# Fire safety of indoor car parks accommodating electrically powered vehicles

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# Preface

I drive an electric vehicle. If NIPV publishes a study on the fire safety of indoor car parks accommodating electrically powered vehicles, I will obviously pay particular attention, since I also park and charge my vehicle in indoor car parks.

The energy transition is progressing at full speed. Just keeping up with sustainability developments in our society places a high burden on the Dutch security regions and the fire service. We are seeing an enormous expansion in the electrification of society, as is also reflected in the increasing popularity of electrically powered vehicles. These electric cars need to be charged and parked, and of course indoor car parks are convenient places for this. However, indoor car parks have not been designed to accommodate electric cars and charging stations for these cars. The growing popularity of these types of cars therefore calls for special attention to be paid to fire safety in indoor car parks. If we compare fires involving conventional vehicles with fires involving electric vehicles, we see that the latter entail different kinds of risks. The risks electric vehicles entail become significantly more important particularly in the context of indoor car parks. An inherent feature of indoor car parks is that opportunities for repressive firefighting are limited and having electrically powered vehicles parked and charged in these car parks restricts these opportunities even more. Because of this, the emphasis should be on prevention to improve fire safety, and provisions for this should be made much earlier in the supply chain: during the production of the electric vehicles and their battery packs.

This paper takes a balanced view of the fire safety issues referred to above. NIPV researchers, in conjunction with fire prevention specialists and repression experts, have developed a set of measures that can help achieve fire-safe indoor car parks accommodating electrically powered vehicles. We are very grateful to the specialists from the safety regions who took part in the focus group: Ron Galesloot (VRAA), Mark van Houwelingen (VRR), Goos Janssen (VRR), Marcel Koene (VRH), Jeroen Keyser (VRU) and Pieter Kruithof (VRH). Together with the three NIPV professorships involved they delivered an impressive volume of input to this publication. The process we followed with the Netherlands Fire Service was remarkably successful: through intensive coordination we have managed to deliver a clear-cut message regarding the fire safety of indoor car parks accommodating electric vehicles while under great time pressure and in spite of the many opinions and the major interests at stake.

And for my part: I drive an electric car and I intend to continue doing so, charging and parking it in indoor car parks. However, I do expect the designers and managers of indoor car parks, environmental services and safety regions to continue or initiate collaborative discussions to jointly achieve fire-safe indoor car parks.

IJle Stelstra
Managing Director of the Netherlands Institute for Public Safety (NIPV)

# Summary

## Background, purpose and method

Electric vehicles have become an integral part of our streetscape. These vehicles also need to be parked and charged, and this is partly done in indoor car parks. The fire safety of indoor car parks with capacity for electrically powered vehicles, more commonly known as 'electric vehicles', is therefore a topical issue. NIPV has prepared this publication to answer topical questions about this subject. Designers and owners/operators of indoor car parks, and the fire service's safety advisor can use this paper and the potential measures described in it as input when discussing the fire safety of indoor car parks with capacity for electric vehicles. This summary presents a brief outline of the paper. Since, by definition, this paper cannot do full justice to the many subtleties, anyone actually putting this subject matter into practice should read the full paper.

The safety risks of electric vehicles are different to those of conventional vehicles running on fossil fuels, but fire safety has always been a dilemma in indoor car parks, even before the arrival of electric vehicles. Experiences with some major fires in indoor car parks in recent years have shown that standard design principles have often failed to keep pace with the reality of fires. Dutch building regulations, standards and guidelines are still based on the characteristics of fires involving conventionally fuelled vehicles. However, modern cars, with their high plastic content, have a greater fire load and a higher heat release rate than older steel models. And recent decades have seen the addition of electric vehicles and the need to charge them.

The public debate tends to narrow down the safety discussion and the differences between electric vehicles and conventional vehicles to merely a comparison between these different types of cars. However, the differences between electric and conventionally fuelled vehicles should be considered as a whole in the context of the fire safety of indoor car parks where electric vehicles are not only parked but also charged – and that is the purpose of this publication. It answers the question of how to deal with the fire safety of indoor car parks in which electrically powered vehicles are parked and charged from a fire prevention (risk management) and repression (incident response) perspective. The request to answer this question was made by the Netherlands Fire Service. This paper provides guidance for fire safety advisers and those combating incidents who work for the security regions. Of course, other parties involved in the development, construction and operation of indoor car parks can also use it.

NIPV employees conducted a desktop study to gain a better understanding of the safety risks of electric vehicles and of charging them. The knowledge thus gained was translated into practical measures through a number of sessions with fire safety specialists at the Netherlands Fire Service, specialising in fire prevention and repression.

## Other types of risks

Parking and charging electric vehicles in indoor car parks involve some specific risks and uncertainties. Many electric vehicles use lithium-ion battery packs to store energy. If these battery packs catch fire, they have their own specific fire development and burning time. Furthermore, the composition of highly toxic and corrosive substances released during a fire in an electric vehicle is different from that in a conventional vehicle. These risks make it all the more difficult or even impossible to fight fires, particularly in indoor car parks. Further studies are needed to get a better understanding of the probability of fire in an electric vehicle in the context of an indoor car park, because this may involve additional causes of fire (e.g. charging). Moreover, the extent to which production defects and ageing play a role in the probability of fire are also still unknown.

## Measures

This paper sets out several potential measures that could increase the fire safety of indoor car parks accommodating electric vehicles. Although the risk of a fire or an inability to suppress it can never be completely ruled out, the measures are also intended to minimise the residual risk of such fires occurring.
These measures are subdivided into categories: architectural, installations, organisational and repression. Various 'general measures' are highlighted as well. These have been specifically identified as a result of the comprehensive fire safety analysis (the combination of indoor car park and electric vehicle). As well as contributing to the indoor car park's fire safety in general, these measures can contribute to reducing the risks involved in electric vehicles and charging them.

A sprinkler or water mist system is an example of this. Such as system reduces the probability of fire spreading to adjacent structures and vehicles, not only in case of a fire in a conventionally fuelled vehicle, but definitely also in case of a fire in an electric vehicle. This is because some of the differences in fire development and the greater complexity of fighting a fire in an electric vehicle make containing a fire in its initial stage all the more important. A sprinkler system is well suited to this, because the fire is tackled 'at source', increasing the probability of preventing it from developing into a major incident.

The measures should not be considered as a complete package that applies to all situations, but as a range of measures which can be used to create a bespoke set of measures to reduce fire safety risks depending on the construction, layout, etc. of indoor car parks. Moreover, the measures are not a detailed standard, but input to enable bespoke arrangements. Some examples of measures related to the specific fire safety risks of electric vehicles are given below.

### Architectural

Measures can be taken to protect the structure of the indoor parking garage against the different types of fire development (long-term, probability of reignition and possible flare fires). An example would be to add extra protection to the building structure near parking spaces with chargers. It is also important to properly seal any gaps in fire-resistant partition structures. To reduce the probability of fire, charging stations can be fitted with collision protection, or placed in locations where collisions are impossible.

### Installation measures

Installation measures can be taken to mitigate the risks of charging electric vehicles and of possible toxic combustion products. An example would be a facility that enables the current to all the chargers to be interrupted. When it comes to toxic combustion products, it is important to give careful consideration during the design process to the location of parking spaces for electric vehicles and charging stations/facilities relative to ventilation openings and escape routes. Furthermore, the use of displacement ventilation/smoke and heat removal can help to increase the probability of a successful offensive interior attack. Smoke removal ducts should be positioned to minimise the probability of any nuisance to the environment being caused by combustion products.

**Organisational measures**

Examples of organisational measures are instructions about the use of the indoor car park and its charging facilities (including their maintenance), informing drivers about what to do in the event of a fire and how to deal with error messages from the battery management system. The option of not allowing any electric vehicles to park or be charged in the indoor car park could also be considered.

**Measures for repressive attack**

Fighting fires involving electric vehicles in an indoor car park is complex: in general, an offensive interior attack by the fire service is *not* a safe option. It is often unclear which vehicles are on fire and how they are fuelled. The depths of attack are often considerable, the logistics are complex and the space for working is limited. Large amounts of water are needed for a long period of time in order to cool effectively; the extinguishing water supply and water extraction should be designed for this. Contaminated cooling water requires attention for environmental reasons. And moreover, how responsibilities should be divided between the salvage company and those combating the incident is something that still needs to be discussed and agreed. In order to increase the fire service's options to fight the fire - provided that the commanding officer on site chooses to do so - a number of measures can be considered. These include: rapid fire alarms and follow-up if a fire has started, smoke removal, proper accessibility (positioning electric vehicles close to entrances and exits and at street level) and installing a sprinkler system. Positioning electric vehicles close to the entrance and exit is also preferable in view of salvaging options. Identifying the locations where electric vehicles are parked helps the fire service form an initial picture of the incident. Finally, during the planning stage, attention could be paid to how an electric vehicle can be moved outside after a fire has been extinguished, e.g. for cooling it in a water tank.

## The future

Further studies are needed into the impact of developments in vehicle, battery and information technology on the fire safety of electric vehicles in indoor car parks. As a consequence, it may be necessary to adjust building regulations in order to keep pace with developments. The consultation round for a proposed amendment to the future Dutch Building Works and Living Environment Decree [*Bbl - Besluit bouwwerken leefomgeving*] in which a sprinkler system will become mandatory for certain indoor car parks started on 10 July 2021. In addition, further studies are needed into, for example, the probability of fire and underlying causes such as production defects, ageing and traffic accidents. Studies into the effects of the thermal load on the structure caused by an electric vehicle on fire, fast and adequate detection capabilities and the effectiveness of fire control systems are also desirable. Another possibility is research into the application possibilities of robots and into expanding these possibilities. Several studies have already been initiated, such as a study into the possibilities of getting water directly into the vehicle's battery pack in the event of a fire.

Finally, we have published this paper in order to contribute to increasing fire safety in indoor car parks and reducing residual risks. The potential measures described in this paper, as well as the various ongoing and future studies, may be quite helpful in this respect.

# Contents

# Introduction

This paper discusses the safety and more specifically the fire safety of indoor car parks accommodating electric vehicles and of charging facilities in indoor car parks. It answers the question of how to deal with the increase in electric vehicles in indoor car parks from a fire prevention and repression perspective. This paper provides guidance for fire safety advisers and those combating incidents who work for the security regions. Of course, other parties involved in the development, construction and operation of indoor car parks can also use this paper. Examples of such parties are designers, consultants, builders and operators of indoor car parks.

This introduction discusses several elements:
> the background to preparing this paper
> its purpose and the question being addressed
> a brief description of the legal framework
> the scope of the subject matter addressed in this paper.

## Background

The energy transition is a development that calls for a proper discussion about safety levels and risk considerations. This transition is also taking place in the mobility sector and has led to a significant increase in the number of alternative fuel vehicles. Alternative fuel vehicles are[1] vehicles that entirely or partially run on non-fossil fuels, in particular electric vehicles. The fuels used are more sustainable and/or renewable. According to the Netherlands Enterprise Agency (RVO), some 67,000 electric vehicles were sold in the Netherlands in 2019 out of a total of about 450,000 new passenger cars sold[2], i.e. approx. 15%. In total, approximately 218,000 electric vehicles were registered in the Netherlands at the end of 2019. This is approx. 2.5% of a total of approx. 8,800,000 registered passenger cars.

Of course, this increase also has implications for indoor car parks, where such vehicles will be found in increasing numbers, especially if dedicated spaces with charging facilities are constructed for them. Several of such facilities have already been constructed now that it has become a statutory obligation to construct charging facilities in new indoor car parks.[3] This obligation does not yet apply to existing indoor car parks.[4]

Parking and charging electric vehicles in indoor car parks involve some specific risks and uncertainties. Many electric vehicles use lithium-ion battery packs to store energy. If these battery packs catch fire, they have their own specific fire development and burning time. Furthermore, the composition of highly toxic and corrosive substances released during a fire in an electric vehicle is different from that in a conventional vehicle.

[1] By this we mean cars that are meant to be used on public roads and can be parked and/or charged in an indoor car park.
[2] https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-en-milieu-innovaties/elektrisch-rijden/stand-van-zaken/cijfers
[3] Section 5.4 of the Dutch 2012 Building Decree [*Bouwbesluit 2012*].
[4] With effect from 1 January 2025 at least one charging point for existing car parks under non-residential structures (Section 5.15(3)).

These risks, as well as the high voltages in electric vehicles (up to approx. 400 V, with peaks of up to 800 V), are one of the reasons why firefighting, especially in indoor car parks, may be limited or not possible at all.

**Intermezzo: fire safety of indoor car parks and vehicle developments**

Fire safety has always been a dilemma in indoor car parks, even before the arrival of electric vehicles. Experiences with some major fires in indoor car parks in recent years have shown that standard design principles have often failed to keep pace with the reality of fires. Examples of such large-scale fires are fires in Paris[5], Liverpool[6] and Stavanger.[7] Examples of smaller-scale fires are fires in the Hague[8] and Twente.[9]

The design parameters for the fire safety measures for existing indoor car parks where fires occurred were mostly based on older vehicles, with a small amount of plastic and fossil fuels such as petrol and diesel. Dutch building regulations, standards and guidelines are still based on the characteristics of fires involving conventionally fuelled vehicles. Modern cars, with their high plastic content, have a greater fire load and a higher heat release rate than older steel models.[10] Because indoor car parks are relatively large spaces of limited height, fires in modern vehicles lead to very high temperatures and dense black smoke. The heat, loss of visibility and great hose distances with which the fire service has to operate and the difficulty of getting one's bearings in indoor car parks make reconnaissance and firefighting by the fire service a difficult and risky task.

The increased speed at which fires spread and the higher heat release rate of modern cars, both in closed and open indoor car parks and even on outdoor car parks, have led to a greater probability that a car fire will develop into a long, intense fire eventually involving a large number of vehicles (10 to 50 or more). The probability of this happening seems higher than even the most recent statistical studies show and is too high to ignore in design regulations (DGMR, 2015).

The above is mainly a consideration of the possible effects of a fire that may occur. However, the likelihood of such fires is still uncertain. There are no reliable datasets on the occurrence and probability of fires in electric vehicles. This is also true for reliable datasets on charging and the charging process, but research institutes are working on these datasets. Moreover, this is a relatively new technology that is still intensively being developed. The extent to which production defects in battery packs and their ageing play a role in the probability of fire, is still unknown as well.

[5] https://www.autogespot.nl/brand-in-parkeergarage-place-vendome-in-parijs!
[6]https://www.bafsa.org.uk/wp-content/uploads/bsk-pdf-manager/2018/12/Merseyside-FRS-Car-Park-Report.pdf.
[7] https://www.thelocal.no/20200108/norway-airport-flights-held-as-hundreds-of-cars-burn-in-fire.
[8] https://www.omroepwest.nl/nieuws/3981194/Bewoner-na-brand-Wateringse-Veld-Het-leek-wel-oorloghet-ging-heel-snel.
[9] https://www.brandweer.nl/brandweernederland/nieuws/cases/brand-in-parkeergarage.
[10] https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2019/March-April-2019/Features/Protecting-Parking-Garages.

However, it is worth mentioning that the charging of electric vehicles in indoor car parks essentially adds a new activity to the existing activity of 'parking' and thus poses an additional risk. New developments are known to initially involve incidents due to 'teething problems'. These incidents gradually disappear as designs improve (Sun et al., 2020). Charging electric vehicles in indoor car parks is a similar activity where things can go wrong.

**Charging facilities**
Charging facilities are divided into 'regular charging' and 'fast charging' facilities (RVO, 2019).

Charging point for regular charging
> A charging point with a capacity of a maximum of 22kW, capable of transferring electric energy to an electric vehicle.

Charging point for fast charging
> Fast charging is transferring electrical energy to an electric vehicle with a capacity greater than 22 kW. Fast charging is developing rapidly and nowadays there are fast chargers that can deliver 175kW of power and more (some even deliver 350kW, and for buses and trucks there are already 600kW chargers).

While there does not tend to be an excessively large number of fires in indoor car parks and their probability is not high, the main question is to what extent the effects of such a fire are socially acceptable. Even although the probability of fire is not high, it is still important to consider its effect and tailor measures accordingly.

This also became evident in the case of the fire in the Singelgarage indoor car park in Alkmaar (1 July 2020).[11] This fire was most probably deliberately lit and also involved one electric vehicle. Poor visibility made it very difficult for the fire service to extinguish the fire since it was difficult to determine the location of the burning vehicles (a firefighting robot was used). A police robot was used to tow away the electric vehicle since its battery pack kept reigniting. Once the car had been removed from the indoor car park it was placed in an immersion container where its battery pack could be cooled for a long time. The fire development and firefighting were investigated by NIPV in collaboration with the Noord-Holland Noord Safety Region[12].

The fire safety of some existing indoor car parks is a matter of concern because of increasing risks and the identified uncertainty about the protection of load-bearing and partition structures that only comply with the Dutch Building Decree requirements. The fact that there have not been any incidents involving fatalities or extreme material damage or loss might justify the assumption that there is no valid reason to conclude that existing indoor car parks are so unsafe that many of them need to be updated. However, the notion that existing indoor car parks are safe is largely based on assumptions about car fire behaviour that were correct in the past but are now demonstrably outdated. The safety of those indoor car parks and particularly the safety of the functions served by plots and buildings above them has decreased due to a different fire development and a higher heat release rate of car fires (DGMR, 2015).

[11] https://www.noordhollandsdagblad.nl/cnt/dmf20200701_16898382/grote-brand-singelgarage-in-alkmaar-brandweer-kan-niet-naar-min-twee-waar-het-te-heet-is-auto-s-op-die-verdieping-afgeschreven-bevestigt-woordvoerder?utm_source=dlvr.it&utm_medium=twitter.
[12] https://nipv.nl/wp-content/uploads/2022/02/20201021-BA-Brand-Singelgarage-Alkmaar.pdf

# Purpose and question being addressed

Several questions have been asked in the Dutch parliament about the safety of indoor car parks in relation to electric vehicles and other aspects:

> to the Dutch Minister of Justice and Security (06 September 2019 by Thierry Baudet of the FvD political party)[13]
> to the Dutch Minister for the Environment and Housing (13 January 2020 by Remco Dijkstra of the VVD political party)[14]
> to the Dutch Minister of the Interior and Kingdom Relations (24 March 2020 by Sandra Beckerman and Cem Laçin, both of the Dutch Socialist Party).[15]

The general gist of the first and second answers to Baudet's and Dijkstra's questions is that electric vehicles are at least as safe as vehicles with internal combustion engines and conventional batteries but require a different extinguishing method. Furthermore, the minister indicated that they considered it important that a new NEN standard, yet to be developed, on the total fire safety of indoor car parks, should not only consider the specific risks with regard to the charging and parking of electric vehicles but should also examine incident control and emergency response options. The minister decided to make the construction of charging facilities in new and existing indoor car parks a statutory requirement first, to be followed by the development of a NEN standard on the integral fire safety of indoor car parks, in which the charging and parking of electric vehicles will be considered. In the most recent response to questions from the Socialist Party members of parliament, the minister referred to this NIPV paper. In anticipation of a new NEN standard on the integrated fire safety of indoor car parks, this paper discusses the specific risks, incident control possibilities and emergency response options in indoor car parks accommodating electric vehicles.

