# SUVEREN

## FIRE PROTECTION GUIDELINE FOR CAR PARKS

The findings of this guideline are based on the SUVEREN research project Part 1 and 2 as well as Part 3 for the protection of car parks, which was funded by the Federal Ministry of Education and Research.

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## Contents

## 1. Introduction / Problem statement

There are overground and underground garages in urban areas. An increase in the latter is to be expected due to competition for limited public space. In the event of a fire, the structural conditions of a car park can make it difficult both to access the source of the fire for fire defence and for people present to escape. This is because, as with all fires in closed and underground buildings, escape routes are likely to be affected by high temperatures and the spread of smoke gases.

Vehicles are the main fire load in garages. The size, weight and material characteristics of passenger cars have changed significantly over the past 30 years (see Figure 1). The amount of combustible materials has increased as heavy metals have been replaced by lightweight materials (plastics, composites, light metals) and, at the same time, vehicles as a whole and individual components have become larger (e.g. larger tires). Plastics and composite materials now account for around 50% of the volume of a passenger car. Their share of vehicle weight has increased by 59% from 1990 to 2018, to an average total of 159 kg per vehicle [1]. These changes in vehicle characteristics have resulted in an increased fire load in garages.

Figure 1: An old (left) and a modern (right) sports car. © 123RF.COM

The purchase incentives of recent years are leading to steadily rising registrations of electric vehicles. As a result, they are becoming more and more common in urban areas, including car parks. Due to similar vehicle design, the fire behaviour of hybrid and electric vehicles shows many similarities with the fire behaviour of conventional diesel or gasoline driven vehicles. The main difference lies in the traction battery. In recent years, research into the fire behaviour of electric vehicles and their batteries has been a central part of international research projects (including Lion Fire II, AGT 2018/006, BRAFA) and the research project SUVEREN funded by the German Federal Ministry of Education and Research (http://www.suveren-nec.info/)

Based on the results of the research project SUVEREN, this guideline provides recommendations for fire protection measures in car parks. The main focus is on fixed firefighting systems (FFS). Taking into account the changed fire behaviour of modern vehicles, this document aims to provide practical guidance to planners, experts, operators and fire services. Legal regulations, standards and requirements of e.g. building authorities remain unaffected.

## 2. Fire behaviour of modern passenger cars

In order to ensure consistent safety while taking into account the changed initial situation in car parks, it is important to review and, if necessary, adapt the existing fire protection solutions. Knowledge of vehicles and fire development is essential for a comprehensive assessment.

Observations and scientific analyses of vehicle fires show that modern vehicles develop intense fires that can release large amounts of heat in a short period of time. As a consequence, the NFPA (National Fire Protection Association) emphasizes in its report on fire hazards of modern vehicles [2] that garage fire assessments should not be based on older vehicles.

To adequately address the fire behaviour of modern passenger cars, a design fire curve was developed in the research project SUVEREN. This is based on the evaluation of experimental vehicle fires, for example [3], [4] and [5], with the aim to conservatively describe fires of common modern vehicles (including gasoline, diesel, hybrid and electric vehicles). For passenger cars, a design fire (Figure 2) was created, which describes the fire load of a vehicle independently of its propulsion system. This is possible because the fire load is mainly determined by the large number of combustible materials installed in and on the vehicle and not by the drive source.

