Office for Zero Emission Vehicles (OZEV)

T0194 – Covered car parks - fire safety guidance for electric vehicles

Interim guidance to support parking and/or charging of electric vehicles and the installation of electric vehicle chargepoints in covered car parks

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This interim guidance for electric vehicle (EV) fire safety in the built environment has been produced to provide an overview of EV fire safety considerations in covered car parks. This is due to the exacerbated fire safety challenges in these spaces. This guidance's definition of covered car parks captures underground, enclosed or open-sided car parks and does not extend to residential garages. Several of the measures outlined in this document also apply to vehicle fires in open spaces and fires in internal combustion engine vehicles (ICEV).

This document is not a legal compliance document and does not replace existing regulations or the need to comply with them, nor does it directly support compliance with:

- The functional requirements of the Building Regulations 2010 (as amended) for new builds, alterations or extensions as covered,
- The Regulatory Reform (Fire Safety) Order 2005 (as amended) for existing premises as covered.

It is the responsibility of those who need to adhere to the above (and other legislation) to demonstrate how they will comply by providing a design proposal or an assessment of the risk. This must be supported with appropriate evidence from a competent person and a risk assessment.

Always refer to the relevant legislation when considering the risk from fire for a covered car park, including but not limited to:

- The Regulatory Reform (Fire Safety) Order 2005 (as amended) (and similar in devolved administrations)
- The Building Regulations 2010 (as amended)
- Health and Safety at Work Act 1974 and associated secondary regulations
- The Building Safety Act 2022 and associated secondary legislation
- Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)
- The Electric Vehicles (Smart Chargepoints) Regulations 2021 (if a private chargepoint)
- Equality Act 2010; enforced by The Human Rights Commission.

The document outlines mitigation measures which should be considered by a competent person to reduce the impact of an EV fire. These are outlined using the ERIC (eliminate, reduce, isolate, control) model. These considerations include, but are not limited to:

- Suppression systems
- Increased structural fire resistances
- Distance between parked cars
- Firefighting water supplies
- Water run-off control and containment
- Locations and features of EV chargepoints
- Enhanced smoke management systems

- Thermal imaging cameras and other early detection methods, to enable early intervention

This guidance has been created in collaboration with fire safety organisations, car parking groups, and the chargepoint industry. A literature review compiling national and international data was conducted to draw conclusions on the safety of EVs parking and/or charging in covered car parks.

This guidance has ‘interim’ status as the measures are based on and limited to the available data surrounding EV fires, which will continue to develop as EVs age, and the industry continues to grow. The guidance is subject to change should new evidence emerge which significantly impacts appropriate mitigation measures.

Executive Summary

This guidance[1] document outlines fire safety considerations and measures that operators, designers, and owners of covered car parks (both new and existing) can take with regards to electric vehicles (EVs) or electric vehicle chargepoints (EVCPs) when:

- Retrofitting existing covered car parks for the provision of EVs/EVCPs.
- Designing new covered car parks for the provision of EVs/EVCPs.

The term 'covered car park' will be used for consistency with Approved Documents which cover infrastructure for charging electric vehicles under the Building Regulations, and encompasses open-sided and enclosed car parks, refer to Section 2.1.

It considers road passenger battery electric vehicles i.e. cars and vans only. It does not consider other forms of electric transport such as hybrid electric vehicles (HEVs), plug-in hybrid EVs (PHEVs), electric bicycles or electric scooters, electric buses or other utility vehicles. Some of the information in this guidance may be relevant to aspects of hybrid-electric vehicles and other passenger vehicles which contain batteries. Elements of this guidance may also be of interest to car park owners and/operators in general.

This guidance document reviews the hazards that could lead to a fire within an EV parked in a covered car park; and, within an EV whilst charging within a covered car park. For each of these hazards, mitigation measures are considered which could reduce the likelihood of a fire occurring involving an EV.

This guidance document also considers, if a fire does occur, what mitigation measures could be introduced to minimise the impact of such a fire on the occupants, the fire service, the car park structure, other vehicles, adjacent buildings, and the environment. Mitigation measures are ranked using the ERIC (eliminate, reduce, isolate, control) hierarchy.

This guidance is based on a review of the literature and global data in relation to EV fires available as of April 2022, as well as stakeholder consultation and UK Government data for vehicle fires up until Q3 2022. Therefore, research publications that have been issued after April 2022 are not considered in this guide. This review shows that there are both similarities and differences between EV and internal combustion engine vehicle (ICEV) fires. Some of the different risks associated with EVs include:

- Reignition: fires which involve the battery can reignite hours or days after the initial fire burned in a process called thermal runaway [1] [2] [3].
- Compressed gas venting causing jet flaming or vapour cloud explosions:
  - Compressed gases can vent from a battery and if ignited can result in flash fires [4] or directional jet flames [4], or

[1] This guidance has 'interim' status as the measures are based on and limited to the available data surrounding EV fires, which will continue to develop as EVs age, and the industry continues to grow. The guidance is subject to change should new evidence emerge which significantly impacts appropriate mitigation measures.

- Compressed gases can vent from a battery, and if accumulating in a confined space at the right mixture could result in a vapour cloud explosion (VCE) [4].
- Different challenges in relation to firefighting activities:
  - Suppressing a fire involving the battery requires different firefighting techniques and equipment and can take longer and in some instances may not be feasible until all flammable material has burned [1] [2] [5]
  - The battery material and smoke produced when involving the battery can be more toxic, which contaminates firefighting water run-off [6] [7] [8] [9].

Most available empirical evidence to date suggests that fires in EVs are less likely to occur than in hybrid vehicles and petrol or diesel vehicles [10] [11] [12]. However, this will need to be monitored as fire risk may increase as cars age, and as EVs become more affordable to a wider range of drivers.

Two case studies are also provided, one for existing basement car parks where EVCPs were installed, and a new multi-storey car park that is future-proofed for 100% EVCP coverage.

This guidance acknowledges different measures to mitigate an EV fire (see Section 5 and 6):

- Mitigation relating to electrical, mechanical and thermal abuse.
- Increased preventative methods such as crash protection for chargepoints; thermal monitoring cameras; water-suppression methods.
- Consideration for spacing.
- Consideration for ventilation.

The car park owner/operator should carry out a fire risk assessment to determine whether the introduction of EVs or EVCPs into their car park creates new or additional hazards and whether any of the mitigation measures discussed within this document could be implemented.

This document should be reviewed in the future to acknowledge new literature as it becomes available, as this may result in changes to the mitigation measures.

This guidance is not a legal compliance document so there will be no liability or sanction for duty holders failing to comply with it. It does not replace existing regulations or the need to comply with them and does not directly support compliance with:

- The functional requirements of the Building Regulations 2010 (as amended) for new builds, alterations or extensions as covered.
- The Regulatory Reform (Fire Safety) Order 2005 (as amended) for existing premises as covered.

1. Introduction

1.1 Who is this interim guidance for?

This guidance is for car park operators, designers, risk assessors and owners who are installing EV chargepoints within covered car parks (both new and existing). It is intended to support a safe increased presence of EVs and EV chargepoints in new or retrofitted car parks.

1.2 What does the interim guidance cover and how should it be used

This guidance considers road passenger EVs i.e. cars and vans only, with lithium-ion batteries, which are currently most common. It considers the likelihood and impact of EV fires, which may arise within a covered car park. The battery technologies used in EVs may be different and may pose different risks than a Li-ion battery. Future battery technologies are not considered within this guidance as they are still in development stages.

It does not consider other forms of electric transport such as electric bicycles or electric scooters, or electric buses and other utility vehicles. It also does not cover hydrogen-powered vehicles, hybrid electric vehicles or plug-in hybrid electric vehicles; although some of this guidance may be relevant to other passenger vehicles which contain batteries (e.g. hybrid electric vehicles).

This interim guidance document considers chargepoints that require a cable to physically connect between the EV and chargepoint. It does not consider inductive charging pads or wireless charging. Prior to installing the chargepoints, a fire risk assessment of the car park should be undertaken to assess the impact these have on existing fire safety measures; and identify any new or increased hazards that may result from the addition of EVs and/or EVCPs within the covered car park.

Given the complexity and potential considerations/measures that may be needed, a competent person with sufficient experience who understands fire safety approaches in car parks should be appointed to undertake the fire risk assessment.

Many of the measures discussed in this guidance document will improve fire safety in covered car parks generally, however there are a number of considerations which are specific to vehicles using EV chargepoints within covered car parks.

The intent of this interim guidance document is therefore to provide an overview of the current knowledge of fire safety of EVs and EV chargepoints and set out fire safety considerations and measures that car park operators, designers and owners of covered car parks (both new and existing) can take on a precautionary principle to manage and mitigate an EV fire.

1.3 What is the legal status of the interim guidance?

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Always refer to the relevant legislation when considering the risk from fire for a covered car park, including but not limited to:

- The Regulatory Reform (Fire Safety) Order 2005 (as amended) (and similar in devolved administrations)
- The Building Regulations 2010 (as amended)
- Health and Safety at Work Act 1974 and associated secondary regulations
- The Building Safety Act 2022 and associated secondary legislation
- The Electric Vehicles (Smart Chargepoints) Regulations 2021 (if a private chargepoint)
- Equality Act 2010
- Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR)

This guidance does not consider any aspects covered under DSEAR. Guidance on managing obligations and risk under DSEAR can be found on the Health and Safety Executive (HSE) website [13].

1.4 Why provide guidance for fire safety of electric vehicles in covered car parks now?

New legislation, The Building Regulations etc. (Amendment) (England) (No. 2) Regulations 2021 [14], which came into force 15 June 2022 requires all new residential and non-residential buildings, and those undergoing major renovation, with associated parking, to have an EV chargepoint installed. Approved Document S was also published by DLUHC [15], to be read in conjunction with the legislation to provide guidance on how the Building Regulations can be satisfied.

Covered car parks have been exempted from the full requirements of this legislation until further research is completed (although cable routes are still required). This legislation applies to England only however we will continue to work closely with our counterparts in the devolved administrations to support the transition to zero emission vehicles. Although electric vehicle chargepoints are not required in covered parking areas under the Building Regulations, cable routes are and chargepoints themselves can be voluntarily installed in new or existing buildings. This guidance has been created for these purposes.

Cars and vans represent one fifth of UK domestic CO_2 emissions. To reduce UK emissions, government announced in the ten-point plan for net zero, in November 2020, that the UK will phase out the sale of new petrol and diesel cars and vans by 2030. The transition to EVs will help the UK meet our climate change obligations and improve air quality and economic growth.

EVs were originally introduced to the UK market in 2010 [16]. Since then, EV uptake has increased steadily, with 1 in every 7 cars sold in the UK in 2021 having a plug according to figures by the Office for Zero Emission Vehicles (OZEV) [17]. There were 2,618 licensed EVs on the roads in the UK at the end of 2011, vs 193,942 at the end of 2020, and 540,079 at the end of Q3 of 2022 [18].

As the uptake of EVs increases, chargepoints in car parks are becoming more common, because of statutory guidance and also because existing car park operators are adapting to meet the current and future anticipated level of EV use. Therefore, fire safety risks associated with EVs and their chargepoints need to be efficiently managed and responded to.

1.5 Why does the guidance have interim status?

All guidance that is not statutory has interim status. However, emphasis is put on the interim nature of this guidance as it is based on currently available data (i.e. up to April 2022, with Government data from Q3 2022) surrounding EV fires which will continue to develop.

Empirical evidence relating to EVs is evolving rapidly as the EV industry is comparatively young (around 12 years old) in comparison with the ICEV industry (around 150 years). The effects that ageing (>10 years) has on fire risk of EVs and their batteries is not yet understood due to the low number of EVs of this age [18].

The intent of this document is therefore to provide an overview of the current knowledge of fire safety of EVs and EV chargepoints and set out fire safety considerations and measures to manage and mitigate an EV fire. The guidance is subject to change should new evidence emerge which significantly impacts appropriate mitigation measures.

There is also an ongoing, larger scale review of fire safety in buildings, currently overseen by the Department of Levelling Up, Housing and Communities (DLUHC) Building Regulations Technical Policy Division. This review will consider whether current provisions for structural fire resistance and fire separation are sufficient to address modern car park designs.

1.6 How to use the guidance

The guidance does not assume extensive prior knowledge of fire safety design principles of car parks, or fire risks associated with EVs or EVCPs.

Section 2 discusses potential hazards EVs and EVCPs can pose, as established from the literature review and stakeholder consultation [19]. This forms the basis of the risks and mitigation measures discussed later in the guidance document.

Section 3 sets out minimum fire safety measures expected in car parks and fire safety issues identified in recent major fires and confidential reporting. These provide context to what active and passive fire safety measures might be expected based on historic guidance.

This is to help establish what fire safety provisions are in place in an existing car park and how those are intended to operate in case of fire, as a baseline against which to assess what additional fire safety measures may be appropriate to support the installation of EVCPs.

Sections 4-6 set out the recommended steps to determine relevant mitigation measures as part of the risk assessment process, hazard mitigation measures to consider and further discussion of mitigation measures.

The reason for the implementation of each mitigation measure and associated benefits is explained to aid the risk assessment process; and where possible more detail on applicable standards is provided.

Two case studies are included, one for a new car park designed for 100% EV chargepoint provision and one from the City of London Corporation.

Appendix A provides an example on undertaking a fire risk assessment when preparing to include EV/EVCPs in a covered car park.

Appendix B provides background information on EVs and EV chargepoints.

2. Background information on EV fire hazards

Chapter summary

This chapter discusses the factors that influence the likelihood and impact of EV fires; and how EV and ICEV fires may differ. This chapter is important as it sets out the research and data which forms the basis of the risks and mitigation measures in Sections 5 and 6. Further background information on EVs and EV chargepoints is included in Appendix B.

2.1 Overview of fire hazards associated with electric vehicles

2.1.1 Thermal runaway

A fire starting in the battery of an EV has a different fire behaviour compared to an ICEV fire, as the battery can undergo thermal runaway and is influenced by factors such as size of battery, battery chemistry and state of charge.

Thermal runaway is a process within battery cells which leads to the decomposition of battery elements and can lead to the onset of fire within the battery.

Thermal runaway describes the overheating event in which high temperatures or high voltage trigger the chemical reactions within the battery cell. This can overcome the cooling systems within the battery and can result in ignition. If ignition occurs, it can cause adjacent battery cells to heat up and undergo thermal runaway. The greater the number of battery cells undergoing thermal runaway within the battery pack, the greater the likelihood of fire starting in successive cells. This can potentially lead to the failure of the entire battery.

Thermal runaway can also occur at relatively low temperatures, with the results of battery failure being in the form of venting flammable gases; this can ignite if an ignition source is present or if the environment provides conditions for combustion i.e. sufficient oxygen, fuel source and heat [20].

Figure 1 shows a diagram of the potential chain events that can occur from an abuse event on a battery cell level. These chain events can lead to a thermal event developing in the entire energy storage system.

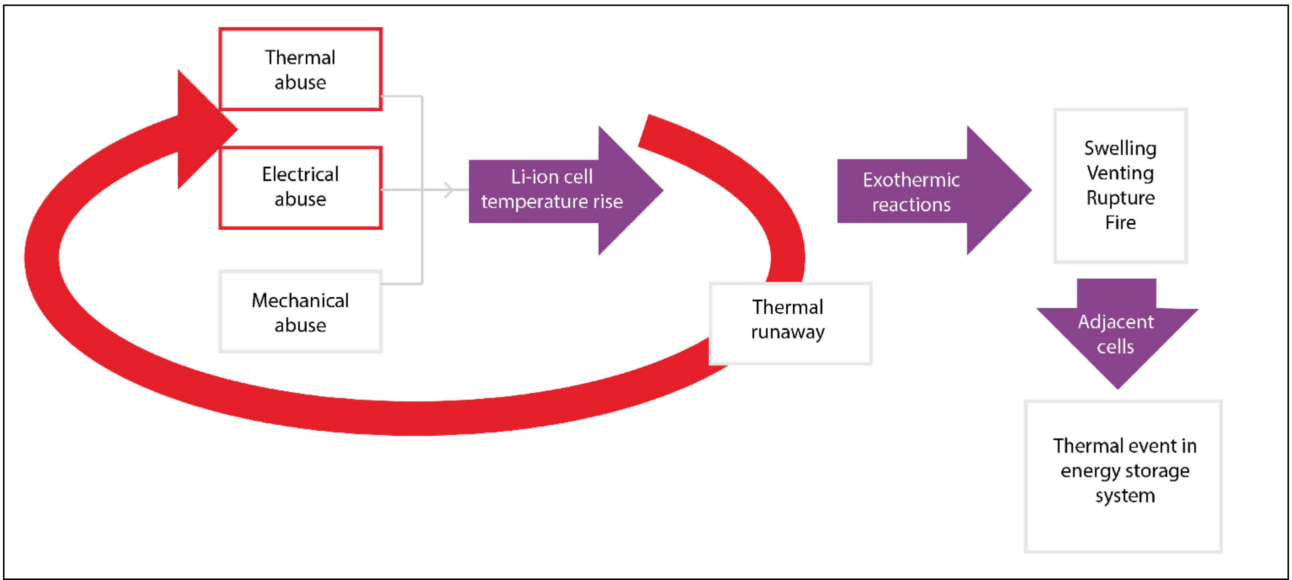


Figure 1: Potential chain of events from a thermal event at a cell level leading to thermal runaway at a system level [adapted from [3] [21]]

2.1.2 Types of fires or explosions that can occur

The Li-ion battery is currently the most widely adopted technology for EVs. Lithium is used as a charge carrier in the form of ions in a hydrocarbon-based electrolyte [22]. The electrolyte within the battery is highly flammable and there is a risk of ignition of the battery if thermal runaway occurs [23]. If there is a reaction between the electrolyte and the electrodes within the battery, an accelerated process can occur – due to the self-supply of oxygen from the chemical reactions occurring [3]. An important differentiator to the standard fire triangle is that in the fire triangle for Li-ion battery, the battery provides the fuel and the oxygen and potentially the heat source, see Figure 18 [20].

Depending on the environmental conditions around the battery, the release of flammable gases can lead to four different scenarios [20].

- Scenario 1: a free burning fire where ignition of the flammable gases occurs in the presence of an ignition source.
- Scenario 2: a jet fire, where the vented gases are released with some momentum in a particular direction and ignite.
    - Some EV batteries are designed to side vent to minimise the overpressure as a result of accumulation of flammable gases within the battery however this can lead to side projection of flames from below the vehicle.
- Scenario 3: flash fire (or deflagration) where the vented gases exist in the right mixture so that a subsonic flame front can propagate through that mixture but in a manner that creates negligible or no damaging overpressure.
- Scenario 4: a vapour cloud explosion (VCE), where the vented gases form a cloud within the flammable range and there is sufficient confinement to generate an explosion [8] [20].

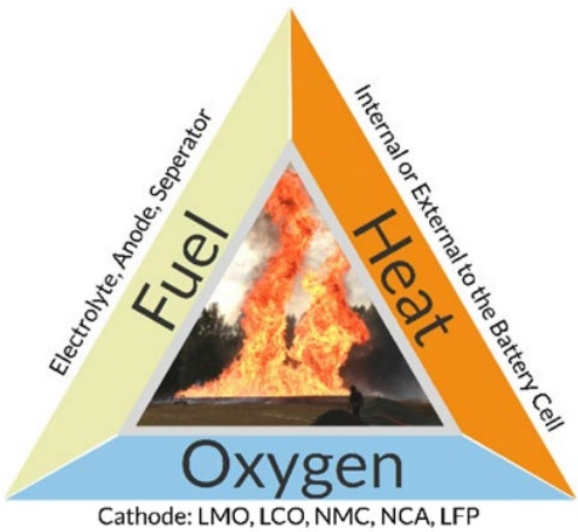


Figure 2: The fire triangle for Li-ion batteries [20]

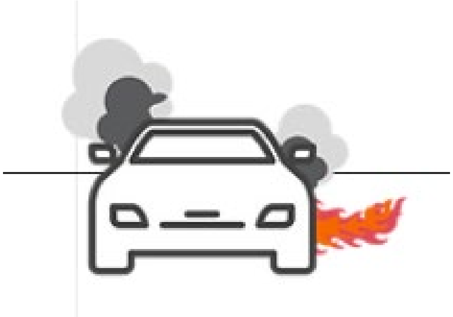
	
Flashfire [24]	Jet flame [25]

Figure 3: Photographs showing a flash fire and jet flame that can occur in EVs

While Li-ion batteries are used in many modern appliances, the batteries in EVs are larger in size and can lead to a greater fire size in terms of peak heat release rate, which can range between 32.6kWh and 118kWh for EVs currently available in the US [26]. The range of battery sizes of registered EVs in Italy was stated to be from 17.6kWh to 90kWh in 2021 [27].

