of the installation to the maximum and improving hereby the quality of the investment made? Maintenance work is only paying out if it results in a long system life.
- Is the company in a position to smoothly modernize the installation after it has reached the end of its lifecycle? A step-by-step system exchange comprises more benefits for the customer than some percents of discount at the time of purchase.
- Is the company able to considerably increase its service level on short notice e.g. to bypass a bottleneck of the customer's internal capacity?
- Does the company have a sufficient stock of all spare parts of the customer's system? Quick reaction is not possible if the defective parts need first to be identified, then ordered and delivered to the service company.
- Does the company work with the original analysis and support tools of the manufacturer? This is a precondition to efficient work.
- Is the company able to execute all tasks themselves or will it require the aid of some other company for the more difficult tasks? This affects efficiency, mean time to restoration (MTTR) and the quality of the work.

The system and its maintenance are linked because the selection of the system largely defines the system maintenance company and because not every system has the capability for step-by-step modernization. Some systems are more apt for maintenance than others: Modularity, exchange options, components interoperation.

Hence, these facts should be considered before selecting a system. Sometimes, it takes more to find out where the stumbling blocks are. And if there is none, the reading was well worth to gain the certainty that the supplier is the right one to choose.

9 Standards, Regulations and Authorities

9.1 Summary

Society has worked out standards for almost all fields of economic and social life and the associated means. Standards are regulations and guidelines to be adhered to by everybody, laying down how particular objects have to function or how particular activities have to be performed. These standards differ by nature according to the geographical and cultural environment.

Standards specifically referring to safety engineering are usually mandatory and define the minimum requirements on function, execution and operation of safety equipment. This includes product standards, system requirements, system engineering standards, as well as standards for product and system providers, maintenance and servicing companies.

Product and system providers must furnish proof that the relevant standards have been adhered to. The relevant standards differ from one region to the next and often from case to case. For the purpose of furnishing proof, each individual area has its own approvals.

In addition to the national standardization associations, approval authorities and insurance companies, testing bodies and professional associations as well as local fire protection organizations or fire brigades, international committees have as well been involved in the development and control of standards, with the objective of their world-wide harmonization. This variety of involved institutions and standards makes the field of standardization rather difficult to understand and obscure for outsiders.

Customers who usually cannot deal with these issues in detail should preferably select renowned suppliers, who are most likely to provide a guarantee for trouble-free project planning and are capable of servicing the system according to the regulations after it has been installed and commissioned.

As the product, the installation and operation of the system as well as all suppliers involved are subject to the standards, compliance with them in all fields is a complex venture.

Standards make sure that a minimum degree of functionality and reliability is not only promised but indeed kept! This makes it possible for the customer, in the scope of system evaluation, to especially consider the performance features exceeding standards, so that he can choose technically and qualitatively superior suppliers.

9.2 Basics

Standards define minimum requirements on product groups, services or companies. Basically, we have to differentiate between the voluntary adherence to a standard and a mandatory requirement. Often, only mandatory standards are adhered to, which is why society tends, especially in the field of safety technology, to make standards obligatory. However, the different institutions take different perspectives and have different demands concerning the significance of individual specifications, functions, system correlations, etc., which in turn results in a variety of relevant standards for safety technology. This variety can hardly be represented in a clearly arranged way.

While adherence to a standard means a performance guarantee for the customer, it is often an indispensable prerequisite for the two following groups:

- **Authorities:** As an integral part of the building and operation approval, the installation of safety systems is often required by law, or by the (local) building authority in charge. Depending on the threat scenario, this may include fire detection systems, gas warning systems, extinguishing systems or combinations thereof.
- **Insurance companies:** In case of special risks, building insurers equally require safety systems as a prerequisite for the insurance contract. For this reason, e.g. fire detection systems and voice alarm systems are demanded in buildings of a particular size or number of people. Sometimes, the availability of a particular safety system is not an indispensable prerequisite for the insurability of a risk, but it may considerably reduce insurance premiums.

The requirements of the relevant authority to install a particular safety system, generally encompasses the standards to be adhered to.

Standards for safety systems include the minimum requirements on function, execution and system operation. As far as available, these requirements revert to existing international and national standards, representing the “state of the art”. The emphasis is always on the locally and nationally applicable standards. However, the international standards by CEN (European Committee for Standardization), CENELEC (European Committee for *Electrotechnical* Standardization) or ISO (International Standards Organization) are increasingly applied. These are standards in which a large part of the national requirements has been standardized by mutual agreement. Some national standards may as well have international effects. This is partly true for the DIN standards (Deutsches Institut für Normung – German Institute for Standardization), the BSI (British Standards Institute) Group, the AFNOR (Association Française de Normalisation – French Association for Standardization) or the UL/ULC (Underwriters’ Laboratories from the US and Canada).

Safety engineering: A wide array of national and international standards

9.3 Standards and how to Secure Adherence to Standards

Regulations only make sense if their adherence can be ensured. This requires knowledge of the applicable standards and their compliance.

Both aspects are still problematic today:

- There is no such thing as a chart showing which standards and regulations apply for each European city or region – the variety of regional requirements is simply too large.
- Sometimes or in some places, compliance with the required standards is not consequently and completely verified, which usually leads to a certain exploitation at discretion.

9.3.1 Types of Standards

In standards and regulations, we can differentiate between the following types (for the definition of the terms “installation”, “product” and “system”, refer to “Glossary” starting on page 297):

- **Product standards:** They define requirements on the function and execution of the different product types used in fire detection systems (fire detectors, control units, power supply units, cables, etc.).
- **System requirements:** They define requirements on the function and execution of systems in order to guarantee the smooth interaction of the many different products combined in a system.
- **System engineering standards:** They lay down requirements to be adhered to in the construction and operation of entire installations (planning, function, setup, operation, maintenance and service).
- **Corporate standards for product and system providers:** They describe the process sequences that shall guarantee the assurance of an acceptable product quality and the compliance to the product specifications according to the product approval within a company.
- **Corporate standards for installers and servicing companies:** They describe the process sequences that shall guarantee the assurance of an acceptable installation quality and the compliance to the installation specifications in accordance with the installation standards in an installer’s company.

9.3.2 Hierarchy of Standards

Each country, almost each region or province and many large cities define additional requirements for safety systems and especially for fire detection systems. These requirements are laid down in special country-specific, regional or municipal guidelines.

These standards, which are applicable in addition to the European standards, usually cover areas not addressed by the European standards. For example, the EN 54 standard, which is applicable for fire detection systems, only encompasses product standards and does not cover the field of system engineering. In individual cases, these standards may even accentuate the European minimum requirements.

Figure 9.1: Hierarchy of standards

Within the EU, the European Commission has declared special requirements for certain products as mandatory all over Europe. These standards are called “harmonized” European standards. All commercially available products must comply with these requirements, i.e. with the corresponding standards, confirmed by the manufacturer by applying the **CE identification** to the product. This also concerns products for the construction of buildings and equipment, including components for safety systems. The new version of the European construction product guidelines therefore also includes the fire detection system regulations (EN 54).

9.3.3 Proof

The proof of adherence to the standards is mandatory for all types of standards.

9.3.3.1 Conformity of Product and System

The proof that the products comply with the product standards is furnished by testing in an acknowledged test laboratory. This laboratory conducts the type tests, or system tests respectively, on behalf of the manufacturer or the distributor. If tests are passed successfully, the product’s compliance with the standard is confirmed in a test report issued by the laboratory. The approval authorities in each country then issue the country-specific approval or acknowledgement based on these test reports. The approval is of limited validity and must be renewed periodically.

As a proof of the compliance with the harmonized European standards, no special approvals are required as the declaration of conformity (by applying the CE identification) by the manufacturer suffices. This means that the manufacturer assumes the responsibility for the products complying with the regulations. This declaration of conformity is based on the type tests to be conducted either by an authorized, approved test laboratory or, in special cases, by the manufacturer himself.