The 'Background' above briefly mentions several specific safety risks relating to electric vehicles and charging them. Since the nature and extent of these risks is inherent in indoor car parks to some extent, we will examine the additional risks of electric vehicles and charging in connection with indoor car parks. All in all, the central question to be addressed by this paper is:

*How should the fire safety of indoor car parks in which electrically powered vehicles are parked and charged be dealt with from a fire prevention (risk management) and repression (incident response) perspective?*

This paper provides guidance for this.

[13] https://www.rijksoverheid.nl/documenten/kamerstukken/2019/12/02/antwoorden-kamervragen-over-het-brandveiligheidsrisico-elektrische-auto-s.
[14] https://www.rijksoverheid.nl/documenten/kamerstukken/2020/01/31/beantwoording-kamervragen-over-het-bericht-fire-at-norway-airport-destroys-hundreds-of-cars-grounds-planes.
[15] https://www.rijksoverheid.nl/documenten/kamerstukken/2020/03/24/beantwoording-vragen-over-brandgevaar-in-parkeergarages-en-onder-woningen.

# Legislation and regulations

We base our discussion of fire prevention regulations on the regulations in the Dutch 2012 Building Decree that concern existing and new-build structures.[16] The 2012 Building Decree also provides regulations for rebuilding or renovations and for temporary structures. The 2012 Building Decree classifies an indoor car park as 'other functional use for parking motor vehicles' (Article 1.1(2)). There are other regulations and guidelines in addition to the Building Decree, such as the Dutch PGS series, which deal with parking vehicles for business purposes.[17] This is not within the scope of this paper, however.

## Performance requirements for new-builds and existing buildings

The 2012 Building Decree provides performance requirements for existing structures and for new-build structures. The regulations for existing indoor car parks are less stringent than those for new-build car parks. For example, a fire compartment in a new-build indoor car park may have a usable area of up to 1,000 $m^2$, whereas the maximum usable area allowed for existing car parks is 3,000 $m^2$.

**Intermezzo: rebuilding or renovations and fire safety**

Once a structure has been completed and put into use, it is considered to be an existing structure for the purposes of building regulations which is subject to the regulations set out in the 2012 Building Decree on the status of existing structures. However, this does not mean that owners are allowed to carry out interventions to structures after their completion to lower their quality level to, for example, the level specified as the minimum level in the regulations for existing structures. Carrying out interventions to change the quality of a structure is considered to be "building" within the meaning of the Dutch Housing Act [*Woningwet*] and therefore such interventions have to comply with the rebuilding or renovation level of the 2012 Building Decree. Barring some exceptions, this is the 'legally attained level' referred to in Article 1.1(1) of the 2012 Building Decree, which basically means that the fire safety level is not allowed to deteriorate as a result of a renovation or of rebuilding work. Of course, the quality of a structure can decrease over time due to ageing. The legislator finds such autonomous decrease in quality acceptable, provided the level of quality of the structure does not fall below the minimum level of the regulations for existing buildings. If the quality level does fall below that minimum level, this is considered to be a violation on the part of the owner of the structure and the competent authorities can take enforcement action (VROM, 2008).

Charging facilities for electric vehicles are part of the electricity supply of a building. Based on Article 6.7 of the Building Decree, if a structure has a facility for taking and using energy, it must be a *safe* facility. Article 6.8 (Electricity supply) of the Building Decree states that an electricity supply must comply with the NEN 1010 standard. This NEN standard has requirements for the safe installation of charging stations.

On top of this, separate safety requirements apply to the individual elements of the charging facilities. More information on safety requirements concerning vehicles and charging infrastructure can be found in the series of international guidelines of the International Electrotechnical Commission (IEC)[18]. Annex 1 of this paper features a list of requirements and standards set for charging facilities and electric vehicles (IFV, 2020b).

[16] The regulations in the 2012 Building Decree are expected to be included in the Dutch Building Works and Living Environment Decree with effect from 1 July 2022 when the Dutch Environment and Planning Act [*Omgevingswet*) is planned to take effect.
[17] PGS is the acronym for: '*Publicatiereeks gevaarlijke stoffen*' (Hazardous Substances Publication Series).
[18] http://e-mobility.provincia.brescia.it/wp-content/uploads/2017/10/d.t1.1.1-e-moticon_charging-infra-analysis-_final-version.pdf.

## Equivalence

There is also the possibility of providing facilities based on equivalence: another facility that does not directly meet the performance requirements of the 2012 Building Decree, but that does achieve a level of safety/fire safety as envisaged by the requirements of the 2012 Building Decree (Berghuis, 2019).

The equivalence article is contained in Article 1.3 of the 2012 Building Decree and reads as follows:

> "Any of the provisions of Chapters 2 to 7 will not need to be complied with if the structure or its use, other than by application of the relevant provision, provides at least the same level of safety, health protection, usefulness, energy efficiency, and environmental protection as envisaged by the provisions of those chapters."

To assess whether a solution is an equivalent solution, the government objectives underlying fire safety regulations can be referred to (Berghuis, 2019):

- preventing victims
- preventing the fire from spreading to another plot.[19]

Essentially, a repressive fire service attack is not an aspect that can be taken into account in an equivalent solution.

The regulations and minimum requirements in the 2012 Building Decree have a direct effect and apply to every structure (Dutch Ministry of the Interior and Kingdom Relations, 2012). Of course, the initiator, owner or operator of an indoor car park can also aim for a higher level than the minimum requirements of the 2012 Building Decree, such as limiting damage to their property, a monument or the environment. However, these goals are not part of the fire safety regulations in the 2012 Building Decree.

An equivalent solution in an indoor car park requires the risk of casualties or fire spreading to another plot to be at least equal to or lower than it would be in the situation where the indoor car park directly meets the performance requirements of the 2012 Building Decree. Methods used for this purpose include the LNB[20] Guideline (withdrawn since 2012 by the then Dutch Board of Fire Chiefs (*BoC*)), NEN 6098 and the guideline on Fire safety of steel indoor car parks [*Brandveiligheid stalen parkeergarages*] issued by Bouwen met Staal.
For existing indoor car parks, the building permit that was granted in the past can also be taken into account for this (Huijzer, 2013). Furthermore, an equivalent solution shall be maintained, according to Article 1.3(2) of the 2012 Building Decree. If the use of the indoor car park differs from the assumptions on which the original equivalent solution was based, this conflicts with Article 1.3(2) of the 2012 Building Decree.

[19] This therefore does not concern other functional use located above the indoor car park, even if it belongs to another owner. Actually, the regulations on fire compartmentation and resistance to fire penetration and fire spread in the 2012 Building Decree ensure that fire growth between an indoor car park and a residential function located above it on the same plot is limited.

[20] LNB is the acronym for: '*Landelijk Netwerk Brandpreventie*' (National Fire Prevention Network).

In practice, equivalence is usually substantiated in a memorandum or report, so that the risk analysis and the considerations of why there is equivalence in a specific situation are recorded. Structural, i.e. architectural, or installation-specific provisions are often necessary for an equivalent solution to be achieved. These provisions can also be recorded in such a memorandum or report. It can also be used as a substantive response to an enforcement decision or as a document to be submitted for an environmental permit for construction, if such a permit is required.

## Damage and nuisance to surroundings and operational safety

The technical regulations of the 2012 Building Decree aim to reduce the probability of casualties as well as the probability of fire spreading to another plot. In addition to these public law objectives, it is important to consider the following questions as regards indoor car parks:

1. **What degree of nuisance is considered acceptable for the surrounding area?**
   The degree of nuisance (e.g. smoke spread or the spread of toxic substances) that is considered acceptable for the surrounding area can be regulated by municipalities in, for example, a zoning plan ('area plan' [*omgevingsplan*]) under the future Dutch Environment and Planning Act [*Omgevingswet*]. So far, this possibility has hardly been employed by the competent authority, but future area plans will be a suitable tool for reducing nuisance to the surrounding area (Van der Graaf and Pothuis, 2018). This is definitely important given the potential social impact of a fire, such as the impact on nearby hospitals, possible failure of vital infrastructure, such as electricity, or roads or motorways having to be closed due to smoke.

2. **What damage (e.g. to the structure) is considered acceptable?**
   Reducing damage or loss is not provided for in the 2012 Building Decree. From a private law perspective, agreements on this can be made between stakeholders, e.g. between an initiator and an insurer.

   These agreements might concern damage to the structure as a result of a long-lasting fire, requiring a structure located over the car park having to be evacuated, for instance, and long-term temporary accommodation having to be arranged for the residents.

3. **Which continuity and operating reliability of activities in the environment have to be safeguarded?**
   Which continuity or operating reliability of activities in the environment have to be safeguarded will largely have to be decided between the interested parties involved, for example businesses that depend on the supply of clean air for their business processes. If smoke from a fire in an indoor car park is drawn in there is a risk that the business process will have to be discontinued. Other examples include companies which become unable to receive or deliver products due to long shutdowns for incident response reasons, which may bring their business process to a halt. It is important for such companies that this is discussed and that agreements under private law are made with the operator/owner of the car park.

## The competent authority's perspective for action

The fire safety aspects of Dutch building regulations (2012 Building Decree) do not specifically focus on parking and charging electric vehicles in indoor car parks. Even if an equivalent solution is used for indoor car parks which deviate from the performance requirements of the 2012 Building Decree (> 1,000 $m^2$ for new build and > 3,000 $m^2$ for existing structures), no assessment methods that take parking and charging of electric vehicles in indoor car parks into account are available at this point in time.

Changes in the use of the indoor car park compared to the original planning permission or environmental permit which negatively affect the fire safety of an indoor car park may be grounds for the competent authority to talk to the owner about improving the fire safety of the indoor car park. According to Article 1.3(2) of the 2012 Building Decree, an equivalent solution must be maintained during the use of a structure. A change in use may even conflict with the standard for existing buildings (in the event of an equivalent solution in an existing indoor car park), which is prohibited under Section 1b(2) of the Dutch Housing Act. The competent authority may apply Section 13 of the Housing Act in extreme situations.

Section 13 of the Housing Act can only be applied if the competent authority can substantiate that the specific situation is unsafe in its opinion. In that case (if applicable to the indoor car park in question), the following changes of use compared to planning permission or an environmental permit granted in the past may be included as factors on which the substantiation is based:

- compared to petrol or diesel cars, parking and charging electric vehicles in an indoor car park pose different risks than those taken into account when the planning permission or environmental permit was granted.
- the increased speed at which fires grow and the higher heat release rate of modern cars, both in closed and open indoor car parks, have led to a greater probability that a car fire will develop into a long, intense fire eventually involving a large number of vehicles (10 to 50 or more (DGMR 2015)).

Actually, in general it will not be possible to limit the substantiation to the fact that electric vehicles are parked and/or charged in an indoor car park, especially given the obligation in the 2012 Building Decree for the installation of charging facilities in new indoor car parks and the future obligation to do so for existing indoor car parks. Moreover, Section 13 of the Dutch Housing Act must be applied in connection with the entire building: for example, if there is a residential building with senior citizens or a hospital on top of the indoor car park, application of Section 13 of the Housing Act is more likely than would be the case with a standalone indoor car park located at a greater distance from buildings.

In practice, the legislative instruments referred to above are enough to sufficiently ensure safety in indoor car parks. Article 7.10 of the 2012 Building Decree (provision on residual risks/article that serves several purposes) and Section 1a of the Housing Act (provision on general duty of care) can also be referred to in this context. These articles and sections provide for an obligation to make provisions if a structure, open yard or site is found to be unsafe or unhealthy, despite the requirements of the 2012 Building Decree having been met and no other regulations having been violated (Berghuis, 2019). In practice, this will involve a situation which is immediately unsafe.

## Roll-out of alternative fuels infrastructure

Besides building regulations, there are European directives and Dutch regulations governing alternative fuels infrastructure. In 2013, the European Commission identified electricity, hydrogen, biofuels, natural gas, and liquefied petroleum gas (LPG) as the principal alternative fuels with a potential for long-term oil substitution. This was subsequently recorded in 2014 in Directive 2014/94/EU [21] of the European Parliament and of the Council, with the aim of establishing a common European framework to the dependence on transport of oil.

This European directive was transposed into Dutch legislation through the Dutch Decree on Alternative Fuels Infrastructure [*Besluit infrastructuur alternatieve brandstoffen*][22] from 2017. Next, the usage requirements that follow from this were laid down in the Dutch Regulation on Technical Requirements and User Information on Alternative Fuels Infrastructure [*Regeling technische eisen en gebruikersinformatie over de infrastructuur van alternatieve brandstoffen*][23]. Articles 2 and 3 of this regulation contain technical specifications for publicly accessible normal and high-power charging stations. The main requirement is that charging stations have connectors as described in EN62196. Further safety requirements for charging stations can be found in Annex 1 to this paper.

## Expected future regulations

The Dutch Environment and Planning Act is expected to come into force on 1 July 2022. The Dutch Building Works and Living Environment Decree [*Besluit bouwwerken leefomgeving (Bbl)*] is an Order in Council [Dutch: *AMvB*] governed by the Dutch Environment and Planning Act and largely adopts the regulations of the 2012 Building Decree. On 10 June 2021, the Dutch Ministry of the Interior and Kingdom Relations started a consultation round on a number of proposed amendments to the draft Building Works and Living Environment Decree[24]. This concerned the following proposed changes:

- the obligation to install a sprinkler system in certain types of indoor car parks
- a facility enabling charging points for electric vehicles to be switched off simultaneously and an obligation to make it clear at the entrance to the car park how this facility is constructed
- an obligation to indicate at the entrance to the car park where electric vehicle charging points are located

# Scope

The present paper deals with both parking and charging ('normal charging' and 'fast charging') of electric vehicles, but only as regards lithium-ion powered passenger cars, both ‘full electric vehicles’ (FEV: Full Electric Vehicle or BEV: Battery Electric Vehicle) and ‘plugin hybrid electric vehicles’ (PHEV). Please note in this regard that ‘lithium-ion’ is an umbrella term for all kinds of lithium batteries whose specific characteristics and responses to fire can differ (for example the temperature at which a 'thermal runaway' may occur (which may range from 50 to 270 ˚C)). These differences will not be discussed in more detail here

[21] https://eur-lex.europa.eu/legal-content/NL/TXT/HTML/?uri=CELEX:32014L0094&from=NL
[22] https://wetten.overheid.nl/BWBR0039567/2017-06-24/
[23] https://wetten.overheid.nl/BWBR0039677/2018-10-12
[24] https://www.internetconsultatie.nl/verzamelwijzigingbbl2021

because, according to current understanding, they do not require different measures (chapter 3) or different firefighting tactics (chapter 4).

This paper does not focus on other types of batteries (such as nickel-metal hydride batteries: these do not pose a specific problem), nor on other fuels (such as hydrogen) since their use is still quite rare. It should be noted that the incident response risks posed by cars on other fuels (such as hydrogen) can be as complex as those posed by electric vehicles. Specific risks for hydrogen vehicles are described in the report on Hydrogen cars in car parks - Part 1 [*Waterstofauto's in parkeergarages – Deel 1*] (Netherlands Institute for Safety, 2021a). However, such fuels are beyond the scope of this paper.

We will not address other safety aspects of electric vehicles either, such as road safety, which is negatively affected by higher numbers of severely injured casualties due to such vehicles' faster acceleration, greater mass and lower noise generation.[25] Deliberate causes of incidents such as illegal tapping of electricity and arson are not addressed either. Since this paper solely focuses on indoor car parks, it does not concern parking outside buildings, such as in the street or in outdoor car parks.

This paper is based on currently applicable legislation and regulations. It will be updated where necessary once the Dutch Environment and Planning Act and the Orders in Council (Dutch: *AMvB's*) governed by it have taken effect. And lastly, this paper focuses on the current situation where there are still relatively few electric vehicles on the roads. However, we anticipate that once their share has increased substantially (and that is more than just an expectation), this paper will have to be updated because of the potential consequences of that increase for the measures mentioned.

[25] https://www.rijschoolpro.nl/rijschool/2020/06/19/meer-zwaargewonden-door-elektrische-auto/?gdpr=accept.

# 1 Physical characteristics

This chapter describes the physical characteristics (measurable properties) involved if an electric passenger vehicle catches fire. They differ from fires involving a conventional vehicle. This chapter gives information on the differences between incidents (especially fires) involving electric vehicles and incidents involving conventional (fossil fuel-powered) vehicles.

## 1.1 Research into electric vehicles

The understanding of and the difference in the physical characteristics of electric and conventional vehicles makes it possible to determine which safety measures make sense. Safety is usually expressed in terms of risk, often made measurable as a probability and a consequence of an incident. However, it should be noted that, in 2021, it was hardly possible to determine the probability component of the risk concept of electric vehicles and charging them on the basis of empirical data (RISE 2019c, Sun et al., 2020). Although electric vehicles have become more prevalent in Dutch traffic, both their number and the time that they have been around in the Netherlands are still so limited that it is not yet possible to make a reliable statement about the *probability* of incidents. NIPV and the Netherlands Fire Service are building a national database partly to obtain more information on this[26].

More reliable information is available about the *consequences* of incidents involving electric vehicles since several studies and experiments on this topic have been conducted. And it is precisely these consequences that are relevant to the emergency services, specifically the fire service, for the purpose of fire prevention advice as well as incident response.

In recent years, dozens of studies have been carried out into the fire hazard of specifically batteries and battery packs used in electric vehicles. However, the number of actual full-scale experimental studies into fire in electric vehicles is much lower. It should be noted that each study has its own specific starting points and research area. Due care should therefore be applied when considering the individual studies, also in relation to the basic assumptions chosen. We cannot effortlessly translate test results from individual studies into generic conclusions on physical differences between electric vehicles and conventionally powered vehicles, since test results can vary greatly, depending on the quantity of fuel in the fuel tank, the capacity of the battery pack and the amount of plastics used in the cars.