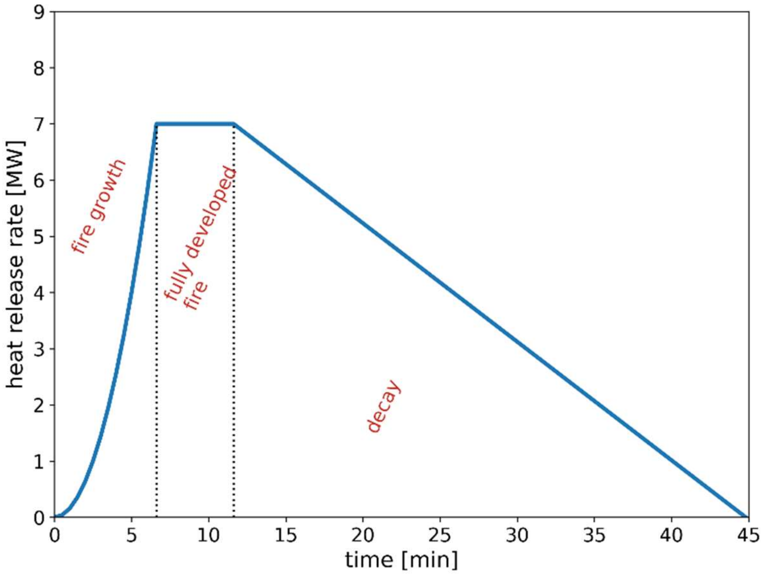


Figure 2: Design fire plot for a modern passenger car (research project SUVEREN, see also [6])

The design fire describes a fire of a single passenger car, with a rapid fire development and a maximum heat release rate of 7 MW. The fire progression described in Figure 2 can be used for the design of fire protection measures if no own data are available. More detailed information on the development of the design fire can be found in [6].

Furthermore, the fire size of a modern passenger car can also quickly ignite neighbouring vehicles. This can be accelerated by involvement of the power source, for example, fuel burning from a leaking gasoline tank. This can lead to dangerous large fires, as each additional ignited vehicle represents a significant fire load contributing to the overall fire event. Subsequently, all vehicles in the garage may be involved in the fire. Such large fire events are additionally accelerated by the small distances between the parked vehicles, which hardly protect against a fire propagation to the neighbouring vehicle. The consequence of such large fire events is considerable damage, which can lead to the collapse of the garage. Examples of such large fires are the fire at Stavanger Airport [7] and the King's Dock parking lot in Liverpool [8].

Regardless of the propulsion system, fires involving multiple vehicles in garages are difficult to control, even for professional fire services. To prevent such large-scale fires, it is essential to contain the fire as early as possible and prevent it from spreading to neighbouring vehicles.

### *2.1 Particularities of electric vehicle fires*

From a fire safety perspective, the traction battery is the major difference between an electric vehicle and a conventional combustion engine vehicle. Modern traction batteries consist of lithium-ion cells, which can be subject to so-called thermal runaway (see information in Figure 3) in the event of damage. Thermal runaway is based on reactions inside the cells and can start even when the vehicle is not in operation. This is a significant difference to conventionally fuelled vehicles, which are less likely to catch fire when parked.