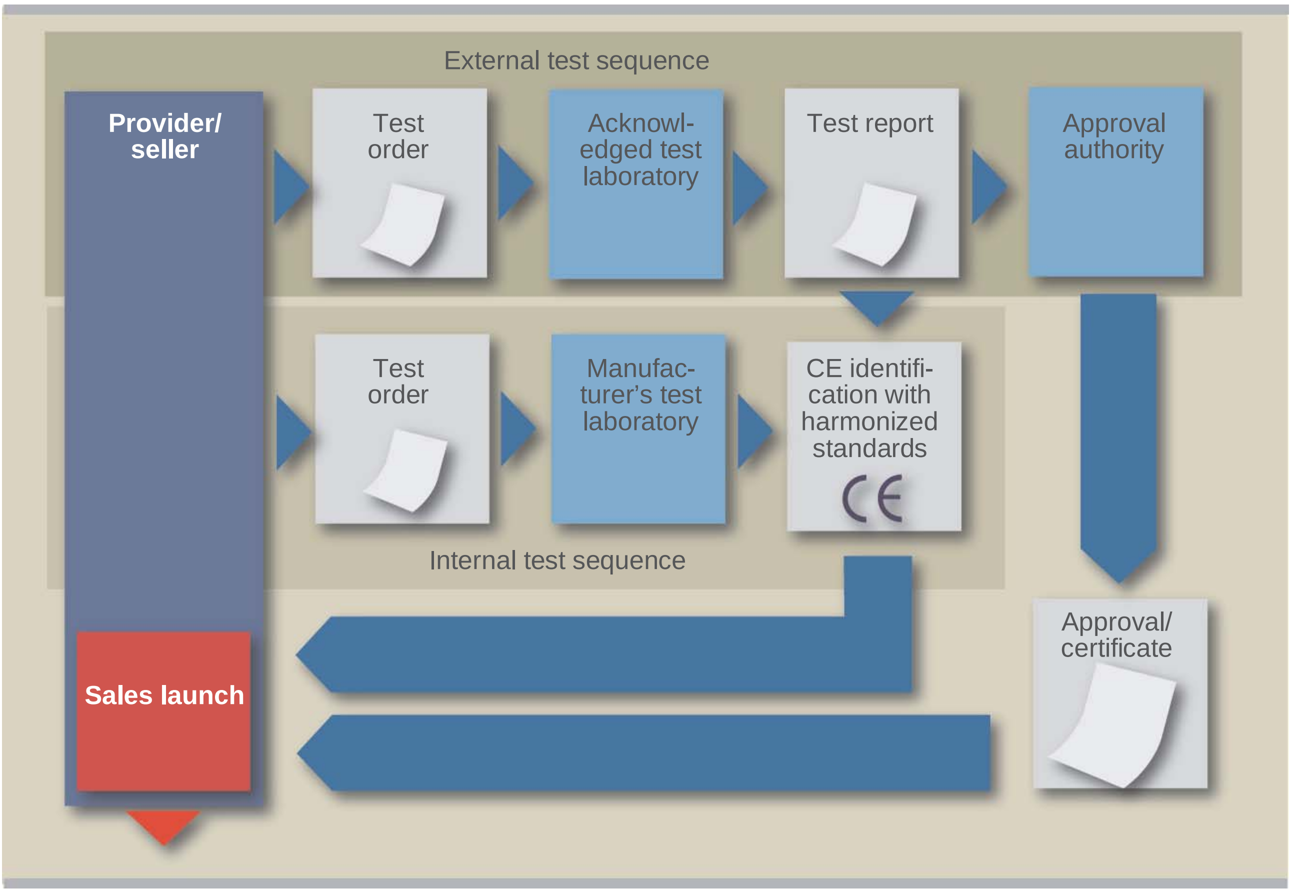


Figure 9.2: Proof of the product's compliance with the standards as a sales prerequisite

9.3.3.2 Conformity of the System / System Test

Completed systems are subject to acceptance tests including comprehensive function tests by the approval authority, or partly also by the fire brigade. If the tests are passed successfully, the system is considered "accepted". This is the prerequisite for the local construction authority issuing the operating approval for the protected building.

9.3.3.3 Conformity of the Product / System Manufacturers

Based on a comprehensive test of the quality assurance organization, the country-specific approval authorities or special certifiers (under private law) issue an approval or acknowledgement for the manufacture of danger detection system components for the product and system providers.

9.3.3.4 Conformity of the System Installers and Servicing Companies

After comprehensive testing of the technical competence and quality assurance organization, the country-specific approval authorities or special certifiers (under private law) issue an approval or acknowledgement for the system installers to build and service danger detection systems.

Most system installers also provide maintenance work on the installed systems.

9.3.4 Overview of the Standard Process

The table below provides an overview of the general and European responsibilities of the authorities and bodies involved in the processes; however, it shall not be considered complete and exhaustive.

The organizations listed with their abbreviations only represent an incomplete and exemplary selection of some important institutions.

Organization	Product standard	Product approval	System standard	System approval	System engineering standard	System acceptance	Standards for product/ system providers	Approval of product / system manufacturers	Standards for installers and servicing companies	Approval of installers and servicing companies
International Standard Associations (CEN, ISO)	S		S				S		S	
National Standard Associations (DIN, BSI, AFNOR, SNV)	S/L		S/L		S/L					
Approval Authorities, Certifying Bodies (VdS, UL, LPCB, DBI)	S	A	S	A	S	A	S	A	S	A
Insurers (FM, LRS)	S		S					A		A
Accredited Testing Bodies (VdS, UL, LPC, DELTA, PTB)		T		T						
National Professional Associations (NFPA, CNPP, BFPSA, VKF)	S		S		S		S		S	
Regional / Local Fire Protection Organization, Fire Brigade	S				S	A				

Legend:
(…) : For meaning of organizational abbreviations, see Annex “Safety Authorities” on page 320
S : Working out / laying down standards
L : Legalizing standards in the country
T : Type / system test
A : Issuing product, system and installation approvals

Table 9.1: Working out standards, ensuring compliance with the standards and issuing approvals

The table above shows that many general and local requirements are placed on safety systems. These requirements can only be fulfilled when they are adhered to from A to Z.

9.4 Implications for Setup and Operation of Safety Systems

An almost unmanageable variety of standards and guidelines regulates each detail from the manufacture of components and system engineering to system maintenance.

Any faults or errors can cause high costs for a building owner or operator, as, owing to circumstances, the relevant authority often only issues approval when the system indeed complies with the requirements. It is mostly irrelevant which supplier has caused the error – it is the building owner who is responsible for the system. If damage indeed occurs, accumulated damage claims can reach astronomic heights, and the insurance company may take regress against the building owner should his responsibility for non-compliance be proven.

As not only national but also local standards have to be taken into account, the supplier must be familiar with the regional conventions. Ensuring the compliance with all requirements is a very complex task calling for local expertise.

Local expertise: Mandatory for successful system engineering

9.4.1 Project Approach

The building owner or operator, or the architect or general contractor entrusted with the work, should preferably pay attention to a high qualification of the suppliers to be selected. If a renowned supplier is selected, serious damage is less probable to occur. Should this nevertheless happen, renowned companies will be ready to assume responsibility and offer accommodating solutions.

9.4.2 Maintenance Obligation

The building owner or operator is obliged by regulations to keep the system in an unobjectionable state and have it checked periodically. In this context, the conclusion of a maintenance contract with the manufacturer or an authorized servicing company is often mandatory. Furthermore, special staff training and alarm or evacuation training sessions are required to ensure the proper functioning of the system or the complete protection concept.

9.5 Prerequisites for Suppliers

To be able to sell systems internationally, a manufacturer must constantly stay in contact with the standard organizations, approval authorities and test laboratories in each country.