In recent years, Swedish scientific knowledge institute RISE has conducted several studies (both literature reviews and experiments) on the safety aspects of electric vehicles (RISE, 2018, 2019a, 2019b, 2019c and 2020). In early 2020, Sun et al. published a comprehensive literature review on battery fires in electric vehicles in which they compiled and studied a lot of information from previous studies and experiments (Sun et al., 2020). This most comprehensive, up to date and peer-reviewed study has formed the basis for our analysis in this chapter of the differences between electric and conventional vehicles.

[26] https://nipv.nl/database-incidenten-met-alternatief-aangedreven-voertuigen/

## 1.2 Electric vehicles' energy supply

This section briefly discusses electric cars' energy supply.

### 1.2.1 Battery packs

Rechargeable battery packs in electric vehicles, such as lithium-ion battery packs, can store substantial amounts of energy (>100 kWh) to drive the electric motors that enable the vehicle to travel. The battery packs consist of battery cells capable of delivering about 4 volts that provide the energy content. These cells are connected together to create modules of up to 60 volts. The number and nature of the cells vary from module to module. Connected modules form battery packs (of 300-1000 volts). Nowadays, battery packs in passenger vehicles can have an energy storage capacity of 100 kWh or more.[27]

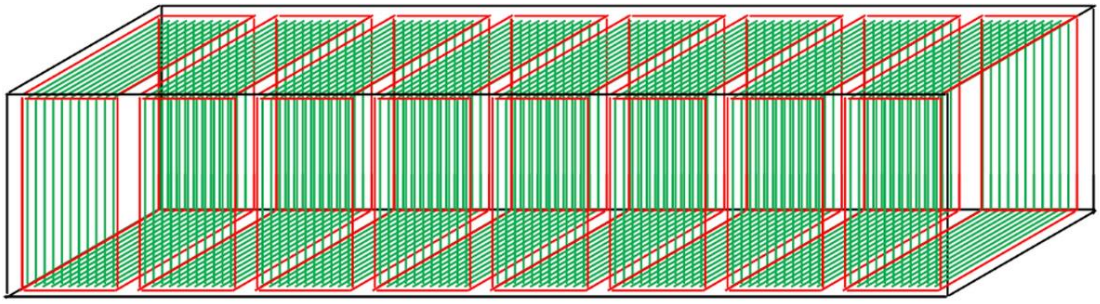


**Figure 1.1 Battery pack structure (Bisschop, Willstrand & Rosengren (2020)**

### 1.2.2 Charging

Electric vehicles can be both parked and charged in indoor car parks. As goes for the production of batteries, charging technology is also developing rapidly. For instance, there are different possible charging modes for electrical devices:

> Mode 1: the electric vehicle is connected to a regular domestic wall socket by a cable. This mode is not used for passenger vehicles because communication with the BMS (battery management system) is only possible through a special Type 1 or Type 2 plug on the vehicle. This charging method lacks communication and thus a safety system.

> Mode 2: the electric vehicle is connected to a regular domestic wall socket by a special cable. The cable features special charging functionalities such as monitoring some charging components and circuit interruption. The control unit integrated into the cable (ICCB: In-Cable Control Box) serves as a mobile safety facility and controls the charging power.

> Mode 3: the electric vehicle is connected to the grid via a separate charging station by means of a special Mennekes plug. This enables high levels of charging voltage. The special plug facilitates communication between the vehicle and the charging infrastructure, thus determining the correct power. This communication is an important safety facility. If an anomaly is detected, the installation is de-energised.

> Mode 4: the electric vehicle is connected to the grid through a charger in a separate charging station. In this mode, the charging cable and monitoring and security functions are permanently connected to the charging station, similar to mode 3. A mode 4

[27] Battery packs can be connected together to create battery systems with a storage capacity ranging from 10 to 400 kWh (for trucks, electric ships, etc.). In the meantime, there are rumours that the energy content of the battery packs for electric passenger vehicles will decrease again due to improved battery technology and charging speeds.

charging station contains an AC/DC converter to ensure that the vehicle is charged and discharged on DC. In modes 2 and 3, the conversion is handled by an on-board charger in the vehicle. The external converter makes mode 4 suitable for fast charging and bi-directional charging. Modes 3 and 4 feature the same safety facilities in and for the loading infrastructure.

## 1.3 Physical characteristics

This section is about 'thermal runaway' and physical characteristics (measurable properties of the fire) in case of incidents involving electric vehicles. This is dealt with in the following order:

> Thermal runaway
> Temperature and heat radiation
> Fire capacity
> Fire development
> Combustion products

### 1.3.1 Thermal runaway

Thermal runaway is a failure mechanism which leads to auto-heating in a battery or battery cell and which can result in fire (Colella et al., 2016). Each battery pack has its own safety window. If this is exceeded, the battery pack can heat up further and thermal runaway can occur (Air Resources Board, 2015). The temperatures where this can occur depend on the type of battery and range from 70 to 250 ºC (Sun et al., 2020). The battery of an electric car always features a Battery Management System (BMS) making the safety window fail safe.

#### What happens if thermal runaway occurs

There is a risk that flammable gases are released when the battery heats up which may ignite if there is sufficient oxygen and the ignition temperature is reached (the temperature of the cell housing may be high enough for this). Thermal runaway causes the fire to maintain itself and to re-ignite until the battery pack’s energy has been depleted. The heating effect of thermal runaway in a single battery cell can lead to a chain reaction: the cell in question heats up adjacent cells, causing thermal runaway there as well. If the gases are in a confined space such as a pouch or cartridge they can be released if the battery pack or pressure valve enclosure fails under (high) pressure. In the right mixing ratio, the gases can lead to a flare fire and/or gas cloud explosion. If there is mechanical damage to the battery pack, the pressure wave can eject - possibly burning - parts and fragments from the battery pack.

Once started, a thermal runaway in a battery pack of an electric vehicle is difficult to stabilise. It is hard to cool the battery cells because the coolant (often water) cannot be applied directly to the cells. This is because the battery pack is sealed from the outside world as well as possible to prevent any moisture and dirt affecting the battery operation (IFV, 2021b). Cooling therefore requires prolonged application of a lot of cooling water (or another coolant). The situation does not become safe again until all electrical and chemical energy from the battery has been neutralised (has burned up).

### Causes of thermal runaway

A failing battery can be due to a design or manufacturing error that may involve the electrode, or equally the separator, electrolyte or interdependent processes, which leads to failures in the battery management system (BMS) and causes overcharging. In general, these errors rarely occur and if detected, they generally lead to the batteries in question being recalled to remedy the error.

The BMS reduces this risk by monitoring the individual cells to detect any anomalies. If threshold values are exceeded, the BMS takes action. This might take the form of active cooling while charging, switching off the charging process and possibly fully disconnecting the battery pack. Since the BMS is a fail-safe design, any faults to the actual BMS also lead to full deactivation of the battery pack.

Batteries can also fail due to external factors such as external heat, misuse or exposure to extreme conditions such as a collision leading to damage.

As it is hard to establish a failure probability for design and production errors and external factors (Battery University, 2016), various different figures abound concerning failure probability. For example, Larsson et al. (2017) talk about a failure probability of one in one million or lower, whereas the MIT Technology review website suggests a failure probability of about one in 100 million (Bullis, 2013). All in all, the probability of battery failure occurring seems to be relatively low. And although li-ion batteries have improved considerably in recent years, Sun et al. (2020) warn that li-ion battery technologies are still in their early stages of development, resulting in 'the usual teething problems' in the production of the batteries and the charging processes. There are no intrinsically safe li-ion batteries,[28] i.e. the battery pack design cannot completely prevent the release of sufficient energy for thermal runaway. However, battery safety is expected to be further improved and failure probabilities are expected to reduce (Battery University, 2016).

### 1.3.2 Temperature and heat radiation

Temperature (heat) is a measure of how hot or cold something is and is expressed in degrees Celsius. The higher the temperature, the greater the impact on people and construction. Sun et al. (2020) do not provide a comprehensive analysis of temperatures of fires involving electric vehicles and conventional vehicles. However, our literature review brought up several fire tests where temperatures were measured and recorded.

The Fire Protection Research Foundation (2011) measured temperatures of more than 600 °C during fires in battery cells. Peng et al. (2020) indicate maximum flame temperatures of 798 °C, 807 °C and 863 °C for batteries with a state of charge (SOC) of 50%, 75% and 100%, respectively. Lam et al. (2016) set fire to electric and conventional vehicles. Similar temperatures in the 800 +/- 100 °C range were measured for both types of vehicles during similar periods (5 to 30 minutes). This data has led us to conclude that there is no significant difference between fires involving electric and conventional vehicles in terms of temperature levels.

Another measure of the impact of the fire is heat radiation (on the structure, for example). Again: the higher the heat radiation, the greater the impact on people and construction. Heat radiation ($kW/m^2$) is the amount of heat (kW) released per unit of floor area ($m^2$) during

[28] In this context, intrinsically safe batteries would be the most fundamental improvement to the fire safety of electric vehicles. Responsibility for this lies with the manufacturers of electric vehicles.

combustion of the flammable materials present. This report is concerned with the amount of heat released as a result of the burning battery pack and the electric vehicle itself. Sun et al. (2020) indicate, based on Wang (2018)[29], that the heat radiation from an electric vehicle with a 100% charged battery pack (a state of charge of 100%) is similar to the heat radiation from a conventional vehicle.

### 1.3.3 Heat release rate

The intensity of the fire is expressed as the heat release rate, which is usually expressed in MW (megawatts). If a battery pack catches fire or is involved in a fire, the energy content of the battery pack contributes to the total heat release rate.

The heat release rate (HRR) is the speed at which heat develops as a result of fire, mostly measured in joules per second or watt. Megawatt or kilowatt are used to make this easier to quantify.

The heat release rate is relevant, as this determines how quickly air and objects heat up, how fast the fire grows and spreads and how much smoke is released per second. This is the reason why the fire scenario for fires in indoor car parks is represented by the heat release rate curve rather than by a temperature curve (DGMR, 2015).

Several comparative studies have been conducted into the heat release rate of electric vehicles and conventional (fossil fuel-powered) passenger vehicles.

Explanation of abbreviations:

**List of the Heat Release Rate (HRR) of EV in Recent Full-Scale Fire Tests, Where tPHRR and THRR are the Time to Reach PHRR and Total HRR, Respectively**

| Type | Vehicle | Weight before test (kg) | Battery or fuel capacity | PHRR (MW) | TPHRR (min) | THRR (GJ) |
|---|---|---|---|---|---|---|
| BEV | 2011 Nissan Leaf [94] | 1520 | 24 kWh | 6.3 | 40 | 6.4 |
| | Unknown [95] | 1122 | 16.5 kWh | 4.2 | ~ 25 | 6.3 |
| | Unknown [95] | 1501 | 23.5 kWh | 4.7 | ~ 20 | 8.5 |
| | Vehicle 1A [91] | Unknown | 100% SOC | 6 | 7 | |
| | Vehicle 1B [91] | Unknown | 85% SOC | 6 | 6 | |
| | Vehicle 2 [91] | Unknown | 100% SOC | 7 | 10 | |
| | 2014 Vehicle A [98] | 1448 | 'Large' LIB 100% SOC | 6.0 | 7 | |
| | 2013 Vehicle A [98] | 1475 | 'Large' LIB 80% SOC | 5.9 | 5.8 | 4.9 |
| | 2013 Vehicle B [98] | 1659 | 'Large' LIB 100% SOC | 6.9 | 10.2 | 4.7 |
| PHEV | Small PHEV [91] | Unknown | Unknown | 6 | ~ 7 | |
| | Large PHEV [91] | Unknown | Unknown | 8 | 7.5 | |
| | 2013 Vehicle C [98] | 1466 | 'Small' LIB 85% SOC & full tank of gasoline | 6 | 7.5 | 4.6 |
| | 2014 Vehicle D [98] | 1711 | 'Medium' LIB 100% SOC & full tank of gasoline | 7.9 | 8.3 | 5.9 |
| ICEV | Unknown [95] | 1128 | Full tank of diesel | 4.8 | ~ 20 | 6.9 |
| | 2003 Honda Fit [94] | 1275 | 10 L of gasoline | 2.1 | 35 | 4.3 |
| | Unknown [95] | 1404 | Full tank of diesel | 6.1 | ~ 30 | 10 |
| | 2015 Vehicle A [98] | 1096 | Full tank of gasoline | 7.1 | 6 | 3.3 |
| | 2013 Vehicle B [98] | 1344 | Full tank of gasoline | 10.8 | 8 | 5.0 |
| | Unknown [91] | Unknown | 40–50 L gasoline | 7–9 | ~ 7 | |

BEV = battery electric vehicle (fully electric)

PHEV = plug-in hybrid electric vehicle (hybrid vehicles that use both a battery pack and fossil fuel)

ICEV = internal combustion engine vehicle, fossil fuel-powered cars

PHRR = peak heat release rate (in MW)

TPHRR = time to peak heat release rate (in minutes until the PHRR is reached)

THRR = total heat release rate

**Figure 1.2 Fire capacities of different types of vehicle (Sun et al., 2020)**

Sun et al. (2020) have summarised the studies known to them in Figure 1.2 on the previous page and have concluded, based on this summary, that the peak heat radiation for electric

[29] Study on fire and fire spread characteristics of lithium ion batteries. In: 2018 China national symposium on combustion.

vehicles and fossil-fuelled vehicles is similar (approx. 6 MW). The range of the average times needed to reach the peak is slightly wider for electric vehicles (6 to 40 minutes) than for fossil-fuelled vehicles (6 to 35 minutes). The total heat released from electric vehicles ranges from 4.7 to 8.5 GJ. This ranges from 3.3-10 GJ for fossil-fuelled vehicles.

Several studies have been conducted into the heat release rate of electric vehicles and their battery packs (Lecocq et al., 2014; Watanabe et al., 2012; Larsson et al., 2017). Although many different variables influence the heat release rate (state-of-charge of the battery pack, storage capacity, et cetera), and different variables are identified in different studies, Sun et al. (2020) concluded that the heat release rate of an electric vehicle is comparable to that of a conventional passenger vehicle. This is also confirmed in the full-scale experiments conducted by RISE (2020). For electric vehicles with a power of around 15-25 kWh, the heat release rate is approx. 4-6 MW. The energy storage capacity of battery packs in electric vehicles has continued to increase, to currently more than 100 kWh. This has also resulted in an increase in heat release rates to approx. 8 MW (Sun et al., 2020), which is significantly higher than the average heat release rate (approx. 6.8 MW) of a mid-range conventionally powered vehicle (Spearpoint and Tohir, 2013). Spearpoint and Tohir (2013) did not make a distinction between the fuel in the tanks of vehicles that were part of the research, i.e. petrol or diesel. The energy content of petrol is about 32 MJ/litre, the energy content of diesel is about 36 MJ/litre. The operational range of a 100kWh electric vehicle is approx. 400 kilometres. The range of a conventionally powered vehicle (with a tank capacity of 50 litres of petrol) is approx. 650 kilometres. An electric vehicle therefore needs more battery capacity (i.e. more than 100 kWh) to travel the same distance of 650 kilometres. This also leads to a higher heat release rate. This approach is also true for smaller vehicles whose battery packs have a capacity of roughly 50 kWh. Due to the lower battery pack capacity, the heat release rate is lower than it would be in the case of a 100-kWh battery pack.
This is because the heat release rate per kilometre travelled in an electric vehicle is greater than it would be for a fossil-fuelled vehicle.

There is also a difference between conventional and electric vehicles in terms of the heat (energy) released by the fuel with a comparable operational range. An electric vehicle has a battery pack of approx. 90 kWh for an operating range of 400 kilometres. A conventional vehicle has a 30-litre petrol tank for the same distance. The energy content of the battery pack is 2.3 GJ (90 kWh x 0.0036 x 7 (7 is a factor assumed by Sun et al. for 'heat of flaming combustion' (the difference between the energy stored and the energy released due to combustion of the battery pack)), compared to 1.0 GJ for the petrol tank (Sun et al., 2020). The consequence is that a fire involving an electric vehicle requires a larger firefighting effort than a fire involving a conventional vehicle. In this context, it should be noted that the capacity of fuel tanks of conventional vehicles is often more than 30 litres which logically means they have a larger energy content as well.

### 1.3.4 Fire development

Fire development is defined as the development of the temperature and heat release rate of a fire over time. It should be noted that here we are comparing the fire development of fossil fuels versus the fire development of a battery pack (and not that of the entire car and the interior). The fire development of car interiors is comparable for both types of car, assuming that similar materials are used (Sun et al., 2020).

The fire curve of hydrocarbons, such as diesel, is such that the temperature rises very rapidly in the first few minutes and the fire therefore develops rapidly. The plastic tanks can fail, due to which the fuel is suddenly released and catches fire. The speed of development is often lower for battery packs. The battery cells need some time to warm up, emit gas and then take part in the combustion. The consequence of this is that, in comparison to conventional vehicles, the fire will develop more evenly in the first few minutes (0.2 °C/min) and will only start to exponentially develop (temperature rise of more than 10 °C/min) when the thermal runaway occurs. A 'normal' passenger car fire generally has a burn time of just over half an hour with a maximum heat release rate of about 5 MW after about 10-15 minutes. A fire involving an electric vehicle develops more slowly. Without any extinguishing intervention (by the fire service), an electric vehicle burns out in approx. 90 minutes (NFPA, 2013). If the fire is extinguished, the energy remains in the battery for longer and the fire can keep reigniting for several hours after it started (Sun et al., 2020).

### 1.3.5 Combustion products

The combustion of battery packs releases hazardous substances. They include corrosive substances from the electrolyte and combustion products from the plastics used (including from the packaging). In this mixture of hazardous substances, the usual combustion products such as methane ($CH_4$), carbon monoxide and carbon dioxide ($CO$ en $CO_2$) and hydrogen ($H_2$) are released, as well as toxic gases such as hydrogen fluoride (HF) and hydrogen chloride (HCl) (Sun et al., 2020). Larsson et al. (2017) concluded that significant amounts of HF are released during a fire involving an electric vehicle fire (about 20-200 mg HF per Wh). A battery pack with a capacity of 100 kWh can emit 2-20 kg of HF, depending on the battery pack's state of charge. Fire tests by RISE (2020) also showed increased concentrations of HF in fires involving electric vehicles compared to conventionally fuelled vehicles.

Based on the research by Wingfors, Fredman and Thunell (2019), a firefighter wearing personal protective equipment (PPE) can carry out a ‘safe’ attack if proper occupational hygiene is assumed and they are not exposed to the smoke for more than 20-30 minutes. Wingfors, Fredman and Thunell (2019) described that at 4000 parts per million (ppm) the PPE from Sweden (comparable to Dutch PPE) is resistant to HF penetration for more than 20 minutes.

