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Fire protection in cleanroom laboratories

Protection of people, assets and reputation

Cleanrooms in universities and commercial research establishments fulfill a key role, as research work in many widely diverse fields would be virtually impossible without them. Cleanrooms, however, are high risk areas, which is mainly due to the high cost of replacing any loss due to fire damage and the consequential loss of revenue during the ensuing reconstruction period. Providing adequate fire protection is essential, as a fire in a cleanroom could have devastating financial consequences.

Aspirating Smoke Detection (ASD) systems are capable of reliably detecting even the smallest aerosol concentrations, which could have been generated by the malfunction of an individual electrical or electronic component. The risk of such an incident developing into a damaging fire can be effectively eliminated by immediately removing power from the faulty unit. If ASD sampling pipes are installed in the air intake vents, any harmful pollutants can also be detected and appropriate measures taken to prevent these from entering the cleanroom atmosphere.

Should a fire occur, the highest priority is the prompt activation of the predefined countermeasures. A fire protection system is therefore required that ensures a fast and reliable response. In addition to the warning and evacuation of all persons in the danger area, smoke must be prevented from spreading to any neighboring cleanrooms. In cases where a fire occurs outside the cleanrooms, smoke must be prevented from entering and the fire must be extinguished as soon as possible.

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Note:
The above 3D-graphic shows a typical cleanroom, but it is not intended to represent the technical solution proposed later in this document.

Introduction

Highlights

- Many university research projects cannot be conducted without cleanrooms
- Cleanrooms represent a significant fire risk
- Electrical installations, electronic equipment and a variety of processes represent a constant threat as potential ignition sources
- The smallest of fires can cause considerable damage and prevent a return to normal operation for many months

Cleanrooms are enclosed areas where dust or smoke particles, airborne microbes, aerosol particles and chemical vapors (that are normally present in the environment) cannot be tolerated, as they may cause unwanted contamination. The procedures and processes being carried out in such rooms demand strictly controlled environmental conditions. The highest priority is maintaining the air quality, which is defined by the number and size of the particles suspended in the air per unit volume. In addition to controlling air quality, the environmental parameters (temperature, humidity and air pressure) must also be kept constant to guarantee comparable conditions at all times.

Typically, cleanrooms have been used in the semiconductor, pharmaceutical, food and beverage industries, as well as in hospitals. Increasingly, however, such facilities can be found in universities, where they serve in such fields as research into nanostructures, which play an important role in solid state and semiconductor physics.

The main objectives of a cleanroom are:

- To protect processes and products from contamination
- To protect persons from health-threatening substances and organisms (e.g. micro-organisms)
- To protect the environment from dangerous and unwanted emissions

Frequently cleanrooms play a central role in the research activities of a university and are consequently a critical area, which must fulfill a higher security level.

Cleanrooms are designed in such a way that:

- The specified air quality level can be guaranteed
- The climatic conditions remain within specified tolerance limits
- Only authorized persons are permitted access; to prevent any adverse effects on the environmental conditions that might be caused by untrained persons
- Each cleanroom is a separate fire compartment and is therefore in no immediate danger from a fire in a neighboring fire compartment
- A fire can be detected and dealt with at the earliest possible stage, thus preventing any impact on a neighboring cleanroom

Basic conditions

This section describes the fire protection objectives, typical fire risks and possible fire development scenarios in cleanrooms. It also lists a number of critical points regarding fire risks, fire detection and appropriate countermeasures.

Objectives

- Recognition of abnormal fire-related aerosol concentrations and transmission of this information to a technician. The situation can then be quickly evaluated and appropriate countermeasures taken (e.g. removing power from the relevant equipment)
- Minimizing damage by suppressing an incipient fire at the earliest possible stage using a reliable residue-free extinguishing system
- Preventing smoke and fire spreading to other areas
- Timely alerting and safe evacuation of all endangered persons

Typical fire hazards

- Overload or short-circuit of electrical or electronic equipment and installations
- Careless handling of heat sources such as hot air guns or Bunsen burners
- Leakages of highly inflammable or pyrophoric liquids (i.e. those liquids that can ignite spontaneously on contact with air or moisture)
- Explosive concentrations of gases or solvent vapors

Typical development of a fire

In a cleanroom we cannot talk about a typical fire development. To a great extent, this will depend on the infrastructure, the materials and substances inside the cleanroom, together with the procedures being carried out.