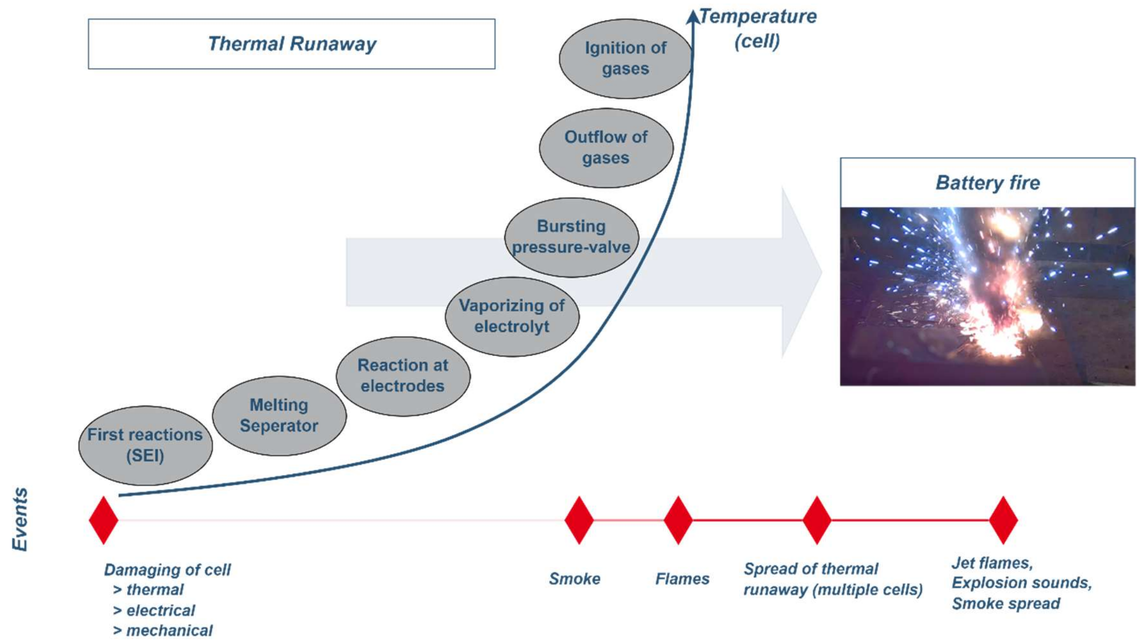


Figure 3: Sequence of thermal runaway in a lithium-ion cell. The reactions listed are temperature-dependent and exothermic. The starting temperature depends on the type (chemistry) of the battery cell. The reactions propagate due to the heating of the neighbouring cells and lead to the battery fire.

In electric vehicles, the traction battery can contribute to a particularly rapid fire development and propagation. In fire tests with traction batteries carried out in SUVEREN, a high heat release was measured shortly after ignition and the production of dense smoke was observed. If the traction battery is installed in a vehicle, such a battery fire with intense reactions can lead to a rapid fire spread to the entire vehicle and subsequently to neighbouring vehicles. As a consequence, fire initiation in the traction battery increases the likelihood that a large fire scenario will develop before the arrival of the fire services. Such a fire is subsequently difficult to control.

## 3. Fire prevention and suppresion measures

A distinction can be made between fire prevention and defensive fire protection. The latter includes all measures and tasks of fire brigades. The highest priority is given to the rescue of persons and effectively extinguishing fires, always taking into account personal safety. Firefighting electric vehicles does not require fundamentally new tactics. However, due to the fire behaviour of traction batteries, the following additional recommendations can be derived:

- If the vehicle is being charged, the charging infrastructure must be disconnected from the power supply before starting to fight the fire. Information on any necessary de-activation of the high-voltage part of the vehicle can be found in the vehicle’s safety manual.
- If the battery is involved in the fire, it must be additionally cooled after the flames have been extinguished to prevent re-ignition. Additional water discharge time must therefore be taken into account.
- Due to its good cooling effect and harmlessness to persons, pure water is expressively recommended as an extinguishing agent.

Further information and specific recommendations for firefighting electric vehicles are available in training courses and publications, e.g. [9], [10], [11].

The measures of fire prevention serve the avoidance or early containment of fires and include organizational measures and structural fire protection as well as provision of FFS. The spread of a fire is to be limited by means of fire prevention at least until a "handover" to the fire brigade can take place, whereby the duration until the arrival of the fire brigade and preparation of the operation on site can vary depending on the location of operation.

The focus of structural fire protection measures is to ensure personal safety in the event of a fire. This is achieved by specifying the number and design of emergency exits, dividing buildings into smoke or fire compartments and a fire-resistant design of ceilings and walls. Additionally, important is prohibiting smoking, open fires and the dumping of waste, as well as the instruction of personnel (e.g. facility manager, security service).

Furthermore, the following measures can be considered:

- Implementation of separate areas for parking electric vehicles. This can concentrate any specific firefighting or vehicle removal measures that may be necessary at specific locations in the car park.
- As vehicles get larger, distances between parked vehicles get smaller. Increasing the size (especially the width) of parking bays can make it more difficult for fires to spread from vehicle to vehicle.
- Wall hydrants on parking levels: Provision of mobile equipment with increased cooling effect for firefighting of burning traction batteries for firefighting intervention from below of vehicles respectively cooling by firefighters.
- Provision of a fire services information point.

## 4. Fire detection and fixed firefighting systems

Fire detection systems and FFS are legally required only in certain cases, since personal safety is usually ensured by structural fire protection and organizational measures. In Germany, for example, FFS are required by law for specific large garages or automatic garages.