Siemens performs these functions via its subsidiaries in the countries, guaranteeing the customers that their systems comply with all legal requirements. This means that in this case, the manufacturer guarantees that all products installed in the systems comply with the standards, and that the manufacturer disposes of all product and system installer approvals. Siemens therefore issues a comprehensive, long-term guarantee for products and systems. The service and maintenance offering is customized for each customer's special requirements.

From product design to servicing an installed system, many requirements must be fulfilled for a system to comply with all standards and requirements. The table below shows how complex it is to comply with standards.

Who?	Action	Documentation
Manufacturer	Compliance with standards in design & production	Technical data / documentation
Accredited test laboratory	Type testing	Type test report
(National) approval authority	National approval	Approval confirmation / certificate
System provider (manufacturer)	System setup complying with standards	System documentation
Accredited test authority / test laboratory	System compatibility testing	System test report
Approval authority	System approval (only DE, BE and UK)	Confirmation of system approval
System provider	System installation complying with standards	System documentation
Local authority; fire protection organization	System test and acceptance	Acceptance; release; operating approval
System owner / operator (and maintenance company)	Periodical testing, maintenance, servicing, staff training, periodical training	Maintenance documentation / training documentation, log book

Table 9.2: Compliance with standards from product to system

Setting up a reliable safety system complying with all requirements means that all parties involved must adhere to the standards.

Adherence to requirements – a prerequisite for the compliance with standards

10 Symbols and Terminology

10.1 Graphic Symbols for Fire Protection Plans

The symbols used for designing safety systems have become less significant with the rapid development of information technology. However, in spite of other options for representing text and graphics, the use of symbols is a very efficient method to show the relevant information on fire protection plans. If someone is familiar with the symbols, he or she can draw up or read and interpret a plan within a short time.

As there are many different kinds of symbol sets (e.g. VdS, NFPA 170, BS 1675), we have decided on a clear, simple symbol language based essentially on ISO 6790, adding some enhancements. However, the symbols required locally may differ – ask your fire brigade safety officer.

The meaning of all symbols used on a plan shall be defined in a legend on the drawing.

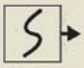
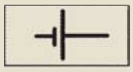
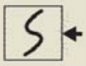
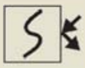
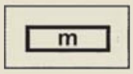
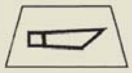
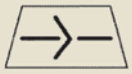
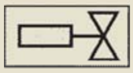
Symbol	Designation	Symbol	Designation
	Detection		**Control and indicating equipment**
	Manual call point		Fire detection control unit
	Smoke detector		Gas detection control unit
	Heat detector		Main distributor
	Flame detector		Intermediate distributor
	Linear smoke detector, sender		Battery
	Linear smoke detector, receiver		Timer
	Linear smoke detector, sender / receiver		Control relay
	Linear smoke detector, reflector		Magnetic door closer
	Linear heat detector		Horn
	Air sampling duct detector		Bell
	Air sampling unit		Loudspeaker
	Gas detector		Visual alarm indicator
			Escape route panel
	Extinguishing		
	Gas extinguishing system		Extinguishing control unit
	Extinguishing nozzle		Extinguishing valve
	Inhibit button		Illuminated warning panel for release of extinguishing agent

Figure 10.1: Graphic symbols for fire protection plans

10.2 Glossary

Term	Definition / explanation
Accredited test authority	Test laboratory recognized by the approval office / body.
Acknowledging messages	Manual confirmation that a message has been issued, that it has been seen by the operator and the necessary actions have been started.
Actuator	An element at field level which is activated with control commands and which activates or controls certain components in the infrastructure, for example the smoke extraction dampers.
Addressable detection system	→ Individual addressing
Aerosol (smoke particles)	Microscopic or submicroscopic particles suspended in air. They consist of unburnt parts of the burning material, intermediate products of oxidization and finely distributed carbon.
Alarm	An acoustic and / or visual signal triggered by a danger detector to report the outbreak of a fire or a dangerous concentration of gas, etc.
Alarm buffering	Precaution against false alarms. The response of the automatic fire detectors is only evaluated as a fire alarm signal when several alarm impulses occur within a specified period.
Alarm devices	→ Fire alarm device
Alarm indicator	→ Response indicator
Alarm organization	Alarm organization comprises all measures which in the event of a fire are used for alerting, evacuation, rescue, prevention of fire spread, fire fighting and information.
Alarm state	Status of a fire detection system or part thereof (e.g. fire detector) as the response to the outbreak of a fire.
Alarm valve	Device or component that releases the flow of water in the sprinkler pipe network and triggers an alarm.
Alarm valve station	Used for distribution to the sprinkler systems. It is positioned between the water supply and the pipe work for the sprinkler system.
Algorithm	The set of predefined calculation rules for processing signals. Depending on the algorithm, the detector evaluates the current measured value, compares it to specifications established with fire tests and generates the appropriate danger level. This is then sent from the detector to the control unit.
Application	How and where which device or system is deployed in practice.
ASA*technology*™	Successor technology to algorithm technology. It improves detection properties mainly with real time interpretation of sensor signals and dynamically adapting the response to the detection.
ASD	→ Aspirating Smoke Detector
Aspirating smoke detector (ASD)	System with one or more smoke detectors which continuously draw in air through a pipe with an integrated fan and conduct it to the sampling chamber with the built-in detector.
Automatic fire detection system	System which detects a fire in the incipient stages of an outbreak and triggers an alarm without human intervention.

Term	Definition / explanation
Automatic fire detector (fire detector)	Part of a fire detection system which monitors a suitable physical characteristic value to detect a fire in an area specified for monitoring, either constantly or at intervals (heat detectors, smoke detectors, flame detectors)
AVC	Alarm Verification Concept. A concept which involves company staff in the alarm procedure to check the automatic fire detection system with the aim of only passing on genuine fire alarms automatically to external bodies, such as the fire brigade.
Boiling point	Temperature at which a liquid vaporizes i.e. at which a liquid becomes a gas at 760 Torr pressure.
Catalytic poison	Substance that permanently impairs the operation of catalytic detectors (pellistors); examples are silicone oils and greases, leaded fuels and some sulfur and phosphorus compounds.
CE mark	Mark on products with which the manufacturer certifies that the product meets all the standards required for that product type by the European Commission.
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CENELEC	Comité Européen de Normalisation Electrotechnique (European Committee for Electrotechnical Standardization)
CIS	Common Intelligibility Scale
Client	→ Client server model
Client server model	Functional principle of modern networks in which different → servers make their services available to clients. Several clients can use the services of one or several servers at the same time. With this principle it is no significance to the user where the server with the data and services is located.
CO_2 gas extinguishing system	Gas extinguishing system with CO_2 (carbon dioxide) as the extinguishing agent
Collective addressing	Traditional detector line technology in which all the detectors connected to the same line have one collective address (shared display and operation, without identification of the individual detectors).
Combustible load (Fire load)	The combustible load corresponds to the heat capacity of all the combustible material in a fire sector, based on its surface area. It is expressed as total of mobile and immobile fire load in MJ/m^2.
Concentration	Quantity of a substance expressed in the weight or volume per unit of volume.
Concentration of valuable property	Important factor in assessing fire risk. It is determined by the value of the building and its contents. It must also be taken into account whether the values at risk of fire can be replaced, which is, for example, seldom the case for cultural objects.
Control unit bus	Local data bus between the control unit(s), operating console(s) and the gateway.
Coverage area	The area monitored by a collection of automatic detectors.
dB	Decibel – the unit for sound volume. The dB unit is logarithmic, i.e. doubling the sound volume increases the decibel number by 10. Doubling the sound energy represents an increase of approximately 3dB as more than double the energy is required to double the volume. The volume in a quiet residential area is around 40dB and around 60-70dB in an office environment. A pneumatic hammer generates a noise level of around 100dB and a jet engine approximately 130dB. The pain threshold for humans is around 120dB.