2.1.3 Vapour-cloud explosion (VCE)

The conditions required for an explosion to occur include the presence of fuel, oxidant, mixing, ignition and confinement (i.e. the explosion pentagon).

Vapourised electrolyte and other gases vented from a Li-ion battery as a result of thermal runaway can form a vapour cloud providing fuel and oxidant, which can appear as a white opaque vapour cloud at low level [4], or as a dark cloud [28]. Common ignition sources include electrical sparks, static electricity, hot surfaces, friction and flame. These ignition sources can be present within the Li-ion battery during thermal runaway.

If vapour cloud accumulates in a confined space in a concentration between the lower explosion limit (LEL) and the upper explosion limit (UEL) and an ignition source is present, then a vapour cloud explosion (VCE) can occur; this has been observed in both enclosed spaces in experimental settings and in EV battery fires open air where a small VCE preceded jet flames [8] [29].

If the vented gases are ignited before the gases reach a sufficient level of confinement, then gases instead burn as jet flame or flash fire.

Detailed consideration of VCEs is outside the scope of this document and falls under the Dangerous Substances and Explosive Atmosphere Regulations (DSEAR). The HSE website provides further information and guidance [13].

2.1.4 Extinguishment and reignition

Large-scale testing and research on firefighting approaches has identified that EVs take longer for the fire service to extinguish and incidents can be protracted [1] [20]. This increase in fire duration can result in the fire affecting the building structure for longer, as well as requiring increased amounts of water to suppress the fire (discussed further in Section 2.5).

An EV fire is harder to extinguish and may re-ignite. Re-ignition of the battery occurs when other nearby cells within the battery pack become damaged in the initial incident and go into thermal runaway sometime after. Following initial suppression, it was found that 13%

of vehicles reignited after initial suppression, and two cases have been recorded where the EV re-ignited multiple times over several hours due to the residual heat that can remain in the battery even after the visible signs of fire (i.e. flame, smoke) have been suppressed [2]. This leads to EVs often reigniting hours after the initial fire event (in one study, 22 hours after the initial fire [1]). This has implications for firefighting, as discussed in Section 2.5.

2.2 Battery Management System (BMS) failure

The BMS can monitor the total battery current, the total battery voltage, the individual cell voltage, battery current and the temperature throughout the battery module [30]. It monitors the batteries health at fixed intervals and can regulate the temperature via thermal management systems to keep the battery within the optimum temperature range for performance [31], even whilst ambient temperatures are outside of the temperature range (15-35 °C [32]).

If the BMS detects a problem, it is programmed to implement countermeasures depending on the severity of the fault detected; this can vary from de-activating faulty cell/cells to de-activating entire modules or even disconnecting the entire battery from the electrical system (to prevent thermal runaway as a result of overcharging) [31]. If the BMS fails, this can result in failure of the battery and a battery fire.

Factors that can lead to incorrect function of the BMS include:

Electrical fault (hardware failure);

Software fault (e.g. bugs) [33].

BMS is part of the car and therefore, within the control of the manufacturer to develop mitigation measures to prevent failure of the BMS [33]. Such mitigation measures can include:

The owner maintains the car in accordance with the manufacturer’s instructions.

Provision of a microcontroller unit as a failsafe, in case of detecting BMS failure.

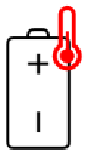
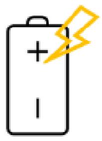
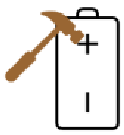
Within the BMS/battery make-up itself manufacturers can deploy the monitoring of cell electrochemical impedance (the frequency of the reactions on the surface of the electrode) to determine when the BMS is failing and thermal runaway may be about to occur, as a fail-safe to shut the battery down [33].

As car park owners/operators and designers have no control over the type of BMS in EVs, this will not be considered further within this guidance.

2.3 Factors leading to battery fires

Batteries in EVs are more likely to ignite if they are damaged [34], either due to thermal, electrical or mechanical abuse. Table 2 below sets out the different mechanisms through which a battery may ignite.

Table 1: Factors leading to battery fires – damage to the battery within the EV

Factors leading to fires	Factors leading to fires	Description of resulting damage and mechanism causing ignition
	Thermal abuse	When a Li-ion battery is exposed to high temperatures (for example by an external fire), the cells within the battery temperatures can increase and induce overheating. If external temperatures directly around the battery pack reach the onset temperature for thermal runaway (approximately 200℃), battery cells within the battery pack will be more likely to ignite and further heat up the adjacent cells; propagating the thermal runaway.
	Electrical abuse	Li-ion batteries are designed to store a certain amount of energy which can be recharged over a certain time period. If a current passes through the maximum limit of energy storage available (for example, due to internal fault within the BMS), the power is dissipated in the form of heat. If the heat cannot be dissipated fast enough this can result in an increase in battery temperature. This can result in thermal runaway occurring. If the voltage limits are exceeded this can lead to excessive heat and eventually electrical abuse and material decomposition.
	Mechanical abuse	Mechanical damage can occur when the battery is exposed to physical damage, e.g. from a collision. Mechanical damage can lead to short-circuiting. Short-circuiting of cells is where the current can pass through the conducting terminals, inducing heat build-up in the cell. Again, if this heat is not dissipated quickly enough, this can cause a thermal runaway.

Batteries within EVs are usually provided with mechanical crash protection to limit the risks of a battery being impacted through an accident. This is usually achieved through a high-strength cabin above and below the battery and an impact-absorbing crumple zone to the front and rear of the vehicle [20], as seen in Figure 4.

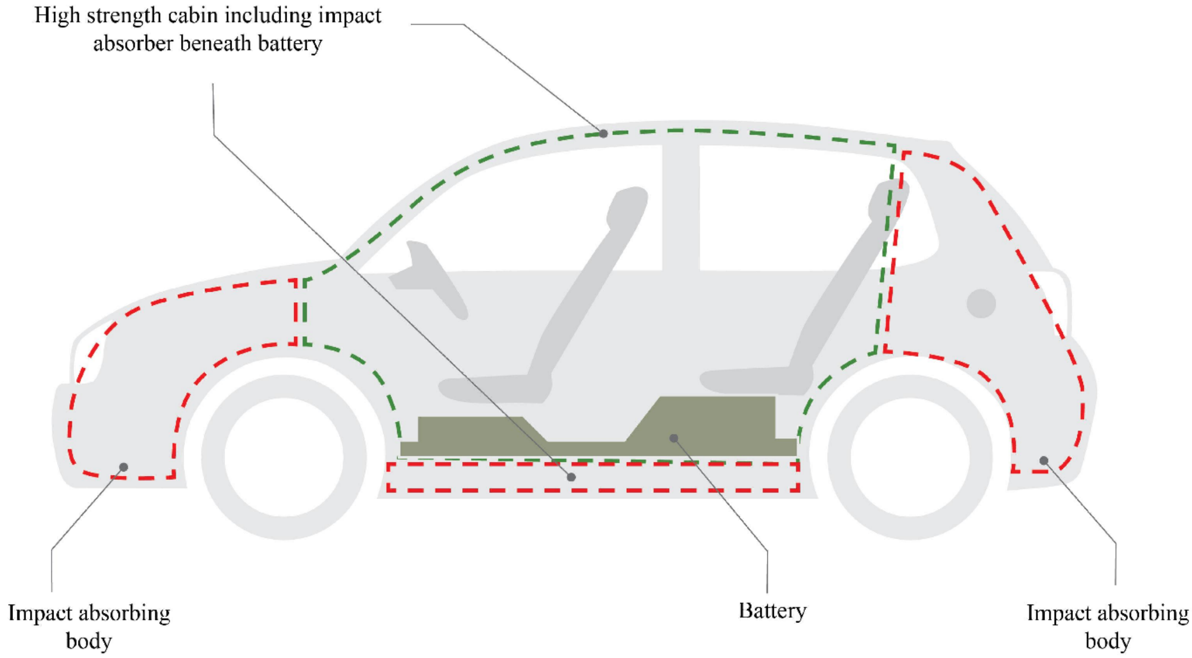


Figure 4: Mechanical crash protection typically provided to an EV [adapted from [20]]

2.3.1 Flood damage as a cause of EV fires

Typically, batteries within electric vehicles are designed to meet the minimum ingress protection (IP) ratings set out in BS EN 61851-1:2019 [35] and BS 7671:2018 [36], or other regulations such as UN/ECE Regulation 100:2015 [37]. As the batteries are for outdoor use, they would typically need to achieve IP66 which protects the product from solid particles that are over 1mm and from low velocity sprays of water from every direction [38] [35].

If the battery has suffered mechanical damage, e.g. by being in a collision, then there is a risk that water could enter the battery and cause a short-circuit between cells.

Ground-fault detection systems within the battery can detect when there is an electrical connection between the battery and metal vehicle chassis. In this instance, the system should automatically shut off the electrical supply to the battery and prevent a short-circuit/electrification of the vehicle chassis [39] [40].

EV FireSafe, an Australian government funded research project providing free information on EV risks to emergency responders, investigated the number of fire events relating to submerged electric vehicles in flood water/sea water recorded that there had been three EV fire events globally, though the time period of their survey is unknown [2].

One of these events involved sea water submersion for several hours, which likely caused electrical short circuits as seawater is a good electrical conductor [41]. As only one fire event globally has been linked to submersion in floodwater, this indicates that flooding events have the potential to cause fires within EVs but the risk of an EV battery fire following submersion in water is low [2].

None of the reviewed literature discusses the hazards posed by chargepoints being submerged by flood water. Therefore, as flood damage remains untested it poses an uncertain risk in terms of fire safety.

Whilst there are mechanisms within the vehicle that prevent water ingress or shut down the electrical supply if penetrated, to prevent the likelihood of a fire, there are some response procedures that should be followed in relation to the recovery of a flooded EV.

Micro bubbling of the water surrounding an electric vehicle can occur for reasons other than thermal runaway or the water being electrically energised [40]. The Emergency Field Guide by the National Fire Protection Association (NFPA), states that micro bubbling is the result of electrolysis, between the positive and negative terminals of the battery which breaks down the water molecules into hydrogen and oxygen gases [40].

Responders should still avoid contact with high voltage components, cabling or service disconnects of a submerged vehicle [40].

As flood waters subside and submerged EVs start to drain, EV FireSafe state that EV owners and emergency responders should take care to watch for signs of a battery fire, which can include:

Dark and light clouds of vapour that look like smoke.

Popping, whistling, or hissing sounds.

Flames protruding from underneath the vehicle.

2.3.2 Fires caused by damage to the EVCP/charging cable

There are different types of charge stations and charge cables available. Usually, cables to connect an EV to a EVCP are provided by the EV driver; unless it is a Mode 4 EVCP where the cable is always tethered to the chargepoint.

There are an increasing number of statistics reported on the total number and likelihood of EV fires as noted in Section 2.6, but they do not break down the data to differentiate between fires in EV cars and fires in EVs whilst charging, or to damage to the EVCP or the charging cable.

At the time of writing the guidance, there is limited data on whether charger power of EVCPs or the charging process itself increases the likelihood of an EV fire.

Each battery requires a set of circumstances from the charger to ensure ideal charging conditions. This includes an appropriate cell voltage (i.e. having the right level of current within the charger, so that the resultant voltage from the charger power is within the suitable range for the battery cell); and an appropriate charging regime (constant-current or constant-voltage). Having an incompatible charger does not pose a fire risk as charging cannot occur.

Whilst there is no empirical evidence available so far that would indicate a correlation of the likelihood of EV fires with damage to the EVCPs/charging cables; the fact that more ignition sources are present in the car park due to a greater amount of electrical infrastructure provided warrants careful consideration of potential consequences when undertaking the fire risk assessment (see Section 4).

2.4 Fire growth

Findings from literature suggest that whilst there are some similarities between ICEV and EV fires, there are a number of differences as well. Large-scale testing and research on firefighting approaches has identified that EVs take longer for the fire service to extinguish - approximately 6 to 49 minutes for an EV [1]compared to 5 minutes to extinguish a typical ICEV fire [20]. This increase in fire duration can result in the fire affecting the building structure for longer, as well as requiring increased amounts of water to suppress the fire (discussed further in Section 2.5).

The battery within the EV leads to a different fire growth pattern. Research by Lam et al [42] shows that an ICEV on fire tends to have a single peak heat release rate (HRR), followed by a steady reduction as the fuel and combustible components of the vehicle are burnt. With EV fires, there tends to be two peaks: the first, when the combustible materials in the car ignite; and the second, when the battery becomes involved in the fire. This is shown in the HRR graph in Figure 21 [42]. In the HRR graph, the A-EV-100 shows the heat release rate for an EV at 100% state of charge, and the A-EV-85 shows the heat release rate for an EV at 85% state of charge. The peak HRR is greatest for the ICEV, while the EV at 100% state of charge sees a second peak, and decays more slowly. The fire duration in Figure 5 exceeds the 5 minutes stated above and is due to no fire service intervention during the test (i.e. the cars were left to burn for 30 minutes). This can lead to increased heating of the surroundings and fire spread to adjacent vehicles more likely. Fire spread to adjacent vehicles was not studied as part of the experiments.

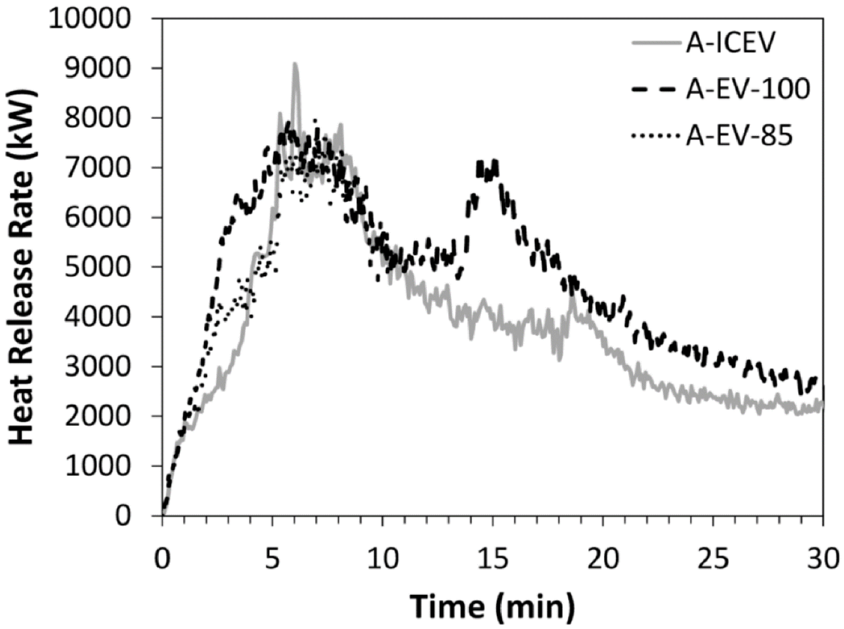


Figure 5: HRR for ICEV and EV fire tests (including a 2MW burner contribution) [42]

The full-scale fire tests which have been undertaken to date [42] suggest that the overall fire size, in terms of heat release rate, are the same between EV and ICEV fires. Both have a peak size of approximately 8 MW, which includes a 2MW burner contribution [42].

An EV fire is harder to extinguish and may re-ignite. Re-ignition of the battery occurs when other nearby cells within the battery pack become damaged in the initial incident and go into thermal runaway sometime after. Following initial suppression, it was found that 13% of vehicles reignited after initial suppression, and two cases have been recorded where the EV re-ignited multiple times over several hours due to the residual heat that can remain in the battery even after the visible signs of fire (i.e. flame, smoke) have been suppressed [2]. This means reignition may sometimes take place hours after the initial fire event (in one study, 22 hours after the initial fire [1]). This has implications for firefighting, as discussed in Section 2.5.

Smaller scale experiments indicate that the fire size is dependent on the state of charge of the battery and the sizes of the battery itself [8]. There is insufficient research available at full scale to determine if increasingly large batteries used in EVs will impact the fire size tested at full scale experiments to date.

Whilst arson activities have not been researched explicitly for EVs; inferences can be taken from full-scale fire tests to gain an idea of the impact that arson might have on an EV. Full-scale tests from which the fire was 'deliberately' started at either the rear bumper, passenger compartment or underneath the car all had the same propagation path and duration as for their ICEV equivalent within the test. Whilst there is limited research and data, it is considered unlikely that arson of the battery pack itself could be performed due to its inclusion within the core of the car, and its protective casing. If a fire was started underneath the car and the fire heated the battery pack to the point at which it became involved in the fire, the fire size would be similar to that of an ICEV fire. As such, arson on an EV would not be likely to cause a greater fire risk than if it had occurred on an ICEV.

There is currently limited experimental data evaluating the risk of fire spread between cars (EV to EV or EV to ICEV or ICEV to EV) in the literature reviewed. NFPA is undertaking research into modern vehicle hazards in car parks in general, including vehicle-to-vehicle fire spread [43]. They have found that cars built in the 2010s were likely to reach their peak HRR sooner (around 5 minutes) than cars in the 1980s (around 15 minutes) or 1990s (around 25 minutes) [43]. The research does not distinguish between ICEV and non-ICEV cars, but the data shows that modern cars are more likely to result in quicker fire spread. This has been attributed to two factors. Firstly, the larger dimensions of the cars leading to reduced separation distances. A Toyota Corolla is noted as being 210 mm wider in 2018 than 1970; a Ford F150, 80 mm wider over the same time period [43]. Similarly, the development in car design means that there is an increased use of combustible material from plastics and other inorganic materials within cars, which can lead to increased fire size. This is backed up by research from the NFPA, which found that the 5-year average of the amount of plastic within cars has increased from 100kg in 1988 to approximately 160kg in 2016 [44]. The risk factors of the increased vehicle size affect both ICEVs and EVs.

2.5 Firefighting of EV fires

Due to the different nature of ICEVs and EVs, the firefighting approach to an EV fire can be different to the firefighting approach of a conventional ICEV fire, particularly if the battery becomes involved in the EV fire [42].

The products of combustion of an EV fire are like an ICEV fire as manufacturers tend to use similar materials and components for the interiors of the EV and ICEV they produce [8]. Modern car's interiors tend to contain substantial quantities of combustible material such as large quantities of cabling and interior and exterior elements made from plastics.

Fires that involve Li-ion batteries will also produce additional gases due to the burning of the electrolyte and Li-ion salt within the battery. When fighting an EV fire in a car park, current firefighting procedures are to use standard fire-fighting equipment which has been shown via research to be sufficient when fighting EV fires [2]. Further full-scale testing is required to analyse if increasingly larger capacity batteries require additional PPE for firefighters [34].

Each incident involving an EV/ EVCP fire can be different as discussed in Section 2.1.2, which will dictate the approach of operational crews. The typical differences and requirement for firefighting of an EV are discussed below.

Larger quantities of water are required to extinguish an EV fire.

Large-scale testing and research on firefighting approaches has identified that EVs take longer for the fire service to extinguish - approximately 6 to 49 minutes for an EV [1]compared to 5 minutes to extinguish a typical ICEV fire [20]. This increase in fire duration can result in the fire affecting the building structure for longer, as well as requiring increased amounts of water to suppress the fire.

Approximately 10,000 L of water [7] is required for an EV fire where the EV battery is involved in the fire [7], compared to 4,000 L for an ICEV fire [42]. These large quantities of water are required to extinguish the fire in the battery, though this does not account for addressing potential re-ignition. The batteries are contained within sealed metal or plastic containers which makes it difficult for firefighters to apply water directly onto the battery [20].

Risk of electrocution is not considered a risk from a firefighting perspective if an EV is on fire, as the battery is not connected directly to the chassis [39]. First responders should undergo training on parts of the EV charging infrastructure and battery which are safe to contact during a fire incident, and only trained personnel should tackle EV fires. From a firefighting perspective, electrocution is not considered a risk if an EV is on fire and connected to a Mode 3 or Mode 4 charging system as the current is not part of the main grid system [45]. Mode 1 should not be provided in covered car parks. Mode 2 is typically found in a domestic context where the socket/plug is not dedicated for EV charging use.

In the unlikely event Mode 2 is used in covered car parks, it has added protection with the use of the RCD box controlling the amount of power that is received by the EV. If properly maintained, the risk of electrocution of a Mode 2 charger should not be higher than the risk of electrocution of a Mode 3 or Mode 4 charger.