In addition to minimum legal requirements, an FFS may also be required for other reasons:

- as compensation for lacking structural fire protection,
- as part of building code requirements for a specific building project,
- at the request of the insurance company.

From the point of view of property value protection, the installation of an FFS is clearly recommended.

### 4.1 System requirements

Specifications for the design, dimensioning and verification of the systems are not regulated by law. The specific requirements for the systems result from the formulated protection aims. As in legal regulations, the primary protection aim is the safety of persons. In addition, there may be further protection aims for the protection of assets such as the building and its installations or for ensuring short downtimes after a fire event. In the case of commercially used garages, such extended protection aims can be expected.

High losses occur in garage fires, especially when several vehicles are involved in a fire event. These risks can be effectively countered by means of fire protection systems. Extinguishing a fire is not the main goal of the system; rather, a fire must be controlled until the arrival of the fire brigade. Following requirements arise:

- limitation of fire to one vehicle – a minimal damage to neighbouring vehicles is permitted, no large-scale ignition,
- operating time of the FFS shall be at least 60 minutes (see EN 14972).

Compliance with these criteria must be demonstrated in a comprehensible and reproducible manner (see section 4.4).

### 4.2 Fire detection

The use of fire detection can be considered for the following applications, e.g. – alerting people, alerting the fire brigade, starting the FFS or shutting down the charging infrastructure. Various systems are available that can be used depending on the application – aspirating smoke detectors and point detectors for detection of smoke, gas (e.g. CO, $H_2$) or heat.

Point detectors are passive, fixed detectors and trigger an alarm when the respective fire parameter reaches the detector in sufficient concentration. Aspirating smoke detectors, on the other hand, can overcome certain distances by aspirating the ambient air and any concentrations of smoke or fire gases contained therein. Given a suitable design, faster detection can be achieved this way. However, it should be noted that the distance to be covered between the aspiration point and the detection unit can in turn lead to delays in alarm generation. A higher number of false alarms can occur with the more sensitive aspirating systems. The fire detection system used in individual cases shall be selected depending on its use and certified for the application.

### 4.3 Fixed firefighting systems

FFS in car parks serve in particular to protect property and perform the following tasks:

- protection of adjacent vehicles by preventing the fire spread,
- limitation of the temperatures under the ceiling and thus protection of the building structure,
- shielding of other critical building components, e.g. pillars, from high thermal loads,
- minimization of consequential fire damage.

In addition to property protection, an FFS can also help minimizing risks for emergency personnel and facilitate the rescue of people. Vehicle fires are mostly solid fires (mainly various plastics), which can be fought with known and proven methods. Water is a commonly used extinguishing agent for solid fires. This approach does not have to change for electric vehicles, since water is also recommended as the most suitable extinguishing agent for traction batteries (e.g. [11]). In the case of lithium-ion batteries, there are no significant reactions between metallic lithium and water (lithium hydroxide reaction) or other dangerous side reactions.

A comparison of different extinguishing agents (gas- and water-based, see [12]) in the SUVEREN research project also showed the particular effectiveness of water in fighting battery fires. This is due to the high cooling ability of water. Efficient cooling of the battery is of major importance, both for extinguishing the flames and for interrupting the propagation of the thermal runaway from cell to cell.

In car parks, the presence of persons is to be assumed. Therefore, the extinguishing agent used must be safe for people. The use of pure water as an extinguishing agent is recommended, also because it is readily available in most cases. The use of water-based FFS in car parks is proven and suitable to reduce damages caused by fires [13]. Common is the installation of sprinkler or high-pressure water mist systems. In SUVEREN fire tests, both systems were compared with regard to their effectiveness in an electric vehicle fire. For this purpose, a test setup developed in the research project was used. The spread of fire from a passenger car mock-up to adjacent target fire loads should be prevented and control of temperatures under the ceiling should be ensured.