Term	Definition / explanation
dBA	Volume corrected for the sensitivity curve of the human ear. Depending on the frequency, the ear experiences a sound with the same volume in dB as louder or quieter. In absolute terms, tones at very low frequencies must therefore exhibit a higher volume, so that they can be experienced subjectively as loud as tones at higher frequencies.
Deceptive phenomenon	Physical quantity simulating a fire quantity. e.g. an increase in temperature without a fire, smoke aerosols from vehicle exhausts, smoke from welding work, steam, dust, etc.
Density	Mass per volume of a material, often specified in g/cm^3.
Density ratio	Ratio of the density of a material to the density of air, water or another reference material.
Detection reliability	The reliability with which physical phenomena are detected at an early stage. Systems with higher detection reliability recognize the fire phenomena (e.g. smoke) early on and can distinguish them from deceptive phenomena (e.g. water vapor).
Detector	Part of a system which monitors a physical phenomenon to detect a danger and reports this to a control unit. Detectors consist of sensor(s), evaluating electronics, device infrastructure and a transmission unit.
Detector line	Monitored transmission path which connects the fire detectors with the fire detector control unit.
Detector zone	A collection of detectors for which unique displays such as the location of the danger are provided in the control unit.
DMS	Danger management system. System which manages one or more sub-ordinate detection systems.
Dry pipe sprinkler system (dry system)	The sprinkler network is filled with compressed air after the alarm valve. When a sprinkler head opens, the pressure in the pipe network falls, the alarm valve opens and the water flows in.
Dry system	→ Dry pipe sprinkler system
Electromagnetic interference	Intrusion of unwanted signals into an electrical or electronic system.
Electromagnetic compatibility (EMC)	Ability of electrical or electronic devices to function correctly without being influenced by or influencing their environment.
Emergency operation	→ Fail safe mode
Equipment	System elements, e.g. devices, appliances, instruments and machines in a room
Equipment protection	System concept to protect individual pieces of equipment with fire detection and extinguishing systems (unit surveillance, equipment protection).
Evacuation	The relocation of endangered persons or animals to a safe area.
Expansion ratio	Ratio between the volume of foam and the volume of liquid required to create it (water and foaming agent solution).
Explosion	Rapid burning of a combustible material with air pressure expanding at speeds of 100 to 1'000m/s.

Term	Definition / explanation
Explosion protection	Measures taken to minimize or limit an explosion. For example, shut-off valves in gas pipes are activated or systems for the fresh air supply or extraction of exhaust air are switched on or off.
Extension	Extension of the functionality and/or the surveillance area of a system which as a rule is carried out as a separate project.
Fail safe mode (emergency operation)	Fail safe mode of operation is the ability for a control unit to issue an alarm, possibly with some limitations, even if primary system elements have broken down.
False alarm	Alarm triggered without an emergency situation. False alarms can be caused by technical issues, incorrect or malicious operation or by deceptive phenomena (see also → Nuisance alarm).
Fault status signal	Signals that indicate faults in the fire detection system as a result of unauthorized interference or technical defects.
FCU	→ Fire detection control unit
Fire	External appearance of combustion, producing heat, flames and smoke.
Fire alarm	Warning of an existing danger to persons or property, which allows protective measures to be initiated.
Fire alarm device (alarm devices, means of alarm)	Fire alarm devices call help so that preventative measures can be taken or to warn people, by acoustic and visual warning devices for example..
Fire alarm signal	Procedure which acknowledges the operation of a manual fire detector or the signal from an automatic fire detector as an alarm and forwards it to specified locations. These are usually the fire brigade, the DMS and other alarm systems.
Fire compartment	Separate area in a building in which constructional measures prevent or delay a fire spreading to an adjacent area.
Fire control installations	Plant and equipment or fire protection facilities controlled either automatically by the fire detector control unit or manually which reduce both danger to persons and fire damage.
Fire detection control unit (FDCU)	Central component of a fire detector system which supplies the detectors with power, receives signals, displays these visually and acoustically, forwards them when necessary and monitors the system for faults.
Fire detection system	The functionally matched equipment and components of a fire detection system.
Fire detector	→ Automatic fire detector
Fire fighting forces (Fire service)	Tactical units available for intervention in case of fire.
Fire load	→ Combustible load
Fire phenomena	Physical properties which in the area of a fire are subject to measurable changes such as temperature increase, smoke and flame development.
Fire precaution	Fire precautions are designed to prevent fires and to limit fire damage. They include constructional, technical and organizational measures.
Fire protection concept	A fire protection concept is understood as the harmonized, constructional, technical and organizational fire protection measures which prevent fire damage exceeding acceptable levels of damage.

Term	Definition / explanation
Fire protection installations	Equipment and installations for fire suppression, fire fighting or preventing fires from spreading. They can be controlled manually or automatically.
Fire protection, constructional	Includes all the constructional measures undertaken to impede or prevent fire breaking out or spreading and which support rescue of persons and the work of the fire department. Constructional fire protection is based on normal building infrastructure, which with appropriate implementation impedes or prevents fires spreading.
Fire protection, organizational	Includes all non-automatic, organizational measures, means and methods of fighting fires with the aim of limiting damage and extinguishing a fire and includes measures to rescue people.
Fire protection, technical	Includes all facilities and systems used to safeguard persons in the event of a fire and which contribute to limiting damage. These are, for example, fire detection and gas warning systems, fire extinguishing systems, smoke protection systems and facilities such as evacuation systems which are used to warn persons.
Fire resistance	Identifies the fire behavior of components. The significant value is the minimum period in minutes during which the component needs to meet the specified requirements.
Fire risk	This term expresses the degree of fire hazard. The fire risk is calculated from the product of the effect of a fire (expected damage) and the activation danger (probability of occurrence).
Fire risk assessment	Quantitative assessment of fire risk using standardized evaluation criteria.
Fire service	→ Fire fighting forces
Fire (hostile fire)	Unwanted burning, i.e. unintentional burning of a substance or material which in general requires active extinguishing measures to be brought to an end.
Fire-proof seal	Constructional measure which prevents flames or smoke spreading through walls and ceilings via ducts and channels and recesses and openings for power cables.
Flame detector	Fire detector which reacts to the radiation from fires (mostly in the ultra-violet or infra-red wavelengths).
Flaming fire	→ Open fire
Flash point	The flash point of a combustible liquid is the lowest temperature at which under specified conditions vapor will develop in such quantity that a combustible mixture of vapor and air is created over the surface of the liquid (saturation vapor pressure = 100% LEL).
Foaming	Process required to create foam (e.g. mixing air with the foaming agent solution).
Full monitoring	Monitoring of all the rooms, corridors and escape routes in a building with automatic fire detectors. Wet rooms such as toilets, showers and washing areas can be excluded from full monitoring.
Gas density	→ Vapor density
Gas detector	Component of a gas warning system. Gas detectors react to combustible gases and vapors and usually send their signals to the gas alarm control unit via a wire-line.