Different tools required to reach the EV battery. Firefighters may need to jack up one side of the car to reach the battery. This approach is considered to be unlikely during firefighting operations by the National Fire Chief's Council (NFCC) given the potential restricted access to an EV in a car park, the additional risk this poses to firefighters and the inability to provide a safe access/ egress route to the scene of operations.

Additional PPE for fire fighters. Additional breathing apparatus may be required for firefighters due to the longer time that it might take to control an EV fire [2].

Recognising flammable vapour clouds. The vapour cloud is a white opaque gas (occasionally dark gas) which could be mistaken for steam; however it contains flammable and toxic components [4]. The white gas has a higher density than air and once release it is likely to be present at low level as opposed to steam which would likely be present at high level. This is one of the indicators which differs from steam. First responders attending an EV fire should be made aware of this.

Removal of vehicle from car park. Other firefighting approaches can involve removal of an EV involved in a fire out of the enclosed building into open air to enable better access to reach the battery for firefighting intervention using towing equipment [9]. The removal of any vehicle from a building whilst burning is an onerous task, especially in urban and metropolitan areas. The use of new equipment is still developing and the availability of this equipment in the UK is limited. The NFCC are reviewing firefighting practices and equipment for fighting EV fires currently; new procedures may therefore be available in the future. Special arrangements may need to be made however if removal of an EV vehicle is essential for e.g. business continuity or property protection purposes as NFCC have advised as part of stakeholder consultation that the fire and rescue services are not responsible for the removal of burning vehicles from a car park.

Reignition of EV batteries can occur, following initial suppression. As noted in Section 2.4, 13% of EV fires studied reignited, and two cases have been documented where the EV re-ignited multiple times over several hours [2]. To reduce the risk of re-ignition for EV batteries that have been partially burnt and suppressed, batteries should be monitored for a period of time with thermal imaging camera and by listening for popping, whistling or hissing sounds of thermal runaway prior to moving the vehicle to be disposed [2].

Submersion is used in some European countries to manage reignition, including the Netherlands and Switzerland. This involves recovering the EV from the building after it has been extinguished and submerging in a dedicated tank of water [9]. This process uses a large volume of water (up to 20 m^3) which can become polluted from the chemicals contained in the battery [9].

Research in China is investigating the installation of a local bund that can be built around the car to flood the base of the car with an extinguishing medium. Examples of these are listed in Figure 6 [46]. The testing involved filling up the bund whilst a fire propagated within the EV within its perimeter. It was found that submerging the battery within water was effective in reducing the temperature within the battery to 30˚C for most of the battery, and to 50 ˚C at the location of initial thermal runaway. The same test was performed using compressed foam which was found to be less effective in cooling the battery. The water consumption in the two tests using water as the extinguishing agent was 5.954 m^3 (5,945 l) and 6.736 m^3 (6,736 l).

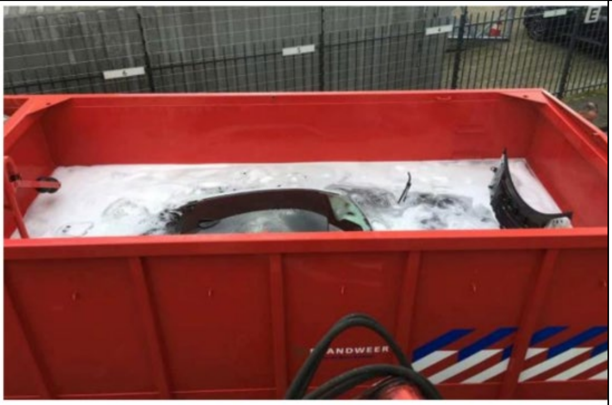
	
External tank to submerge the EV car and the battery [47]	Mobile bund to enable in situ flooding of the battery [46]

Figure 6: Firefighting tools developed to control EV battery fires [47] & [46]

Post-fire observations When removing the EV post fire from the premises, the handling and storage of the EV should be away from other structures and vehicles until the battery has been fully discharged [1]. This can be monitored using a thermal imaging camera (refer to Section 6.3).

Car park operators/owners should liaise with their local fire and rescue authority to understand their current approach to fighting a fire in an EV; and how this may affect design plans and/or mitigation measures provided (see Section 5).

2.6 Frequency and likelihood of fires involving EVs vs ICEVs

There are several studies [48], [2] regarding the quantity of EV fires at a national and global level which when compared, indicate that the data presented has a high degree of uncertainty; as data capture is not yet sufficiently coordinated at these different scales. Due to the infancy of data collection regarding EVs, parameters which could provide insight into issues causing EV fires are often omitted; such as if the EV was charging, the cause of the fire, if the battery pack was involved, or the age of EVs involved in the fire.

Norway represents one of the largest markets for EVs in the EU. Statistics for the number of total EVs in Norway was 270,309 as of 2020, which was 9.7% of all cars in Norway. The rescue operation reports database in Norway (BRIS) outlines 110 fires in passenger car EVs for the years 2016-2021 [12]. In this same time period, there were 4,026 ICEV fires. Therefore, EVs made up 2.7% of all fires in EVs and ICEVs. Similarly, other details about the fire incidents were not recorded.

For 2021, BRIS details that there were 29 fires involving EVs and 658 ICEV fires. EV car fires made up 4.1% of all car fires in 2021 in Norway [12]. This data suggests that EVs have a proportionately lower contribution to fires.

This may contrast with data in London. The London Fire Brigade (LFB) attended 811 car fires in 2021, of which 56 (6.9%) involved electric vehicles. Note: this data includes all vehicles that have an EV power supply (drive), so includes battery electric vehicles, plug in hybrids and hybrid electric vehicles. The cause of 25 (3%) of these was attributed to an electrical fault (not necessarily the lithium-ion batteries or related to charging) [11]. 2% of London's vehicles are ultra-low emission vehicles based on data for the first half of 2021

[49], which includes battery electric (EV), plug-in hybrid electric and fuel cell electric vehicles [18].

Thatcham Research, the UK motor insurers' research centre, used the data from the Motor Insurance Anti-Fraud and Theft Register (MIAFTR) and their own data to categorise fire claims by vehicle fuel type, excluding claims relating to theft as they could be due to arson. This data was compared against data on the UK Government website [16] to calculate the percentage of fires per year per average number of cars of a particular propulsion type for the years 2018-2020.

This analysis showed that the average percentage of fire claims per year for an EV out of the average number of licenced EVs was 0.001%, and 0.003% for both plug-in hybrid vehicles and REEVs. This is lower than 0.007% for petrol vehicles and 0.011% for diesel vehicles. This is shown in Figure 7 and Table 2.

Research did also identify that arson is a significant cause of vehicle fires. England fire statistics from 2010 to March 2021 indicate that 46.5% of car fires are due to arson [50]. The data does not distinguish between propulsion type or age.

Norwegian fire statistics taken from the reporting system BRIS detail that between 2016 and 2018, there were a total of 998 fires in car parks and garages. Of these, only 7 fires were in car parks, with 4 of the 7 fires (57.1%) recorded as arson [51]. The data states that there were no EV fires in car parks in this time period. This data presented does have uncertainties as 60% of the 998 fires listed the cause as "unknown/cause not recorded" [51].

Although this data in England and Norway has its limitations, it does suggest that within car parks arson is deemed to be one of the leading causes of fire and therefore further investigation is required to better understand the impact of arson and whether it is more likely to occur in ICEVs or EVs.

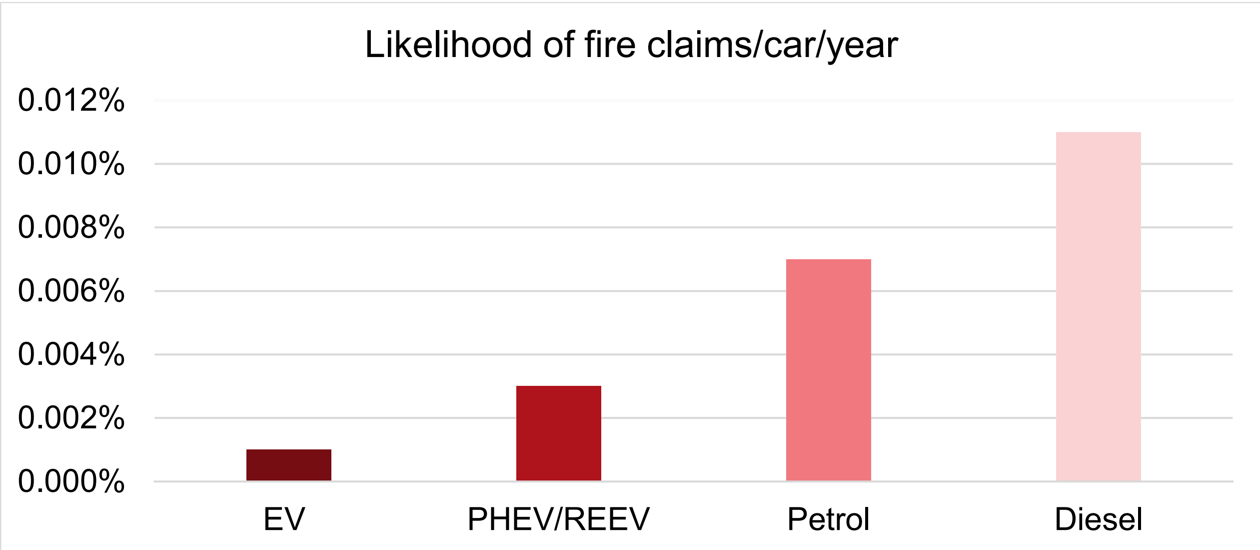


Figure 7: Illustration of likelihood of fire claims per car per year, sorted by propulsion type [10]

Table 2: Likelihood of fire claims per car per year, sorted by propulsion type

Likelihood of fire claims/car/year (%)	Type of car
0.001	EV
0.003	PHEV/REEV
0.007	Petrol
0.011	Diesel

The early research and available data suggest that EVs are less likely to catch fire than ICEVs. It is acknowledged that as cars age, they are more likely to have a fire [10]. This may be a factor in why EVs present a lower fire risk than ICEVs; the oldest EVs are only 12 years old compared to ICEVs which can be significantly over 12 years old.

Tesla, a global EV manufacturer, have also compared the number of fire incidents in their EVs with ICEVs. Tesla's Vehicle Safety Report – Vehicle Fire Data [52] evaluated from records data between 2012 and 2020, the frequency of a Tesla EV fire for a given number of miles travelled and compared it with data from the National Fire Protection Association (NFPA), an international non-profit organization devoted to eliminating death, injury, property and economic loss due to fire, electrical and related hazard; and U.S Department of Transportation (DOT). Tesla's report estimated that there is one Tesla EV fire for every 205 million miles travelled compared with the national average of one ICEV fire every 19 million miles in the U.S., according to the (NFPA) and U.S. Department of Transportation (DOT) [52]**.** This suggests that Tesla EV fires are less likely than ICEV fires, although it should be noted that as Tesla is a premium brand, and all ICEVs are considered, there may be socio-economic factors behind the discrepancy.

None of the research considers socio-economic factors associated with ownership of EVs; this is relevant as EVs to date are comparatively more expensive than ICE vehicles. The research is also limited to a small number of vehicle brands. As EVs become more affordable to a wider user group, the frequency of fire incidents and associated consequences of such EV fires may change in the future as the number of EVs increases in the coming years.

Overall, the data currently available suggests that EVs do not present an increased likelihood of fire compared to ICEV equivalents. The data is limited as it is not yet fully co-ordinated or captured consistently between countries/companies. In addition, as EVs age and become more widely used, risk of fire may increase.

2.7 Ecological considerations

Firefighting water run off: Research performed in Switzerland in a tunnel in 2019 [9] on a battery module of 4.15 kWh (compared to an EV battery system that has around 8-10 times the power) studied the impact on the chemical makeup of firefighting water after fighting an EV battery. The firefighting water run off was found to contain contaminant levels for Lithium and heavy metal concentrations which far exceeded the limits permitted for industrial effluent entry into their sewage system. This emphasises that water used to fight an EV fire may need to undergo treatment before it can be released into sewers / the environment [9].

3. Common fire safety features of covered car parks and reported fire safety issues

Chapter summary

The chapter summarises the common fire safety features provided in car parks designed in accordance with fire safety guidance Approved Document B (ADB) [53]. To help car park owners, operators and/or designers and fire risk assessors establish what existing fire safety provisions are in place in the car park and how those are intended to operate in case of fire.

It is important to establish the fire safety strategy of the car park into which EVCPs are to be installed, as a baseline against which to assess what additional fire safety measures may be needed to support the installation of EVCPs.

3.1 Common fire safety features

Current statutory fire safety guidance, Approved Document B (ADB) [53], sets minimum fire safety precautions expected to be in place for compliance with the Building Regulations in England, summarised in Table 3. These provisions have not substantially changed for many years and would generally apply to existing and new car parks. At the time of drafting, there is an ongoing review of fire safety in buildings which will consider whether current provisions are sufficient to address modern car park designs.

It is important that car park owners, operators and/or designers establish what existing fire safety provisions are in place in the car park and how those are intended to operate in case of fire, as a baseline against which to assess what additional fire safety measures may be needed to support the installation of EVCPs.

This is needed because existing arrangements may:

Affect the mitigation measures in Section 5 that could be provided to address different hazards identified as part of the fire risk assessment (if the car park is existing).

Provide a level of fire safety that is insufficient once EVs/EVCPs are considered, either from a life safety or property protection perspective; and therefore, require additional measures to meet their requirements.

Table 3: Common fire safety features in covered car parks

Fire safety	Common fire safety features
Means of escape and warning	Car parks usually operate under a simultaneous evacuation where the entire car park evacuates at once. Car parks with floors above ground would usually have two means of escape, with one refuge in each escape stair for a person with restricted mobility, and a management plan to assist persons unable to evacuate independently without support from the fire and rescue service. Travel distances in car parks need to be limited, with single direction travel distances no longer than 25 m, and two-way distances no longer than 45 m, measured to the entrance of a protected stair, protected lobby or an exit direct to outside.

Fire safety	Common fire safety features
	As a minimum, manual call points and a means to raise an alarm for evacuation are usually provided. Where the car park is linked to other buildings, it may be part of the evacuation zone of that building, or a separate evacuation zone if the car park is separated by fire resisting construction of at least 60 minutes. *Note: Bespoke tenability analysis may also have been undertaken for a car park, using evidence from historic fire research to justify longer travel distances for a defined fire scenario representing a fire spreading to one car or a limited number of cars, combined with smoke control and potentially automatic suppression provisions.*
Internal fire spread (linings)	Internal linings within car parks are usually non-combustible as the main structural elements of car parks are formed of concrete and steel.
Internal fire spread (structure)	For car parks constructed from A1 (non-combustible) materials (with limited exceptions set out in ADB) that are also open-sided, i.e. buildings with a high degree of natural cross ventilation, and a top storey up to 30 m in height, the loadbearing elements of the structure may have fire resistance periods of only 15 minutes, increased to 30 minutes where elements protect means of escape.
External fire spread	Fire spread risk to adjacent buildings is commonly evaluated using enclosing rectangle method set out in BR187:2014 [54]. For car parks with split level configuration or internal ramps linking floors, the enclosing rectangle is commonly taken as the full height and width of the car park, allowing for potential fire spread over multiple floors. For configurations with full fire resistant floors, the enclosing rectangle might be limited to one floor only. The fire properties of any external cladding also influence the external fire spread risk to adjacent buildings. *Note: Bespoke fire spread analysis may also have been undertaken, using evidence from historic fire research to justify a smaller enclosing rectangle representing a fire spreading to one car or a limited number of cars.*
Smoke ventilation system	A means to vent smoke is required; this can be provided via permanent openings in the external walls or via mechanical means. Naturally ventilated car park: at each level, the aggregate free vent area should be a minimum of 1/40 of that level's floor area, at least half of which should be provided equally by two opposite walls (1/160 on each side). The remaining free area can be distributed wherever possible. Where mechanical ventilation is provided, automatic fire suppression is also needed if the car park is a basement, to control the fire size and smoke temperatures. The mechanical smoke control system would usually achieve 10 air changes per hour (ACH), be provided with independent power supply

Fire safety	Common fire safety features
	if mains power fails and can be activated via a dedicated fire detection system or may be linked to the suppression system. *Note: Car parks can also have a bespoke smoke control strategy designed to maintain a clear smoke layer height for a defined maximum fire size.*
Firefighting access and facilities	For car parks with a top story under 18m in height, firefighting access is usually provided via the building perimeter; the extent of access required is a function of the projected floor area of the car park, which increases with an increase of floor area. Over 18m, internal firefighting provisions are provided via a firefighting shaft, comprising a protected stair, ventilated lobby fitted with a fire main and a firefighting lift. For basement car parks, a firefighting shaft is required where there is a basement more than 10m below the fire and rescue service access level. It should comprise a protected stair, ventilated lobby fitted with a fire main and a firefighting lift. Where the building is less than 10m below access level, firefighting shafts (which do not need firefighting lifts) should be provided where there are two or more basement storeys, each exceeding 900m^2 in area.

3.2 Fire safety issues reported specific to car park structures

Collaborative Reporting for Safer Structures UK (CROSS) [55], a secure and confidential safety reporting system, has two reports relating to fire safety of multistorey car parks, one relating to the Liverpool Echo Arena Fire in December 2017 where an ICEV fire spread rapidly to other cars, and one report noting the same issues in a separate car park structure.

The 2018 CROSS report into the Liverpool Echo fire notes specifically that for the 2006 BRE research 'Fire spread in car parks' [56] the cars used *"were [..] 2001-2006 models which were very different from current vehicles in terms of their behaviour in fires".* It gives guidance for consideration of fire safety risk in existing car park structures, of which the key points are:

Structural fire resistance – the Liverpool Echo car park had localised structural failure. Although it remained standing, it was seriously damaged and subsequently demolished and rebuilt. ADB allows 15 minutes structural fire resistance for certain car parks and therefore, CROSS recommend considering whether 15 minutes would be sufficient given the nature of the car park. This minimum fire resistance is currently part of the review by DLUHC as part of research into fire safety in car parks.

Sprinkler provision is effective at controlling fire development within covered car parks and should be considered as part of a cost-benefit analysis when designing new open-sided/enclosed car parks (MSCPs).

Developments in car design have resulted in an increased use of plastics within modern cars which facilitates easier fire spread. Current car park design often relies on a fire not spreading beyond the first vehicle and therefore assumes no more than a single vehicle burning at one time. This assumption, and the effect it can have on external fire spread, may no longer be valid and should be considered as part of the car park design.

The NFPA is undertaking research to identify how car design has changed and what impact modern car design has on existing fire safety measures within car parks [44]. Their initial review (2020) found that the change in car design means that vehicles are generally heavier than they were in the past (although this is not the case everywhere) with an increase of 430kg and 150kg respectively in the two most popular vehicles (Toyota Corolla and Ford F150) in the US between 1970 and 2018 [43]. This trend for vehicle weights is also observed in the UK, based on a review of the 10 popular car types in grey literature [57], more than half increased in weight by more than 35% compared to the first generation.

Vehicles of greater weight will generally have a greater heat release rate due to the inclusion of a greater fire load (i.e. fuel and combustible material from plastics and other inorganic materials used in the design of modern cars). Heavier cars will also have implications on the design of a car park structurally [57]. The larger review of Approved Document B and fire safety in buildings will consider the legislative and policy changes that may need to be made to improve building safety, including in the event of an EV fire.

4. Steps to determine relevant mitigation measures

Chapter summary

This chapter describes the risk assessment approach that should be considered prior to the installation of EVCPs. This chapter also introduces the ERIC hierarchy of control measures which has been used to help categorise the size of impact that different mitigation measures would have.

4.1 Establishing fire safety objectives and constraints

To determine what mitigation measures should be considered when introducing EVs/EVCPs to a covered car park, the fire safety objectives and constraints should be established first. This means:

1. For an existing car park:

    a. review the fire safety strategy setting out what active and passive fire safety precautions, and fire safety management provisions it has, and
    b. establish how the fire safety measures are expected to operate in case of fire and their maintenance and testing status.

If this is not available, Section 3 sets out common features for carpark structures, which may help develop a retrospective fire strategy by a competent person.

This should establish if there are specific property protection or business continuity considerations that apply.