For a fire duration of 30 minutes, both systems were able to prevent ignition of the target fire loads, which were placed at the sides at a close distance (simulating vehicles parked next to each other). The development of the temperature distribution at measuring points approx. 10 cm below the ceiling shows that lower temperatures were measured with high-pressure water mist FFS during the entire period considered (manual extinguishing after 30 minutes) (see Figure 4). The high-pressure water mist system was able to keep the temperatures below 200 °C, thus providing good protection for the ceiling structure. Due to the excellent cooling ability of the water mist in the gas volume, a high-pressure water mist system is preferable to a conventional sprinkler, according to this comparison (Figure 4). In addition, the use of water mist results in a significantly reduced quantity of extinguishing water, which is contaminated with several heavy metals in the case of a battery fire. Further information on the investigations and fire tests can be found in [14].

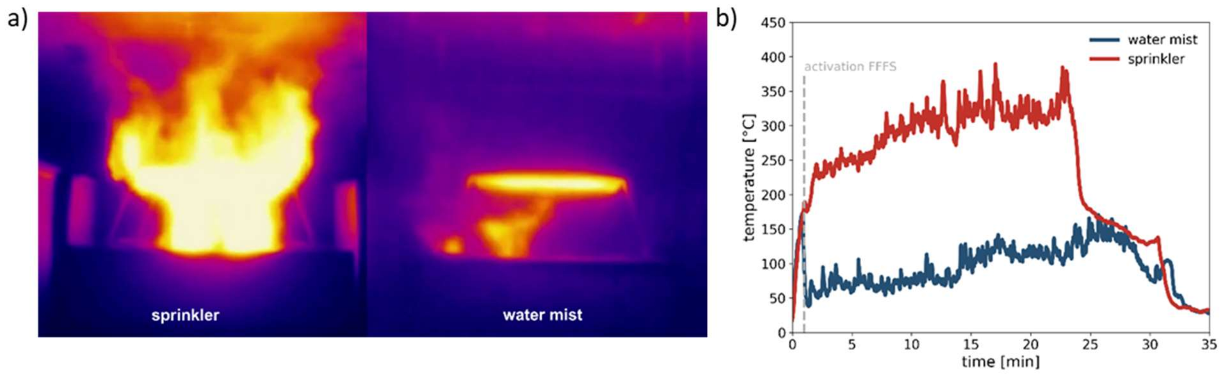


Figure 4: Comparison of sprinklers and high-pressure water mist FFS. a) Thermal image (IR) taken approx. 10 minutes after the start of firefighting; b) Temperature curve under the ceiling during a vehicle fire (solid fire) when FFS is used.

The traction batteries in most vehicles are installed in the underside of the vehicle. In the event of a fire in an electric vehicle involving a traction battery installed in the underbody of the vehicle, a large amount of heat is released in the immediate vicinity of the floor. Spilled burning fuel also applies a high thermal load on the ground. Therefore, the question arises as to whether firefighting approaches should be undertaken from below through nozzles installed on the floor. It has been shown that a ceiling installation meets the protection goals for car parks built of concrete or brick stone buildings. Only in the case of building materials that lose their strength even at low temperatures (aluminium or steel) or catch fire (wood), additional fire protection with nozzles installed in the floor area is advisable in order to reduce the heat radiation to the building material underneath vehicles (see chapter 5.2).

### *4.4 Performance-based design (Nachweisführung)*

Whenever FFS are installed, they must be tested for the application in full scale fire tests in order to demonstrate their effectiveness in the expected demanding fire scenario of a car fire (see section 2). The dimensioning of an FFS has to be based on the specific requirements, including the size and propulsion system of the vehicles. The effectiveness of the FFS must be verified and documented by a certified fire laboratory or comparable institution.

The safety of persons is regulated by legal requirements, and these do not require FFS except in a few specific cases (e.g. underground garages). Therefore, the implementation of FFS is rather based on commercial interests or requirements of the insurance companies. The respective protection aims are determined for each individual case and the effectiveness of the system technology has to be proven accordingly. The design of the FFS shall be carried out on the basis of guidelines for performance-based design in order to obtain an adequate and individual fire protection solution with simultaneously high and proven effectiveness at acceptable costs. The iterative process of such performance-based design approach is shown in Figure 5.