Term	Definition / explanation
Gas extinguishing system	Automatic extinguishing system usually controlled by a fire detection system. It uses a gas such as CO_2, N_2 or Ar to extinguish the fire.
Gas sensor	The part of a gas detector which measures the gas concentration.
Gas warning control unit	Central component of a gas warning system which supplies the detectors with power and which receives information from them about the concentrations of gas measured. In danger situation, it independently takes predefined measures (e.g. activates explosion protection devices) and triggers an alarm.
Gas warning system	Detects dangerous concentrations of combustible and toxic gases or vapors in the air.
Gateway	Network bridge that connects two different systems / networks with each other and translates the different communication or transmission standards or transmission protocols.
Heat detector	Reacts to an increase in temperature.
High expansion foam	Foam with a high expansion ratio (> 200).
Hostile fire	→ Fire
HVAC	Collective term for the automatic heating, ventilation and air conditioning systems in a building.
Ignition temperature	The lowest temperature of a hot surface established in prescribed test set-ups at which the gas-air or vapor-air mix of the material in question can be ignited and made to produce flames.
Immunity to deception	Reliability that none of the many different interferences from the environment and work process will trigger an alarm signal.
Incipient fire	Developing fire in its starting phase.
Individual addressing	Property of a system which can receive, evaluate and display signals from a single element such as fire detector separately.
Inhibitor	Substance which temporarily affects the function of pellistors (e.g. halogenated hydrocarbons).
Interface	The interface adapts the signals of two different subunits. It usually refers to a complete plug-in card, the function of which usually goes beyond providing the interface.
Intrusion protection	All the measures taken against the intrusion of an unauthorized person into an object (usually a building).
Ionization detector	Fire detector which ionizes air with a source of radioactive radiation, hereby inducing a very low current flow. In presence of fire aerosols this current flow is weakened.
LAN	Abbreviation of "Local Area Network", a designation for a local network. This network technology is used to link small distances up to a maximum of a few kilometers apart (also see → WAN).
LEL	Lower explosion limit. The lowest possible concentration of a fuel-air mixture which can be ignited.
Life cycle, system life cycle	Period beginning with the planning and ending with the disposal of the system.
Light extinction smoke detector	Smoke detector which measures absorption and scattering of light caused by products of combustion in the air.

Term	Definition / explanation
Linear smoke detector	→ Light extinction smoke detector
Loop line	→ Ring line
Low expansion foam	Foam with a low expansion ratio (≤ 20).
Maintenance	The combination of all technical and administrative measures and management action undertaken during the → life cycle of a system (or more generally a unit) to maintain its functional status or to return it to its functional status, so that the system can fulfill the function required of it.
Maintenance, corrective	Maintenance, carried out after a fault is detected to put a system (or a unit) into a state in which the system can fulfill the function required of it.
Maintenance, preventative	Maintenance, carried out at specified intervals or according to prescribed criteria to reduce the likelihood of a unit breaking down or its function becoming restricted.
Manual fire detector (non-automatic fire detector)	A manually activated fire detector.
Maximum temperature detector	Reacts when the measured temperature exceeds a specific value for a sufficiently long time.
Means of alarm	→ Fire alarm device
Melting point	Temperature at which a material melts, i.e. goes from being a solid to being a liquid.
Modernization	Change of generation of a system in a seamless transition from old to new.
Mole	Quantity of matter in a system consisting of as many single particles as atoms in 12g of the nuclide ^{12}C. If the term mole is used, the single particles must be specified and can be atoms, molecules, ions, electrons or other particles or groups of particles with a precisely specified composition. This definition refers to free atoms of carbon-12.
Molecular weight	The molecular weight or the molecular mass is the total of the relative atomic weights of all the atoms making up a molecule i.e. the relative mass of a molecule.
Molecule	The smallest unit of materials which can exist independently and with the same properties as the raw material.
Monitoring area	The area monitored by an automatic detector.
Multidetector dependency	Comparison and evaluation of signals from several detectors. Measures such as issuing an alarm or closing fire doors are not initiated until the defined dependencies are present (e.g. two detectors report an alarm).
Multidetector logic	→ Multidetector dependency
Multidetector zone	Area with several detectors in multidetector dependency.
Multisensor detector	Detector which with several sensors evaluates one phenomenon using different procedures or evaluates different phenomena. Typical multisensor detectors monitor the fire phenomena smoke and heat.
Network system	System with more than one control unit in which at least one control unit or parts of a control unit carry out a higher level function within the system.
Non-automatic fire detection system	Allows the alarm to be given manually. The presence of a person is a prerequisite.

Term	Definition / explanation
Norm	A standard and binding guidelines that have become or been made compulsory. Norms are defined by society and describe how certain things must be structured, how they must function, or how certain activities must be carried out.
Norm, harmonized	Norm declared by the EU Commission as applying to the whole of the EU.
Nuisance alarm	Alarm created when a fire phenomenon is simulated, e.g. cigarette smoke, steam, dust, etc.(see also → False alarm)
Open fire (flaming fire)	Open fires form visible flames, considerable heat and heat radiation. Generally, less smoke develops than with smoldering fires and it is often hardly visible. Combustion is also more complete than with smoldering fires.
Optical smoke detector	→ Scattered-light smoke detector → Light extinction smoke detector
Oxidation	Chemical process in which a material gives off electrons. Compounds with oxygen frequently form in this process.
PA	Public address system for transmitting non-safety relevant announcements and music. With the correct configuration, voice alarm systems can also carry out PA functions.
Pellistor	Two coordinated measuring elements consisting of an active and a passivated, heated ceramic bead which is used in explosion protection to detect combustible gases and vapors.
Ppm	Parts per million. A specification of concentration which gives information about the number of particles in question present in a million particles.
Production facilities	Facilities that directly or indirectly maintain an operation and which should be switched on or off in a fire (e.g. conveyor systems or climate control systems).
Rate-of-rise temperature detector	Reacts when the temperature rises at more than a specified rate for a sufficiently long time.
Reset	Procedure to end the alarm or malfunction status. Operating one of the elements provided for the purpose of resetting ends the alarm and or malfunction status of a control unit.
Response indicator (alarm indicator)	Visual display on the detector to indicate an alarm status.
Ring line (loop line)	Detector line which, to increase operational reliability, runs from the fire detector control unit to the fire detectors and back again (UL864 class A wiring).
Risk	Expresses the potential level of danger. Very safe means low risk, low levels of safety mean high risk.
Scattered-light smoke detector (optical smoke detector)	Reacts to combustion products which affect the scattering of light in the infra-red, visible and / or ultraviolet wavelengths.
Sensor	Component of a detector which, depending on how it works, can detect a natural phenomenon in its environment.
Server	Designation for computers in a network which supply other members of the network with data and programs (→ Client server model).

Term	Definition / explanation
Smoke	Smoke is a mixture of air, water droplets and aerosols. In an open fire, normally most of the combustible material is vaporized. The less complete the combustion, the lower the vaporization - the creation of smoke plays a more major role.
Smoke and heat exhaust system	System installed in a building for the efficient extraction of smoke and heat.
Smoke detectors	React to the products of combustion and or pyrolysis (aerosols) in the air.
Smoke particle	→ Aerosol
Smoldering fire	Incipient fire which develops from the seat of a fire and then later, usually after generating a considerable amount of smoke, becomes an open fire.
Source of ignition	Source of energy triggering a chemical reaction. This may be an explosion or a combustion. The supplied energy may be thermal, electrical, mechanical or of other origin.
Sprinkler	→ Sprinkler system
Sprinkler head	Extinguishing nozzle with a temperature sensitive seal in the pipe. When the temperature reaches trigger level, the seal breaks and sprays water over a predefined area.
Sprinkler system (sprinkler)	Fixed fire extinguishing system which reacts to the heat set free by open fires and which sprays water around the area of the sprinkler head which has reacted.
Standard	A level of excellence regarded as a measure of adequacy (see also → Norm)
Standby	Waiting status of a device or a system.
States of aggregation	The three physical states in which all pure substances occur: Solid, liquid and gaseous.
Stub line	Detector line which runs from the fire detector control unit to the last serially connected fire detector (UL864 class B Wiring).
System	All of a functional unit made up of several separate parts which is used to carry out a specific function. A system is often formed by a network of separate devices.
System	All the devices used for a specific purpose.
Terminal	Display and operating unit in the fire detector control unit which can be sited in a remote location.
Test report	A report drawn up by an accredited test centre giving the results of a type test
Transmission equipment	Equipment such as a transmitter or telephone dial-up device for passing on an alarm or fault signal to a reception unit.
Type test	Test to establish whether a product meets all requirements imposed on it by the relevant norms.
UEL	The upper explosion limit is the highest possible concentration of a fuel-air mix which still contains sufficient oxygen to ignite.
Use	The purpose to which buildings and operations are put. This is significant for fire protection in the demands that it creates for fire and gas detecting, alarms, evacuation and extinguishing.