1. For a new car park:

    a. The new risks associated with EVs present some differences to ICEVs as discussed in this document. A performance-based fire safety engineering approach to the design of car parks may be considered appropriate (e.g. BS 7974), in addition to standard guidance such as ADB and BS 9999.

4.2 Risk assessment to establish mitigation measures

Prior to installing the chargepoints a fire risk assessment (which should be conducted by a competent fire risk assessor of the car park) must be undertaken. To assess the impact these have on existing fire safety measures; and identify any increased or different risks that may result from the increased numbers of EVs and/or EVCPs within the covered car park.

It is expected that safety measures/features of new car parks would be covered by the inherent risk assessment process that forms part of the fire safety design following standard guidance as noted in Section 4.1. If desired by the designer, design team or client, the process outlined below can be applied to new car parks also.

Given the complexity and potential considerations/measures that may be needed, a competent person with sufficient experience who understands fire safety approaches in car parks should be appointed to undertake the fire risk assessment.

The aim of the assessment is to evaluate the different fire risks of EVs and EVCPs; although some considerations will also be applicable to ICEVs expected within the car park due to the similarities between the two types of vehicles, over time, as discussed in Section 2.4.

In most buildings the Regulatory Reform (Fire Safety) Order 2005 (RR(FS)O) [58] places the responsibility on the Responsible Person as defined under Article 3, which could be employers, occupiers, those who have control and/or owners of almost all premises and requires them to take such fire precautions as may be reasonably required to ensure that premises are safe for the occupants and those in the immediate vicinity.

The principles of prevention set out in Part 3 of Schedule 1 to the RR(FS)O need to be considered:

The principles are—

- *(a) avoiding risks;*
- *(b) evaluating the risks which cannot be avoided;*
- *(c) combating the risks at source;*
- *(d) adapting to technical progress;*
- *(e) replacing the dangerous by the non-dangerous or less dangerous;*
- *(f) developing a coherent overall prevention policy which covers technology, organisation of work and the influence of factors relating to the working environment;*
- *(g) giving collective protective measures priority over individual protective measures; and*
- *(h) giving appropriate instructions to employees.*

There are a number of different risk assessment guidance documents available which could be used, such as:

HSE’s steps needed to manage fire risk [59].

PAS 79-1:2020 [60].

- An example of this approach is given in Appendix A.

HM Government’s guide to fire risk assessment [61].

CROSS also contains useful guidance on fire risk in car park structures, as set out in Section 3.2.

The fire risk assessment as a minimum, should consider life safety of relevant persons in accordance with RR(FS)O.

In some cases, there may be additional property protection and/or business continuity aspects to consider and address as part of the fire risk assessment.

4.3 Factors relevant to car parks to be considered when undertaking the assessment

There are several factors to consider when undertaking the fire risk assessment, which can influence and impact the outcomes of the fire risk assessment.

A number of fire safety features in existing carparks may have been based on historic fire data for ICEVs or developed using bespoke fire safety analysis using assumptions of fires not spreading beyond one or a small number of cars. These may no longer be appropriate for modern larger cars (and consequently greater fire sizes) in general.

These features are, for example:

Fire resistance and reaction to fire performance (combustibility) of the structure.

Fire spread risk to adjacent buildings.

Smoke and heat exhaust ventilation systems.

Firefighting access and facilities, including smoke ventilation systems and water.

Other features that need to be considered are:

Means of escape and warning.

Internal fire spread.

These are diagrammatically identified in Figure 8 below.

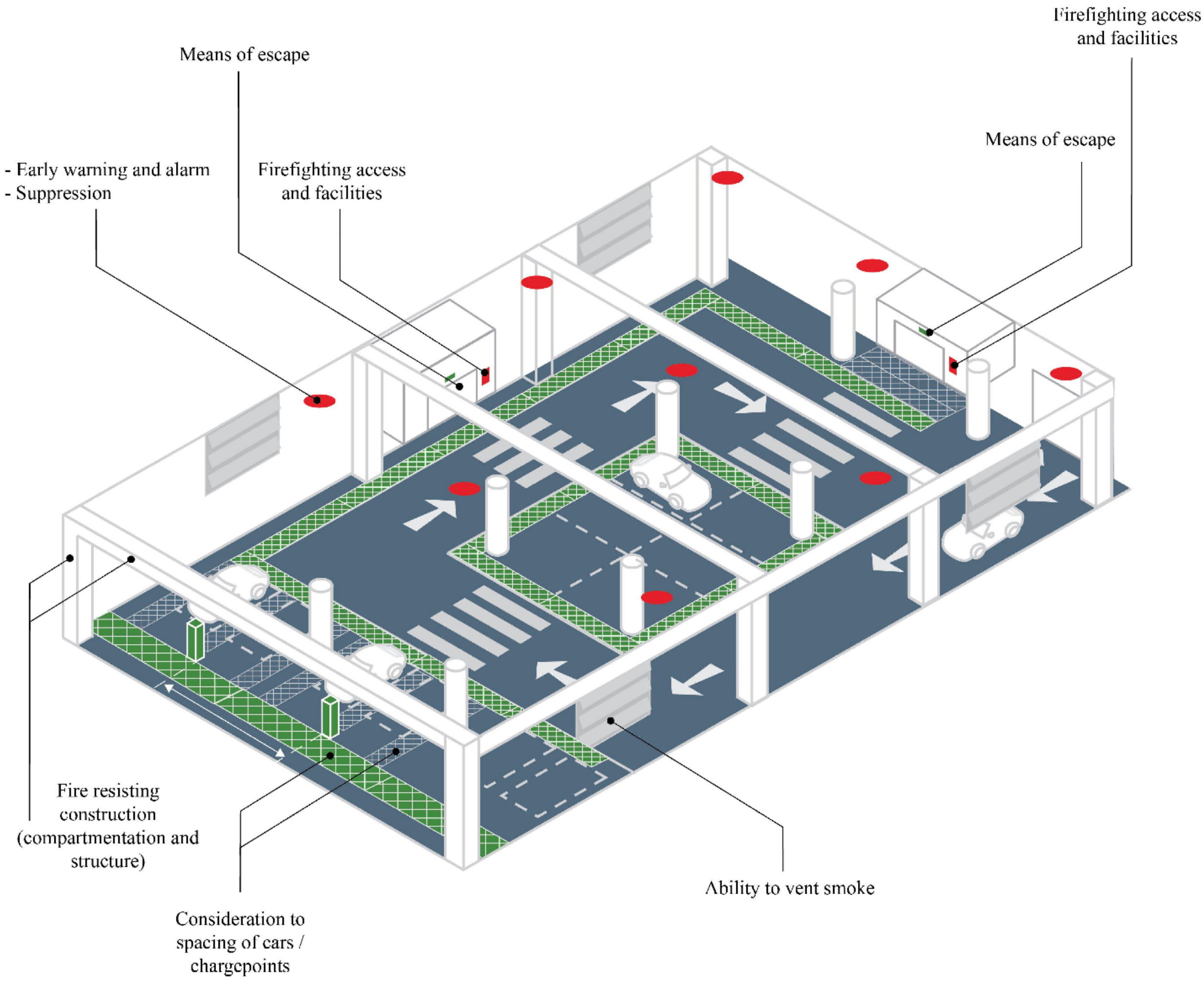


Figure 8: General considerations for a low-rise car park with EV chargepoints

4.4 Risk assessment process

It is the responsibility of those who need to comply with the above (and other legislation) to demonstrate how they will comply, by providing a design proposal or an assessment of the risk, supported with appropriate evidence from a competent person.

HSE risk assessment guidance for workplaces sets out steps to adopt to evaluate risk, which forms a useful framework. It contains the following steps:

Identifying hazards.

Who might be harmed.

- Based on the specific car park in question this will include persons in the car park, and persons or other buildings in its vicinity.

Evaluate the risks.

- If the risks are not acceptable, then mitigation measures need to be identified until the risks are acceptable, considering measures set out in Sections 5 and 6.

Record findings.

Review.

This should be adapted to include property protection/business continuity considerations if applicable. As EVs and EVCPs are novel technologies that are subject to extensive research globally, the review stage is very important as new evidence and guidance relating to fire safety of EVs and EVCPs becomes available.

4.5 Mitigating the risk – ERIC hierarchy of control

Having identified the hazards or changes to existing hazards being introduced to the car park because of EVCP installation and predicted EV usage, appropriate mitigation measures of the identified hazards should be considered.

There are a number of different means to categorise mitigation measures, such as the hierarchy of control. The hierarchy of control has been used for this guidance as it introduces the concept of applying different methods to minimise documented hazards as far as is reasonably practicable at an early stage of the design process. The underlying methodology is based on prevention through design. As there are differing levels of measures that can be introduced, this allows the user to understand and assess the applicability of the control measures to their car park, including considerations that could be taken when retrofitting EVCPs into existing car parks.

For the purposes of this document, the eliminate, reduce, isolate, control, or "ERIC" hierarchy for categorising mitigation methods has been used.

Eliminate – Remove the hazard completely and prevent it occurring.

Reduce – Decrease the likelihood of the hazard occurring.

Isolate – Implement measures so that the effect of the hazard is limited.

Control – Adopt procedures/measures to manage the consequences when the hazard occurs.

The most effective measures are those which eliminate the risk, with the least effective measures relating to those that use management protocols or procedures that require specific training for staff and potentially additional safety equipment to undertake specific procedures. This is shown illustratively in Figure 9.

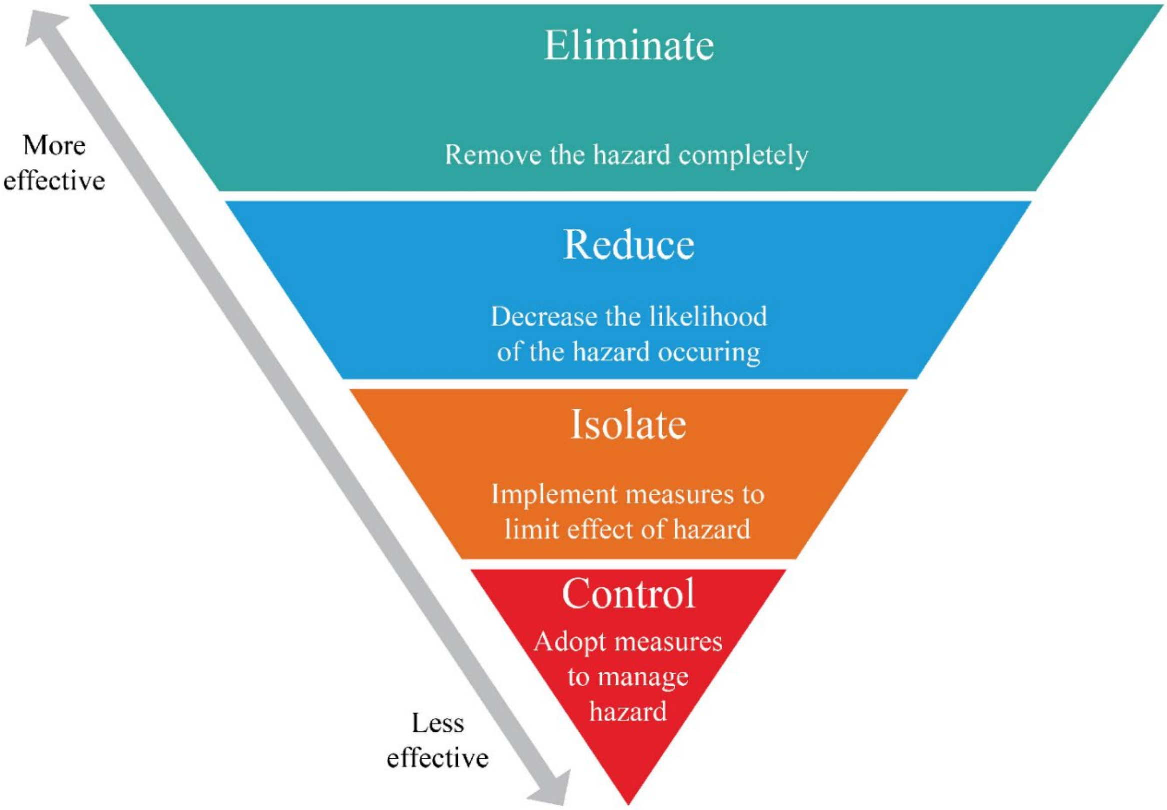


Figure 9: Hierarchy of mitigation measures [adapted from [62]]

5. Hazard mitigation measures

Chapter summary

The use of this guidance document is to help provide owners, operators and designers with the information to reduce the risk and/or impact of an EV fire in a covered car park. This chapter introduces the mitigation measures that can be implemented to either eliminate, reduce, isolate or control the likelihood and impact of a fire resulting from an EV or EVCP. The mitigation measures in each table are provided in relation to the risk that they are mitigating. These are then supported by a reason for this mitigation measure.

This chapter also contains two case studies, one for a new car park designed for 100% EV chargepoint provision and one from the City of London Corporation which aimed to find the optimum suppression system for limiting fire spread.

Section 6 provides further discussion on the mitigation measures introduced within this section.

5.1 Mitigation measures addressing risk of fire starting in an EV or EVCP

This section considers each of the hazards within an EV or EVCP which could start a fire or lead to a fire spreading to multiple cars. Associated mitigation measures that could be implemented are set out for each hazard in Table 4 to Table 8. The hazards discussed were identified during a literature review carried out using information available as of April 2022 that Arup has performed to inform these considerations. The literature review also identified that there were areas which required further research due to the relatively new nature of EVs. Where there is a lack of research/data, but a sound theoretical understanding of a risk, cautionary mitigation measures are suggested until further evidence and/or research is available which can suggest alternative courses of action.

Each risk mitigation measure has been assessed against the ERIC hierarchy of control, to assist the car park operator and/or designer in considering the effectiveness associated with each measure. It is necessary to consider all hazards identified as part of a holistic approach to determine which mitigation measure or suite of measures would be best to adequately address the hazards identified.

Table 4: Mitigation measures relating to thermal abuse of EV batteries

Description of mitigation measures	Classification of control measure
Measure: Provide water-based fire suppression within the car park. **Reason:** In the case of a vehicle adjacent to EV(s) being on fire, water-based fire suppression provides water coverage to the fire and the surrounding area, cooling to the surrounding environment and reduces the risk of increasing the temperature of the battery within the EV as a result of external heating. An increase in temperature of the battery within the EV can potentially trigger thermal runaway. The provision of water-based fire suppression should in the event of vehicle fire reduce the rate of fire spread to adjacent vehicles and buildings. Refer to Section 6.4.	Reduce
Measure: Increase distance between parked cars. **Reason:** Increased separation distance between parked vehicles reduces the likelihood of fire spread to adjacent vehicles, as it reduces radiant heat exposure of adjacent EV batteries. An increase in temperature of the battery within the EV can potentially trigger thermal runaway.	Reduce
Measure: Provide fire resistant construction between parking bays. **Reason:** Providing fire resistant construction between parked vehicles, will reduce the likelihood of fire spread to the adjacent vehicles as it will provide a physical barrier to the spread of heat and flames between the cars. This fire resistant construction could be full or partial height. The potential reduced visibility should be accounted for in design but is considered to be similar to the visibility drivers have when pulling out between two cars.	Reduce
Measure: Provide thermal monitoring cameras within the car park. **Reason:** Monitoring the temperature of the batteries within the EVs may give an indication of the status of the battery as it may detect early increases in temperature. It is important to note that, as batteries in EVs are at the base of the vehicle, effective monitoring of the battery is best placed at ground level for early detection. From this information, thermal imaging cameras may identify that the battery within the EV is going into thermal runaway. This can allow for early intervention which could prevent an uncontrolled fire. Refer to Section 6.3.	Isolate

Table 5: Mitigation measures relating to electrical abuse of EV batteries

Description of mitigation measures	Classification of control measure
Measure: Provide certified and approved electric vehicle chargepoints (EVCP). **Reason:** EVCPs should meet the minimum set of technical requirements as set out in BS EN 61851 and any other applicable regulations. A faulty EVCP may trigger a short-circuit within the EV battery or provide too much charge to the EV battery. Both can lead to thermal runaway. Consider choosing an EVCP which has overcurrent protection, tilt sensors, damage/fault reporting, temperature sensors and ventilation. Refer to Section 6.1. Put in place a maintenance regime for EVCP.	Reduce
Measure: EVCPs installed by competent persons. **Reason:** EVCPs should be installed by a competent person who is a member of the Competent Persons Scheme.	Reduce
Measure: Provide a manual isolation switch to cut power supply of EVCP. **Reason:** If an EV is on fire and charging, the continued supply of energy may increase the internal battery temperature and intensify reactions within the battery cell. Cutting the supply of energy can control and reduce the likelihood of an energised electrical fire. This should be installed so it can be operated in a safe environment and clearly labelled to identify which chargepoints will be isolated. Refer to Section 6.6.1.	Control
Measure: Provide automated isolation of power supply linked to detection system/suppression system/automatic de-energisation of connection cables. **Reason:** If there is an automatic detection system installed, it can be interlinked with the power supply to the EVCPs to automatically cut off the power supply to either all EVCPs in the car park or EVCPs on the floor of fire detection. Suppression systems can also be linked to automatic isolators. Refer to Section 6.6.2.	Isolate

Table 6: Mitigation measures relating to mechanical abuse of EV batteries

Description of mitigation measures	Classification of control measure
Measure: Provide controlled speed limits in car park. **Reason:** Collisions which have enough impact to deform the battery pack within an EV may cause failure of the internal components of the battery. This may lead to a short-circuit and trigger thermal runaway of the EV battery.	Reduce
Measure: Provide car park layout that reduces the likelihood of collisions. **Reason:** Providing good sight lines and lighting, sufficient space to turn and park vehicles, suited to current car dimensions, providing a one way system and providing rubber pads to columns can help reduce collisions and hence damage to the EV battery.	Reduce
Measure: Secure storage of vehicles. **Reason:** Where vehicles are known to be prone to mechanical abuse, e.g. police cars, consideration should be given to placing them in a secure/segregated parking area away from other vehicles or not allowing these EVs into covered car parks.	Isolate

Table 7: Mitigation measures relating to damage to EVCP and/or charging cables

Description of mitigation measures	Classification of control measure
Measure: Provide crash protection to the EVCP. **Reason:** This could provide impact protection and as a result reduce the likelihood of faults developing in the EVCP. This could be via bollards or physical barriers, designed in accordance with BS 6180:2011 [63] or PAS 68:2013 [64].	Reduce
Measure: Routine inspections by a responsible organisation. **Reason:** Routine inspections can pick up faults/damage that the EVCP internal monitoring system is not able to identify. Consideration should be given to undertaking regular inspections of chargepoints. Consider choosing an EVCP which has tilt sensors, damage/fault reporting and temperature sensors.	Reduce
Measure: Position the EVCP so that the charging cable can easily attach to EV with minimum length of cable. **Reason:** To reduce the risk of damage to the charging cables, the EVCP should be positioned so that charging cables do not lay where other vehicles can drive over them or in the main circulation space where people could trip or step on them.	Reduce
Measure: Provide security systems to deter deliberate damage. **Reason:** Security cameras with clear signage and a management strategy can help to deter people deliberately damaging the EVCP.	Isolate
Measure: Install Mode 3 or Mode 4 EVCP. **Reason**: Mode 3 and Mode 4 type EVCP have an inbuilt interface to monitor faults within the chargepoint. EVCPs with the ability to monitor overcurrent protection, tilt sensors, damage/fault reporting, temperature sensors and ventilation are likely to terminate charging and prevent events leading to an uncontrolled fire. Refer to Section 6.1.2.	Reduce
Measure: Ease of returning the cable to its rest position. **Reason:** When selecting a Mode 4 charger, consideration should be given to a model that allows for the cable to be returned to its resting place more easily. This makes it easier for users to put the cable back in its intended resting place; thereby reducing the likelihood that cables will be left trailing on the floor.	Reduce

Table 8: Mitigation measures for faulty EVCP

Description of mitigation measures	Classification of control measure
Measure: Remove the faulty EVCP immediately. **Reason:** Charging with a faulty EVCP could lead to a fire as discussed in Table 5. An EVCP may be found to be faulty either through routine inspections, self-damage/fault reporting, or reporting of visible faults by a member of the public or via CCTV. Faulty equipment should be reported to the manufacturer for rectification; the product safety body enforcing EVCP should also be notified.	Eliminate

5.2 Mitigation measures to protect someone or something from fire involving one or more EVs

Should an EV fire occur within the car park, risk mitigation measures can be introduced to the car park to minimise the consequence of such a fire, as set out in Table 9 to Table 14 and categorised by who or what they are protecting and also against the ERIC hierarchy of mitigation measures.