The study by Lecocq et al. (2014) specifically aimed to measure and compare releases of combustion products from electric and conventional vehicles. They summarised the results measured in Figure 1.3 (see the section below). They conducted comparable fire tests on both electric (EV) and conventional (ICE) vehicles that were as similar to each other as possible, from two manufacturers. The row on the far left shows the elements measured.

RIVM research (2021) showed that HF, being a reactive substance that binds to other substances and smoke particles, forming deposits on the floor, walls and ceiling. This deposition of HF reduces the concentration of HF in smoke by more than half within 10 to 20 minutes. Firefighting clothing becomes more contaminated due to the deposition of HF.

The main conclusion is that there is hardly any difference in the toxic gases generally produced by electric or conventional cars that are on fire. However, more hydrogen fluoride acid (HF) appears to be produced when an electric vehicle is on fire: approx. 1.8 times more than is produced if a conventionally fuelled vehicle is on fire (Lecocq, et. al., 2014).

The flammability of the gases released during a thermal runaway should also be taken into account for an electrical vehicle. As mentioned above, the various battery cells start degassing as soon as they go into thermal runaway. If these gases are not immediately ignited by a fire, an explosive mixture of fire gases can build up in a confined, enclosed or poorly ventilated space (Bisschop et al., 2020). If the lower explosion limit of this gas mixture is reached and the mixture is ignited, a fire gas explosion can occur.

| *Tested element* | *EV manufacturer 1* | *ICE vehicle manufacturer 1* | *EV manufacturer 2* | *ICE vehicle manufacturer 2* |
|---|---|---|---|---|
| *Test* | *Fire* | *Fire* | *Fire* | *Fire* |
| *Nominal Voltage (V)* | 330 V [a] | - | 355 V [a] | - |
| *Capacity (Ah)* | 50 Ah [a] | - | 66,6 Ah [a] | - |
| *Energy (kWh)* | 16,5 kWh [a] | - | 23,5 kWh [a] | - |
| *Mass (kg)* | 1 122 kg | 1 128 kg | 1 501 kg | 1 404 kg |
| *Lost mass (kg)* | 212 kg | 192 kg | 278,5 kg | 275 kg |
| *Lost mass (%)* | 19% | 17% | 18,6% | 19,6% |
| **Online gas analysis – total quantity of emitted gases (FTIR and online analyzers)** | | | | |
| ***$CO_2$ (g)*** | **460 400** | **508 000** | **618 490** | **722 640** |
| *$CO_2$ (mg/lost g)* | *2 172* | *2 646* | *2 220,8* | *2 627,8* |
| ***CO (g)*** | **10 400** | **12 040** | **11 700** | **15 730** |
| *CO (mg/lost g)* | *49* | *63* | *42* | *57,2* |
| ***THC (g)*** | **2 430** | **2 380** | **2 860** | **2 730** |
| *THC (mg/lost g)* | *11,5* | *12,4* | *10,3* | *9,9* |
| ***NO (g)*** | **500** | **679** | **770** | **740** |
| *NO (mg/lost g)* | *2,4* | *3,5* | *2,8* | *2,7* |
| ***$NO_2$ (g)*** | **198** | **307** | **349** | **410** |
| *$NO_2$ (mg/lost g)* | *0,9* | *1,6* | *1,3* | *1,5* |
| ***HF (g)*** | **1 540** | **621** | **1 470** | **813** |
| *HF (mg/lost g)* | *7,3* | *3,2* | *5,3* | *3* |
| ***HCl (g)*** | **2 060** | **1 990** | **1 930** | **2 140** |
| *HCl (mg/lost g)* | *10* | *10,4* | *6,9* | *7,8* |
| ***HCN (g)*** | **113** | **167** | **148** | **178** |
| *HCN (mg/lost g)* | *0,5* | *0,9* | *0,5* | *0,6* |
| **Thermal effects** | | | | |
| *Maximal HRR (MW)* | 4,2 MW | 4,8 MW | 4,7 MW | 6,1 MW |
| *Heat of combustion (MJ)* | 6 314 MJ | 6 890 MJ | 8 540 MJ | 10 000 MJ |
| *Heat of combustion/unit mass loss (MJ/ kg)* | 29,8 MJ/kg | 35,9 MJ/kg | 30,7 MJ/kg | 36,4 MJ/kg |

[a] *Characteristics of the battery pack of the EV.*

**Figure 1.3 Results of measurement of combustion products of EVs and ICEVs (Lecocq et al., 2014)**

## 1.4 Differences between electric and conventional vehicles

Now that we have covered the physical characteristics of electric vehicles, some relevant differences in safety between electric vehicles and fossil-fuelled conventional vehicles are listed below.

### 1.4.1 Probability of a fire occurring in an electric vehicle in an indoor car park

The probability of a fire starting in a parked electric vehicle in an indoor car park is unlikely to be higher than the probability of a fire starting in a fossil-fuelled vehicle (Sun et al., 2020).

We can expect that a consequence of charging the battery packs of electric vehicles in an indoor car park will be that the probability of fire does increase, because

> an additional activity is being carried out in the indoor car park introducing several additional possible causes of fire (see below)

> developments of this technology are taking place rapidly and therefore the technology is still in the 'teething problems' phase

> it cannot be assumed that an existing electrical installation is safe enough: consider, for example, an electrical installation that cannot handle the amperage required for charging, is damaged or is poorly maintained.

The extent to which production defects in battery packs and their ageing play a role in the probability of fire, is still unknown. UL (2013) researched the effects of ageing on the safety of li-ion batteries. A test showed that heat-generating reactions occurred in older specimens sooner than in new specimens, a possible consequence of which was that the temperature at which thermal runaway occurs will be reached sooner. However, a BMS reduces the risk of this failure mechanism.

Based on TWV (2015), it is plausible to assume that increased internal resistance and reduced capacity are examples of the main ageing parameters of li-ion batteries. The increase in internal resistance will not only have a negative impact on battery performance (loss of power), but also on energy efficiency. The greater resistance increases heat development in the cells, which in turn will further strengthen and accelerate ageing effects.

However: as batteries age, their maximum possible State of Charge (SoC) decreases compared to that of a new battery. Since the intensity of a thermal runaway depends on the SoC, the intensity of the thermal runaway decreases as the battery ages (Essl, Golubkov & Fuchs, 2021). Furthermore, an older battery that is subject to thermal runaway produces fewer flammable gases than a new battery.

Finally, it is worth mentioning that any failures in the battery pack of the electric vehicle are flagged by the BMS (Battery Management System)[30]. However, it is the electric vehicle owner's responsibility to have the vehicle properly serviced if there is a failure and not to park in an indoor car park during that time.

[30] Any faults affecting other parts of the car, for example a flat tyre, are communicated by the on-board computer of the vehicle.

In short: the number of uncertainties regarding the quality of li-ion cells increases as battery packs age. The share of ageing electric vehicles will also increase in the next few years. Since our literature review did not bring to the fore any publications on the extent of these kinds of ageing mechanisms and how they work, it is important that this issue be included in future research on the probability of fire occurring in electric vehicles, in order to understand how these mechanisms work and how often they occur.

### 1.4.2 Additional fire causes

Parking and charging electric vehicles in indoor car parks have introduced several causes of fire which do not exist with conventional vehicles (Sun et al., 2020):

- improper/damaged cable or charging station
- problems with the battery management system directly or indirectly leading to a thermal runaway and fire
- cars colliding with a charging station
- electric vehicles with a 'defective' battery pack, whose failure has gone unnoticed, entering the indoor car park

There is no information yet as to possible additional fire safety risks of fast charging stations. For example, it is not clear whether fast charging stations will be compatible with all battery packs.

### 1.4.3 Fire development

- Fires in electric vehicles develop differently: they develop more slowly and last longer.
- Fires in electrically powered vehicles can involve repeated minor explosions, parts flying about and flash fire.
- Electric vehicles are expected to increase the probability of 'travelling car fires'. Travelling car fires are fires in indoor car parks that pass from one vehicle to the next and 'travel' through the car park, as it were. Because the battery packs of electric vehicles can burn for a long time, the heat radiation between the vehicles is prolonged and the fire travels for a long time. The explosions and flare flames also contribute to this.
- A thermal runaway without direct ignition of the gases it produces can result in a fire gas explosion if the lower explosion limit is reached and an ignition source is present.

### 1.4.4 Toxic risks

- Electric vehicles produce more hydrogen fluoride (HF) during a fire than conventionally powered vehicles.
- There is lithium oxide in burnt li-ion battery packs. If immersed in water, lithium oxide reacts with water to form lithium hydroxide. The pH of cooling water (which is still in contact with a burnt-out battery pack) can continue to rise to ever higher levels over time (RIVM, 2019). Here, the degree of contamination also depends on how badly damaged the battery pack is.
- Research has shown that the impact on the environment of extinguishing water used to extinguish fire involving electric vehicles is hardly any greater than that of extinguishing water used to put out fires involving conventional vehicles (NFPA, 2013). This means that this water can be drained through the sewers. The pH of cooling water in an immersion tank (which is still in contact with a burnt-out battery pack) can continue to rise to ever higher levels over time and may have a greater impact on the environment than the water used to extinguish electric vehicles.

### 1.4.5 Escape safety

- The generation of toxic combustion products can create a situation which makes escape more difficult. As is also the case with conventional vehicles with plastic parts, the rest of the burning vehicle (especially the plastic parts) already creates severely toxic smoke, seriously limiting escape possibilities (RISE, 2020). Systemic health effects from exposure to smoke containing HF from li-ion battery packs seem unlikely.
- The release of HF can cause symptoms. In the event of slight exposure to HF, these symptoms may be limited to skin irritation, whereas severe exposure may cause chemical burns (RIVM. 2021). However, the impact of this increased amount of HF on escape safety is zero: by definition, inhaling smoke from vehicle fires means that a harmful mixture of toxic gases is inhaled, regardless of how the vehicle is powered (RISE, 2020).
- There is a possibility that smoke with an increased HF concentration is dispersed from the indoor car park through open doors to escape routes and stairwells of overhead buildings, or through the open structure (in the case of open indoor car parks).

### 1.4.6 Repressive attack

- The occurrence of explosions, the amount of water needed (cooling capacity), the presence of toxic gases, the fact that it is not known how stable the structure is and how the fire will develop (spread to several cars) affect the execution and outcome of a repressive attack. Compared to a situation without electric vehicles, the risks and uncertainties in connection with repressive attack have increased.
- Electric vehicles whose battery pack is an element in the fire are very difficult or impossible to extinguish because of the closed construction of the battery pack and the repeated reignition of the gases released during the self-propagating thermal runaway.
- A consequence of the fire development is that a fire in a battery pack can only be controlled by prolonged cooling with lots of water. Extinguishing the fire requires water to be applied directly inside the battery pack. Currently, if the battery pack does not feature any special facilities, the most successful way to apply this water is by immersing the vehicle's battery pack in water (IFV, 2021b).
- There is a risk that an electric vehicle which is on fire will start moving.
- Repressive attack requires the firefighters' clothing to be decontaminated because of the toxic and corrosive gases that are released, including large amounts of HF; this is different from conventionally powered vehicles (RIVM, 2021).

### 1.4.7 Risk of concrete rot due to leakage currents

**Description of the risk**

The increase in electric vehicles has led to a shift from the use of alternating current (AC) to direct current (DC)[31]. This has also increased the risk of concrete rebar corroding due to DC leakage currents. This phenomenon is called concrete rot. This is because DC leakage currents are conducted by metal, such as rebar, causing this metal to slowly corrode and eventually dissolve.

This problem is more prevalent with DC than with AC because, in the case of AC, the direction of the current naturally changes (frequency), whereas in the case of DC the current flows in one direction. This change of direction of AC causes the leakage current to cancel itself out, as it were, but this is not the case for DC. The standard solution to this problem is to use a residual current device which switches the installation off if the current or the leakage current exceeds 6 mA. However, if the leakage current remains just below this 6 mA for a long time, the concrete can corrode.

**Description of possible solutions**

There are two possible solutions to this problem: preventing leakage current and providing reverse current. Leakage currents can be prevented by using products that are designed to be leakage current-free. Currently, there are no standards that prescribe this. The other possible solution is to provide reverse currents that emit exactly the same value as the leakage current. This should be included in the installation design for existing devices and/or installations.

[31] https://www.nen.nl/nieuws/dc-en-betonrot

# 2 Scenarios

So far, few case histories are available on fires involving electric vehicles in indoor car parks. Although it is not possible to make any statements about the probability of their occurrence, some realistic scenarios can be sketched that could potentially occur and their effects can be considered. We have decided on three realistic scenarios for this paper. They are described below.

The scenarios serve 'only' as a conceptual framework to arrive at fire prevention and suppression measures as described in chapters 3 and 4 of this paper. Moreover, in practice, firefighters will partly determine the attack strategy based on the scenario they find when they arrive at the fire.

## 2.1 Scenario 1

The li-ion battery pack of the electric vehicle *is on fire*: one passenger vehicle is on fire and this fire continues for a long time.

**Explanation of possible fire cause/fire spread**

The most obvious cause is that the fire started in the battery pack and continues to burn for a long time due to a thermal runaway. The vehicle may or may not be connected to a charging station. So in this scenario, the fire has not spread to other vehicles yet. At this stage of the fire, there are more options for a repressive attack than in the scenarios below (however, see also chapter 4 which gives further details of the limitations of repressive attack in an indoor car park).

## 2.2 Scenario 2

The li-ion battery pack of the electric vehicle *is exposed to heat radiation*: one passenger vehicle is on fire and this fire may possibly spread.

**Explanation of possible fire cause/fire spread**

In this scenario, we assume that a vehicle next to an electric vehicle is on fire. The electric vehicle may or may not be connected to a charging station. The electric vehicle including its battery pack is exposed to heat radiation from the car on fire, which might cause the fire to spread. The heat radiation that the battery pack is exposed to may possibly cause a thermal runaway in the battery pack.
The battery pack can also be exposed to heat radiation due to the failure of the fuel tank of the adjacent car on fire and from a burning puddle of liquid under the electric vehicle.

## 2.3 Scenario 3

Several battery packs of electric vehicles are on fire.

**Explanation of possible fire cause/fire spread**

In this scenario we assume that several electric vehicles are on fire and that their battery packs are also on fire. The vehicles may or may not be connected to a charging station. This scenario may be due to a travelling car fire.

We considered the above scenarios to determine the effectiveness of fire prevention measures (chapter 3), of possible fire-fighting tactics (chapter 4), and to specify measures for each type of indoor car park (chapter 5).

# 3 Measures

## 3.1 Introduction

This chapter details possible measures aimed at reducing fire safety risks in indoor car parks where electric vehicles are parked or charged. We first present the outlines of the recommendation. This is followed by a darkly shaded block of text in which we give either a more detailed explanation of the recommendation or possible alternatives, application conditions and points for further consideration. The measures should not be considered as a complete package that applies to all situations, but as a range of measures which can be used to create a bespoke set of measures to reduce fire safety risks in indoor car parks depending on their construction, layout, etc. Moreover, the measures are not a detailed standard; they enable bespoke arrangements.

We have divided the measures into the following categories[32]:
- architectural measures
- installation measures
- organisational measures
- repressive measures.

Measures are presented that can reduce fire safety risks in indoor car parks in a general sense (and therefore also in indoor car parks where electric vehicles are parked and charged) and measures specifically aimed at parking and charging electric vehicles. Section headings indicate this distinction. Each section first deals with the general measures, followed by the specific measures for parking and charging electric vehicles

The measures have been drawn up in the form of a recommendation that fire service safety consultants can give to:
- the designer/architect
- the consultants involved
- the party applying for an environmental permit to build a new car park
- the builder
- the owner of an existing indoor car park
- the operator of an indoor car park
- the user of an indoor car park.

[32] Since we think that our categorisation suits the broad group of potential users of this paper, we decided not to use a categorisation according to the characteristics scheme for categorising the measures.

## 3.2 Architectural measures

### 3.2.1 General measures

> Take architectural measures to reduce fire spread in the indoor car park.

The main measures that might be considered in this regard are dividing or further dividing the into car park into fire compartments or constructing some form of shielding between vehicles. The compartmentation can be based on the performance requirements of the 2012 Building Decree (compartments with a surface area of up to 1,000 $m^2$), or smaller. This will enable the fire to be confined to a smaller part of the car park and a travelling car fire to be contained depending on the fire compartmentation applied.

Fire compartmentation can be achieved in different ways.

- Physical fire partitions can be created by placing walls/cladding or fire screens between vehicles or around a small number of – possibly electric – vehicles.
- A fire-resistant separation of the indoor car park from other spaces adjacent to the car park (such as storage units for goods) can be created.
- A fire rated sliding door or fire-resistant rolling shutter can be used, but their adverse effects, as explained below, should be considered.

Start from the idea that it should be possible to escape from any fire compartment and that the fire can be approached (for purposes of orientation in connection with escape and the repressive attack).

Actually, dividing or further dividing the indoor car park into fire compartments may have some adverse effects on ways of fighting fires.

- The smaller the fire compartment, the more quickly temperatures can rise and this may lead to flashover conditions.
- It may be more difficult to locate the vehicle on fire and thus fight the fire.

The application of fire compartmentation or additional fire compartmentation therefore requires careful consideration of the advantages and disadvantages outlined and a solution tailored to the situation in question. In this context, from a fire safety point of view, an open, clearly arranged area with a sprinkler system (see section 3.3) is preferable to further division into fire compartments.

If escape routes from, for example, dwellings or other functional uses lead directly to the car park, it is recommended that a smoke vent be fitted there so that smoke does not enter the escape route directly. Another possibility is installing doors with improved smoke resistance matching European classification Ra and R200 between the indoor car park and the escape route. Such doors have been mandatory since 1 July 2021 for the entrance doors of new-build residential buildings or when renovating such buildings[33]. A final recommendation is to protect pipes for infrastructure that are part of the building structure, such as the energy supply to an overhead building that may run through the indoor car park.

### 3.2.2 Measures specifically aimed at electric vehicles

> Consult a structural engineer on possible additional protection of the building structure near parking spaces with charging facilities.

[33] https://www.rijksoverheid.nl/actueel/nieuws/2021/03/05/wijzigingen-bouwregelgeving

Possible measures are fire-resistant cladding or creating a more robust construction at the charging points. Fire-resistant cladding reduces the thermal load on the structure; more robust construction increases resistance to collapse.