- When electrical or electronic components overheat, they generate increasing quantities of visible aerosols. If appropriate countermeasures are not taken at this stage, such as removing power from the devices concerned, then the smoldering fire can develop into an open fire. This can cause immense damage and create a significant threat to any persons in the area.
- Careless handling of heat sources, spontaneous ignition of dust deposits in the ventilation ducts, or self-igniting liquids can lead directly to an open fire, which (depending on the fire load) may spread very rapidly.
- An explosion (a rapid increase in volume and uncontrolled release of energy) can occur, if an explosive concentration of gases is allowed to build up.

Critical Points

- Even the smallest of fires can cause enormous damage
- High air circulation rates dilute the aerosol concentration, making it more difficult to detect incipient fires at an early stage
- Very little heat will be created by a smoldering fire and consequently the fire aerosols generated will not spread throughout the entire room
- To minimize fire damage, the consequences of a fire must be restricted to the cleanroom itself
- Fire aerosols from a neighboring room must be prevented from entering
- An explosive mixture of gases must not be allowed to develop
- The extinguishing process itself must not cause any additional damage (e.g. the ruining of electronic equipment, water damage or other types of residue)

Solution

Depending on the area of application, cleanroom requirements can differ significantly. In the pharmaceutical industry topics such as particle emission, chemical stability or cleanability play an important role. Such topics, however, would not have the same importance in, for example, the photovoltaic sector. Demands on the air purity can also vary considerably as they can be influenced by the outside air, contamination caused by personnel, process-dependent contamination and inappropriate production facilities.

Although cleanroom requirements may vary considerably, this has only a limited influence on the design of a suitable fire protection system. What is important, however, is that the ventilation conditions in the room are taken into consideration when selecting and positioning the appropriate fire detectors. During an extinguishing incident the agent itself should, of course, not cause any additional damage. Consequently, the type of equipment and materials used in the room will largely determine the most appropriate extinguishing agent to be used.

Cleanrooms are at the core of many diverse research projects and any contamination caused by dust, micro-organisms or smoke particles can severely disrupt the research work. On the other hand, health and safety considerations also present their own particular challenges. Active substances (in pharmaceutical research projects), dangerous pathogenic bacteria (in a high security laboratory), flammable cleaning solvents and toxic chemicals all pose significant health risks for research personnel and for the environment.

The objective of the solution presented here is to minimize the damage that could result from the greatest single risk – FIRE. Achieving this objective requires a combination of organizational, structural and technical measures.

Organizational measures

On the organizational side the two most important factors are access control and training. It is important to ensure that only authorized persons who have received the necessary training are able to enter the cleanroom. As the research in universities is mainly carried out by the students themselves, it is essential that they receive adequate training, where the importance of appropriate behavior is impressed upon them.

In addition to training regarding the correct use of the equipment, topics such as technical cleanliness, the correct handling and safe disposal of the various materials (solids, liquids and gases) must also be dealt with. In this context special attention should be paid to the prevention of fire. It is also important, however, to be fully acquainted with the automated extinguishing system and how (and when) fire extinguishers should be used to deal with minor incidents.

Structural measures

Both cleanroom-specific and fire protection aspects must be taken into consideration when designing and implementing the appropriate structural measures. As overpressure in a cleanroom can prevent pollutants from entering the room through the air, the room-in-room construction is often the preferred design concept. The air inlet and exhaust take place via air vents, whereby the air inlet is equipped with a filter system which purifies the air before it enters the cleanroom.

Fire protection considerations require that the cleanroom be designed as an independent fire compartment with appropriate smoke seals and fire doors. In the event of a fire, it would also be desirable if the smoke could be vented directly into the open air, however, this would be inconsistent with the room-in-room concept. For this reason, the experts responsible for the cleanroom system design must be consulted to help provide a suitable smoke extraction solution.

Technical measures

Fire protection incorporates a wide range of technical disciplines and dedicated systems including access control, gas warning, fire detection and extinguishing. The access control system should ensure that only authorized persons (who have received the appropriate training) are permitted entry into the cleanroom. The gas warning system must be able to prevent the development of any dangerous gas mixtures by controlling the ventilation in the individual areas. In case of a dangerous situation arising (e.g. due to the malfunction of the ventilation system) it must also generate a warning signal, and an alarm if the danger becomes imminent.

The fire protection system must detect an incipient fire at the earliest possible stage and activate the acoustic and optical warning devices. In addition, it must activate the pre-programmed functions that control the ventilation and smoke extraction systems. If an automated extinguishing system is present, this must also be activated.