Table 9: Risk mitigation measures to limit fire damage to other vehicles

Description of mitigation measure	Classification of control measure
Measure: Provide water-based suppression. **Reason:** Refer to Table 4 and Section 6.4 for further information.	Reduce
Measure: Provide increased spacing of cars. **Reason:** Refer to Table 10 for further information.	Reduce
Measure: Provide fire resistant construction between EV parking bays. **Reason:** If a parked car is involved in a fire, providing fire resistant construction between the vehicles will reduce the likelihood of fire spread to the adjacent vehicles as it will provide a physical barrier to the spread of heat and flames between the cars. This fire resistant construction could be full or partial height. Refer to Table 10.	Reduce
Measure: Provide automatic fire detection and alarm. **Reason:** The provision of automatic fire detection allows early detection of the fire and can help facilitate first-aid firefighting intervention, e.g. by onsite management team (not all car parks are managed by on-site staff) or the measures outlined in the row below, or early notification of the fire and rescue service. Providing automatic fire detection and alarm will also alert the occupants of a fire, allowing them to evacuate whilst the fire is in its early stages. See Section 6.5.	Isolate
Measure: Provide manual firefighting measures. **Reason:** If fire extinguishers and dedicated EV fire blankets are provided near to the EV charging bays, this may allow early intervention by appropriately trained staff whilst the fire is still small, **if it originates in an area of the EV other than the battery.** Fire blankets for use on EV fires are in development, prior to this solution being adopted the fire testing and certification should be reviewed for appropriateness. This review should also consider how the fire blanket is to be safely deployed.	Control

Description of mitigation measure	Classification of control measure
The use of these measures should be addressed via the fire risk assessment and the operator should determine the level of training required by attendants.	

Table 10: Risk mitigation measures to assist the fire service

Description of mitigation measure	Classification of mitigation measure
Measure: Provide sufficient firefighting water supply. **Reason:** More water is required to tackle an EV fire compared to an ICEV fire. When the battery becomes involved in an EV fire, the increased water supply is required to cool the battery and prevent further thermal runaway reactions from occurring within the battery pack. Therefore, the supply of water provided within the car park may need to be increased to meet the current recommendation for 1,500 l/min for 60 minutes in BS 9990:2015 [65]. Where increased firefighting water provision are provided consideration should be given to the drainage system and its capabilities to disperse this increased volume of water, refer to Section 6.7.2. The contamination of firefighting water should be considered, see Table 14.	Reduce
Measure: Provide access for removals of EVs that have been on fire. **Reason:** To minimise the risk of re-ignition of the battery, the EV that was on fire may need to be physically removed post-fire for monitoring and further extinguishment external to the covered car park. It is not the responsibility of the local fire and rescue service to remove the vehicle so a contract with a car removal company might need to be considered. If this mitigation measure is adopted the clear headroom in the car park needs to be taken into consideration as this may limit what types of recovery vehicle can enter the car park. Refer to Section 6.7.3.	Isolate
Measure: Provide increased spacing between cars – either in the design of new car parks or by re-painting the car park spaces in an existing car park so they are larger than previously. **Reason:** Where a new car park is being provided, the car park layout could be designed to incorporate parking spaces of increased width, or with walking routes between bays (as provided to accessible parking bays). This increased distance between parked cars means that if a parked car is involved in a fire, the adjacent vehicle is exposed to less radiant heat and is therefore less likely to become involved in a fire. Current research from NFPA suggests that increased car sizes over the last 40 years have reduced the space between cars and therefore made car-to-car fire spread more likely [43] and therefore, larger spaces should help mitigate this.	Reduce
Measure: Provide fire resistant construction between EV parking bays. **Reason:** If a parked car is involved in a fire, providing fire resistant construction between the vehicles can reduce the likelihood of fire spread to the adjacent vehicles as it will provide a physical barrier to	Reduce

Description of mitigation measure	Classification of mitigation measure
the spread of heat and flames between the cars. This fire-resistant construction could be full or partial height.	
Measure: Provide suitable water-based suppression. **Reason:** Refer to Table 4 and Section 6.4for further information.	Reduce
Measure: Provide additional information to the premises information plans to help inform firefighting operations. Refer to Section 6.7.4. **Reason:** Additional information allows fire and rescue services to understand what measures are available in the building to protect firefighters and inform firefighting tactics to fight a fire. Refer Section 6.7.4 for details.	Control
Measure: Provide an enhanced smoke management system. **Reason:** Due to the greater presence of toxic gases released during an EV fire, an enhanced smoke clearance system with increased air changes per hour for a mechanical system or increased area of ventilation for a natural system should be considered. Refer to Section 6.7.5.	Control
Measure: Provide appropriate structural fire resistance. **Reason:** Current guidance recommends 15 minutes structural fire resistance for some car park arrangements. With the integration of EVs within car parks, it could take up to 60 minutes for the fire service to extinguish the fire [20]. To account for this, a higher structural fire resistance period is needed; i.e. a minimum of 60 minutes should be considered, unless additional measures such as water-based suppression is also installed, or extensive fire damage can be tolerated without impacting the life safety of occupants or firefighters. This issue is being considered, at the time of drafting, as part of the ongoing review of Approved Document B which includes ‘construction technologies and design’, and ‘compartmentation and fire resistance’. At time of publication, no further information regarding this wider review is available [66].	Control

Description of mitigation measure	Classification of mitigation measure
Measure: Consider the location of EVCPs. **Reason:** The location of EVCPs should be considered in relation to the following factors to provide a balance which best satisfies the competing demands. It is understood that there is no single ‘best place’ to locate EVCPs and the below is information to help inform the user when making decisions on EVCP locations. The locations chosen should ideally be where the EVCPs are located away from the exits from the car park, but not so remote that they could pose a challenge to firefighters attempting to tackle an EVCP fire. Locating EVCPs in areas with increased ventilation are advantageous as they can help with the removal of heat and smoke; but based on available research, do not require increased ventilation compared to ICEVs due to the fire sizes being similar. As discussed in Section 2.3.2, there is limited data available regarding EVCP fires, but suggests that it is unlikely to affect the fire size (i.e. regardless of charge, it will be a similar size to an ICEV fire). On this basis, there is no requirement to consider omitting EVCPs from underground car parks or restricting the underground car park areas to a certain type of charger. If the car park is an existing building, these considerations should be assessed on a case-by-case basis and evaluated in line with the restrictions of the existing car park geometry. Refer to Section 4.3.	Reduce

Table 11: Risk mitigation measures to protect persons in and around the covered car park

Description of mitigation measure	Classification of control measure
Measure: Location of EVCPs. **Reason:** Refer to Table 10 for information on choosing location of EVCPs.	Reduce
Measure: Provide automatic fire detection and alarm. **Reason:** Current statutory guidance does not require automatic fire detection and alarm in most car parks. With increased EVs within the car park, there are additional benefits that automatic fire detection and alarm can provide. Detecting fire earlier can reduce spread as it would speed up the FRRS response. Providing automatic fire detection and alarm will also alert the occupants of a fire, allowing them to make their escape whilst the fire is in its early stages. The system can alert the fire service, potentially leading to a faster response time (than without detection). See Section 6.5 for additional detail.	Isolate
Measure: Provide voice alarm to alert occupants to evacuate. **Reason**: A voice alarm is able to provide greater communication to occupants within the covered car park and can often encourage occupants to escape quicker than a continuous siren, especially in unstaffed car parks. Some cover car parks have difficulties with voice alarms being intelligible from all locations, and this should be something that could be considered by the fire risk assessor when assessing the benefits of adding a voice alarm.	Reduce
Measure: Maintain general means of escape – signage, lighting, horizontal/vertical means of escape. **Reason:** The general means of escape as per the statutory guidance for car parks should be met and maintained in good order so that occupants have the same opportunity to escape as previously (if existing car park). This could be assessed through a fire risk assessment as discussed in Section 4.1. Where performance-based fire safety precautions were developed based on historic car fire data, they should be revisited to check if they are still appropriate for modern ICEVs and EVs.	Control
Measure: Maintain existing fire resisting construction to maintain protection of escape routes. **Reason:** Provision of new penetrations and services can reduce the fire resisting performance of the wall. Prior to installing EVCP, the location of existing lines of fires resistant construction within the car park should be identified. If cables to feed the new EVCP need to	Reduce

Description of mitigation measure	Classification of control measure
pass through an element of fire-resistant construction, then the opening should be adequately fire stopped to maintain the period of fire resistance of that element. Guidance on the installation of fire stopping is given in the Association For Specialist Fire Protection (ASFP) Red Book [67].	

Table 12: Risk mitigation measures to protect the structure of the car park

 Description of mitigation measure	Classification of control measure
Measure: Provide water-based suppression. **Reason:** Refer to Table 4 and Section 6.4 for further information.	Reduce
Measure: Maintain existing fire resisting construction to maintain escape route protection. **Reason:** Refer to Table 11 for further information.	Reduce
Measure: Provide a structural design appropriate for risks (material selection). **Reason:** When designing a new car park, materials which provide an increased level of fire protection should be considered e.g. concrete or reinforced concrete or steel with appropriate fire protection.	Reduce
Measure: Provide appropriate structural fire resistance. **Reason:** Refer to Table 10 for further information.	Reduce

Table 13: Risk mitigation measures to manage fire spread to adjacent buildings

Description of mitigation measure	Classification of control measure
Measure: Provide water-based suppression. **Reason:** In the case of a vehicle adjacent to EV(s) being on fire, water-based fire suppression provides water coverage to the fire and the surrounding area, cooling to the surrounding environment and reduces the risk of fire spread to the adjacent car and adjacent structures. See Section 6.4.	Reduce
Measure: Increase separation distance between buildings (for new car parks). **Reason:** Locating buildings closer together may require a larger percentage of the façade to be constructed to be fire resisting and/or from A1 or A2 classified materials, to control the risk of fire spread from one building to another sufficiently. During the design of a new car park, assess the fire spread risk to adjacent buildings and persons in the vicinity arising from car types. The car park geometry, and other relevant fire safety measures including e.g. fire resisting construction, fire suppression, materials on external walls, and access and facilities provided to the fire and rescue service, should be considered. BRE 187: 2014 [54] could be used to undertake such an assessment.	Isolate
Measure: Façade design. **Reason:** The external wall construction of the car park should meet the statutory guidance. As EVs may be parked adjacent to walls, Euro class A1 or A2 classified elements for the façade system are recommended to limit fire spread from a potential EV fire via the external wall to other levels.	Isolate

Table 14: Risk mitigation measures to manage the ecological impact

Description of mitigation measure	Classification of control measure
Measure: Provide appropriate water run-off control and containment. **Reason:** The firefighting water/suppression used to fight an EV fire will likely contain higher concentrations of contaminants. If the car park is in an area where firefighting water run off can result in significant ecological impact, a process to contain and transfer the water to an effluent treatment plant, before introducing the water into the sewage system should be provided. See Section 6.8 for further detail.	Control

5.3 Case studies

This section provides two case studies:

Case Study 1 discusses a fire risk assessment undertaken by the City of London Corporation to enable the installation of chargepoints within existing basement car parks. As part of this fire risk assessment, the City of London identified additional measures to address property protection and business continuity considerations, in addition to life safety. These control the risk of an EV fire spreading to the adjacent infrastructure to an acceptable level.

Case Study 2 sets out the design approach taken for a new multi-storey car park that was to be future-proofed so that 100% of the spaces could be provided with fast-charging EVCPs.

The findings for each case study are specific to their scenario, fire risk assessment and objectives of each project.

Case study 1 City of London Corporation underground car parks

The following case study is reproduced with permission of the City of London Corporation. It is abridged from information provided as part of the stakeholder consultation.

Background

In 2019, the City of London Corporation (CoL) started to develop the infrastructure for charging electric vehicles, both commercial and private. This involved providing EVCPs within the eight underground car parks that CoL owns and maintains. As part of these works, CoL identified that this may impact the fire safety design of the car parks. Therefore, they decided to undertake a risk assessment, to determine whether additional measures or features were required.

Risk assessment approach

CoL reviewed the existing guidance for car parks as well as existing literature on the hazards that EVs pose within covered car parks. They found that the current statutory guidance in England regarding fire safety in car parks had not been updated significantly since the 1960s and may not fully reflect the changes to design and risks posed by modern ICEVs or EVs.

CoL held stakeholder workshops looking at EV charging with the London Fire Brigade (LFB), City of London Police and CoL electrical engineers and District Surveyors (Building control).

CoL identified fire safety objectives that included life safety, as well as property protection and business continuity objectives. To achieve these objectives additional features were needed to accommodate the provision of EVCP within the car parks. Considerations included for example:

The land in The City is a valuable commodity to CoL; risk reduction to prevent a fire from damaging the site and/or causing a loss in revenue from the car park was important. Some of the car parks support critical infrastructure/buildings. It was important to be able to contain an EV fire and prevent it spreading to/affecting the adjacent critical operations/systems.

Findings of risk assessment

As part of the review and consideration of property protection/business continuity requirements, CoL found that the following risks applied from a fire perspective:

Fire spread between vehicles, especially from battery fires, was the main risk in an EV fire. Although the risk and fuel loading of EVs are comparable with traditional ICEVs, the decision by manufacturers to use side venting of battery gases has the possibility of creating the issue of side flame discharge from batteries under vehicles. If the vehicle batteries become “irritable” (i.e. pressure build up due to exposure to heat), the batteries can vent gases. If that occurs near an ignition source (e.g. an adjacent vehicle fire) then they could ignite, causing a chain reaction.

Charging was considered by CoL to be the highest-risk aspect of EVs. A means of shutting this down in the event of a fire was desired. Faulty chargers/installations were also identified as a key risk/cause of ignition.

Thermal damage to the battery was a major cause of fire. Lithium-ion batteries were believed to become unstable at 70°C, so limiting temperatures within the battery to below this or having safety precautions that activate at a lower temperature were required.

Overcharging a battery could cause a rise in temperature and thermal runaway and ignition of the battery.

Mechanical damage to batteries could cause short-circuiting or thermal runaway, both of which could cause ignition of the battery.

Firefighting approaches/facilities should be adapted. Up to 2 hours water supply could be required to control an EV fire; current firefighting approaches and facilities provided to the fire service would not be sufficient to enable appropriate and effective response by LFB.

Measures

To address the risks identified as part of their assessment, the CoL decided to examine the measures presented in Table 15.

Table 15: Case study 1 adopted design approach for EV related fire safety features

Fire safety feature	Adopted design approach
EVCP	Preference for EVCP with tethered cables so that cables are maintained as part of EVCP, to reduce risk of faulty cables being used.
Spacing of EVCP and signage	All EVCP are located with between 900 – 1200 mm clear width, to enable access to the chargepoint and allow greater distance between EVs. This meant three car parking spaces were converted to two spaces with an EVCP. The access areas are hatched, with a clear sign in the centre to identify this as a charging parking space. Refer to Figure 10.
Automatic detection and alarm	Category P2 system throughout the car parks designed in accordance with BS 5839-1:2017; upgraded to a Category L5 system around the charging bays for early detection.
Automatic suppression	Existing town mains fed sprinkler system has sprinkler heads with an activation temperature of 68 °C. This was supplemented by localised drenching system over EV chargepoints, activated by 57 °C rated bulb above the vehicle parking space, with spacings of heads around the EVCP of no more than 2m. Design density of system follows FM Hazard Category 2, with a density of 8 mm/min over 230 m^2 (300 m^2 for dry systems), as well as BS EN 12845 and LPC rules. Two options developed, a deluge system for up to 20 heads activating at once, and a multi-jet system where 6 activate at once, activated by a frangible bulb located above the car park space associated with the EVCP. The bespoke arrangement was verified through a full scale demonstration in February 2022. Refer to Figure 11. This testing did not involve a live fire but evaluated the discharge capabilities of the designed system.

Fire safety feature	Adopted design approach
Smoke ventilation system	Mechanical smoke ventilation system upgraded beyond 10 ACH, with ACH informed by constraints of existing car park configuration. System activated with delay after sprinkler activation to limit risk of forced ventilation delaying sprinkler activation.
Electrical supply to EVCP	Dedicated electrical supply to EVCP.
Isolation switches	Facility to manually isolate the EVCP from fire service entrance area, as well as automatic isolation of EVCP upon activation of the fire detection system. Reset of the electrical supply only permitted manually (no auto-reset).
Fire resisting barriers between EVCP	Discounted as not possible to achieve accessible arrangement, nor cost effective.
Structural fire resistance	Where practical, upgrades were made to the existing structure.
Fire mains	Dry falling mains provided where feasible to enable firefighting water application.
Post fire	Provisions in place with third party hauling company for EVs to be removed from the car park. Surfaces of car park to be impermeable to support post fire environmental clean-up of contaminated firefighting water. Drainage should incorporate receptors such as those used for oil spills and the design should avoid having contaminated water entering natural water supplies such as rivers or bore holes.

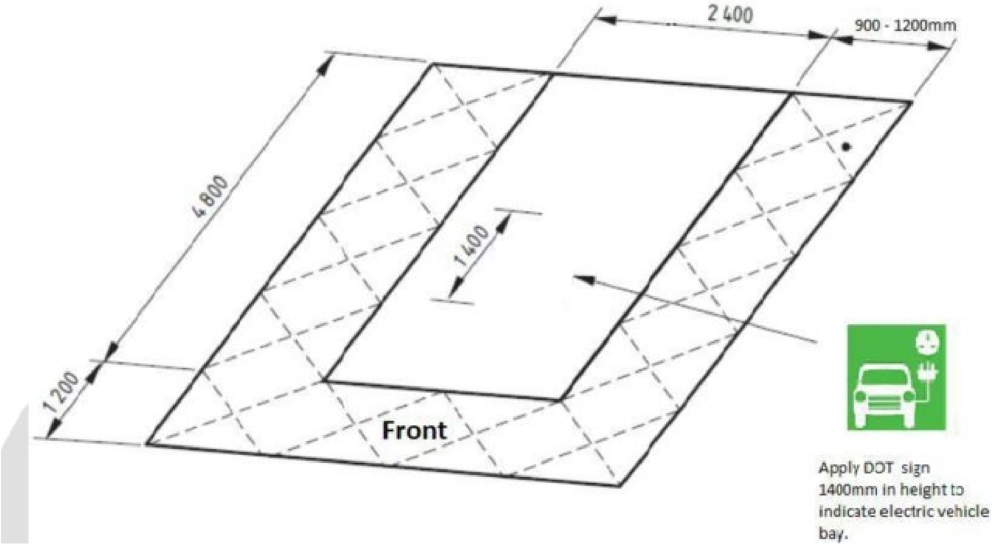


Figure 10: Illustration of CoL-recommended car park space dimensions. © City of London Corporation Fire Safety Department (with permission)

Figure 11: Image of multi-jet sprinkler system test undertaken by City of London Corporation, 9th February 2022. © City of London Corporation Fire Safety Department (with permission)

Case study 2 – New multi-storey car park – concept design

Background

A new multistorey car park (MSCP) is proposed to support a large masterplan development comprising commercial activities across large development site in England.

The client wishes to adapt the site for future increases in EV usage, the MSCP is designed for fast-charging provision to 20% of the parking spaces upon completion; and futureproofed for that to increase to 100% over the life of the building.

Measures

The following measures in Table 16 were provided following Arup's review and FRA.

Table 16: Case study 2 adopted design approach for EV related fire safety features

Fire safety feature	Adopted design approach
EVCP	EVCPs should have collision protection.
Signage	Instructions and information on using charging facilities correctly should be easily accessible to all users of the car park.
Automatic detection and alarm	A Category L2 automatic fire detection and alarm systems designed and installed in accordance with BS 5839-1 [75] should be provided throughout. Separate, analogue, addressable heat detectors are to be provided above each chargepoint to allow isolation of the chargepoint power supply.
Automatic suppression	A sprinkler system designed in accordance with BS EN 12845 [73] and the Fire Protection Association's (FPA) LPC automatic sprinkler installation rules should be provided. The system should be designed so that in the event of sprinkler activation, power supply to all EVCPs is isolated.
Smoke ventilation system	MSCPs should remain open-sided, to allow for adequate ventilation.
Isolation switches	A manual isolation switch should be provided at each floor, to isolate the power supply to EVCPs on that floor.
Fire resistance of stairs	The existing stair cores should be upgraded to become 120-minute fire resistant firefighting shafts. This was to allow space for firefighting operations to be staged and to allow hose coverage requirements to be met.
Structural fire resistance	On the basis of sprinkler provision, the current structural fire resistance of the MSCPs (30 minutes in terms of load-bearing capacity) would not need to be upgraded.
Fire mains	Each stair core should be provided with a dry riser to allow deployment of water to all areas of the car park.