Term	Definition / explanation
Vapor	The expressions gas and vapor are synonyms. The expression vapor is usually used for materials which are liquid at room temperature (20°C). The “vapor cloud” in colloquial language is physically seen no vapor but consists of finely distributed droplets.
Vapor density	Weight ratio of one unit of volume of a gas to one unit of volume of dry air. The ratio is determined by the molecular weight (dry air = 29g/Mol). Heavy gases with a vapor density ratio of more than 1.0 tend to sink to the ground in still air.
WAN	Abbreviation for “Wide Area Network“, a name for a supraregional network. This network technology can cover large distances, allowing integration of branches in other towns or abroad in the network (also see → LAN).
Warning	Preventative signal to check a possible danger or deception.
Wet pipe sprinkler system (wet system)	The sprinkler network is filled with water from the alarm valve to the sprinkler head. If one or more sprinkler head reacts, the water is sprayed out.
Wet system	→ Wet pipe sprinkler system
Zone	Section of a building (e.g. room, floor, stairway) used to uniquely identify the source of a fire alarm.

A Appendix

A.1 Toxicity of Fire Gases

As we have noted in several chapters, fires generate toxic carbon monoxide. The carbon dioxide it produces is also dangerous in large concentrations. Furthermore, fires create other substances in varying quantities which are also characterized by toxicity to a higher or lesser extent.

The following table gives an overview of the physiological effect of the gases that can be expected in fire. However, the literature is contradictory on how hazardous these substances are. Also, toxicity depends strongly on a person's constitution, body weight and state of health at any particular point in time. The concentrations [ppm] should therefore be considered approximate values.

Gas	Name	Quantity that can be smelt	Quantity that can irritate the throat	No effect for several hours	For 1 hour w/out effect	Dangerous in ½ - 1 hour	Fatal in ½ hour	Immedi-ately fatal
CO	Carbon monoxide	Odorless	No irritation	100	400	1'500	4'000	10'000
CO_2	Carbon dioxide	Odorless	No irritation	1'000	3'000	4'000	Not known	60'000
CL_2	Chlorine	4	15	0.5	4	40	150	1'000
HCl	Hydrochloric acid	15	35	10	50	1'000	2'000	1'300
$COCl_2$	Phosgene	6	3	1	5	25	30	50
H_2F_2	Hydrogen fluoride	Not known	10	3	10	50	250	Not known
HCN	Hydrocyanic acid	Varies largely	Not known	15	50	100	150	180
NH_3	Ammonia	20	140	100	200	500	2'200	2'500
H_2S	Hydrogen sulfide	1	100	20	100	300	600	1'000
SO_2	Sulfur dioxide	0.5	0.4	10	60	150	400	500
NO_X	Nitrous gases	5	62	10	80	100	Not known	200

Table A.1: Physiological effects of fire gas components (ppm)

A.2 Heat Generation and Calorific Values

Fires generate considerable amounts of heat. Approximately 90% of this heat is dissipated to the environment via thermal radiation, thermal conduction and thermal convection. This can have undesirable consequences (heat damage) which are not directly associated with the fire itself. The temperature of solid materials in a fire is normally between 700 and 1200°C, rarely higher. The color of the embers from the material is a very clear indicator of its temperature.

Color	Temperature approx. [°C]
Starting to glow red	500
Dark red	700
Light red	900
Yellow	1'100
Starting to glow white	1'300
White	1'500

Table A.2: Temperature of burning materials

When a combustible material burns, energy is released. The calorific value is an indicator of the amount of energy released in the combustion. If water is produced by the combustion process, a distinction is made between the upper and the lower calorific values. The upper calorific value takes into account the vaporization heat of the water created in the combustion, the lower calorific value does not.

All the fuels traditionally used by humans and almost all combustible loads are of organic origin, meaning that they were once created by a living being. Every combustible organic substance contains carbon.

There are only a very few inorganic combustible materials. If such inorganic combustible material burns, organic material in the environment almost always burns with it, which means that carbon plays a part in almost every hostile fire.

The following comparisons illustrate the energy content of the materials:

- The same energy that is released when one kilogram of wood is burnt (18MJ=18 million joule) could lift a mass of approximately 18 tons 100 meters high (at ideal efficiency).
- An approximately 40-year old man in a physically demanding occupation needs around 3’500kcal per day. This is equivalent to approximately 14'000KJ or 14MJ (1kcal = approx. 4KJ). The energy released by burning 1kg of wood (18MJ) is therefore slightly more than the daily nutrition requirements of a human.

Fuel type and name	**Upper calorific value** approx. [MJ/kg]	**Lower calorific value** approx. [MJ/kg]
Traditional fuels		
Wood	18	17
Lignite	16	-
Hard coal	30	-
Heating oil	43	41
Petroleum	44	42
Charcoal	30	-
Other organic materials		
Ethyl alcohol	28	25
Petrol	46	42
Methane	55	50
Acetylene	50	48
Propane	50	46
Rubber	42	-
Plastics e.g.		
– polyethylene	46	43
– polyamide	31	28
– polyurethane	23	22
– polyvinyl chloride	18	17
Phenol resin	13	12
Cellulose	33	16
Inorganic materials		
Hydrogen	142	120
Carbon monoxide	10	-
Carbon (graphite)	33	-

Table A.3: Calorific values of various materials

A.3 Fire Classes

Classifying fire into classes helps allocate correct extinguishing methods and agents for the materials concerned.

Fire class	Description
A Solid materials	Solid materials subject to thermal decomposition which form embers such as wood, paper, leather, textiles and coal
B Liquids	Liquids or materials which melt under heat and which only create flames, such as alcohol, oil, wax, resin, paraffin, tar and acetone
C Gases	Gaseous materials which are often stored under pressure, such as hydrogen, acetylene, methane, ethane, propane, butane and mine gas
D Metals	Strongly ember-forming, combustible metals such as aluminum, magnesium, potassium, sodium, beryllium, barium and uranium

Table A.4: Material fire classes

As most materials react with almost every substance when burnt, special attention should be paid to how and where combustible materials are stored. As a general rule:

Only store chemically related materials with each other!

The greater the difference between the chemical composition of materials, the further apart they should be stored. For example, acids do not usually cause fires and the same applies to alkalis. However, if they should come together, a fire is the inevitable outcome.

A.4 IP Protection Categories

Electrical equipment must be designed so that it can function reliably in the environment in which it is used. The IEC (International Electrical Commission) norm 529 describes types of protection from penetration by water and hard objects into the protective housing of electrical appliances with IP protection classes (IP = International Protection).

Overview of the most important IP protection classes for electrical equipment in line with IEC 529 IP = International Protection		No protection	Protection from water							
Protection against			Vertically falling drips straight	Vertically falling drips angled	Spray	Splashing	Water jet	Flooding	Dipped in water	Full submersion
IEC	IP	. 0	. 1	. 2	. 3	. 4	. 5	. 6	. 7	. 8
No protection	0 .	IP00								
Contact and foreign body protection: Max. ∅ 50mm – Large foreign bodies	1 .	IP10	IP11	IP12						
Max. ∅ 12mm – Medium foreign bodies	2 .	IP20	IP21	IP22	IP23					
Max. ∅ 2.5mm – Small foreign bodies	3 .	IP30	IP31	IP32	IP33	IP34				
Max. ∅ 1mm – Foreign, granular bodies	4 .	IP40	IP41	IP42	IP43	IP44				
Dust deposits	5 .	IP50				IP54	IP55			
Dust penetration	6 .	IP60					IP65	IP66	IP67	IP68

Table A.5: IP protection classes

A.5 Zone Division of Explosion Areas

Areas threatened by explosions are divided into zones. The division into zones depends on the likelihood in terms of time and location of the presence of a dangerous, potentially explosive atmosphere. Plant and equipment for zones that are permanently at risk of explosions (zone 0) are subject to stricter requirements. Those that are at a lower risk (zone 2) are subject to less strict requirements.