This measure can be particularly effective in 'scenario 1' (see chapter 2: one passenger car on fire and burning for a long time). In scenarios 2 and 3 (e.g. travelling car fire or a compartment fire), cladding or a more robust construction in certain sections is no longer effective. A possible measure for such scenarios is to configure the entire building structure such that it offers greater fire resistance and is less likely to collapse. If there is another building over the indoor car park, the latter option is a wise decision anyway so that the risk of damage and/or collapse in case of fire can be reduced. The objective of these measures is to increase the probability of the indoor car park surviving 'a burn-out scenario'. A burn-out scenario mains that no action is taken to extinguish the fire, but the fuel is left to burn up.

Actually, further research is needed to determine the effects of fires in electric vehicles on the structure of indoor car parks, in view of the differences in fire development compared to conventional vehicles that catch fire and flame egress (such as a flare with a short-term peak load). It should also be borne in mind that the designs and dimensions of the structures of indoor car parks are generally based on a normative fire development. The question is what effect an anomalous fire development, such as with an electric vehicle, has on the structure.

> Place collision protection devices in front of the charging stations or place the charging stations in a location where cars cannot collide with them.

The first option can be achieved, for example, by placing one or more posts or a railing in front of the charging station so that it cannot be damaged due to a collision. The alternative option is to place the charging station in a location where vehicles cannot collide into it (e.g. 1.5 – 2 m above the floor).

## 3.3 Installation measures

### 3.3.1 General measures

> Install an effective fire suppression system, such as a sprinkler or water mist system.

An automatic fire suppression system can independently contain fire to a small number of cars (localised fire) for a long time, thus preventing a travelling fire. This localised fire results in a short-lived (localised) limited thermal load on the load-bearing structure of the car park (IFV 2021c). The consequences of this are that:

> the risks of collapse, fire spread and smoke spreading to other parts of the building and the surrounding area are reduced,
> the risk of casualties is reduced,
> the probability that anyone present can escape without help is increased,
> escape and attack routes remain intact is increased,
> demand for the fire service to render assistance (extinguishing and rescuing) is reduced,
> the probability that the fire service will be able to carry out an effective attack and keep the situation manageable is greater.

Such a system can also be used to cool and dilute gases. More information can be found in the CCV fire safety inspection scheme.[34]

[34] https://hetccv.nl/fileadmin/Afbeeldingen/Certificatie-en-inspectie/Inspectie_brandbeveiliging/CCV-Inspectieschema_Brandbeveiligingssysteem__VBB-BMI-OAI-RBI__versie_12.0__01-01-2019_.pdf.

As regards electric vehicles, it should be noted that such a system cannot extinguish a fire in a car: water droplets simply cannot enter the battery pack and reach the seat of the fire. However, the probability of the fire growing and spreading to adjacent structures and vehicles can be reduced (RISE, 2018). Further research is needed to determine whether a sprinkler or water mist system is also suitable for containing an incipient fire involving an electric vehicle, or whether this always requires an additional fire service attack. Further research is also needed to determine which type of fire suppression system is best suited to a fire scenario involving electric vehicles.

A possible future development: If a sprinkler is installed in the battery pack, it can properly cool the cells affected by a thermal runaway and it can lead to the fire actually being extinguished (RISE, 2019a).

> Install a fire detection system with smoke and/or heat detectors and a gas detection system that detects carbon monoxide.

An automatic fire alarm system with full detection is already mandatory under the 2012 Building Decree for enclosed indoor car parks of more than 1,000 $m^2$. But fast detection is also very important in car parks of less than 1,000 $m^2$, especially at night. It ensures that the fire is detected and a fire alert is put out quickly, so that actions can be taken to minimise the incident, but this depends on proper alarm follow-up by an in-house emergency responder or residents' organisation. This is an important point to consider, particularly in residential buildings. A system that tackles the source of the fire (such as a sprinkler system) is preferable, as this increases the probability that the incident will be minimised.

There are also other options besides fire detection in the car park itself. Battery pack-integrated technologies to detect pressure, gas generation, changes in volume etc. are being developed in the US (RISE, 2019). It is likely that future vehicles will feature more of such innovative detection capabilities.

A study testing several different detectors showed that CO detectors are the fastest to give an alert (DNV-GL, 2019). In this context, it should be noted that CO detectors exist in the Netherlands (often in conjunction with LPG) but not as a form of fire detection. Dutch standardisation and certification are not geared to this either.

In general, sprinkler systems also feature thermal detectors. The application of the equivalence principle (Article 1.3 of the 2012 Building Decree) may lead to optimisation and avoid duplication in the form of a separate fire alarm system (with its own thermal detectors). However, this involves a bespoke solution that will have to be tailored to the situation in question (*Dutch Adviescommissie toepassing en gelijkwaardigheid bouwvoorschriften* [Advisory Committee on Application and Equivalence of Building Regulations], 2016).

> Consider extra detection, such as fire detection using 'ribbon detection' (also suitable for indoor car parks and requiring little maintenance).

Extra detection and alerting will enable evacuation to be initiated faster and actions to be taken to minimise the incident.

> Consider applying displacement ventilation.

Displacement ventilation is used in order get a view of the fire and increase the probability of an offensive interior attack. An example of how this might be done is by creating a sufficiently high air speed along the full cross-section of the indoor car park (e.g. 1.5 m/s according to NEN 6098). This might easily lead to 40-fold ventilation. However, this will only improve firefighting conditions, since in most cases the ventilation does not kick in until people have escaped from the car park. Another setback is that the principle of displacement ventilation works only in tunnel-shaped indoor car parks (the system requires a specific shape and design to work) and its added value is not yet fully known.

> Consider installing a smoke and heat extraction system.

The use of smoke and heat extraction systems (mostly in the form of zero to ten-fold ventilation) can also contribute to the removal of combustion products but, depending on where they are positioned, they can also cause unwanted fire and smoke spread within the indoor car park. This option is basically only effective if the fire is out; it can then be applied to clear the car park of smoke. Many existing indoor car parks of more than 1,000 m$^2$ feature such a system. but these types of systems have not been used since 2012 as their added value was found to be virtually non-existent and the Dutch LNB guideline which used to prescribe them is no longer effective.

### 3.3.2 Measures specifically aimed at electric vehicles

> Install a facility that enables the fire service[35] or others present to cut the power to all charging facilities all at once in case of an emergency, preferably combined with a signal (a red light, text sign, etc) indicating that the current to all the charging facilities has actually been cut.

There are several possible options for cutting the power.

> A system where the charging facility is automatically switched off by a fire alarm system that is already present.

> A vandal-proof emergency button placed at the main entrance or in another strategic location (the exit or entrance to the indoor car park). An example might be a neon switch that the fire service can switch off by means of a hook. Clearly identify the emergency button and coordinate its exact location, design and recognisability with the fire service.

> An emergency switch/button on each charging station/facility that immediately interrupts its power supply. It can be located on or next to the charging station. Mark the emergency switch/button so that it can be easily identified.

Alternatively, a floor plan could be installed at the fire service entrance indicating the location of the meter box for the fire service. If several meter boxes are present, indicate the meter box with the charging station connections, as well as the meter box with the main switch for the entire building (if the other meter box cannot be reached). Clearly indicate in the meter box how all charging stations/facilities can be disabled.

Points for consideration.

> Check whether the capacity of the power supply is sufficient for simultaneously operating a fire safety facility (e.g. smoke and heat removal) and the charging facilities. If not, the charging facilities must be switched off automatically anyway, since the fire safety facility will not work otherwise.

> The power supplies to the charging stations in private car parks are sometimes connected directly to residential units. In that case, the electrical system will have to be designed such that central deactivation of the charging stations is made possible.

[35] It is expected that the future Dutch Building Works and Living Environment Decree will stipulate such a facility as a mandatory requirement: https://www.internetconsultatie.nl/verzamelwijzigingbbl2021.

> Follow these guidelines for the locations of the parking spaces for electric vehicles, the charging stations or other charging facilities:
  – do not place them in locations where ventilation air is supplied, e.g. an open façade of the car park.

This will prevent combustion products spreading into the car park if an electric vehicle is on fire. Actually, in practice the car entrance to the car park is often the inlet for ventilation air. From a repressive point of view, locating electric vehicles near the car entrance is actually preferred (see section 3.5). It is recommended that, *in this situation,* the importance of firefighting (to prevent fire, damage, nuisance and the like from spreading) should take precedence over reducing smoke spread in the car park.

Food for thought: smoke spread negatively affects escape safety. Assuming that people will leave the car park immediately after the fire is detected and/or the fire alarm is raised, they will only briefly be exposed to toxic or other combustion products due to smoke dispersion. However, those who cannot escape, or who take longer to escape, can be exposed to toxic or other combustion products for longer. Depending on the design and construction of the car park, ventilation in the indoor car park can have both favourable and unfavourable effects on reducing the spread of toxic combustion products.

  – if possible, on an open upper parking deck of a car park.

If located on the upper parking deck, the load on the structure and the smoke nuisance from smoke within the structure will be minimal. From the perspective of a repressive attack, the higher-level parking decks are not always easily accessible. This may create a dilemma which requires the local situation to be considered. A location close to the vehicle entrance of the car park is preferred, since a fast repressive attack might then be possible, depending on the actual situation, and there is a better probability that the vehicle can be towed out of the car park. In practice, the possibility of locating the parking spaces for electric vehicles near the car entrances decreases as the number of electric vehicles increases. Locating them on the upper parking deck is then an alternative.

  – not close to a pedestrian escape route.

Do not locate charging stations/facilities near pedestrian escape routes, as toxic and caustic decomposition and combustion products may be released in a thermal runaway and can spread. Such substances can impact on escape possibilities, for example if they accumulate near the entrance to a stairwell, or flow into the stairwell. From a repressive point of view, the preferred fire location would be close to the fire service entrance. However, the fire service entrance can also be an escape route. In such a situation, there are conflicting safety interests at play and so consideration has to be given to which would be the better option. It is recommended that, *in this situation,* repressive considerations should prevail and that, if the fire service entrance is also an escape route, the electric vehicles should be positioned as close as possible to the fire service entrance. This is because an indoor car park does not tend to be an area with many people in it. Assuming that people will leave the car park immediately after the fire is detected and/or the fire alarm is raised, they will only briefly be exposed to toxic or other combustion products due to smoke dispersion. However, those who cannot escape, or who take longer to escape, can be exposed to toxic or other combustion products for longer. Depending on the design and construction of the car park, ventilation in the indoor car park can have both favourable and unfavourable effects on reducing the spread of toxic combustion products.

> Smoke removal ducts should be positioned to minimise the probability of any nuisance to the environment being caused by combustion products escaping from the indoor car park.

There are several different possibilities for the locations of ducts to remove smoke from the car park.
> Smoke removal ducts should not be positioned near windows or doors, the intake openings of the air handling system/ventilation ducts, or locations from which firefighters need to take repressive action.
> The upper side of the smoke removal duct in a location should be positioned such that the smoke and combustion products do not cause any nuisance to the direct surroundings (i.e. do not let them discharge onto market squares etc.).
> Position smoke removal ducts at a sufficient distance from the escape routes of the building itself (e.g. a residential building located over the car park), and from the escape routes of surrounding buildings.

## 3.4 Organisational measures

### 3.4.1 Measures specifically aimed at electric vehicles

> Consider the possibility of not facilitating charging and/or parking of any electric vehicles in the indoor car park if it is not possible to achieve the desired level of safety.

As an extreme measure, if the application of architectural or installation measures does not lead to the desired level of safety and an acceptable residual risk in existing indoor car parks, the competent local authority can also consider not permitting the charging and/or parking of electric vehicles in the indoor car park (restriction of use).

> Make sure that any fire alarms are followed up on promptly.

To improve the odds for fighting a fire involving an electric vehicle, both rapid fire detection and prompt follow-up of the fire alarm are important. This might be achieved by linking the fire detection system to a fire alarm system that relays the fire alert to a private incident room. The private incident room verifies the alarm and alerts the fire service if necessary.

> Give residents/users clear instructions so that they know what to do in case of emergencies and record these instructions in 'Instructions on what to do in case of a fire'.

It is imperative that the users of the car park know what to do in case of a fire. Incidents involving electric vehicles differ from those involving fossil fuel vehicles in some respects. Practical instructions to residents/users of car parks could include:
> if the battery management system in your car is defective or if the system gives an error message, do not park your car in the indoor car park, but contact the dealer/service company
> keep your distance if any gases/smoke are released
> press the emergency button to stop the charging process if there is an emergency

> alert the fire service and tell the fire service incident room that the incident concerns a fire involving an electric vehicle
> meet the fire service and give them the necessary information.

In practice, such personal instructions only work for non-public car parks. In public car parks one might consider providing instructions on the customary evacuation floor plans posted on the walls near the entrances.

> Make proper arrangements for safe use of charging stations

The users of charging stations are an important factor in preventing incidents. It is recommended that the applicant or the future owner/ Apartment or Homeowners' Association draws up a user agreement for the safe use of the charging stations/facilities, setting out, for example, the following possible rules. Have users sign the agreement to confirm that they have taken note of the rules and will abide by them (in case of an Apartment Owners' or Homeowners' Association). These agreements and rules aim to reduce the probability of failure of the combination of charging station and battery pack.

Having users sign a user agreement for a public car park is not possible in practice. In that case, the possible rules below (if applicable) can be clearly displayed near the charging facility in the form of user instructions.

> Only use approved, undamaged charging cables.
> Immediately have the charging facilities serviced if they show any visible defects or damage.
> Only charge using modes 3 or 4 and prohibit mode 2.
> Place the charging cable such that:
  – no other vehicles can drive over the cable
  – the cable cannot get caught on another vehicle, damaging it
  – people cannot trip or get caught on the charging cable.
> Hang the charging cable in a bracket installed next to the charging station/facility or store it carefully in the vehicle.
> Stop the charging process before connecting the charging cable to or disconnecting it from the charging station/facility. This will prevent sparking.
> Do not place any flammable items near or on top of the charging stations/facilities.
> Visually inspect the charging cable at regular intervals and have it repaired or replaced immediately if damaged or defective.

> Contact the insurance company to check that charging facilities are allowed under the existing policy.

## 3.5 Repressive measures

Fire service deployment must not be seen as a kind of substitute for fire prevention measures, since the fire service has a best-efforts obligation and does not have an obligation to achieve a specific result. And what's more, the outcome of a repressive attack is by definition uncertain.

### 3.5.1 Measures specifically aimed at electric vehicles

> Position parking spaces and charging stations/facilities:
  – close to the vehicle entrances and exits of the car park as much as possible

– at street level as much as possible.

This measure is relevant from an incident response point of view as it aids accessibility. It increases the probability that a fire can be fought from the outside or that a vehicle can be removed from the car park more quickly.

However, it should be borne in mind that this measure is only future proof to a limited extent and it cannot be implemented in practice in all cases, because:
> in the future, many cars will be electric cars
> residents will want to charge their cars in their own parking spaces.

> Make sure that the charging stations are concentrated near a specific location in the car park and provide relevant signage at the entrance to the car park.

Identification of electric vehicles is essential to enable proper and quick action. In practice, the fire service often uses the CRS (Crash Recovery System) if the vehicle's licence plate is still visible. It is then preferable that the fire service knows that there can be electric vehicles at a pre-agreed location in the indoor car park, rather than being randomly dotted around the car park. However, it should be considered that such a clustering of electric vehicles can lead to a travelling car fire. The effects of such a travelling car fire involving electric cars compared to the effects of such a fire involving conventional vehicles should be researched in more detail.

> Make sure that a parking space with a charging station/facility can be easily identified.

To enable fast identification by the emergency services, a parking space with a charging station should be clearly marked on the car lane. In general, this is already the case in most indoor car parks to prevent fossil-fuelled vehicles from making using of these parking spaces.

> Set up the fire extinguishing water supply/water extraction for the presence of electric vehicles.

A lot of fire extinguishing water is needed for long-term cooling of electric vehicles. Chapter 4 (firefighting tactics) discusses this in more detail.

> Draft a plan for how an electric vehicle can be removed from the car park once it has been extinguished.

To prevent an electric vehicle from catching fire again in the car park after being extinguished, it must be removed from the car park by the fire brigade in cooperation with the salvage company. It can then be transported in a special salvaging container, so that it can eventually continue to react in a water tank until the thermal runaway has stopped. Involve a properly equipped salvage company early in the incident.

# 4 Firefighting tactics

This chapter discusses the repressive measures that can reduce the consequences of a fire in an electric vehicle and enable possible repressive action. These are consistent with the basic principles of firefighting (IFV, 2018a).

Compared to a situation without electric vehicles, the risks and uncertainties of repressive attack have increased. Fires involving electric vehicles involve additional issues that firefighters need to consider during repressive deployment which are not relevant to fires not involving electric vehicles:

- unfamiliarity with how the fire may develop (spread to more cars)
- a longer burning time (the battery pack might reignite due to a thermal runaway)
- the occurrence of explosions
- the creation of a flare fire
- the presence of specific toxic gases
- a fire in a battery pack is very difficult to extinguish because it can repeatedly reignite
- a fire in a battery pack in combination with a thermal runaway can only be stopped by long-term cooling or immersion in water because of the closed construction of the battery pack
- the need for a lot of water
- the fire deployment may be lengthy
- the presence of high voltage (however, if extinguishing from a distance, the probability of electrocution is negligible).

More information on fire service action in case of an accident or fire involving an electric vehicle can be found in:

- *Richtlijn voor brandweeroptreden bij elektrische voertuigen* (IFV, 2020c)
- Zakkaart handelingsperspectief bij E-voertuigen
- Aandachtskaart bestrijding incident e-voertuig (elektrisch of hybride).

## 4.1 Basic principles of firefighting

The fire service follows several basic principles for fires in a building structure and has arranged the tactics and objectives of firefighting in the ‘quadrant model’. The goal of firefighting can be to prevent fire growth or to extinguish the seat of the fire; this can be done inside the building or from the outside. This section outlines the basic principles according to which firefighters will preferentially fight the fire from the outside and will only carry out an interior attack in a small room or small structure if an exterior attack fails and provided it can be done safely. A smoke-filled structure or space is considered dangerous and will only be entered if the benefits outweigh the risks. Reducing material damage is not a reason for the fire service to take any risks.
The basic firefighting principles are intended for firefighters and are included in Annex 2 to this paper. The basic firefighting principles can be summarised as follows (IFV, 2018a):

1. Take more **time** (stop and think).
2. Carry out an **exterior reconnaissance** (goal: locate the fire from the outside, extinguish from the outside).
3. Answer **three questions** (the answers to the questions determine the type of attack):
    (1) Is it known where the fire is?
    (2) Can the fire be reached and can it be reached from the outside?
    (3) Is sufficient cooling capacity available?
4. Generally, if certain conditions are met, an offensive interior attack is safely possible in a **small structure**.
5. Assess the **potential fire capacity** and bring sufficient cooling capacity.