Fire safety feature	Adopted design approach
Fire water supply	The current guidance to provided 25 L/s of water for firefighting purposes should be met. Given the provision of sprinklers and research showing similar fire sizes between EVs and ICEVs, additional water was not considered necessary.
Fire service information	A fire brigade information box containing the as-built charging system, location of chargepoint units and isolation switches should be provided.
Management Procedure	An appropriate management procedure should be developed for all staff who would be expected to respond to a fire in the MSCP.
Fire extinguishers	Portable fire extinguishers (in accordance with BS 5306-8 and BS 5306-3).
Installation of EVCPs	Charging equipment must be installed in accordance with: – BS EN 61851-1:2019, Electric vehicle conductive charging system. General requirements (incorporating corrigendum February 2020). – BS 7671:2018+A1:2020, Requirements for Electrical Installations – IET Wiring Regulations 18th Edition. – IET Code of Practice for Electric Vehicle Charging Equipment Installation. Electricity Safety, Quality and Continuity Regulations 2012.
Water run-off	There should be provision for run-off of firefighting water.

6. Discussion of mitigation measures

Chapter Summary

Some of the control measures in Table 4 to Table 14 require substantial investment and planning, while others are low impact/low cost. Some of the mitigation measures are discussed below to provide additional information regarding the benefits that they provide and to give further detail on applicable standards.

6.1 Select appropriate EVCP

There is no accreditation list for EVCPs in the UK, however for reference the UK Government has a list of grant eligible chargepoints which have been used for car parks in the UK [68].

For further confirmation the chargepoint is in accordance with BS EN 61851-1:2019 and suitable for use in UK car parks, you can use production certification schemes developed by standard bodies.

6.1.1 Inbuilt protective features

Approved chargepoints can contain features which can help to reduce the likelihood of a fire occurring within the EV battery such as:

Overcurrent protection which can stop the electricity supply if the current being provided to the battery is too great;

Tilt sensors which can detect when the chargepoint has been knocked and prevent its use;

Damage/fault reporting which can alert the maintenance company of issues which require remediation;

Ventilation, to help regulate the temperature within the charger and surrounding area;

Temperature sensors which can stop the electricity supply when the temperature is too high/low;

When selecting chargers, the fire risk assessment may identify features within the car park which require some or all these measures to help mitigate the risk from the chargepoint.

6.1.2 Mode selection

Mode 3 and Mode 4 type EVCP have an interface built-in to monitor faults within the chargepoint, while Mode 1 and Mode 2 type EVCP do not.

Mode 3 or Mode 4 EVCPs can provide the ability to monitor the features discussed in Section 6.1.1 and to terminate charging when outside standard operating parameters and prevent events leading to an uncontrolled fire.

Mode 1 EVCP do not meet statutory guidance AD P or AD S so should not be used.

6.2 Location of chargepoints

6.2.1 Means of escape and fire service access

The location of EVCPs should be considered in relation to the following factors to provide a balance which best satisfies the competing demands:

Means of escape: a fire in an EVCP should not block the only available means of escape.

Firefighting access: the EVCP should be accessible within recommended hose reach for the fire and rescue service so they can effectively fight a fire.

EVCPs with inbuilt batteries should be located in suitable areas so that the operating temperature of the equipment is not exceeded.

6.2.2 Accessibility

The accessibility of chargepoints for all users, including disabled and older people, should be taken into consideration when designed and installed. The British Standards Institution (BSI)'s PAS 1899:2022 [70] provides technical requirements on how to ensure accessibility is achieved for public EVCPs, including the dimensions of EVCPs and their surrounding built environment.

6.3 Thermal monitoring cameras

Thermal monitoring cameras allow operators to be alerted to the possibility of an EV fire earlier and take action by either calling nearby staff or call the fire service. This can reduce firefighting intervention time which may be important where a car park is remotely operated. This may also be of greater benefit where property protection/business continuity concerns suggest early intervention is necessary.

There is no specific UK guidance on thermal monitoring design standards. However, ISO 18251-1:2017 [71] and NFPA 1801:2021 [72] "Standard on Thermal Imagers for the Fire Service" both set out guidance for the design and testing of thermal imaging equipment. This use of thermal imaging camaras is a new application of existing technology. Further research is required regarding the practicalities of a thermal imaging system identifying an issue with an EV, e.g. as the battery may be located at the centre of the vehicle. Where thermal imaging camaras are used consideration should be given to providing this to supplement other forms of fire and smoke detection.

If ceiling mounted, they should be set so that they can view the sides of the car (not just the top of the car). As the battery starts to undergo thermal runaway, the heat of the battery could spread to the surrounding car components. As the battery is at the base of the car, it would take longer for the heat to spread to the top of the car than the sides and therefore longer to detect (if located directly above the car).

6.4 Automatic water-based fire suppression within the car park.

The provision of an automatic water-based suppression system should, in the event of vehicle fire, limit its spread to adjacent vehicles and buildings. It may also reduce damage to the car park's structure and assist with firefighting activities.

Water-based suppression (e.g. sprinklers) will likely not extinguish the fire in the EV, due to the location of battery within the car and the car body preventing the water from targeting the fire's source..

Certain features in car parks warrant a detailed consideration as part of the risk assessment, as to whether suppression should be provided, including:

Lower periods of fire resistance (e.g. 15 minutes minimum in accordance with fire life safety guidance) as suppression can help limit the growth and impact of the fire on the structure.

Instances where external fire spread assessments for the car park fire have been developed on the basis of only a small number of cars being involved in a fire, as suppression can help limit fire spread within the car park and to adjacent buildings.

For multi storey car parks and basement car parks where evacuation and/or firefighter access is more complex, or car parks where the parking bays are small and/or close together.

Where sprinklers are provided in a car park, they should be designed and installed in accordance with BS EN 12845:2015 +A1:2019 [73]. Sprinklers within car parks are typically classified as Ordinary Hazard 2 (OH2). It is recommended that the car park operator discusses with their insurer/other stakeholders, whether compliance with LPC rules is also appropriate.

The residential sprinkler system standard BS 9251:2021 [74] sets limitations for use of that system to only small car parks below flats no larger than 100 m^2. This is due to lower discharge densities, fewer heads operating and shorter water supply durations, varying between 10 and 60 minutes depending on the category of system. Such a system should not be considered to protect against an EV fire in a covered car park without detailed review of the fire strategy of the building and risk assessment. The selected suppression system needs to take account of any smoke ventilation system also expected to operate in case of fire.

If a water mist system is incorporated, it should be in accordance with BS 8489-1. This guidance does not set out testing for car parks and therefore specific testing in conjunction with the smoke ventilation system is required which should be agreed with the Authority Having Jurisdiction (AHJ i.e. building control). As part of this the designer could choose to do a 3rd party review as water mist is more susceptible to air movement and would need to be proven by testing, given the high degree of natural or mechanical ventilation usually provided in covered car park structures.

Where automatic suppression systems are used in conjunction with mechanical smoke clearance systems, the order of operation of these systems needs to be carefully considered such that the operation of the mechanical ventilation system doesn’t delay the operation of automatic suppression system.

Due to the additional time it takes to suppress an EV fire, consideration should be given to providing a sufficient water supply for the reasonable worst-case scenario. Alternatively, the local fire service should be consulted regarding the potential to install an inlet to the suppression tank to allow the fire service to supplement the supply for an extended period of time.

6.4.1 Property protection/business continuity

This guide has predominately focussed on the fire life safety of occupants in and around the car park. However, fires can have a significant impact on the car park itself and nearby buildings and businesses. If the fire spread is extensive, it can take a very long time for impacted communities and businesses to return to normal operations.

Multiple mitigation measures may be needed to meet specific property protection and/or business continuity considerations, in addition to life safety requirements. Case study 1 set out in Section 5.3 describes the development of a bespoke system, in consultation with relevant stakeholders and evidenced through full scale testing.

6.5 Automatic fire detection and alarm

The provision of a fire detection and alarm system in accordance with BS 5839-1:2017 [75] would enable early fire detection, initiation of evacuation of occupants and to alert occupants and the car park owner/operator. If the car park is remotely monitored, then it could notify the remote monitoring service and/or call the fire and rescue service automatically.

The type of detection needs to be carefully selected to avoid the risk of particulates in ICEV exhaust emissions resulting in false activations. Heat detectors may be more appropriate where ICEV use is still anticipated. Smoke detectors are useful for detecting EV fires.

There are detection methods such as volatile organic or gas detectors coming into the market which could provide an advanced warning of fire by detecting vapour cloud gases. The applicability of this detection method should be reviewed as part of the risk assessment, given the context of how ventilated the car park is against the sensitivity of the detection systems.

Consideration could also be given to linking the fire alarm system with thermal imaging cameras, to raise an alert if a car with an unusually high temperature is detected.

Car parks with mechanical smoke ventilation systems should have automatic fire detection fitted to activate the smoke ventilation system; that could be extended to specifically install detection near the EVCP bays.

The automatic fire detection and alarm system could also be connected to automatic isolation switches to the EVCP power supply, allowing early de-energisation of the EVCP.

Refer to Section 6.6 for discussion on isolation switches.

6.6 Isolation switch to cut power supply of EVCP in a fire scenario

6.6.1 Manual isolation switch

A manual isolation switch can provide control to the fire service if a charging EV is on fire, to allow for the entire power supply to the EVCP to be stopped and help de-energise the EVCP.

Currently, there is not a distinction by manufacturers between EVCPs which are installed in public areas and EVCPs which are installed in private car parks. Due to concerns of passers-by maliciously cutting the power supply to EVs whilst they are charging, e.g. on a public road, manufacturers usually do not have isolation switches installed on the EVCP.

If a manual cut-off switch is installed, it would usually need to be at the distribution board/circuit serving the EVCP.

The manual isolation switch could be particularly effective where the car park is staffed and staff intervention could be used at an early stage once a fire is confirmed, limiting the impact that ongoing electricity supply could have on the fire.

To assist the fire service, the ability to isolate power to EVCPs should be located near a firefighting entrance, or adjacent to the fire alarm panel/fire service information point.

CoL has adopted this measure within their underground car parks, refer to case study 1 in Section 5.3 for the case study.

6.6.2 Automatic isolation switch

As with a manual isolation switch, this would help to cut the power supply to the EVCP and de-energise the EVCP.

An automatic isolation switch could be linked to the fire alarm and/or suppression system, so that when fire is confirmed by detector activation or operation of the suppression, the power supply to the EVCPs on a floor, or to the entire car park is cut off.

An automatic isolation switch may be considered where there is no staff present in the car park or where response times by staff may be too great to allow for early/effective isolation of the power supply.

6.7 Measures to assist the fire service

6.7.1 Consultation with the local fire service

As part of determining which measures (if any) could be provided to assist the fire service in tackling an EV fire within the car park, the fire service should be consulted. This should occur prior to installing any measures specifically for the benefit of the fire service. Each fire service tends to have different approaches, equipment and capabilities with regards to tackling EV fires. Early discussion with fire services can help to make the measures provided more effective/beneficial to them.

6.7.2 Firefighter water supply

As noted in Section 2.5, significantly more water is required to tackle an EV fire than an ICE vehicle fire. The supply of water may need to be increased to meet the current recommendation for 1,500 l/min for 60 minutes in BS 9990:2015 [65]. Depending on what the local water provider can guarantee via the mains supply, this may be via increased hydrant/mains water provision; or a tank (or series of tanks) and pumps that can supplement the mains water supply to provide the fire service with the required amount and duration of water to tackle the fire.

6.7.3 Removal of EVs post-fire

It is not the responsibility of the fire and rescue services within the UK to remove vehicles post-fire from car park premises, and instead is the responsibility of premises management.

If it is considered desirable or most effective for the car park design to rely on this method, a contract with a car removal company and/or installation of a water tank for removal and submergence of the EV post-fire would need to be provided. If this mitigation measure is adopted the clear headroom in the car park needs to be taken into consideration as this may limit what types of recovery vehicle can enter the car park.

Clear headroom would give the fire service better access to the car; making it easier to monitor for signs of re-ignition and therefore minimise risk to adjacent vehicles, adjacent buildings and the car park structure.

When taking this approach, the fire management plan should address how a removals company would be notified and how they would work with/as part of the fire service response. Safe methods of work should be established to undertake this activity while there is a potential risk of fire in the EV battery.

6.7.4 Provide premises information plans with details of EVCP

Premises information plans should be provided at the main entrance point for the fire service to aid incident response planning for complex buildings. The plans should include, for EVCPs:

- Position of manual isolator switch(es) (if provided);
- Position of EVCP on all floors, where provided;
- Fire main outlet location in relation to EVCP;
- Position of thermal imaging cameras (if provided).

Other information regarding fire safety systems (e.g. smoke clearance, suppression, exits etc.) would already be included in the premises information plans and is not listed here. Recommendations on what information should be provided is available from fire and rescue services, e.g. London Fire Brigade Guidance Note GN70 Premises Information Boxes [76].

6.7.5 Smoke management systems

As there is a greater presence of toxic gases in lithium-ion battery fires than in ICEV fires, car parks that rely on bespoke smoke ventilation designs to demonstrate tenable conditions to justify e.g. extended travel distances or firefighting approaches for a controlled fire size should review if the safety measures are still adequate for EV fires.

The volume of smoke produced from an EV fire is not significantly different from an ICEV fire. However, consideration may be given to increasing the air change rate a mechanical system achieves, or the area of ventilation provided for a natural system. This should also be considered against the noise, practicality and air speed/force impacts that increasing ventilation rates can have within a covered car park. Consideration should also be given to the length of time for a mechanical smoke ventilation system to operate in the event of a fire as part of the fire risk assessment. This is important to determine for instances where the mechanical smoke ventilation system is operating on back-up power conditions with a limited supply.

Where automatic smoke ventilation systems are used in conjunction with automatic suppression systems, the order of operation of these systems needs to be carefully considered such that the operation of the mechanical ventilation system doesn’t delay the operation of automatic suppression system.

CoL adopted this approach when installing EVCP within their underground car parks; refer to the case study 1 in Section 5.3 for further details.

6.7.6 Location of EVCPs

Refer to Section 6.2 for considerations regarding the location of EVCPs.

6.8 Ecological considerations

Limited research conducted to date suggests that there is a higher concentration of contaminants present in water which has been used to fight battery fires, above safe levels for discharge into the environment or sewers.

Consideration should be given to contain firefighting water/suppression water from an EV fire and transfer it to an effluent treatment plant, to limit environmental damage.

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The research undertaken to identify relevant sources of information referenced in this document was concluded in April 2022. Therefore, research publications that have been issued after April 2022 are not considered in this guide.

7. Definitions & assumptions

7.1 Definitions

The guidance uses the following definitions:

AC charger: EV supply equipment that supplies alternating current to an EV (From BS EN 61851-1 [35]).

Arson or malicious ignition: act of wilfully and maliciously setting fire to another person's property, or to one's own with the intention to defraud (From BS 4422 [77]).

Battery: a group of two or more cells connected together to furnish electric currents[2].

Battery abuse: a situation occurring as a result of external factors (e.g. heat, intense use, etc.) which causes damage to the battery and/or causes the battery to operate in such a way that causes damage to the battery[3].

Battery electric vehicle (BEV): an automobile or other vehicle having an electric motor that is fully powered by batteries[4].

Battery management system (BMS): is any electronic system that manages a rechargeable battery (cell or battery pack), such as by protecting the battery from operating outside its safe operating conditions, monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and/or balancing it[5].

Cable assembly: assembly consisting of flexible cable or cord fitted with a plug and/or a vehicle connector, that is used to establish the connection between the EV and the supply network or an EV chargepoint (From BS EN 61851-1 [35]).

Charge plug: specific plug intended to be used as part of EV supply equipment and defined in the IEC 62196 series or accessory having contacts designed to engage with the contacts of a socket-outlet, also incorporating means for the electrical connection and mechanical retention of flexible cables or cord (From BS EN 61851-1 [35]).

Covered car park: one or more parking spaces which are situated beneath a roof, but it does not include a carport or a residential garage (as per Part 9B of The Building Regulations (Amendment) (England) (No. 2) Regulations 2021 [14]). This includes basement car parks, standalone multi storey car parks and car parks integrated within other buildings.

DC charger: EV supply equipment that supplies direct current to an EV (From BS EN 61851-1 [35]).

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[2] From merriam-webster.com

[3] Adapted from merriam-webster.com

[4] From Dictionary.com

[5] From en-academic.com

Electric vehicle (EV): a vehicle that is capable of being propelled by electrical power derived from a storage battery (From The Electric Vehicle (Smart Chargepoints) Regulations 2021 [78]).

Electric vehicle chargepoint (EVCP): the point where the EV is connected to the fixed installation. Note: The chargepoint is a socket-outlet where the charging cable belongs to the vehicle, or a connector where the charging cable is fixed to part of the EV supply equipment. (From IET Electrical Vehicle Charging Equipment Installation [79]).

Electric vehicle supply equipment (EVSE): equipment or a combination of equipment, providing dedicated functions to supply electric energy from a fixed electrical installation or supply network to an EV for the purpose of charging (From BS EN 61851-1 [35]). For example, a DC power supply to a Mode 3 charger and charging cable would be considered EVSE.

Fast charger: EV charger which provides power between 7kW and 22kW.

Fire hazard: potential for injury and or damage from fire (From BS 4422 [77]).

Heat flux: power emitted, transferred or received in the form of radiation (From BS 4422 [77]).

Heat release rate (HRR): the thermal energy released per unit time by an item during combustion under specified conditions (From BS4422 [77]).

Internal combustion engine vehicle (ICEV): a vehicle that is powered by an internal combustion engine. Petrol or diesel is burned within the engine to generate motive force.

Kilowatt hour (kWh): a measure of electrical energy equivalent to the power consumption of one thousand watts for one hour.

Lithium-ion battery: a lithium-ion battery is a family of rechargeable battery types in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.

Mechanically ventilated car park: at each level, a mechanical smoke control system achieving at least 10ACH, provided with independent power supply if mains power fails and can be activated via a dedicated fire detection system or may be linked to the suppression system (From Approved Document B [53]).

Naturally ventilated car park: at each level of the building, aggregate free vent area should be a minimum of 1/40 of that level's floor area, at least half of which should be provided equally by two opposite walls (1/160 on each side). The remaining free area can be distributed wherever possible (From Approved Document B [53]).

Open-sided car park: a naturally vented car park, with permanent openings at each car parking level. The aggregate vent area is a minimum of 1/20 of that level's floor area, at least half of which is provided equally by two opposite walls (From Approved Document B [53]).

Plug-in hybrid electric vehicle (PHEV): electrical vehicle that can charge the rechargeable electrical energy storage device from an external electric source and also derives part of its energy from another on-board source (From BS EN 61851-1 [35]).

Range: is the maximum driving range of an electric vehicle using only power from its on-board battery pack to traverse a given driving cycle.

Range extended electric vehicle (REEV): a battery electric vehicle that includes an auxiliary power unit (APU), which can replenish the electric supply before recharging is required [16].

Rapid charger: chargepoint that allows for a transfer of electricity to an electric vehicle with a power of not less than 50kW (From The Electric Vehicle (Smart Chargepoints) Regulations 2021 [78]).

Roadworthy: a vehicle which is safe to drive [80]. It is a legal obligation for drivers to make sure their car is roadworthy [81].

Self-ignition: spontaneous ignition due to self-heating (From BS 4422 [77]).

State of charge: the level of charge in an electric battery relative to its capacity expressed as a percentage.

Thermal runaway: is a process induced by over-heating of the battery, in which batteries undergo a positive feedback loop of increasing temperature leading to exothermic reaction of materials.

Toxic gas: a gas which is capable of causing damage to living tissues, impairment of the central nervous system, severe illness or, in extreme cases, death when ingested, inhaled, or absorbed by the skin or hair.

Ultra-rapid charger: EV charger which provided power at either 100kW, 150kW or 300kW.

Visibility: ability to see through smoke (From PD7974-2 [82]).

Zero emission vehicle: is a vehicle that does not emit exhaust gas or other pollutants from the onboard source of power.