Research facilities can be very diverse and depend greatly on the specialization of the individual university



An Aspirating Smoke Detection (ASD) system is designed to detect the smallest quantities of fire-related aerosols and is the ideal smoke detection system for cleanrooms. This is due to the requirement that a fire in a cleanroom must be detected as early as possible in its incipient stage and that no deceptive phenomena whatsoever should be anticipated in a cleanroom environment. Modern ASD systems are capable of generating different warning and alarm signals. These signals can be used to control the ventilation and smoke control systems as well as activating the automated extinguishing system. In the service zones (i.e. those areas immediately outside the cleanroom working areas themselves) multi-criteria fire detectors or special detectors such as flame detectors may be employed, depending on the fire load and the local processes. In addition to the automatic fire detectors, manual call points are also installed to enable fire alarms to be triggered manually.

Where an automated extinguishing system has been installed and local regulations require multiple zone dependency (independent alarm signals across two zones in the same room) before the extinguishing system can be activated, then either an additional high sensitivity smoke detector or a second ASD system must be installed.

Alarming and evacuation

Alerting persons in the cleanroom areas of a fire alarm and possible evacuation is extremely important. The selection of appropriate warning devices must take a number of factors into account (e.g. visibility, audibility, ambient noise levels and the type of fire detection employed in that area). In the example presented here, the acoustic environment is considered to be benign, with noise levels similar to an office environment.

In areas where fire detectors are used, each detector is fitted with a voice sounder beacon base, as this solution ensures optimal visibility from all locations. In the working areas, where smoke detection is provided by the ASD-system, ceiling mounted voice sounder beacon bases with blanking plates are used. This solution is not only chosen to ensure optimal visibility from all locations, but also to maintain consistency with the detector-monitored areas. A solution with a mix of ceiling-mounted and wall-mounted devices could be seen as confusing.

Example: Cleanroom for nanotechnology

The following paragraph describes a solution for a cleanroom that may typically be found at a university offering courses in the highly interdisciplinary field of nanotechnology. The example is based on a room-in-room construction with a surface area of 440 m² (20 x 22 m).

In the cleanroom working areas, the tempered and humidified air enters the working areas through ceiling filters. These filters are designed to achieve the ISO air quality class 5. The air from these areas then passes through air vents into the service zone, corridor, changing room and storeroom. The air in these areas is purer than the outside environment (e.g. ISO 7) but is contaminated with particles that were generated in the working areas. The air from these service areas is then extracted through the ceiling of those areas.

Details	Comments/Notes
Automatic fire detectors Aspirating Smoke Detection system ASA neural detectors Smoke detectors	ASD systems ensure early detection of incipient fires and recognition of air pollutants <ul style="list-style-type: none"> Parameter set selected for high sensitivity Evaluation of fine dust particle concentration The quantity and size of the sampling holes can be determined with the aid of the calculation software provided Early and reliable fire detection of all types of fire <ul style="list-style-type: none"> Parameter set selected for high sensitivity Reliable fire detection <ul style="list-style-type: none"> Parameter set selected for high sensitivity
Manual call points MCPs	Manual activation of a fire alarm (via the fire detection panel) <ul style="list-style-type: none"> Single or double action (depending on local regulations)
Warning devices Voice sounder-beacon bases	In areas where smoke detection is provided by the ASD-system, ceiling mounted voice sounder beacon bases with blanking plates are installed In areas where ASA-neural and standard smoke detectors are used, each detector is fitted with a voice sounder beacon base.
Manual suppression Hand-held fire extinguishers	Hand-held fire extinguishers; for the manual suppression of minor fires <ul style="list-style-type: none"> Recommended type: CO₂
Positioning of system elements (see Figure 1)	ASD system <ul style="list-style-type: none"> ASD evaluation unit in the technical room Sampling pipes in the areas to be protected (within working area) Air recirculation to the working areas ASA neural fire detectors and smoke detectors <ul style="list-style-type: none"> On the ceiling Minimum distance from air outlet vent 1 m Manual call points <ul style="list-style-type: none"> Next to the exit door (inside the cleanroom) At a height of 1.4 m ± 0.2 m Hand-held fire extinguishers <ul style="list-style-type: none"> In all cleanrooms Handle height 1.0 m ± 0.2m above the ground
Further Comments/Notes	
Air flow considerations <ul style="list-style-type: none"> When selecting the best positions for the sampling pipes and detectors, all possible air flow scenarios must be taken into consideration. Only in this way can we be sure that (in the event of a fire) the smoke will reach the sampling pipes and the associated detectors. Furthermore <ul style="list-style-type: none"> Fume cupboards and processes where a higher risk of fire exists, should be protected by automatic detectors (e.g. flame detectors) and an automated extinguishing system (e.g. CO₂). 	