However, these basic principles are not a cut-and-dried recipe for all fires. This is not possible anyway, given the many different fire scenarios that exist. However, they do provide the ingredients for safe and effective deployment.

## 4.2 Possibilities for repression or incident response (quadrant model)

This section discusses the application of the basic principles.

### 4.2.1 Principle 1: Stop and think

Taking more time makes it possible to see more and to correctly interpret what we have seen and choose a quadrant from the quadrant model based on this (IFV, 2018a).

### 4.2.2 Principle 2: Carry out exterior reconnaissance

If the seat of the fire can be detected from the outside – by performing exterior reconnaissance – there is no need to try and locate it from the interior (as is currently the standard). More technical resources can be used for exterior reconnaissance, e.g. a thermal imaging camera.

### 4.2.3 Principle 3: Answer three questions

- If the seat of the fire can be located from the outside (question 3.1), is accessible from the outside (question 3.2) and there is sufficient cooling capacity (question 3.3), an offensive exterior attack can be performed and the fire can be extinguished from the outside. The heat release rates and burning times of electric vehicles call for an attack using low pressure. If several vehicles are on fire, it is quite likely that several low-pressure jets will be needed.
- If the answer to one of these questions is ‘no’, an offensive exterior attack is not possible in principle. We then have to go for a defensive exterior attack and the building is basically considered to be beyond saving. This applies anyway to large structures such as indoor car parks.

### 4.2.4 Principle 4: Is a safe offensive interior attack possible?

Generally, an offensive interior attack could be possible if certain conditions are fulfilled, provided that:

> the structure is relatively small (also because fire gas cooling can be effectively applied); however, this does not apply to a fire in an indoor car park, which is a large structure.

> door control can be applied; in practice this is virtually impossible for an indoor car park (e.g. due to the open vehicle entrance and the presence of openings in the façade). This means that it will generally not be possible to reduce the oxygen supply into a car park, adding to the risks.

> the depth of attack is not too great, so that the firefighters will not have to move through smoke for too long (in this case, the electric vehicles should be close to the fire service entrance or the vehicle entrance).

> sufficient cooling capacity is available (see basic principle 5).

In short, after applying the above basic principles to a car park (with electric vehicles) the conclusion will be that an offensive interior attack is generally *not* safely possible. Given the extra elements that play a role when fighting fires involving electric vehicles mentioned earlier in this paper, an offensive attack is even less likely. It is up to the commanding officer on site to decide whether an offensive interior attack can be carried out after all.

**Intermezzo**

In general, an offensive exterior attack in the event of a fire in an indoor car park is as limited as possible and in most cases, it will simply be impossible, specifically in underground car parks. The only option that then remains, besides a defensive exterior attack where the car park burns out, would be an offensive interior attack which is generally not safely possible considering the basic principles (see above). If, based on an on-site risk analysis, the commanding officer still decides to perform an interior attack, this interior attack should be carried out as quickly as possible. To avoid having to go too deeply into the car park, it is important that electric cars are parked as close to the entrance as possible (see the measures in chapter 4). However, it should be considered that an attack where the firefighters will have to advance through smoke (as is the case with other functional uses) cannot be ruled out here either; even if the fire has triggered the sprinkler system, there will still be smoke and visibility will be poor. Careful consideration will have to be given to the extent to which a safe and effective fire service attack (also at a greater depth of attack) is still possible in relation to the risks involved. This is to be decided by the commanding officer.

### 4.2.5 Principle 5: Assess the potential fire capacity and bring sufficient cooling capacity

The following rules of thumb can be used for cooling capacity:

> High pressure: 125 litres per minute (generally sufficient for a heat release rate of up to 2.5 MW). If the vehicle's heat release rate is greater, extinguishing the fire using high pressure jets will take more time.

> Low pressure: 450 litres per minute (generally sufficient for a heat release rate of up to 10 MW).

An offensive interior attack involves rapid action by the fire service, with the vehicle being close to the entrance or exit of the car park and within quick reach. The international assumption in this situation is that two low-pressure jets are used to quickly cool the vehicle on fire and extinguish the flames (CTIF, 2019).

This is because two low-pressure jets shorten the time to extinguish the fire compared to the situation where only one jet is used. This is because they provide a greater cooling capacity that can be applied directly to the car and to the energy carrier.

However, in case of an electric vehicle, it should be taken into account that the battery pack will catch fire again within a short time (thermal runaway) and therefore requires continuous cooling. Therefore, once the fire has been extinguished, it will have to be kept under control and its temperature monitored for a prolonged period of time.

To prevent an electric vehicle from catching fire again in the car park after being extinguished, it might be towed out of the car park by the fire brigade in cooperation with the salvage company. The specific tasks and responsibilities of the fire service and of the salvage company should be properly coordinated, but this will not always be possible. For example, not all salvage companies have the proper equipment. And salvaging vehicles from underground car parks is not always immediately possible, also given the circumstances in the car park (e.g. a smoke-filled car park, poor accessibility).

At present, the use of an immersion container is the best method available for the long-term cooling of battery packs (IFV, 2021b)[36]. The effectiveness of an immersion container depends on the extent to which water can reach the battery pack and battery cells. An immersion container is relatively easy to use, but it does involve some potential risks and/or complications. A mobile sprinkler is the best available means for the fire service to cool the battery pack from the moment the car fire has been extinguished until the vehicle is salvaged.

## 4.3 Extinguishing and cooling water

A lot of fire extinguishing water is needed for extinguishing fires in and long-term cooling of electric vehicles. As regards extinguishing, a distinction can be made between:
- putting out the flames
- long-term cooling of the battery pack in question to prevent it from reigniting due to a thermal runaway.

Putting out the flames does not require more capacity or attack force than would be needed for a conventional vehicle (NFPA, 2013). If an electric vehicle repeatedly reignites, more extinguishing water will be needed. The long-term cooling of the battery pack definitely requires much more water. How much more is needed depends on the battery pack and the state of charge of the battery pack. If an electric vehicle is on fire, it can be decided to either extinguish continuously or to extinguish the fire whenever it is reignited. This means that continuous temperature monitoring is important.

Research has shown that the impact on the environment of *extinguishing* water used to extinguish fire involving electric vehicles is hardly any greater than that of extinguishing water used to put out fires involving conventional vehicles (NFPA, 2013). This means that this water can be drained through the sewers. The pH of *cooling* water in an immersion tank

36 The Stichting Incidentmanagement Nederland foundation has made a protocol available for accounting for the handling of accidents and fires involving electric vehicles which can be used when salvaging electric vehicles on roads. Further information can be found here: https://www.stichtingimn.nl/210511-elektrische-voertuigen-getemd.php.

(which is still in contact with a burnt-out battery pack) can continue to increase to ever higher levels over time. It seems that the longer a battery has burned, the more lithium oxide is present in the battery residue (this cannot always be measured by means of pH paper on the outside of the residue). Burnt battery residues may show a neutral pH on the outside after a fire. However, this does not mean that the residue is free of heavy metals and other hazardous substances (RIVM, 2019). This means that cooling water may actually have a greater impact on the environment.
In order to be able to remove the excess fire extinguishing water, the car park should have good water removal facilities (such as overflow device(s) and/or a pump) that can remove at least the extinguishing water supplied. Contaminated cooling water from an immersion tank is not permitted to be discharged directly in the sewer. The salvage company must make provisions to properly dispose of the possibly contaminated cooling water.

## 4.4 Other points for consideration/comments

- Using robots is still seen as something innovative, but their deployment might actually be successful in indoor car parks in the future. Further studies in the short term into how robots could be used and how their applications could be extended would be very welcome.
- Covering an electric vehicle in foam is not a useful firefighting method for the time being, because the fire can reignite under the foam layer as a consequence of thermal runaway. Laboratory studies have shown that battery packs can reignite if thermal runaway occurs, even if little oxygen is available.
- It is very important that the fire service is alerted as soon as possible if there is a fire. As long as only one car is on fire, the probability of successful suppression is the greatest since the fire has not turned into a travelling car fire yet.
- The consequence of a defensive exterior attack is that there may be some smoke nuisance for surrounding buildings and the surrounding area for a longer period of time.
- The operating time of the sprinkler system (typically 30-120 minutes, depending on the standards/guidelines applied) is a relevant limitation in view of repressive attack. If the vehicle has not been removed from the car park by that time and conditions in the car park are such that the fire service cannot enter, there is a probability that several cars will catch fire and the car park will still burn down or burn out.
- There are no reasons to assume that a fire in an electric vehicle requires additional personal protective equipment for firefighting compared to a fire in a conventionally fuelled vehicle.
- It is very important to inform the parties involved (developers, architects, builders, consultants etc.) of the fact that the fire service will not automatically enter the structure if there is a fire and that a consequence of this may be that the car park might burn out. The probability of this scenario increases as the risks involved in the attack increase. Aspects to be considered in this context are different fuels, great attack depths, uncertainty as to the location of the fire, etc. or combinations of these aspects.

# 5 Discussion of points for consideration and measures for the individual types of car park

## 5.1 Introduction

This chapter discusses the combination of preventive measures from chapter 3 and firefighting tactics from chapter 4 for the specific types of indoor car park and we mention some specific points for consideration for the individual types of car park. To avoid repeatedly describing the same points for consideration and measures, we will only discuss the most relevant types of indoor car parks in this chapter. A full list can be found in annex 3.

> Most measures can increase fire safety in indoor car parks in a general sense. If any measures/solutions specifically target electric vehicles, this is explicitly indicated in the tables in annex 3.

## 5.2 Discussion of points for consideration and measures for the individual types of car park

### 5.2.1 Open indoor car park

By ‘open’ indoor car park we mean a naturally ventilated car park all of whose sides are open to the outside air, such as an indoor car park with largely open façades. The open façades enable smoke to spread directly to the surrounding area. Since a fire involving an electric vehicle lasts longer and is more difficult to extinguish, the surrounding area may experience nuisance for a longer period of time.

The open façades give an open indoor car park some favourable characteristics compared to a closed car park if there is a fire involving an electric vehicle. Heat and smoke can be removed via the open façades. This may lead to less heat build-up in the structure. And, although it also depends on wind speed/wind direction, the probability of the entire car park filling up with smoke also seems lower. However, it should be considered that strong winds can actually increase the probability of fire spreading from one car to the next.

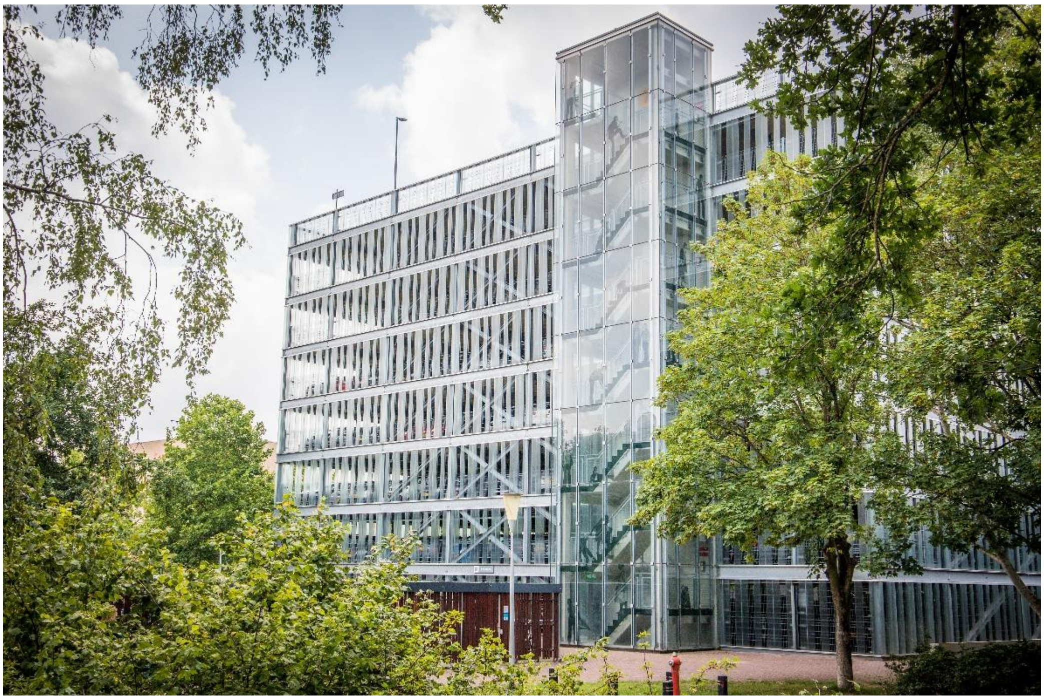

**Figure 5.1 Open indoor car park (source: Tom Hessels, NIPV)**

Weather influences make sprinkler systems less suitable for use in open indoor car parks, although such systems are the most obvious solution in order to contain a fire involving a vehicle and prevent fire travelling from one car to the next.

### 5.2.2 Closed indoor car park

In general, heat development and heat build-up in the structure will take place faster in a closed indoor car park since the heat will generally be removed less quickly than would be the case in an open indoor car park.

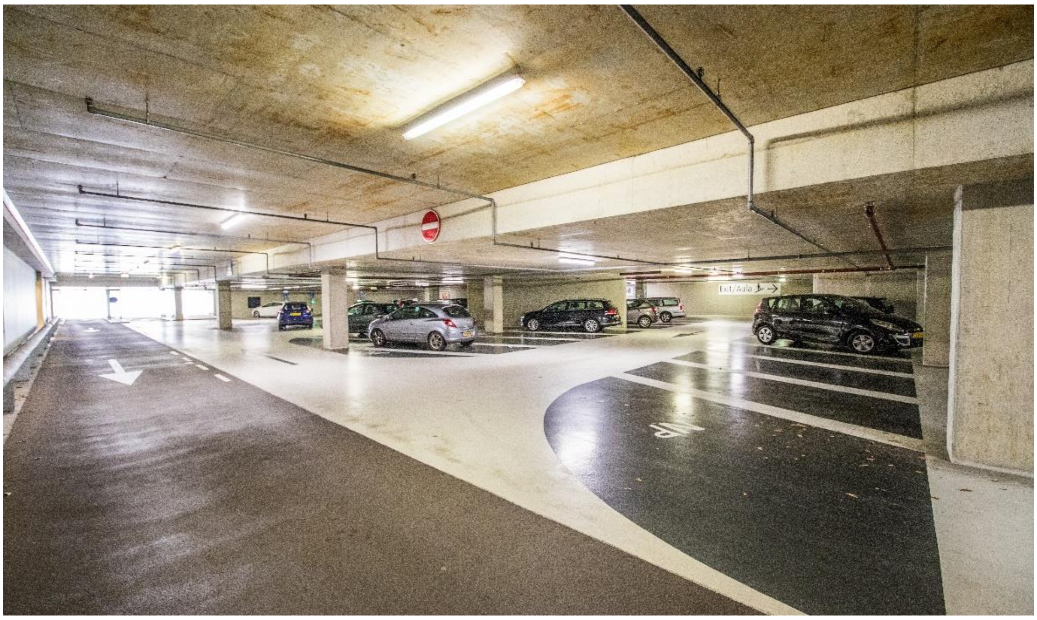

**Figure 5.2 Closed indoor car park (source: Tom Hessels, NIPV)**

Installing a sprinkler system is the most obvious measure to reduce fire development and to reduce the probability of the fire spreading from one car to the next and reduce heat development in the structure. This also increases the probability and possibilities of fighting a fire in an electric vehicle in a car park.

Smoke and toxic or other gases accumulating in the indoor car park adversely affect the possibilities of escape, and of locating the fire (view of the fire) and fighting it. Since a fire in an electric vehicle lasts longer, smoke will spread for longer if the fire service does not take action. The use of displacement ventilation/smoke and heat removal can help to increase the probability of a successful offensive interior attack.

### 5.2.3 Automatic and semi-automatic parking

An automatic car park incorporates a fully automatic parking system. Users park their cars in an entrance area and exit it. They then scan their badges outside, after which the car is parked in the car park fully automatically.[37]

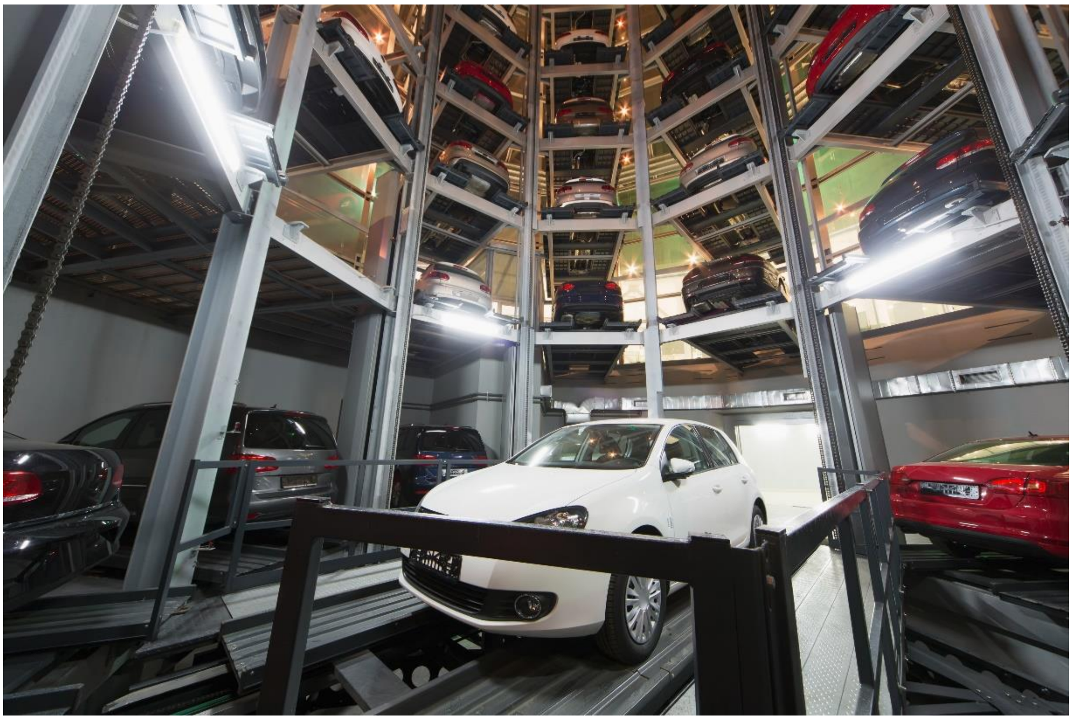

**Figure 5.3 Automatic parking (source: Shutterstock)**

A semi-automatic parking system enables several cars to be parked above or next to each other. This creates more parking capacity. Users park and remove their cars themselves. The driver places their car on a platform. The next user causes the system to go up one level and parks their car underneath.[38]

Automatic and semi- automatic parking involve the risk of larger fires, involving several cars. This is because the cars are much closer together (on top of, underneath, next to each other) resulting in constructions heating up more quickly and increasing the probability of the fire spreading between the vehicles faster. The parking system also implies a fire load (hydraulics, oil). Vehicles are completely or partially hidden from view, making it difficult to

[37] www.carparkers.nl.
[38] www.carparkers.nl.

locate, find and fight a fire. And on top of this, a fire involving electric vehicles lasts longer and is more difficult to fight than a fire involving conventional vehicles. This is because the fire service cannot take action itself due to the risk of falling and getting trapped.