7.2 Assumptions

This guidance document assumes that the EVs entering the car park are in good working order without any obvious damage. It also assumes the EV chargepoints are compliant with relevant electrical standards and have been installed by a competent person, for example someone listed as an authorised installer on the Competent Persons Scheme.

An EV considered in “good working order” is one that is roadworthy and passes MOT.

7.3 Compliant EVs and EVCPs

All the following regulations should be complied with, or any regulations that have replaced them since the time of writing.

It is assumed that the batteries within the EVs comply with UNECE Regulation No. 100., Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train; 2015 [37].

The final installation of the chargepoints must be in accordance with:

The Electric Vehicles (Smart Charge Points) Regulations 2021 (in certain circumstances);

IET Wiring Regulations (BS 7671:2018+A1:2020) [36];

Electricity safety, quality and continuity regulations 2002 [83];

BS EN 61851-1: Electric vehicle conductive charging system general requirements [35] [79];

They should also comply with the recommendations of the IET Code of practice for electric vehicle charging equipment installation [79].

If the chargepoints are being installed to meet requirements under the Building Regulations, this should be in accordance with:

The Building Regulations etc. (Amendment) (England) (No. 2) Regulations 2021 [14].

Approved Document S: Infrastructure for the charging of electric vehicles [15].

Equipment installed must meet the applicable minimum ingress protection (IP) ratings set out in BS EN 61851-1:2019 and BS 7671:2018 according to the usage location. Equipment may also be tested to meet other regulations such as UN/ECE Regulation 100: 2015.

7.4 Competency of EVCP installers

All the following regulations should be complied with, or any regulations that have replaced them since the time of writing.

EVCP’s must comply with IET Wiring Regulations (BS 7671:2018+A1:2020) [36];

The IET – Code of Practice Electric Vehicle Charging Equipment Installation 4th Edition 2020 [79] set out guidance on how to install chargepoints in a safe manner and be compliant with regulation [84].

Competent installers can be verified through their registration with a Competent Person Scheme Operator [84].

Concerns over the competence of an installer or quality of an installation should be reported to the provider of the Competent Persons Scheme.

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Appendix A Fire risk assessment worked example

Appendix Summary

Appendix A provides an example on undertaking a fire risk assessment when preparing to include EV/ EVCPs in a covered car park.

Fire risk assessment worked example

The following example sets out the process for undertaking a risk assessment for a multi-storey, standalone car park using the likelihood / consequence matrix approach from PAS 79-1 [85].

In this worked example, the risk assessment considered the life safety of occupants and firefighters. There were no specific property protection considerations.

The example is for illustrative purposes only and care should be taken to identify appropriate design features, hazards and consequences specific to the car park being assessed.

Establishing the fire strategy of the existing car park

The fire strategy for the multi-storey car park that supports a large commercial office estate has the following features:

It comprises four storeys of carparking, arranged as split level decks (i.e. 8 total) with internal ramps, constructed from steel and reinforced concrete.

Each level is provided with permanent openings, sufficient to be classified as ‘open-sided car park’ [53].

Accessible parking is provided at grade level.

There are 20 car parking spaces on each split level (i.e. 160 spaces total).

There is a maximum expected occupancy of 320 people (based on 2 people/car parking space [53]).

It has two protected stairs (one at either end), one of which has two lifts accessed via a protected lobby; travel distances are within recommended limits set out in fire safety guidance.

Each split level has access to both stairs.

The carpark is provided with manual call points which, when pressed, activate sounders throughout the building to initiate a simultaneous evacuation.

Disabled refuges are provided in each stair, provided with an emergency voice communication system linked back to a central management suite at the car park owner’s office.

Emergency lighting is provided across the clearly marked escape routes in the car park.

There is no suppression system provided.

The structure achieves 15 minutes fire resistance (load-bearing capacity only), with stairs and lifts protected by 30 minutes fire resisting construction (integrity, insulation and, where applicable, load-bearing capacity).

Firefighting access is via the surrounding street to the building perimeter, with the firefighting supply water provided from a nearby street hydrant.

There are no buildings within 20 m of the car park.

It is intended to install EVCPs on each level.

The car park owner is implementing a management regime to inspect the EVCPs weekly and take faulty EVCPs out of use until repaired.

There are no property protection and business continuity considerations to consider.

Identify fire hazards

The ignition sources that are identified within the building are:

ICEVs and EVs across all levels of the car park.

EVCPs across all levels of the car park.

Plant room at ground level housing incoming electrical supplies and other electrical plant.

The fuel sources that are identified within the building are:

ICEVs and EVs across all levels of the car park.

Litter which tends to accumulate on all levels of the car park.

Identify occupants at risk

The following people could be at risk of a fire within the car park:

Occupants across all levels of the car park, some may be mobility impaired as all levels are accessible. They are expected to be awake but are familiar with the layout of the carpark.

All occupants are expected to be at least 17 or accompanied by someone who is at least 17 (i.e., someone of legal driving age).

Evaluate the risks - likelihood of hazard

The likelihood of a hazard can be ranked as “low”, “medium” or “high”, as noted in Table 14.

Table 17: Likelihood ratings and descriptors [taken from [60]]

Likelihood	Descriptor
Low	Unusually low likelihood of fire because of negligible potential sources of ignition.
Medium	Normal fire hazards (e.g. potential ignition sources) for this type of occupancy, with fire hazards generally subject to appropriate controls (other than minor shortcomings).
High	Lack of adequate controls applied to one or more significant fire hazards, such as to result in significant increase in likelihood of fire.

Consequence of hazard

The potential for harm (the consequences) should the hazard occur can be ranked as “slight”, “moderate” or “extreme”, as noted in Table 15.

Table 18: Consequence ratings and descriptors [taken from [85]]

Consequence	Descriptor
Slight	Outbreak of fire unlikely to result in serious injury or death of any occupant.
Medium	Outbreak of fire could foreseeably result in injury (including serious injury) of one or more occupants but is unlikely to result in multiple fatalities.
Extreme	Significant potential for serious injury or death of one or more occupants.

Risk matrix

The assessed level of risk for each assessed hazard is then determined by the matrix in Table 16.

Table 19: 3x3 risk matrix as a function of likelihood and consequence [60]

Consequence Likelihood	Slight	Moderate	Extreme
Low	Trivial risk	Tolerable risk	Moderate risk
Medium	Tolerable risk	Moderate risk	Substantial risk
High	Moderate risk	Substantial risk	Intolerable risk

The outcomes of the risk rankings are listed in Table 20 below.

Table 20: Risk rankings and descriptors [taken from [69]]

Risk ranking	Descriptor
Trivial	No action is required, and no detailed records need be kept
Tolerable	No major additional controls required. However, there might be a need for improvements that involve minor or limited cost.
Moderate	It is essential that efforts are made to reduce the risk. Risk reduction measures should be implemented within a defined time period. Where moderate risk is associated with consequences that constitute extreme harm, further assessment might be required to establish more precisely the likelihood of harm as a basis for determining the priority for improved control measures.
Substantial	Considerable resources might have to be allocated to reduce the risk. If the building is unoccupied, it should not be occupied until the risk has been reduced. If the building is occupied, urgent action should be taken.
Intolerable	Building (or relevant area) should not be occupied until the risk is reduced.

Example fire risk assessment

The hazards in Table 18 below are based on the understanding of the car park and the ignition sources, fuel loads and people at risk identified as part of the assessment.

Table 21: Example risk assessment process using a 3x3 risk matrix for a multistorey standalone car park

Example Hazard	Discussion	Likelihood	Consequence	Risk level	Mitigation measure(s) adopted to reduce consequences	Adjusted consequences with mitigation measure(s)	Residual risk
Fire occurring within an ICEV/EV	Presence of EVs and modern ICEVs could lead to prolonged fire duration, which could spread beyond vehicle of fire origin, leading to a multiple-car fire. A multiple-car fire could result in the structure being exposed to fire for longer than its design capacity (15 minutes). This could lead to structural failure whilst undertaking	Medium	Extreme	Substantial	Increase spacing of car park spaces. The car park owner believes this will also help make spaces more accessible for modern vehicles. Provide water-based suppression to limit spread of fire from car of fire origin and limit growth/heat of fire.	Slight	Tolerable

Example Hazard	Discussion	Likelihood	Consequence	Risk level	Mitigation measure(s) adopted to reduce consequences	Adjusted consequences with mitigation measure(s)	Residual risk
	firefighting operations.						
Fire in EV taking longer to extinguish than ICEV fire.	EV fires can take longer to suppress than ICEV, even contained to a single-vehicle fire. Prolonged firefighting operations could result in the structure being exposed to fire for longer than its design capacity (15 minutes). This could lead to structural failure whilst undertaking firefighting operations.	Medium	Extreme	Substantial	Provide additional protection to the structure to achieve a longer fire resistance period. Provide water-based suppression to limit spread of fire from car of fire origin and limit growth/heat of fire.	Slight	Tolerable

Example Hazard	Discussion	Likelihood	Consequence	Risk level	Mitigation measure(s) adopted to reduce consequences	Adjusted consequences with mitigation measure(s)	Residual risk
Fire resulting from faulty EVCP	A faulty EVCP could cause a fire to occur within the EVCP. The car park has a weekly inspection regime to assess the EVCPs. Faulty chargers are removed and therefore, this is an unlikely scenario. If a fire were to occur, occupants should still be able to escape using an available exit.	Low	Slight	Trivial	N/A. Proposed management procedures sufficient for this risk.	N/A	Trivial

Appendix B Background information on EVs and EV chargepoints

Chapter summary

This chapter provides background information on electric vehicles. The chapter includes, how they differ to ICEVs, information on battery technology and details the different types of EVCPs available.

Difference between an ICEV and an EV

The primary components of an EV are the motor, inverter/controller and battery. The motor converts the energy into propulsion power, the AC/DC inverter and power electronics controller controls the flow of electricity from the battery to the electric traction motor. The motor draws power from a battery, which is charged via a charge port [88].

Other components of an EV include a traction battery pack, an onboard charger and a thermal cooling system. The traction battery pack stores the charged electricity, which is used to propel the EV, the onboard charger converts the incoming AC electricity to DC power for charging the traction battery and the thermal cooling system maintains an operating temperature for the internal components of the EV [86].

The different components of an EV are shown diagrammatically in Figure 12.

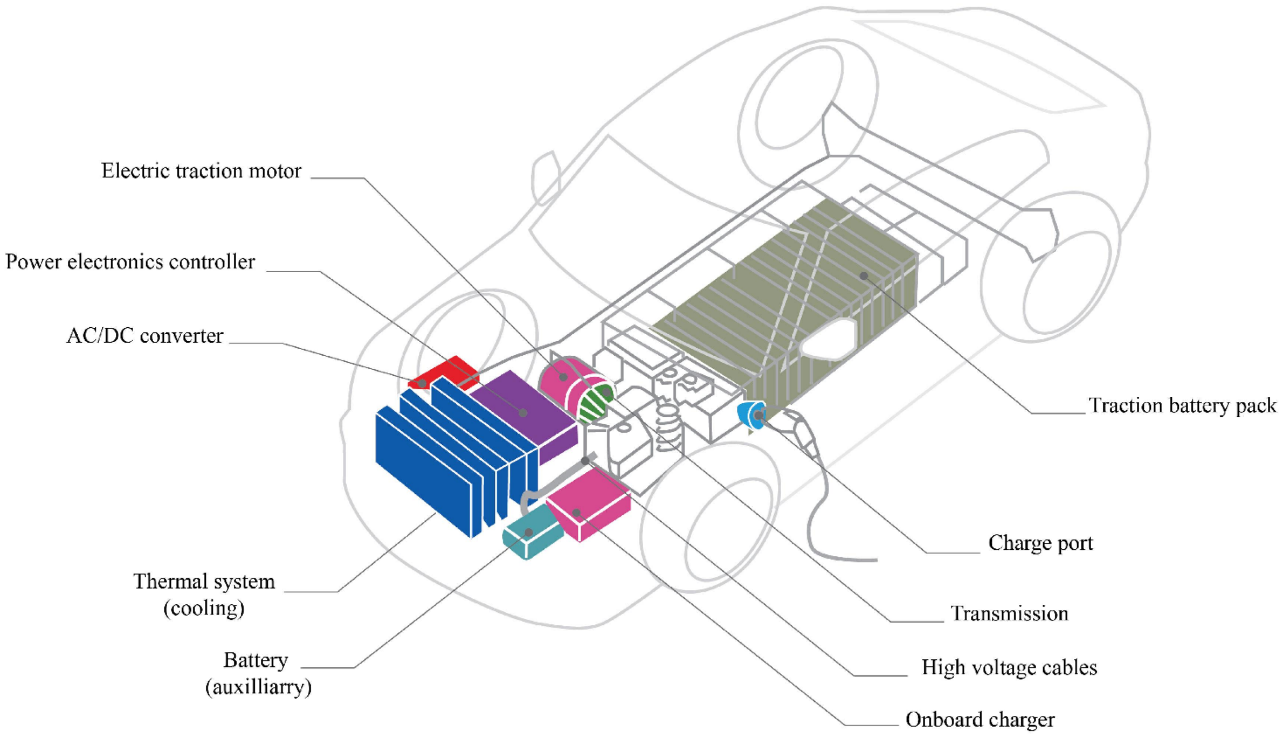


Figure 12: The system components of an EV [adapted from [86]]

Sockets in EVs can be located where the fuelling points are in an ICEV, either side towards the rear of the car or on the front wing, or in the centre at the front, as shown in Figure 13.

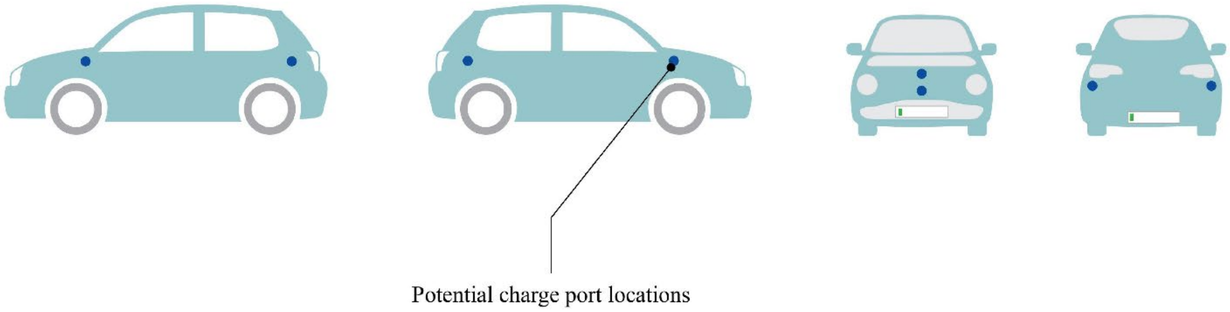


Figure 13: Typical location of charge ports on EV [adapted from [79]]

Batteries used within EVs

A lithium-ion (Li-ion) battery is the most widely adopted chemical technology for battery powered vehicles [23]. Nickel-metal hydride batteries were used during the early years of electric vehicles, such as for General Motor’s EV1 [89]. However, as they have insufficient energy and power densities, limited cycle stability and a high self-discharge rate; they are not preferred in current EVs [90], and became obsolete in EVs from the early 2000s. Whilst Nickel metal hydride batteries were often used in PHEVs [91], these are outside the scope of this guidance and are not considered further within this guidance.

A typical single lithium-ion battery is in the form of a cylinder, or pouch (see Figure 14), containing the components of a battery i.e. anode, cathode, separator (usually made from PTFE, polyethylene or polypropylene) [92], and an electrolyte sealed in between them [34]. The cathode may be composed of a range of different materials but is typically a form of lithium metal oxide, and the anode is typically composed of graphite (carbon). Lithium is used as a charge carrier in the form of ions in a hydrocarbon-based electrolyte [93], see Figure 15.

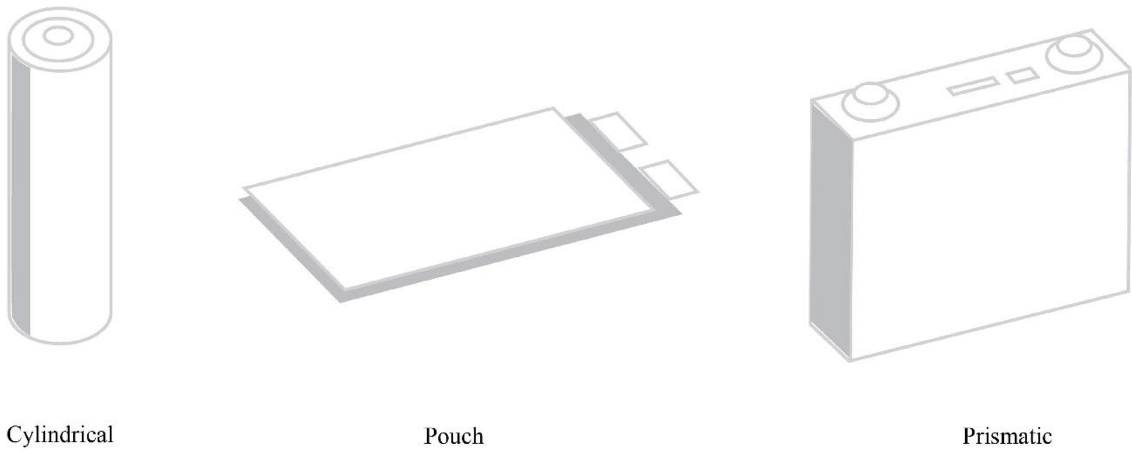


Figure 14: Typical housing types for lithium-ion battery cells

During charging, lithium ions flow from the positively charged cathode through the electrolyte to the negatively charged anode. The structure of a typical lithium-ion battery in its cylindrical base form is shown in Figure 4, with the diagram showing a discharging cell [10].

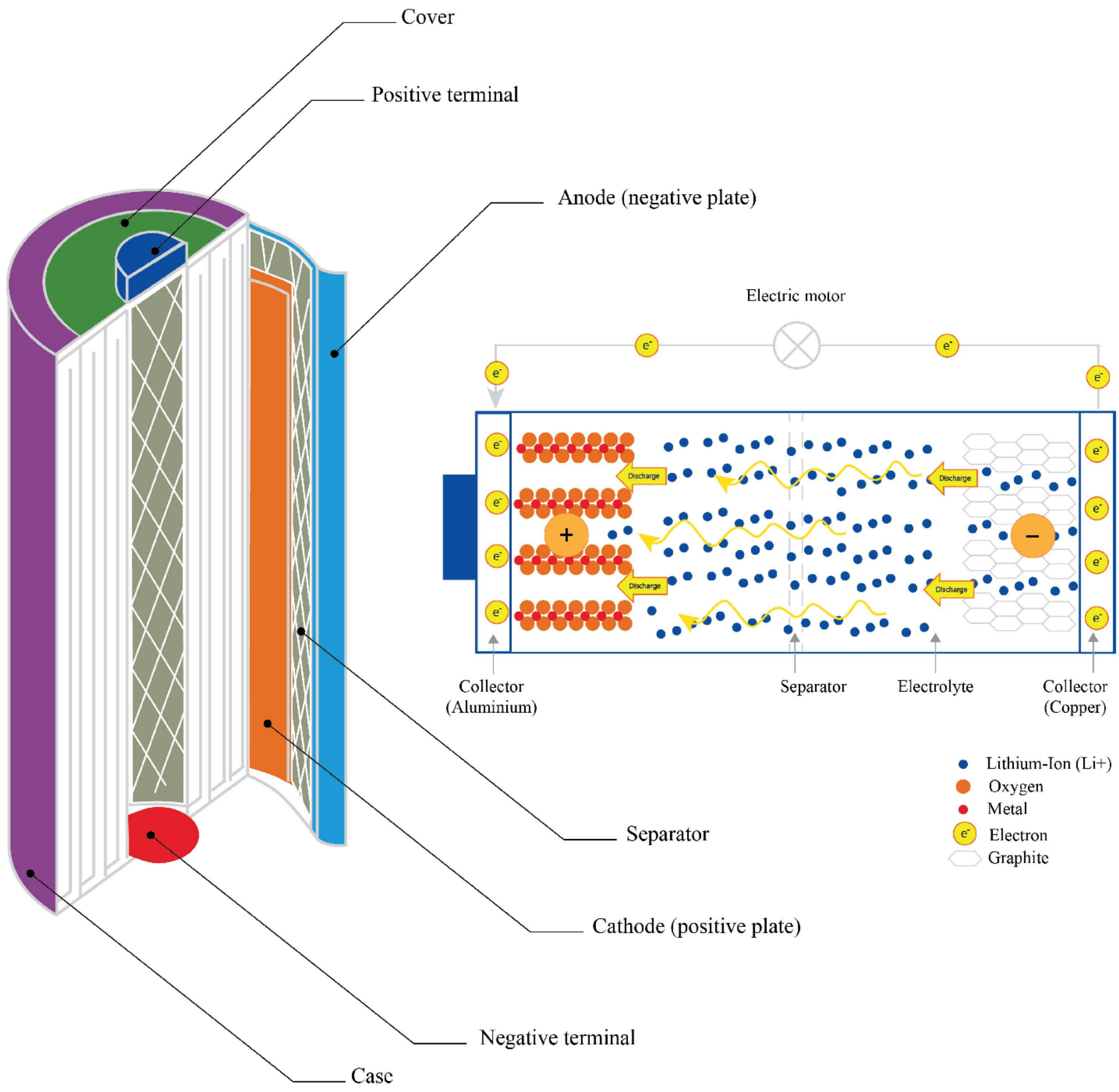


Figure 15: Structure of a lithium-ion battery (cylindrical cell) [adapted from [9] & [87]]

Within an EV, Li-ion battery cells are connected in series or parallel to form a battery module. Safety features are included within the battery cell design itself, through selection of cell chemistry, cell design and packaging and short circuit protection. A battery module typically contains between 8 and 12 battery cells [94] [95], with some Tesla modules containing as many as 444 cells [96] . These are fixed into a frame with additional components (e.g. battery disconnector, which can turn off power to the battery) and sensors (e.g. temperature sensors) to aid in the performance, safety and integration of the battery cells with other battery modules within the battery pack [97].