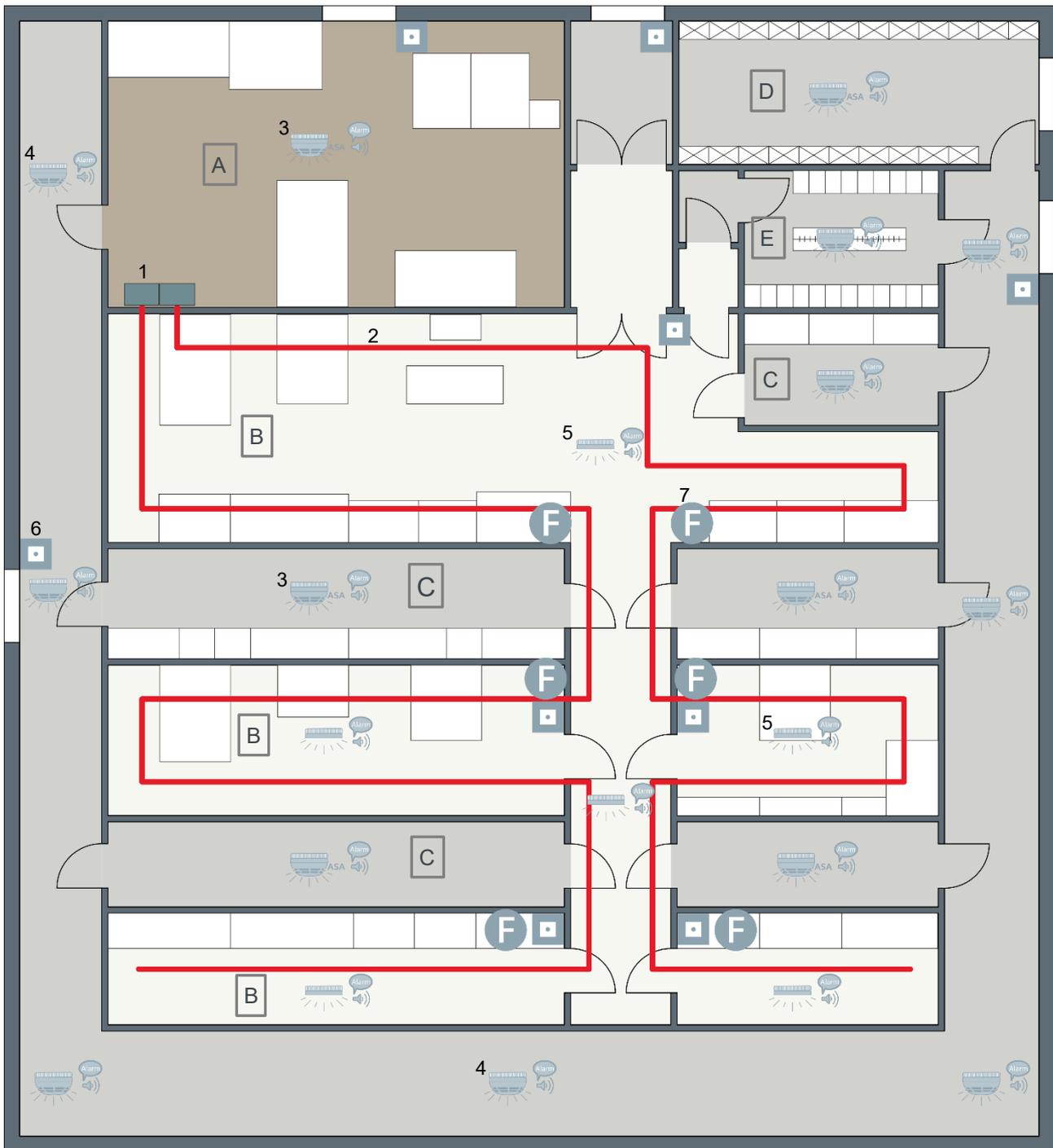


Figure 1 Positioning of system elements

System elements

1. ASD evaluation units
2. ASD sampling pipes
3. ASA neural fire detector with voice sounder beacon base
4. Optical smoke detector with voice sounder beacon base
5. Voice sounder-beacon base with blanking plate
6. Manual call point
7. Hand-held fire extinguisher