Materials	Zone description	Equipment category
Gases and vapors	**Zone 0** Areas in which dangerous concentrations of combustible gases / vapors are constantly present or present over longer periods	1G
	Zone 1 Areas in which dangerous concentrations of combustible gases / vapors are occasionally present	2G, 1G
	Zone 2 Areas in which dangerous concentrations of combustible gases / vapors are rarely present and then only for very short periods	3G, 2G, 1G
Dust	**Zone 20** Areas in which dangerous concentrations of combustible dust are constantly present or present for longer periods	1D
	Zone 21 Areas in which dangerous concentrations of combustible dust are occasionally present	2D, 1D
	Zone 22 Areas in which dangerous concentrations of combustible dust are rarely present and then only for a very short periods	3D, 2D, 1D

Table A.6: IEC / CENELEC zones for gases, vapors and dust

In Europe, the areas potentially at risk from explosions are divided into zones according to their degree of hazard. Authorized equipment is divided into the zones by category according to their intended use. The category therefore states in which zone the equipment can be used.

In North America (USA and Canada) the zones potentially at risk from explosions are divided into divisions (traditional system, according to NEC 500 in the USA) or zones (new system modeled on the IEC system, according to NEC 505 in the USA).

A.6 Ignition Protection Classes

An ignition protection class is considered to be the set of measures which are put in place on electrical equipment to prevent them igniting an explosive atmosphere. The norms describe several types of ignition protection which can be used individually or in combination. The methods normally used for avoiding ignition are:

Name / standard	EN id	Principle
Flame-proof enclosures	EEx d	The housing prevents an explosion on the inside from spreading to the outside
Pressurized enclosures	EEx p	The inside of the equipment is protected by the pressurized ignition protection gas (air, inert gas, etc.)
Sand-filled apparatus	EEx q	Filling the housing with fine granulation material (e.g. sand) prevents an electric arc in the housing igniting the ambient atmosphere
Oil-immersed apparatus	EEx o	Flooding or partially flooding with oil or a non-combustible, insulating liquid prevents gases and vapor outside the liquid being ignited by an electric arc in the liquid
Increased safety	EEx e	Additional measures which prevent ignition even if temperatures rise above permitted levels
Non-sparking equipment	EEx nA	The design reliably ensures that arcs, sparks, etc., are not produced
Compound apparatus	EEx m	Critical components are completely embedded in a non-ignitable, inert and thermally stable compound to prevent ignition
Hermetically sealed equipment	EEx nC	Reliably prevents ambient air penetrating the cavities of the structure
Encapsulated device	EEx nC	Similar to compound apparatus, but allows cavities
Protection from housing	Ex tD	Sealed housing with controlled surface temperature prevents penetration of combustible dust
Intrinsic safety	EEx i	All the components and circuits are designed so that sparks or thermal effects cannot trigger ignition

Table A.7: Ignition protection classes

More detailed information may be found in the general requirements of the international standards series IEC 60079 respectively EN 60079 “Electrical Apparatus for Explosive Gas Atmospheres” (the general requirements of these standards correspond to the predecessor standard EN 50014).

A.7 Explosion Groups and Temperature Classes

Explosion Groups

Equipment for explosive atmospheres is classified into equipment group 1 (equipment used in operations underground, in mines and their plant above ground) and in equipment group II (equipment used in all other areas). Equipment group II is further subdivided into the following explosion groups:

Explosion group	Max. explosion-safe gap [mm]	Min. igniting current ratio
II A	> 0.9	> 0.8
II B	0.5 to 0.9	0.45 to 0.8
II C	< 0.5	< 0.45

Table A.8: Explosion group in equipment group II

The maximum explosion-safe gap is the gap which, in a test container with a 25 mm long gap, does not allow flames from the mix to penetrate. To ignite an explosive atmosphere, the ignition spark must have a minimum energy content. The minimum energy content required is a specific property of the ignitable gases and vapors. A measurement for this is the minimum igniting current ratio. This is the ratio of the minimum igniting current of the gas in question to the minimum igniting current of methane under laboratory conditions.

Temperature Classes

Temperature classes T1 to T6 have been introduced for electrical equipment in explosion group II. The equipment is assigned to a group on the basis of its maximum surface temperature. Equipment in a higher temperature class can also be used for applications with a lower temperature class.

IEC/CENELEC/NEC 505 temperature classes	Highest permissible equipment surface temperature [°C]	Ignition temperatures of the combustible materials [°C]
T1	450	> 450
T2	300	> 300 to 450
T3	200	> 200 to 300
T4	135	> 135 to 200
T5	100	> 100 to 135
T6	85	> 85 to 100

Table A.9: Temperature classes in explosion group II

The ignition temperature of a combustible gas / liquid is the lowest temperature on a heated surface on which ignition of the gas-air or vapor-air mix can occur. The highest surface temperature of equipment must therefore always be lower than the ignition temperature of the ambient atmosphere.

A.8 Safety-Related Key Figures for Pure Substances

The table below summarizes safety-related key figures for some important gases and liquids which occur in industry as pure substances or which are components in combustible gas or liquid mixes.

Substance name	Chemical formula	Relative molecular weight	Melting point [°C]	Boiling point [°C]	Density, liquid [g/cm³]	Density ratio [Air=1]	Flash point [°C]	LEL [Vol.-%]	UEL [Vol.-%]	Ignition temp. [°C]
Acetone	C_3H_60	58.1	-95	56	0.79	2.0	-19	2.5	13.0	540
Acetylene	C_2H_2	26.0	-81	-84	0.40	0.9	-18	2.3	78	305
Ammonia	NH_3	17.0	-78	-33	0.61	0.6	-20	15.4	33.6	630
n-Butane	C_4H_{10}	58.1	-138	-1	0.58	2.1	-60	1.4	9.3	365
Butyl alcohol	C_4H_9OH	74.1	-89	118	0.81	2.6	29	1.4	11.3	340
Carbon disulphide	CS_2	76.1	-112	46	0.13	2.6	-30	0.6	60	102
Carbon monoxide	CO	28.0	-205	-191		0.97		10.9	76	605
Cyclohexane	C_6H_{12}	84.2	7	81	0.78	2.9	-18	1.2	8.3	260
Cyclopentane	C_5H_{10}	70.1	-94	49	0.75	2.4	-51	1.5	8.7	380
Decane	$C_{10}H_{22}$	142.3	-30	174	0.73	4.9	46	0.7	5.4	205
Ethane	C_2H_6	30.1	183	-89	0.44	1.0	-135	2.7	14.7	515
Ethyl alcohol	C_2H_5OH	46.1	-114	78	0.79	1.6	12	3.5	15	425
Ethylene	C_2H_4	28.0	-169	-104		0.97	-136	2.3	32	425
Ethylene oxide	C_2H_4O	44.0	-112	11	0.88	1.52	-18	2.6	100	440
n-Hepthane	C_7H_{16}	100.2	-91	98	0.68	3.46	-4	1.1	6.7	215
Hexane	C_6H_{14}	86.2	-95	69	0.66	2.79	-21	1.0	8.1	240
Hydrogen	H_2	2.0	-259	-253		0.07		4.0	77	560
Hydrogen sulfide	H_2S	34.0	-86	-60		1.19		4.3	45.5	270
Methane	CH_4	16.0	-182	-161		0.55	-188	4.4	16.5	595
Methyl alcohol	CH_3OH	32.0	-98	65	0.79	1.11	11	5.5	36	455
Nonane	C_9H_{20}	128.3	-54	151	0.72	4.43	30	0.7	5.6	205
Octane	C_8H_{18}	114.2	-57	126	0.70	3.94	12	0.8	6.5	210
n-Pentane	C_5H_{12}	72.2	-130	36	0.63	2.48	-20	1.4	7.8	285
Propane	C_3H_8	44.1	-188	-42	0.50	1.56	-60	1.7	10.9	470
Toluol	C_7H_8	92.1	-95	111	0.87	3.18	6	1.2	7.8	270
Xylene	C_8H_{10}	106.2	-25	144	0.88	3.66	30	1.0	7.0	465

Table A.10: Data of some combustible gases and liquids

In some cases, different sources give different values. This variation is due to different measuring procedures and measurement conditions. Sometimes, undetected impurities in the substances also play a part. Values that have not been entered are either unknown or they do not exist. All the key figures refer to properties of the substance when mixed with air. The most common name for the substance was chosen and listed in alphabetical order.