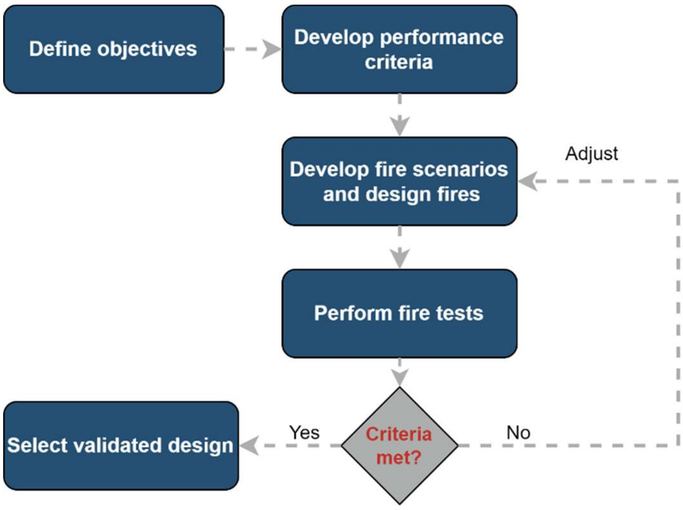


Figure 5: Diagram showing the iterative approach to performance-based design (based on [15]).

The approach should be as follows:

1. Appropriate protection goals have to be defined for the system, e.g.
   a. ensuring the safety and possibility of self-rescue of persons (legal requirements),
   b. enabling firefighting measures by the fire brigade,
   c. maintaining the stability of the building,
   d. maintaining the function of the building or concerned parts of the building.
2. The defined protection goals shall be used to derive criteria for evaluating the performance of the system, e.g.
   a. fire containment to one vehicle,
   b. compliance with limit values (temperature) on load-bearing components.
3. Agree on a procedure that allows verification of the required criteria.
   a. FFS: Development of a test scenario that can be used to verify the performance criteria derived in 2,
   b. smoke extraction: definition of scenarios for verification by means of tests/simulation,
   c. fire detection: test scenario if required by the application.
4. Carrying out the proofs of effectiveness.
   a. Fire tests are conducted. More reproducible results are possible by the use of mock-up with reference fire loads for the traction battery and for other combustible materials of the vehicle.

If the system tested has met the defined performance criteria, it has been successfully validated. Otherwise, adjustments to the design must be made and, usually, additional tests have to be performed.

The performance-based design can include all important elements of a garage and thus allows, for example, the compensation of structural measures by FFS. Further information is summarized in corresponding manuals and guidelines (e.g. [16]).

### 4.5 Handling extinguishing water

A burning battery is usually cooled with water for an extended period of time before it can be removed. This is necessary to prevent re-ignition and resulting fires. Consequently, large quantities of extinguishing water are required for electric vehicle fires involving the battery. Analyses of extinguishing water from fire tests show that it is contaminated with various heavy metals [17]. The contaminated extinguishing water must be collected, as it should not be discharged into the sewage system without further treatment.

The installation of mobile facilities to collect the water is often not possible during a firefighter operation [18]. Therefore, in car parks it is recommended to install tanks for the retention of extinguishing water. These should collect both the extinguishing water generated by the fire brigade and the FFS. The share of the latter depends on the FFS used and the calculated service time. Sprinklers generate significantly larger quantities of water than high-pressure water mist FFS. Unless other information is available, the system should be assumed to operate for at least 60 minutes (see EN 14972). Corresponding values for a fire brigade operation must be agreed with the responsible local authority and depend on the available equipment as well as the foreseen tactics.

## 5. Safety in special types of car parks

When establishing fire protection concepts for garages, the specific conditions of the garage must be taken into account in order to minimize the risk to pedestrians and emergency personnel as well as to keep damage to the construction and building installations to a minimum.

### 5.1 Multi-purpose garages

It can be seen that additional types of use, such as car rentals, car washes as well as stores with goods displays, are increasingly finding their way into car parks. Such applications can be commercially interesting for the operation of a car park. Thus, an increasing number of such multi-purpose garages can be expected. This results in a change and a potential increase of the overall fire load as well as additional possible causes of fire. The effects of these changes must be considered and integrated into the procedure of the performance-based design presented in section 4.4.