Rooms

- A. Technical room
- B. Working areas
- C. Service zone
- D. Storeroom
- E. Changing room

Practical experience

There is no standard solution for cleanroom laboratories and the example described above should be regarded as a “basic solution”. Frequently additional fire protection measures are required to further reduce the fire risk to the “accepted” level. The fire risk is the product of the probability of a fire occurring and the consequential damage from that fire. Hence the risk can be lowered either by reducing the probability of fire occurring or by reducing the possible damage. The probability of a fire occurring can be significantly reduced by observing the following recommendations:

Personnel training

The greatest source of risk stems from the people working in the cleanrooms. Practice shows that many fires could have been avoided if instructions and safety procedures had been followed. It is therefore absolutely essential that all persons who work in the laboratories are not only trained in self-protection topics, but also in how to prevent fires from starting and how to combat a fire if an incident should occur. Careful handling of easily flammable materials and careful attention to possible ignition sources such as flames, hot objects, chemical reactions or spontaneous combustion are topics that must be dealt with in user training sessions. Regular monitoring also helps to maintain the awareness level for fire protection issues and make improvements where necessary.

Testing of electrical equipment and installations

A wide variety of electrical equipment can be found in a cleanroom. Most of these pieces of equipment consist of a power supply and electronic components and are therefore potential ignition sources. Defective electrical appliances, extension cables or overloaded multi-way power sockets are further potential ignition sources. To minimize the potential danger from electrical equipment and installations, they must be tested regularly. Defective equipment and installations that do not comply with the specified safety standards must be repaired immediately or taken out of service.

Prevention of explosive atmospheres

Gases and solvent vapors can create an explosive atmosphere. Consequently, activities involving gases and solvent vapors should only be permitted in fume cupboards with appropriately designed ventilation. If for some reason this is not possible, then the area must be monitored with a gas detection system. This system should control the ventilation according to the gas concentration and trigger a warning before a critical concentration can develop.

The consequences (incurred damage) resulting from a fire can be kept to a minimum through a combination of early fire detection and targeted firefighting.

Early fire detection

The earlier a fire can be detected, the sooner the corresponding countermeasures can be initiated (e.g. removal of power, ventilation control, extinguishing). In this way, any resulting damage can be kept to an absolute minimum.

All persons responsible for supervising the processes must be trained in how to react correctly to any fire-related situation that might arise.

A timely warning from an automatic fire detector can only be guaranteed if the detector reacts to the fire phenomena generated (smoke, temperature, heat radiation, gas) and these reach the detector with sufficient intensity. As airflow rates in a cleanroom are high, optimal positioning of the ASD sampling pipes is crucial. Even at the highest airflow rates it must be ensured that the developing smoke is delivered to the ASD evaluation unit in adequate quantities. The most appropriate positions can only be determined in close cooperation with ventilation experts. Experience has shown that although suitable positions can be determined on the basis of theoretical considerations alone, these are not always the optimal positions. For this reason and before the final cleaning of the installation, the response behavior of the ASD system should be verified with a “test fire” and appropriate modifications made if necessary.



University research projects are often supported by local high-tech industries.



Targeted extinguishing

Targeted extinguishing means that the fire should be dealt with quickly and with the most appropriate means.

The majority of cleanrooms require that a sprinkler system is installed. Such systems help to keep the escape routes accessible for a sufficiently long period of time to allow evacuation and can help prevent a total loss. However, sprinkler activation in a cleanroom can often lead to considerable water damage. In order to limit this damage, additional forms of extinguishing must be considered for the more critical areas.

Practice shows that fires only cause limited damage when processes are supervised by people, assuming that they react quickly and are fully conversant with the usage of the available extinguishing equipment (e.g. fire blanket or hand-held CO₂ fire extinguisher).

Objects with a heightened fire risk and without permanent supervision should be equipped with an automated extinguishing system. Of course, it must be ensured that the ventilation in the affected areas is switched off and the ventilation flaps are closed before the extinguishing agent is released. The preferred extinguishing agent in cleanroom applications is carbon dioxide.