If there is a defect in the parking system, it is not possible to remove the vehicles. This also makes it impossible to salvage electric vehicles and place them in an immersion tank. Similar problems also occur if differences in height between different storeys are bridged by means of a car lift.

### 5.2.4 Underground car park

An underground car park is an indoor car park where one or more floors are below ground level.

The complexities of fighting a fire involving an electric vehicle combined with its being parked and/or charged in an underground car park present some difficulties. Rising smoke can make vehicles in underground car parks more difficult to find; moreover, it is not possible to locate the vehicle on fire from the outside. The possibility of locating vehicles in underground car parks can be enhanced by creating smoke-free access to the underground storeys of the car park. This may be achieved for example by means of a stairwell that can be used as an attack route for the fire service and that contains a connection point for a dry riser (to shorten the attack depth). In practice, most car parks tend to have such a stairwell.

**Figure 5.4 Underground car park (source: Tom Hessels, NIPV)**

In addition, an electric vehicle is more difficult to salvage from an underground car park (gravity requires the vehicle to be hoisted or pulled up). If parking electric vehicles on the ground floor is not possible, consult the vehicle salvage company to discuss whether special facilities are needed in order to salvage electric cars.

### 5.2.5 Indoor car park ≤ 1,000 m²

Indoor car parks with a usable area of ≤ 1,000 m² come in all kinds of designs and configurations. The performance requirements of the Dutch 2012 Building Decree apply directly to indoor car parks with a usable area of ≤ 1,000 m². Since, in practice, indoor car parks with a usable area of ≤ 1,000m² are designed on the basis of the minimum performance requirements of the 2012 Buildings Decree, they tend not to have any additional installations that would have a favourable impact on the effects of fire involving an electric vehicle (such as sprinklers to limit the extent of the fire and fire spread and increase the probability of successfully fighting the fire). In addition, the smaller surface area compared to car parks of more than 1,000m² is conducive to unfavourable situations developing more quickly from the perspective of fire physics, due to the absence of specific facilities and the smaller volume of the space.

Note: when an application for an environmental permit for an indoor car park that directly meets the performance requirements is assessed, the use of the car park (i.e.: whether electric vehicles will or will not be parked and charged in it) is not a criterion. This also precludes the possibility of setting requirements supplemental to the performance requirements in the 2012 Building Decree.

### 5.2.6 Indoor car parks > 1,000 m²

Since an indoor car park of more than 1,000 m² does not directly meet the performance requirements in the 2012 Building Decree, any parties applying for an environmental permit for building such a car park will have to demonstrate to the satisfaction of the competent authority which fire safety facilities will create an equivalent level of fire safety as that envisaged by the regulations of the 2012 Building Decree. They can include the different risks that exist when parking electric vehicles compared to conventional vehicles in this. The competent authority also has some discretion when it comes to accepting an equivalent solution and thus more control over which fire safety facilities should be implemented.

In practice, in indoor car parks of more than 1,000 m², we generally find facilities to reduce fire spread (e.g. a sprinkler system), and/or facilities that can improve the probability of an interior attack (such as displacement ventilation/smoke and heat removal).

### 5.2.7 Multi-storey car park

A multi-storey car park has several floors where cars can be parked. Fire can spread to several storeys. Compared to a single-storey car park, this makes it more complex to locate a vehicle that is on fire. Repressive attack in a multi-storey car park is also more complex (find the stairwell, bring hoses, bridge differences between storeys, etc.). Salvaging an electric vehicle from a floor is not easy either. Electric vehicles should therefore preferably be positioned on the ground floor to make them more accessible and increase the possibility of fighting a fire.

### 5.2.8 Indoor car park with adjacent building structures

An indoor car park is often integrated with other buildings. Examples are a residential building on top of the car park or other buildings in the immediate vicinity of the car park. In that case, a burn-out scenario is less likely to be an option because of damage to or failure of parts of the structure and the safety of people who are, for example, in an upper building. This calls for extra attention to fire resistance.

Since a fire in an indoor car park with electric vehicles lasts longer, the duration of the incident and the duration of the nuisance on the surrounding area are also longer. This has more adverse effects in built-up areas than in other areas.

### 5.2.9 Existing indoor car parks

The differences between existing and new car parks mainly concern the familiarity of the parties involved, such as the competent authority, with the level of the facilities applied. In practice, fairly complete documentation on the facilities applied in a new car park tends to be available, for example in the form of an environmental permit. Such documents are often lacking for existing car parks and it is not always possible to discover which fire safety facilities have been applied and which fire safety concept they are based on.

The control options available to the competent authority in order to enforce higher fire safety levels in existing car parks tend to be limited. Moreover, prescribing a higher fire safety level (Section 13 of the Dutch Housing Act) requires specific justification by the competent authority. The impact of charging and parking electric vehicles in a car park will have to be assessed on a case-by-case basis, and any measures to be taken will depend on the specific situation and the level of facilities already in place. This will require a customised solution.

# 6 Knowledge gaps and developments

This paper is based on the information available from Dutch and international research. As the previous chapters have shown, several topics require further research. In addition, developments in electric vehicle and charging station technologies are still taking place at a high speed. We pointed out some of these developments earlier in this paper.

Section 6.1 of this chapter summarises the need for further research; section 6.2 deals with some future electric vehicle developments that may influence fire safety in car parks.

## 6.1 Knowledge gaps

### 6.1.1 General

First and foremost, it is very important that electric vehicle developments be constantly monitored. For example, chapter 1 of this paper shows that the heat release rate increases proportionally with electrical power. This means that changes to the composition of the battery packs of electric vehicles and their charging may require this paper to be updated.

### 6.1.2 Building regulations and standards

Further research is needed to determine whether the risks of electric vehicles described here require the regulations of the 2012 Building Decree[39] to be changed. This actually not only applies to electric vehicles, but to modern vehicles in general. Moreover, there is a need for a standard for assessing fire safety in indoor car parks including basic assumptions (such as heat release rates) based on the latest new information and distinguishing between different types of fuel and electric propulsion. An initial exploration carried out for a study by TNO (2020) has shown that there is little to no specific regulation internationally for electric vehicles in indoor car parks.

### 6.1.3 Probability of fire

Further research is needed to better understand the probability of fire in an electric vehicle. There are no reliable datasets on the occurrence and probability of fires in electric vehicles. This also goes for charging them, and in relation to the charging process. For example, the extent to which production defects and ageing play a role in the probability of fire is still unknown. The Netherlands Institute for Public Safety (NIPV) has started registering and recording fires and accidents involving electric vehicles. This data can potentially enable a better understanding to be gained of the probability of a battery pack catching fire and it will provide more information about actual fire service deployments that have taken place.

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[39] After 1 July 2022: Dutch Building Works and Living Environment Decree [*Besluit bouwwerken leefomgeving (Bbl)]*.

### 6.1.4 Thermal runaway

Further research into the exact process of thermal runaway in relation to the fire development is important in order to arrive at innovative solutions for reducing and fighting fires. This is because there is a difference between the process of thermal runaway and the burning process. They can both be fought on an individual basis if it is made clear how they exactly take place. Further research is also needed into the conditions that enable a battery pack to reignite. This is because laboratory studies have shown that battery packs can reignite during a thermal runaway even if little oxygen is available.

### 6.1.5 Thermal load on the structure

Further research is needed to determine the effects of fires in electric vehicles on the structure of the indoor car park, in view of the differences in fire development and flame egress (flare). This actually also applies to vehicles powered by alternative fuels, such a hydrogen or CNG.

### 6.1.6 Effects of travelling car fire with electric vehicles

Further research is needed into the effects of a travelling car fire involving electric vehicles compared to a similar fire involving conventional vehicles, and its impact on, for example, the structure of a building.

### 6.1.7 Detection resources

Some more research could also be done on detection resources, for instance to answer the question of which combination of detection systems (point detection, ribbon detection), indicators (smoke, CO, heat, HF) and conditions provides the most adequate indication that an incident involving an electric vehicle has occurred.

### 6.1.8 Fire suppression system

Further research is needed to determine whether a sprinkler or water mist system is also suitable for containing an incipient fire involving an electric vehicle, or whether this always requires an additional fire service attack. More specifically, it could be considered whether a sprinkler system in the floor of the parking deck can effectively cool battery packs. Further research is also needed to determine which type of fire suppression system (such as a sprinkler or water mist system) is best suited to a fire scenario involving electric vehicles since it is not certain that all fire suppression systems are able to keep a fire in an electric vehicle under control.

### 6.1.9 The use of robots

Using robots is still seen as something innovative, but their deployment might actually be successful in indoor car parks in the future. Further studies in the short term into how robots could be used and how their applications could be extended would be very welcome.

### 6.1.10 Cooling the battery pack

Further research is needed into the effect of cooling the battery pack in an electric vehicle from the outside and for how long this should be done.

### 6.1.11 Salvaging an electric vehicle after a fire

Further research is needed into the optimum way of salvaging an electric vehicle from an indoor car park after a fire and which equipment this requires. Practice has shown that not all salvage companies have the right resources to do so. Coordination of the tasks and responsibilities of the fire service (such as preventing reignition while salvaging) and the salvage company (removing the car from the car park) can be scrutinised as well.

## 6.2 Future developments

### 6.2.1 Increasing safety of battery packs

The safety of battery packs is expected to continue to be improved and failure probabilities are expected to be reduced further (Battery University, 2014). We also expect other types of battery packs to be developed in the future.

### 6.2.2 Battery pack extinguishing system

The possibilities of getting water into the battery pack are the subject of current research. Three examples are listed below.

> If a sprinkler is installed in the battery pack, it can more effectively cool the cells affected by a thermal runaway and possibly actually extinguish them (RISE, 2019a).
> Renault has conducted experiments with a kind of fire hose connection ('tube in the casing of the battery pack'), which firefighters can connect their equipment to and thus introduce water directly into the battery pack.
> Dekra has investigated the use of a 'fire lens'. This involves a marking on the battery pack indicating where the steel jacket of the battery pack can be punctured to introduce extinguishing water directly into the battery pack.

### 6.2.3 Information technology

Information technology is developing rapidly. Systems such as e-call and license plate recognition might provide information to the operators of indoor car parks and the emergency services about the nature of the car on fire, its status and location. This also goes for information from the charging infrastructure. Such information might be put to direct use for the information-controlled repressive service.

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# Annex 1 Summary of safety standards

Table B1.1 lists a select number of safety and other standards for the vehicles including the batteries.

**Table B1.1 Safety standards and other standards for the vehicles including the batteries**

| Standard | Subject |
|---|---|
| ECE-R100 | Safety of electric power train including batteries |
| ECE-R10 | Electromagnetic compatibility |

Appendix IV, annex 4, of the Regulation on vehicles sets requirements for vehicle wiring, the facility to cut high voltage and the placement of the battery pack. With effect from 2011, high-voltage cables must be orange. High-voltage cables from before this year may have a different colour.

Table B1.2 lists safety standards and other standards for the distribution stations and charging stations.

**Table B1.2 Safety standards and other standards for the distribution stations and charging stations**

| Standard | Subject |
|---|---|
| NEN 1010 | Safety provisions for low-voltage installations |
| IEC 61851-1<br>IEC 61851-22<br>IEC 61851-23 | Basic standard for charging<br>AC charging station<br>DC charging station |
| IEC-62752 and IEC-62893 | Charging cable |
| IEC-61851-21-2 | Standard that concerns ‘off-board’ chargers for modes 1 - 4, both AC and DC. |
| IEC 62196 | Charging connectors |
| IEC 60364-7-722 | Charging infrastructure connection |
| ISO 15118 | Communication between vehicle and charging facility |
| ISO 17409 | Conditions for connection to the power supply |

Figure B1.3 visualises the current safety standards for charging vehicles. This figure consists of two parts: the charging infrastructure (top left) and the vehicle (bottom right)

The existing guidelines for the *charging facilities* and their components are listed at the top, on the left. The existing guidelines for energy storage in *vehicles* and the communication *hardware* and their components are shown bottom right.

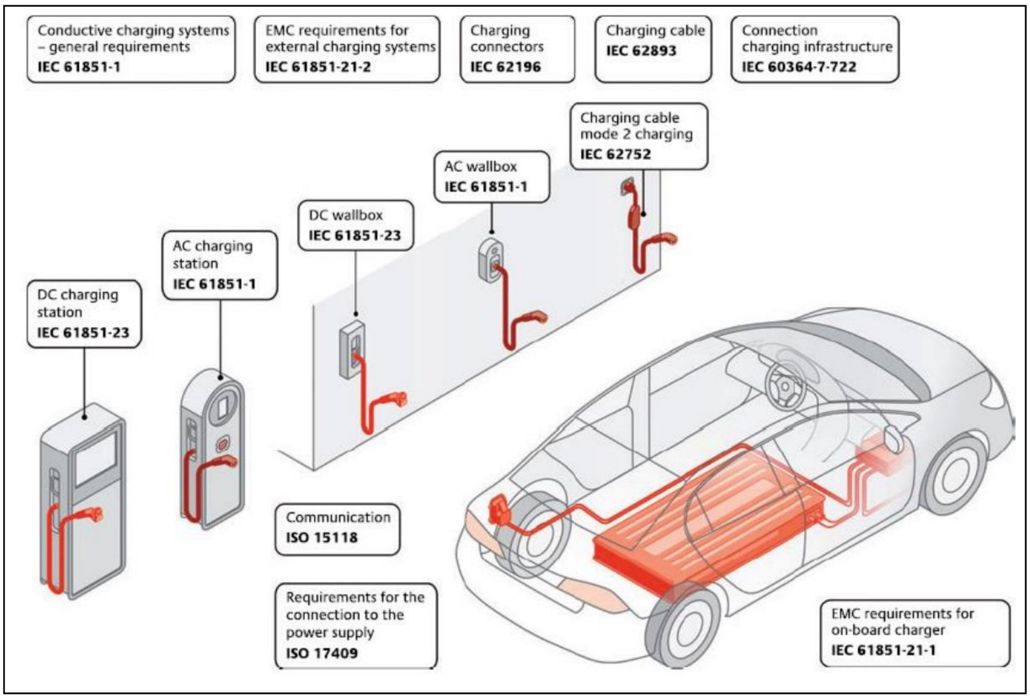


**Figure 1: Standards for the wired charging of electric vehicles (Nationale Plattform Elektromobilität 2017)**

### Figure B1.3 Safety standards for charging electric vehicles

# Annex 2 Basic principles of firefighting

The basic principles of firefighting follow the following steps:

1. Take more **time** (stop and think).
2. Perform an **outdoor reconnaissance** in order to locate the fire from the outside and extinguish the fire from the outside.
3. This should answer **three questions**:
    1. Is it known where the fire is?
    2. Can the fire be reached and can it be reached from the outside?
    3. Is sufficient cooling capacity available?

If the seat of the fire can be located from the outside, is accessible from the outside and there is sufficient cooling capacity, the fire can be extinguished from the outside. If this is not possible, the structure should be considered to be beyond saving and we will have to go for a defensive attack. This applies anyway to large structures.

4. If the fire concerns a **small structure**, such as a dwelling, or a building with small rooms and there is sufficient cooling capacity, an offensive interior attack is generally safely possible if certain conditions are fulfilled. In that case: think in terms of the Fuel, Heat, Oxygen and Chemical Chain Reaction fire tetrahedron.
    > Control doors.
    > If possible, make use of anti-ventilation (by keeping the structure closed).
    > If possible, implement a ‘transitional attack’ if the fire is fully ablaze.
    > Apply water to the fire as quickly as possible.
    > Remember the limitations inherent in fire gas cooling: shortest distance to the fire.
5. Assess the **potential fire capacity** and bring sufficient cooling capacity.

However, these basic principles are not a cut-and-dried recipe for all fires. This is not possible anyway because there are many different fire scenarios, but they do provide the ingredients for a safe and effective attack by the fire service.

The figure below visualises how applying the basic principles leads to the choice of an attack quadrant from the quadrant model (see section 4.1).


**Figure B2.1 The basic principles combined with the quadrant model**

# Annex 3 Comparison of types of car parks, measures and points for consideration

We will compare several types of car parks in this example (for example: ‘open’ or ‘closed’ indoor car park) and we will present the differences in tables. The tables deal with several themes (e.g. ‘fire development') relevant to a particular type of indoor car park. These themes are not the same for each type of indoor car park. Where relevant, we will also identify some measures and points for consideration.

| |
|---|
| Most measures/solutions can increase fire safety in indoor car parks in a general sense. If any measures/solutions specifically target electric vehicles, this is explicitly indicated in the tables. |

## Open or closed indoor car park

### General description of the differences between the types of car parks

By ‘open’ indoor car park we mean a car park which has an open connection to the outside air on all sides. The further details are based on an indoor car park with fully open façades.

### Characteristic differences, problems, measures and solutions

Several items are detailed in table B3.1 on the next page.

- Some characteristic differences between open and closed indoor car parks. Column 1 represents the attribute (e.g. ‘influence of the type of weather on the car park’).
- Columns 2 and 3 of the table contain a description of the comparison between an open and a closed indoor car park.
- This table is divided into three themes:
  - inside-outside and outside-inside influences
  - fire development
  - smoke development

The table ends with some points for consideration.