### 5.2 Wood or metal garages

Most regulations on fire protection are based on structures made of concrete, which corresponds to the majority of the current buildings. However, alternative building materials and techniques are also present on the market, for example constructions made of wood (cross laminated timber) or metal (steel, aluminium). In the context of fire protection design, the relevant differences such as mechanical strength under the influence of temperature or flammability must be identified and evaluated. The specific limit values form the basis for the performance-based design.

For wooden or metal garage structures, a system installed in the floor of the parking deck is recommended for improved cooling of the vehicle underbody and the floor of the parking deck. In addition, this type of system may be more effective in fighting localized fires (fuel spills, thermal runaway of the traction battery).

### 5.3 Small garages

Small garages (≤ 100 m²) with a few parking spaces are found in residential buildings in particular. The fire risk and the possibility of fire propagation are quite similar compared to the larger and usually commercially used facilities. The fire load (vehicles and neighbouring vehicles) is also basically the same. Likewise, the use of charging points must be assumed. To ensure the safety of persons, the legal regulations apply and thus there are only deviations concerning the commercial situation, on which the performance-based design described in section 4.4 is based on. To what extent the recommendations presented in this guideline are applied must be evaluated in each individual case.

## 6. Fire protection of charging stations

Directly related to electro mobility is the installation and operation of charging stations for electric vehicles in car parks. The charging stations themselves do not significantly change the fire load, even if it is generally true that a fully charged battery tends to cause a more severe fire. However, the likelihood of thermal runaway is increased during charging [19]. This is because the battery is in an electrochemically active state and electrical energy is being supplied. Therefore, the risk of fire initiated by the traction battery is higher in charging areas than in the rest of the garage.

Furthermore, damage inside the battery can occur as a result of the charging process without being visible from the outside. The vehicle is usually unattended during charging. This means that a fire can start while electric vehicles are parked.

Safety in charging stations can be increased by the following measures:

- Proper installation and regular maintenance (more information e.g. in [20]).
- Separate assessment of the installation of points for fast charging (> 22 kW) or high-power charging (> 150 kW) and, if necessary, providing them with separate fire protection. This applies to locations where manual firefighting is only possible to a limited extent or not at all (e.g. enclosed garages).

- Use of specific fire detectors, which detect battery failure at an early stage.
- Collision guards and emergency shutdown of the charging point.
- Internal protection of the charging point (e.g. short-circuit protection, temperature monitoring, cooling).
- Provision of an FFS. For optimal protection of medium and large charging areas, an FFS activated by a fire alarm system is recommended. For small charging areas, such as in a garage in a residential building, protection with automatic nozzles (glass bulb) is usually sufficient.

Furthermore, it must be ensured that other power sockets available in the garage cannot be misused for charging electric vehicles.

If a separate battery energy storage system (ESS) is used to operate the charging station, it should be separated from the garage in terms of fire protection. In addition, a separate fire protection solution is necessary if the ESS has a larger capacity (>20 kWh). Information on this can be found in the *SUVEREN_Storage White Paper*.

## 7. *Summary*

In addition to the rescue of persons, the objective in case of garage fires should be to avoid severe thermal stress on load-bearing building structures and to enable effective extinguishing work by the arriving emergency services and the fire brigade. This objective minimizes consequential fire damage due to smoke exposure and destroyed infrastructure, and preserves the stability of the building so that building operation can be resumed in a timely manner after a fire has occurred. These objectives can be achieved through effective control and containment of fire spread.

Early fire detection enables countermeasures to be initiated at an early stage and can reduce the extent of damage, especially by activating a firefighting system. Water is a particularly safe and efficient extinguishing agent, with high-pressure water mist systems being particularly effective due to their excellent cooling effect in combination with comparatively low water consumption. The actual configuration of the firefighting system should be based on the performance-based design approach. In order to adequately take into account the changed fire behaviour of modern vehicles, the design fire curve developed in the SUVEREN research project can be used for verification of the effectiveness of fire protection measures.

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