A.9 Safety Authorities

The list of authorities below represents an arbitrary and incomplete selection of institutions which deal with safety-related norm and approval issues amongst other things. The selection focuses mainly on Europe.

Abbreviation	Name	City	Country
AENOR	Asociación Española de Normalización y Certificación	Madrid	Spain
AFNOR	Association Française de Normalisation	Saint-Denis La Plaine	France
BSI	British Standards Institution	London	England
CEN	Europäisches Komitee für Normung	Brussels	Belgium
CNPP	ENTREPRISE Electronique Alarm Systems Division	St.-Marcel, Vernon	France
DBI	Danish Institute of Fire Technology	Hvidovre	Denmark
Delta	DELTA Electronics Testing	Hoersholm	Denmark
DIN	Deutsches Institut für Normung e.V.	Berlin	Germany
DS	Dansk Standard	Charlottenlund	Denmark
FM	Factory Mutual	Norwood, MA	USA
IBN	Institut Belge de Normalisation	Brussels	Belgium
IPQ	Instituto Português da Qualidade	Caparica	Portugal
ISO	International Standardization Organization	Geneva	Switzerland
LPC	Loss Prevention Council	Garston, Watford	England
LPCB / BRE	Loss Prevention Certification Board	Garston, Watford	England
NEN	Nederlands Normalisatie-instituut (NEN)	Delft	Netherlands
NO	Standard Norge	Lysaker	Norway
ON	Österreichisches Normungsinstitut	Vienna	Austria
PTB	Physikalisch Technische Bundesanstalt	Braunschweig	Germany
SFS	Suomen Standardisoimisliitto r.y. (SFS)	Helsinki	Finland
SIS	Swedish Standards Institute	Stockholm	Sweden
SNV	Schweizerische Normen-Vereinigung	Winterthur	Switzerland
UL	Underwriter’s Laboratories	Northbrook, Illinois	USA
ULC	Underwriter’s Laboratories, Canada	Toronto	Canada
UNI	Ente Nazionale Italiano di Unificazione	Milan	Italy
VdS	VdS Schadenverhütung	Cologne	Germany
VKF	Verein Kantonaler Feuerversicherer	Berne	Switzerland

Table A.11: Selected authorities for safety-related norms, testing and approval

A.10 Reducing Risk in Fire Protection

The following check list is an aid to improving fire protection:

- Combustible gases, liquids and materials must be stored in safe locations.
- Large quantities of chemicals must be stored so that as few chemical reactions as possible take place if there is a fire. For example, acids and alkalis must be stored separately from each other.
- Areas with hazardous goods must be marked appropriately and no-smoking signs posted.
- Unnecessary combustible loads such as combustible material that is not required immediately must be stored in a safe place and not at the place of work.
- Waste must be managed so that no combustible waste collects in areas other than those provided for it.
- Radiators, fan heaters, etc., represent a particular fire risk. Ensure that they are a safe distance away from combustible materials. For this reason, it is preferable not to use portable fans or those which cannot be fitted permanently.
- Specially designated smoking areas with ashtrays, etc., permit a disciplined approach to cigarettes, etc., and prevent the careless disposal of butts and matches.
- Up to 40% of fires are the result of arson. A system to control access to critical areas can reduce the risk of arson, particularly by outsiders.
- Most electrical fires break out when a device is in standby mode. Equipment that is not required should always be switched off at the mains.
- Extension cables and multiway connectors should be avoided as far as possible.
- Electrical appliances and cabling must be inspected by an electrician at regular intervals.
- Fuses must be rated correctly for the appliances and installations.
- Appropriate measures must be put in place to prevent smoke and flames spreading between rooms and fire sectors.
- Fire doors should either be kept shut or close with an automatic closing device when a fire breaks out. The closing devices should undergo preventative maintenance at regular intervals to ensure that they function correctly.
- Nothing should be deposited in the area around the fire doors. They should also be labeled as such.
- Where at all possible, emergency exits should lead directly to safe streets or areas. For example, it is not permitted for an emergency exit to lead to an enclosed interior courtyard as it would not be possible to move further away from the building if necessary.
- Emergency exits must be clearly marked and adequately lit, also in an emergency.
- Ensure that emergency exits are not obstructed by furniture, trolleys, etc.
- The emergency exits must be safe. This means no loose carpets or slippery surfaces, etc., on the floor and no obstacles which can cause falls, such as electrical cables or wet floor surfaces.
- Doors in emergency exits must always open outwards and it must always be possible to open them from the inside. If they are misused, a key cabinet with a breakable pane or a door alarm (alarm sounds when the door is opened) can help. However, these solutions require clear and easy-to-understand notices.

- It has been proven that automatic fire detection systems provide the fastest warning of fires. They must undergo preventive maintenance at regular intervals to ensure that they are working correctly.
- A fire detector system should call fire service either directly or via an alarm reception point.
- Staff should be trained to ensure that the alarm process proceeds quickly and correctly and that the building can be evacuated in an orderly fashion.
- Portable fire extinguishers and fire blankets can extinguish incipient fires rapidly and a sufficient quantity must be positioned in clearly visible locations.
- Staff should be taught about basic fire fighting and be trained in how to use fire extinguishers to fight fires manually (portable fire extinguishers and fire blankets, etc.).
- If the building has undergone a change of use, the fire precautions must be reviewed and adapted if necessary.
- Risk analysis and fire prevention planning documents should be kept safe and continually updated to reflect any changes.
- Companies insuring against fire often give helpful advice on how to protect real estate from fire.

B Directories

B.1 Keyword Directory

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B.2 Tables

B.3 Figures

B.4 End Notes

Siemens and the former Cerberus have conducted basic research for many decades and have worked out many documents on fire protection. Most of them have been made available for internal use only. This Fire Safety Guide is based on these documents and on the extensive knowledge and experience of Siemens and the former Cerberus. References appear only where they refer to documents that have been made publicly available.

1 Gustav Hamilton: This is Risk Management, page 21
2 10 years average according to the building insurance of the canton of Zurich, Switzerland, 2003
3 The Geneva Association Risk & Insurance Economics, Geneva: World Fire Statistics 2003, page 5
4 The Geneva Association Risk & Insurance Economics, Geneva: World Fire Statistics 2003, page 4
5 According to the German vfdb, “Arbeitsgruppe Brandforschung“, total cost of German fire damages is higher than 6 billion €
6 German FVLR, “Fachverband Lichtkuppel, Lichtband und RWA“, D-32758 Detmold: “Brand Aktuell“, No. 16/03
7 E.g.: US property insurer Allendale Mutual and FVLR, „Fachverband Lichtkuppel“, “Lichtband und RWA”, “Brand Aktuell”, Nr. 16/03
8 Report No. 9, International Technical Committee for Preventive Fire Protection and Extinguishing
9 Research report “Evaluation of Safety Guidance Systems under Smoke Conditions“ of the TU Ilmenau, March 2003, page 80