### Table B3.1 Open and closed indoor car parks

| | Open indoor car park | Closed indoor car park |
|---|---|---|
| **Inside-outside/outside-inside influences** | | |
| influence of the type of weather on the car park | Wind and weather have a greater influence on fire and smoke development. | Wind and weather have hardly any influence. |
| Influence of the car park on the surrounding area | Smoke spread from the car park to the surrounding area is greater. | More limited smoke spread towards the surrounding area; the smoke can linger. |
| **Heat build-up and fire spread** | | |
| Heat build-up in the structure | Less (heat is removed via the façades) | Faster heat development/faster heat build-up in the structure (heat is not removed or is removed less quickly). |
| The probability of fire spreading to other vehicles | Normally less (heat can be removed through openings in the façades). However, it may be faster if the wind direction/speed are unfavourable. | Normally a faster heat development in confined spaces: a higher probability of fire spreading to other vehicles. |
| **Smoke development** | | |
| The car park being filled with smoke | More limited: smoke can be removed via façades. | A closed indoor car park can fill up with smoke quickly; reduced view of the fire; more toxic or other gases accumulating. |
| View of the fire when the fire service arrives | Depending on the wind direction/speed a slightly greater probability of:<br>> Better view of the fire<br>> A better probability of properly locating where the fire started<br>> Improved repressive attack possibilities. | Smoke cannot escape, so poor/no view of the fire |
| **Points for consideration:**<br>> Detection using smoke detectors in an open car park is less effective than in a closed indoor car park. There is a probability that smoke will be blown away by the wind, making it less likely that the smoke detectors will detect smoke. Heat-based detection (e.g. ribbon detection) is a better alternative.<br>> The use of a sprinkler system influences fire development, reduces the probability of fire spreading to other vehicles and thus also slows down heat build-up in the structure.<br>> The use of a water mist system is less effective in an open indoor car park because of the influences of wind and weather that reduce the operation of the water mist. | | |

> For the purpose of the facilities analysis with regard to the repressive attack (see also the reservations/restrictions/conditions for a repressive attack in chapter 5): the time it takes to bring water to the fire affects the development of the fire and the ability to suppress it. The use of a dry riser can shorten the attack time, since the length of hose to be rolled out will be shorter. When designing an indoor car park, consider the most effective location of a dry riser: where the fire service enters the car park.
> The use of ventilation/smoke and heat removal in a closed indoor car park can have a positive impact on the attack possibilities for the fire service.

# Manual, semi-automatic or automatic parking

## General description of the differences between the types of car parks

**Manual parking**

Manual parking is when drivers park their own cars in parking spaces in the car park.

**Automatic parking**

An automatic car park incorporates a fully automatic parking system. Users park their cars in an entrance area and exit it. They then scan their badges outside, after which the car is parked in the car park fully automatically.[40]

**Semiautomatic parking**

A semi-automatic parking system enables several cars to be parked on top of or next to each other. This creates more parking capacity. Users park their cars themselves by driving them onto a platform. The next user causes the system to go up one level and their car is parked underneath.[41]

## Characteristic differences, problems, measures and solutions

Several items are detailed in table B3.2 on the next page.

> Some characteristic differences between manual parking and automatic or semi-automatic parking. Column 1 represents the attribute (e.g. ‘heat build-up in the structure’).
> Columns 2 and 3 of the table contain a description of the comparison between a car park in which drivers park manually and a car park with automatic or semi-automatic parking.
> This table is divided into two themes:
  – fire development
  – suppressibility.

The table ends with some points for consideration and tips.

[40] www.carparkers.nl.
[41] www.carparkers.nl.

**Table B3.2 Manual, semi-automatic and automatic parking**

| | Manual parking | Automatic and semi-automatic parking |
|---|---|---|
| **Fire development** | | |
| Fire scenario | Local car fire scenario: the extent of the fire can probably be limited for a longer time. | The extent of the fire can increase. (Cars are much closer together, on top of, underneath and next to each other). The parking system itself also implies a fire load (hydraulics, oil). |
| Heat build-up in the structure | Less fast. | Faster, with greater thermal loads on load-bearing and partition structures. |
| The probability of fire spreading to other vehicles | Less fast. | Faster, both between cars and to other buildings (in case of a compartment fire). |
| **Suppressibility** | | |
| Locating electric vehicles | Easier. Often only cars parked next to each other. | Locating/findability is more complex in case of automatic or semi- automatic parking, because cars may be parked partially or fully out of sight. |
| Repressive attack | Easier. However, also see the limitations and conditions listed in chapter 4. | > Seldom if ever possible for vehicles that are completely or partially hidden from view or completely inaccessible to the fire service from the entrance to the car park.<br>> If there is a defect in the automatic or semi-automatic system, the vehicle cannot be removed from the car park in the event of a fire anyway. |
| **Points for consideration:**<br>> Use of a local sprinkler system in locations in the automatic or semi-automatic parking system where electric vehicles can be parked, so that a fire in an electric vehicle can be nipped in the bud and contained.<br>> If a car lift is installed instead of a ramp to reach a higher storey: recovery of an electric vehicle will be more complex. | | |

# Above-ground or underground indoor car park

## General description of the differences between the types of car parks

By an above-ground car park we mean an indoor car park whose lowest floor is at ground level ('reference level'). An underground car park is an indoor car park where one or more floors are below the reference level. From a fire safety point of view, indoor car parks below the reference level involve a number of additional complexities. Underground car parks often have different 'superstructures' on the 'roof', such as a residential building or a shopping centre built on top of the car park. Sometimes there is an open area over the underground car park where events such as the weekly market are held. From an escape and firefighting perspective, underground car parks of 'exotic designs' ('corkscrew design'/split level) are even more complex, especially when it comes to finding and fighting a fire in an electric vehicle.

## Characteristic differences, problems, measures and solutions

Several items are detailed in the table below.

- Some characteristic differences between above-ground and underground parking. Column 1 represents the attribute (e.g. 'smoke nuisance').
- Columns 2 and 3 of the table contain a description of the comparison between above-ground and underground car parks.
- This table is divided into three themes:
  - escape possibilities
  - Impact on the surroundings
  - suppressibility.

The table ends with some points for consideration.

### Table B3.3 Above-ground and underground indoor car parks

| | Above ground | Underground |
|---|---|---|
| **Escape possibilities** | | |
| Direction of escape | Escaping 'against the smoke' (generally 'faster out of the smoke'). | Escaping from lower floors requires escaping 'upwards' and 'along with the smoke and heat'. This is less favourable. |
| **Impact on the surroundings** | | |
| Smoke nuisance | There is often a possibility to remove the smoke 'above the roof', reducing the impact on the surroundings compared to an underground car park without anything built on its roof. | For example, if there is a market square on top of an underground car park, the smoke nuisance to the surroundings will be greater (no 'above roof' removal). |
| **Suppressibility** | | |
| Locating electric vehicles | Locating electric vehicles is slightly less complex. | > Locating electric vehicles is more complex in connection with rising smoke/heat.<br>> Electric vehicles cannot be located from the outside (because they are underground). |
| Repressive attack | Easier. However, also see the limitations and conditions listed in chapter 4. | > Electric vehicles are more difficult to salvage (gravity |

| | | |
|---|---|---|
| | | means the vehicle has to be hoisted/pulled up). |

**Points for consideration:**
> Preferably position electric vehicles on the ground floor near the fire service entrance in connection with accessibility and suppressibility.
> A burn-out scenario is less likely to be an option if infrastructure or buildings are on top of the indoor car park, or if activities such as a market take place on top of the indoor car park. Consideration could be given to making the structure bigger or providing the structure with fireproof cladding so that it will resist thermal loads longer.
> The probability of locating an electric vehicle in an underground car park can be enhanced by creating smoke-free access to the underground storeys of the car park. One way of doing this could be by means of a stairwell that can be used as an attack route for the fire service and that contains a connection point for a dry riser (to shorten the attack depth).
> Consult with the vehicle salvage company to ascertain whether facilities are needed for salvaging electric vehicles from an underground car park.

# Usable area of ≤ 1,000 $m^2$ or > 1,000 $m^2$

## General description of the differences between the types of car parks

The performance requirements of the Dutch 2012 Building Decree apply directly to indoor car parks with a maximum usable area of 1,000 m2. Since an indoor car park of more than 1,000 $m^2$ does not directly meet the performance requirements in the 2012 Building Decree, any parties applying for an environmental permit for building such a car park will have to demonstrate to the satisfaction of the competent authority which facilities will create a level of fire safety equivalent to that envisaged in the regulations of the 2012 Building Decree. In practice, indoor car parks of more than 1,000 $m^2$, generally have facilities to reduce fire spread (e.g. a sprinkler system), and/or facilities that can influence smoke spread and/or repressive attack by the fire service (ventilation facilities/smoke and heat removal). Such facilities are not normally found in indoor car parks of up to 1,000 $m^2$. This means that fires in indoor car parks of a maximum size of 1,000 $m^2$ pose different risks than fires in indoor car parks larger than 1,000 $m^2$.

The 1,000 $m^2$ threshold has been in the Dutch Building Decree since 2003. This means that these differences can exist, certainly in indoor car parks built after 2003. Since these threshold values were different for indoor car parks built before 2003, the level of facilities may also be different. Until 2003, compartments of up to 5,000 $m^2$ tended to be allowed in indoor car parks, without any facilities being required.

## Characteristic differences, problems, measures and solutions

Several items are detailed in the table below.
> Some characteristic differences between indoor car parks of up to 1,000 $m^2$ and indoor car parks larger than 1,000 $m^2$. Column 1 represents the attribute (e.g. 'fire safety facilities').
> Columns 2 and 3 of the table contain a description of the comparison between indoor car parks smaller than 1,000 $m^2$ and indoor car parks larger than 1,000 $m^2$.
> This table is divided into three themes:
  – environmental permit for building
  – fire safety facilities

– fire development.

**Table B3.4 Indoor car parks smaller and larger than 1,000 m²**

| | Usable area ≤ 1,000 $m^2$ | Usable area > 1,000 $m^2$ |
|---|---|---|
| **Environmental permit for building** | | |
| Control options for the competent authority/safety region | Fewer control options for the competent authority, since performance requirements apply and they are not allowed to set additional requirements. | Better control options for the competent authority (local authority)/safety region as regards facilities. This is because the competent authority has some discretion in accepting an equivalent solution. |
| **Fire safety facilities** | | |
| Fire safety facilities | Often 'standard/minimum Building Decree'. | Often additional facilities to reduce fire spread and smoke spread, and/or to enable a repressive attack. |
| **Fire development** | | |
| How long it takes for the situation to become unfavourable | Because of the smaller surface area there is a greater probability that situations that are unfavourable from the perspective of fire physics will develop more quickly due to the absence of specific facilities and the more limited volume of the space. | Due to the larger surface area combined with the presence of specific facilities (sprinkler, ventilation, smoke and heat removal), there is a greater probability that situations that are unfavourable from the perspective of fire physics will take longer to develop. |

# Single or multi-storey car parks

## General description of the differences between the types of car parks

The difference between single-storey or multi-storey car parks is the number of storeys. When dealing with the differences between single- and multi-storey car parks, we will compare a single-storey car park at ground level with a multi-storey car park with several storeys above or below ground. The only difference discussed in this section is that, instead of one storey, there are multiple storeys; the other assumptions are kept the same. Please refer to the other sections for single-storey car parks not at ground level.

## Characteristic differences, problems, measures and solutions

Several items are detailed in the table below.

> Some characteristic differences between single and multi-storey indoor car parks. Column 1 represents the attribute (e.g. 'fire scenario').

> Columns 2 and 3 of the table contain a description of the comparison between single and multi-storey indoor car parks.

> This table is divided into two themes:
  – fire scenario
  – firefighting.

The table ends with some points for consideration.

**Table B3.5 Single and multi-storey indoor car parks**

| | Single-storey indoor car park | Multi-storey car park |
|---|---|---|
| **Fire scenario** | | |
| Fire scenario | Fire will be contained in one storey; better transparency when it comes to locating the seat of the fire. | Fire can spread to multiple storeys; the seat of the fire is harder to locate. |
| **Firefighting** | | |
| Firefighting | Interior attack easier. However, also see the reservations regarding an interior attack described in chapter 4. | Interior attack on other floors than the ground floor is more complex/virtually impossible. |
| | Faster deployment and firefighting are possible. | Fire service deployment takes longer in a multi-storey car park: find the stairwell, bring hoses, bridge storeys, find any people that may still be in the smoke above the fire, etc. |
| | Salvaging an electric vehicle is less complex. | Salvaging an electric vehicle is more complex on storeys of an indoor car park other than the ground floor. |
| | Extinguishing water is on the ground floor: easier to drain. | Draining extinguishing water from other floors than the ground floor of a multi-storey car park is more difficult (especially on underground storeys). |
| **Points for consideration:**<br>> Preferably position electric vehicles on the ground floor to ease accessibility and suppressibility.<br>> In terms of a repressive attack, especially in a multi-storey car park, the question is how the fire service can enter as easily as possible and apply water to the fire as quickly as possible.<br>> As regards the ability to suppress a fire in a multi-storey car park, the depth of attack is also a point for consideration: it also depends on walking distances in the car park and the fire safety concept used. | | |

# Built-up or non-built-up immediate surroundings

## General description of the differences between the types of car parks

Indoor car parks can be entirely detached from other structures. However, most indoor car parks are near or integrated with all kinds of other structures. Examples are a residential building on top of the car park or other buildings in the immediate vicinity of the car park. In our description of the differences, we compare a detached indoor car park to an indoor car park with other structures on top of or near it.

## Characteristic differences, problems, measures and solutions

Several items are detailed in table B3.6 below.

> Some characteristic differences between indoor car parks in built-up areas and in non-built-up areas. Column 1 represents the attribute (e.g. 'impact on the surroundings').

> Columns 2 and 3 of the table contain a description of the comparison between a car park in a built-up area and a car park in a non-built-up area.

> This table is divided into two themes
  – fire scenario
  – Impact on the surroundings.

The table ends with some points for consideration.

### Table B3.6 Indoor car parks in built-up and non-built-up areas

| | Built-up area | Non-built-up area |
|---|---|---|
| **Fire scenario** | | |
| Fire scenario | A burn-down or burn-out scenario is less likely to be an option in an indoor car park in a built-up area because of damage to or failure of parts of the structure and the safety of people who are, for example, in an upper building. | A burn-down or burn-out scenario is a more obvious option. |
| **Impact on the surroundings** | | |
| Impact on the surroundings | A fire in an indoor car park quickly has more adverse effects on the built-up area such as dwellings, but also on infrastructure:<br>> smoke nuisance, gases/combustion products that are released pose a risk to the operational safety of businesses in the area.<br>> people may have to be evacuated from buildings in the surrounding area (particularly at night where people spend the night in such buildings). | A fire in an indoor car park has fewer and less direct impacts on its surroundings. It may take longer for a plume of smoke to reach the built-up area and by then, such plumes have usually already reached a high altitude. However, such a fire/smoke could have an impact on air traffic if there is an airport near the car park. |
| | Since a fire in an indoor car park with electric vehicles lasts longer, the duration of the incident and the duration of the nuisance on the | If the incident and the nuisance to the surrounding area due to a fire in an indoor car park with electric vehicles last a long time, their |

| | | |
|---|---|---|
| | surrounding area are also longer. This has more adverse effects in built-up areas than in non-built-up areas. | impact tends to be less in a non-built-up area. |
| **Point for consideration:**<br>When selecting the fire safety level in the car park and the measures to be taken, take account of the impact on buildings in the vicinity. | | |

# Existing or new car park

## General description of the differences between the types of car parks

The characteristic differences between existing or new indoor car parks mainly concern familiarity with the level of facilities present. In practice, fairly complete documentation on the facilities in a new car park tends be available, for example in the form of an environmental permit. Such documents are often lacking for existing car parks and it is not always possible to discover which fire safety facilities have been applied and which fire safety concept they are based on.

## Characteristic differences, problems, measures and solutions

Several items are detailed in the table below.

- > Some characteristic differences between existing and new car parks. Column 1 represents the attribute (e.g. 'facilities present').
- > Columns 2 and 3 of the table contain a description of the comparison between existing and new car parks.
- > This table is divided into two themes:
  - – facilities and fire safety level
  - – granting of permits and supervision.

### Table B3.7 Existing and new indoor car parks

| | Existing indoor car park | New indoor car park |
|---|---|---|
| **Facilities and fire safety level** | | |
| Facilities present | How the fire safety features in existing indoor car parks perform is not always documented and cannot always be traced. | How fire safety facilities in new car parks perform is normally documented and traceable to a fair degree. |
| Basic assumptions for the facilities applied | Similar indoor car parks in different towns or cities can have different facilities/fire safety levels. This is because of different determination methods / substantiation of equivalence applied in the past. | In general, there will be a somewhat more clear-cut picture of the level of facilities applied for new indoor car parks. |
| **Granting of permits and supervision** | | |

| | | |
|---|---|---|
| Different departments/people | Usually, the competent authority assigns the supervision of existing indoor car parks to a different department or different people than to the departments or people who grant the permits. | The department or the people who grant permits for new indoor car parks on behalf of the competent authority tend to differ from the department or people who supervise existing indoor car parks. |
| Control options at safety level in enforcement/granting permits | The control options for the competent authority/safety region to enforce a higher fire safety level tend to be limited and must be accompanied by specific justification. Moreover, supervision/enforcement does not usually have a high priority in the policy of the competent authority. | The control options for the competent authority/safety region to exercise influence when granting permits are somewhat greater in practice. The competent authority has the authority to accept an equivalent solution. |

# Other types of indoor car park

Other types of indoor car parks than the car parks discussed above are also possible. Some of those types are listed below, with some points for consideration.

## Managed and non-managed car parks

Several indoor car parks are managed by a manager. Some managers are present at the car park all day long, e.g. in a security office, and some manage the car park remotely. If it also possible that managers are only present at specific times or that they only come to the car park when necessary. Actually, fewer and fewer indoor car parks seem to have managers.

The advantage of an indoor car park with a manager is that the manager can immediately supervise the correct use of the charging stations, their state of maintenance etc. and can take action if there is a fire. However, a prerequisite for this is that the manager is at the car park at that time and knows what to do.

## Public and non-public indoor car parks.

NEN 2443 distinguishes between public and non-public indoor car parks.[42] A characteristic of a public indoor car park, e.g. under a shopping centre, is that many people come and go and cars move frequently. Non-public indoor car parks, e.g. under a residential building, generally have designated parking spaces for residents, leaving fewer possibilities to position the parking spaces for electric vehicles in positions favourable to firefighting. Public indoor car parks generally offer more possibilities in this regard.

[42] NEN 2443 is used only for a useful definition of public and non-public indoor car parks in this context. The standard is not intended for assessing the fire safety of an indoor car park and is not considered further in this paper.