- CO₂ is very reliable and is completely residue-free. After an extinguishing event has occurred it is only necessary to ensure that the affected area is well ventilated. Care must be taken as the CO₂ concentration required for the extinguishing process is toxic. A special case, however, is the extinguishing of very hot materials such as burning magnesium. The very high temperatures split the CO₂ into carbon (C) and oxygen (O₂), which then supplies the fire with additional oxygen.
- In applications where the use of CO₂ would create a heightened risk to personnel, argon may be used as the extinguishing agent. The non-toxic inert gas argon also provides residue-free extinguishing and is electrically non-conducting. In comparison with CO₂ more attention must be paid to ensure that the required concentration is maintained over a sufficient period of time, especially in cases where the room is not airtight.

- Powder is also a very efficient extinguishing agent and would guarantee rapid extinguishing. However, it would create excessive, large scale contamination and is consequently not at all suitable for cleanroom applications.

The choice of extinguishing agent must be based on the process that needs to be protected and the associated risk to personnel. When calculating the required quantity of the extinguishing agent, the volume of the room(s) to be protected and the expected leakage must be taken into account.

Alarming and evacuation

The complexity of cleanroom design may vary widely. The shape and size of such rooms will generally determine the type of warning devices (ceiling-mounted or wall-mounted) to be installed as well as their positioning. Clear visibility from all locations is always the primary concern when making these decisions. Other considerations may also include ease of installation and wiring.

As mentioned in the solution example, consistency is also a factor. A mix of wall-mounted and ceiling-mounted devices would not generally be recommended.

It can be expected that the acoustic environment in cleanrooms would be suitable for the use of voice sounder beacons. The voice component is an important factor in increasing the speed and efficiency of an evacuation, if this becomes necessary. It has been demonstrated that people react more readily and correctly to spoken commands than to alarm signals, which may not be correctly interpreted.

In universities equipped with a voice alarm system, appropriate loudspeakers would also be installed throughout the cleanroom complex. Such systems have the advantage of delivering clearly audible voice messages even in acoustically challenging environments, e.g. where noise levels generated by the processing equipment could be particularly high.

Aspirating Smoke Detection

Early fire detection with excellent reliability and genuine alarm guarantee

Aspirating Smoke Detection (ASD) systems from Siemens ensure reliable fire detection in demanding application areas, where very early fire detection is required and business continuity is paramount. Aspirating smoke detection systems continually draw samples of air from the areas requiring protection and evaluate these samples for the presence of smoke. The high detection reliability of ASD-systems and their ability to prevent false alarms caused by deceptive phenomena is backed up by our genuine alarm guarantee.

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ASATEchnology

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ASATEchnology is a unique technology from Siemens that converts signals into mathematical data which is compared with programmed values in real time using intelligent algorithms. The special signal analysis process is very reliable in preventing false alarms caused by deceptive phenomena, such as steam, tobacco smoke or exhaust emissions.

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Incorporated in a concept tailored to your customers' requirements, Siemens and its Solution Partner network provide:

- Early and reliable fire detection solutions, offering an unrivalled financially backed "Genuine Alarm Guarantee"
- Fully forwards and backwards compatible systems, to ensure any system provided is equipped to integrate the latest technology Siemens has to offer
- Clear and fast alerting and evacuation processes
- Appropriate response measures, e.g. reliable and fast extinguishing

All these aspects are at the core of comprehensive fire protection. Only when these are fulfilled can you be assured that people in your buildings are safe and assets and business operations are protected.

In order to offer your customers peace of mind, Siemens and its Solution Partner network have a variety of service and solution offerings that can be tailored to an individual client's needs. To find out more about this, please visit our Web site at [siemens.com/firesafety-markets](https://www.siemens.com/firesafety-markets) or contact your local Siemens organization through the [online contact form](#).

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With our dedicated program for consulting engineers, you can benefit from our extensive application know-how and complete portfolio.

With Siemens, you can offer your customers comprehensive fire safety for any application and environmental condition. Your customers will appreciate this as it enables them to reliably protect people, assets and business processes from fire.

Backed by more than 160 years of experience in the field, our offerings for early detection, reliable alarming, orderly evacuation and safe extinguishing are based on innovative and unique technologies. They provide you with convincing arguments like maximized life safety or environmental friendliness, and open the door to strong, long-term customer relationships. And with Siemens, you gain a reliable partner at your side and benefit from our smart tools, in-depth trainings and personal support – wherever you are, wherever you go.

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Article no. SI_0187_EN (Status 03/2020)

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