Multiple battery modules are arranged in a battery pack, as seen in Figure 16. The battery pack is placed within a watertight casing intended to shield from external impact. The battery pack is provided with a battery management system (BMS) as well as thermal management system. This software monitors the state of the battery modules/cells. The BMS is preventative (i.e. it can flag if it detects an issue and recommend repair/servicing before the problem grows/causes the battery to fail) and can monitor, the total battery current, the total battery voltage, the individual cell voltage, battery current and the temperature throughout the battery module [30].

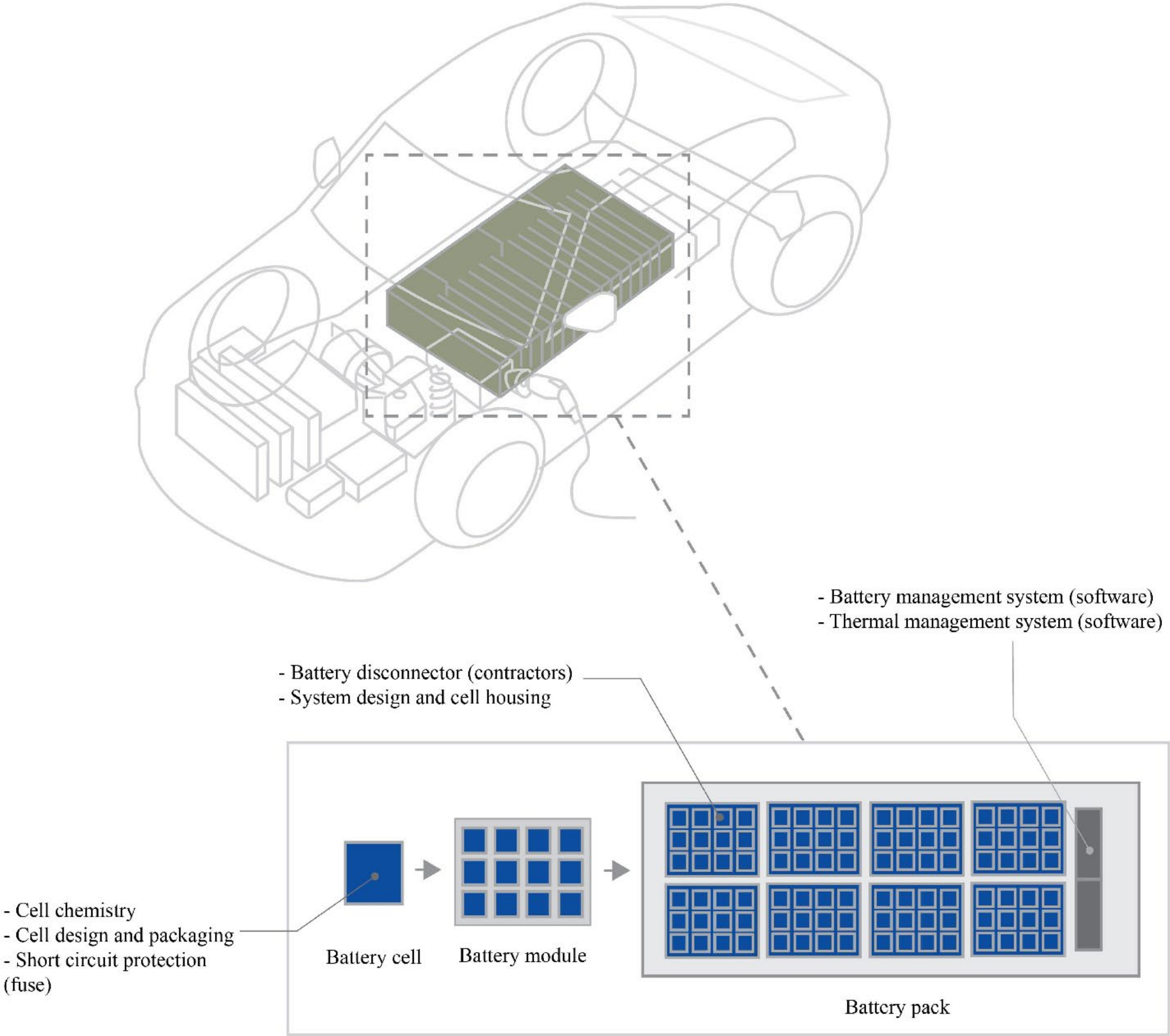


Figure 16: EV battery pack elements [adapted from [20]]

The BMS also performs a reactionary role, implementing processes and shutdowns with the aim to prevent a thermal runaway event. A BMS can limit the progression of factors which lead towards thermal runaway by monitoring the temperature, and providing an alarm, or cutting off power to the battery if the temperature exceeds a specified safety level.

There are various types of battery chemistries which utilise Li-ions to transfer charge. Typically, the difference between these battery chemistries is based on the chemistry of the cathode i.e. the active material. Each battery chemistry varies in its properties and performance, including key metrics such as: capacity, charge/discharge rate and thermal runaway temperature [93].

For EVs, battery chemistries for the cathode are typically Lithium Nickel Manganese Cobalt Oxide (NMC) or Lithium Nickel Cobalt Aluminium Oxide (NCA) [98]. It is acknowledged that Lithium Iron Phosphate (LFP) Cathodes are common in the Chinese market and may become a world-wide battery technology in the future. However, these have not been evaluated in this document as they are not currently in use in the UK market.

EV chargepoints (EVCP)

There are four different charge station modes, described as Mode 1, Mode 2, Mode 3 and Mode 4, which are described in Table 20 below. These modes are used to categorise the power output and different types of charging cable arrangements, as well as different electrical safety features available as part of the EVCP.

Approved Document S [15] states that chargers installed under Building Regulation requirements should be designed and installed as described in BS EN 61851-1:2019 [99] and have a universal socket (i.e. a means by which any EV can use the charger) [15].

None of the different mode EV charge stations have an in-built readily accessible 'off' switch to isolate power supply to the charge station.

The length of charge cables is not standardised and may be up to 50m or so in length.

Generally, each cable has two plugs, one either end – one to be inserted into the socket on the EV and one to be inserted into the socket on an EVCP. The plug on both ends for Modes 2-3 include a control pilot pin. The control pilot pin communicates between the EV and the EVCP to determine the power the EV is safely able to receive from the EVCP. Once the control pilot pin is connected on both sides, charging begins.

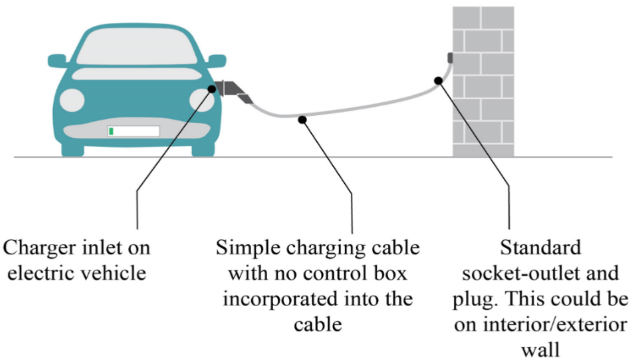
For Mode 1, the plug to be inserted into the EVCP does not include a control pilot pin. Therefore, Mode 1 should not be used to charge EVs day-to-day – it is reserved for emergency use only. Modes 2 and 3 can be either tethered or untethered connections. For Mode 4, the cable is always tethered so the control pilot function is within the EVCP itself.

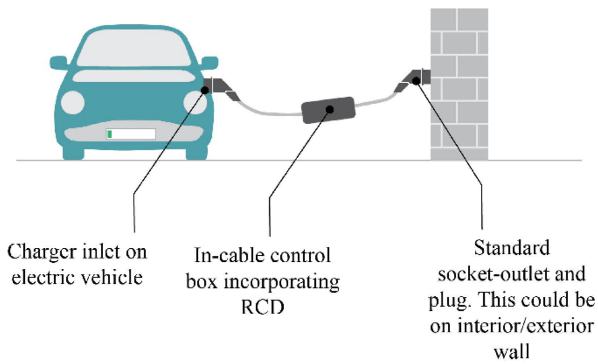
Additional safety measures are included in Mode 3 and Mode 4 charging where an electrical or mechanical system prevents the plugging/unplugging of the plugs once they are connected securely unless the supply has been switched off [79].

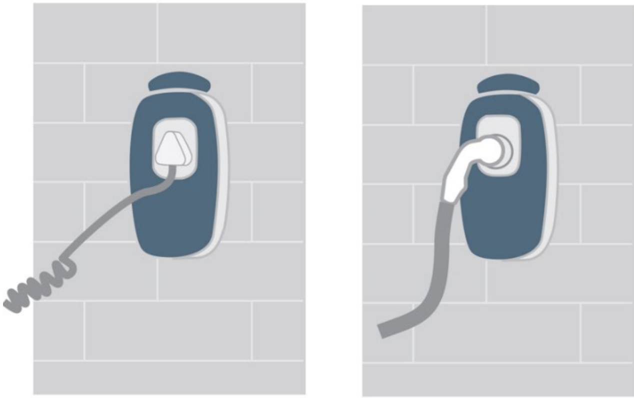
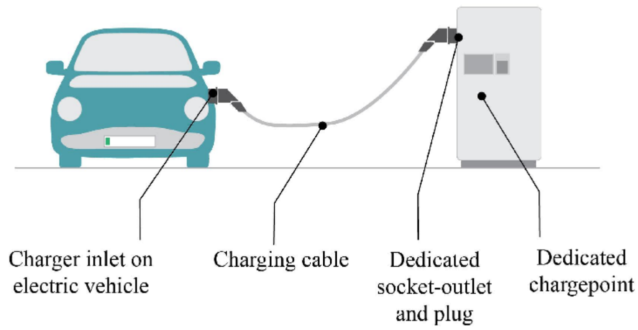
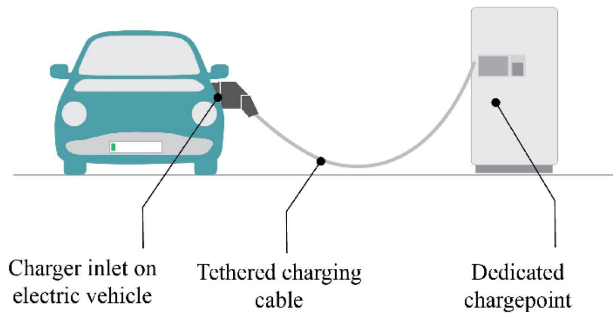
The common EVCPs provided in public, industrial and business settings are Mode 3 and Mode 4 [79].

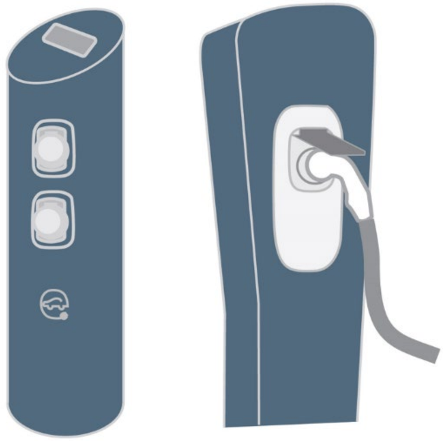
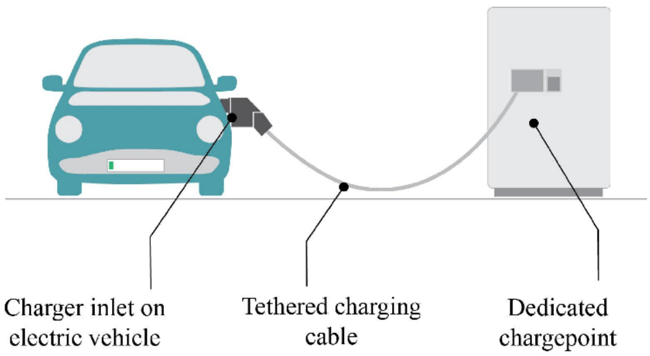
EVCPs which are being installed to meet Building Regulations requirements should follow the technical requirements outlined in Approved Document S [15].

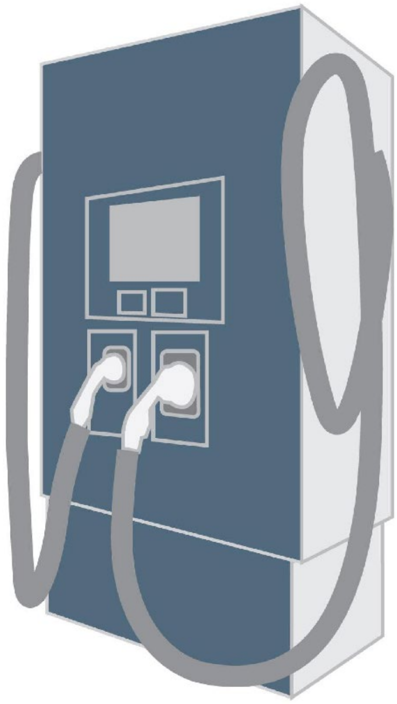
Table 22: Mode 1 – Mode 4 EVCP [adapted from [79]]

Type of EVCP	Description	Images [adapted from [79]]
Mode 1 (emergency use only)	Standardised (domestic) socket-outlets, i.e. 3-pin plug, which do not exceed 7kW. Mode 1 is connected to the main grid system. Mode 1 is not a mainstream charging technology and should not be installed in covered car parks for the purpose of electric vehicle charging. As per the IET Code of Practice Electric Vehicle	 **Figure 17: Mode 1 Charging: Vehicle to standard (domestic) socket-outlet and 3-pin plug using a simple charging cable (no in-cable control box)**

Type of EVCP	Description	Images [adapted from [79]]
	Charging Equipment Installation 4th Edition [79] the socket-outlet should comply with BS EN 60309 Parts 1 [100], 2 [101] and 4 [102] to prevent the socket contacts being live when accessible. It does not provide a control pilot function and system of personnel protection against electric shock between the EV and the socket-outlet. Charging cable may be tethered or provided by the EV user.	 **Figure 18: Mode 1: Wall - mounted charge point**
Mode 2 (typically referred to as 'standard' charging)	Domestic socket outlet or dedicated EV socket-outlet provides Mode 2 charging and does not exceed 15 kW. Mode 2 is connected to the main grid system. As per the IET Code of Practice Electric Vehicle Charging Equipment Installation 4th Edition [79] the socket-outlet should comply with BS EN 60309 Parts 1 [100], 2 [101] and 4 [102] to prevent the socket contacts being live when accessible. An in-cable control box is provided which adds protection against electric shock and it incorporates a residual current device (RCD). A control pilot function is also provided once connected to a Mode 2 EVCP.	 **Figure 19: Mode 2 Charging: Vehicle to standard domestic or dedicated EV socket-outlet and plug using a charging cable with an in-cable control box incorporating RCD (residual current device)**

Type of EVCP	Description	Images [adapted from [79]]
	Charging cable may be tethered or provided by the EV user. Standard Type 2 connector is recommended.	 Figure 20: Mode 2: Wall - mounted charge point with 3-pin plug (LHS) and dedicated EV plug (RHS)
Mode 3 (typically referred to as 'Fast charging')	A dedicated electric vehicle supply equipment is utilised for Mode 3 charging i.e. it supplies electrical power for charging plug-in EVs only and is not connected to the main grid system. The control pilot function extends to the control equipment in the supply equipment and is permanently connected to the AC supply network. The cable is either tethered to the supply equipment or sockets are provided. Power may flow from a single-phase supply (single conductor) or three-phase supply (three conductors) at approximately 7kW and 22kW. Up to 22kW the EV user typically provides a charging cable which is supplied with the vehicle or is purchased from an aftermarket cable supplier. Depending on if the cable is tethered or untethered,	 Figure 21: Mode 3 Charging: Vehicle to dedicated socket-outlet and plug using a charging cable  Figure 22: Mode 3 Charging: Vehicle to dedicated socket-outlet and plug using a tethered charging cable

Type of EVCP	Description	Images [adapted from [79]]
	as per the IET Code of Practice Electric Vehicle Charging Equipment Installation 4th Edition [79] each Mode 3 EVCP should incorporate a Type 1 vehicle connector, a Type 2 socket-outlet or vehicle connector or a Type 3 socket-outlet or vehicle connector that complies with BS EN 62196-2 [103]. A Mode 3 supply equipment can be either wall mounted or built into free standing posts. Charging cable may be tethered or provided by the EV user.	 **Figure 23: Mode 3: Standalone AC chargepoint**
Mode 4 (typically referred to as 'Rapid' charging)	A dedicated electric vehicle supply equipment is utilised for Mode 4 charging i.e. it supplies electrical power for charging plug-in EVs only and is not connected to the main grid system. Mode 4 charging is commonly referred to as rapid or ultra-rapid charging where AC supply is converted to DC within the supply equipment. The resulting DC (over 22 kW) is supplied to the EV via a charging cable which is tethered to the supply equipment. The control pilot function extends to the equipment permanently connected to the AC supply. Depending upon the initial state of charge, an EV can be fully charged in less than 30 minutes.	 **Figure 24: Mode 4 Charging: Vehicle to dedicated socket-outlet and plug using a tethered charging cable**

Type of EVCP	Description	Images [adapted from [79]]
	Mode 4 charging can include built in safety features to monitor heat build-up. The supply equipment can stop charging if a safety concern arises. Mode 4 supply equipment are usually free-standing units with tethered cables.	 Figure 25: Mode 4: Rapid DC chargepoint

Not all chargers are compatible with each type of EV currently on the market [104] [105].

Appendix C Image Permissions

Table 23: Image permissions

Figure	Figure Title	Adapted/ Used	Rights Holder / Reference	Consent
Figure 1	Potential chain of events from a thermal event at a cell level leading to thermal runaway at a	Adapted	RISE Research Institutes of Sweden [3]	Permission received
Figure 4	Mechanical crash protection typically provided to an EV [adapted from [20][20]]	Adapted	RISE Research Institutes of Sweden [20]	Permission received
Figure 6 (LHS)	Firefighting tools developed to control EV battery fires [47] & [46]	Used	Auto-Medienportal.net [47]	Consent to use images displayed on website
Figure 6 (RHS)	Firefighting tools developed to control EV battery fires [47] & [46]	Used	Cui et. al. [46]	Consent received via email
Figure 7	Illustration of likelihood of fire claims per car per year, sorted by propulsion type	Arup produced from data	Thatcham Insurance Research Department [10]	N/A
Figure 8	General considerations for a low rise car park with EV chargepoints	Arup produced	Arup	N/A
Figure 9	Hierarchy of mitigation measures [adapted from [62]]	Adapted	NIOSH [62]	Gratis consent
Figure 10	Illustration of CoL-recommended car park space dimensions. © City of London Corporation	Used	© City of London Corporation Fire Safety	Consent provided
Figure 11	Image of multi-jet sprinkler system test undertaken by City of London Corporation, 9th February 2022. © City of London Corporation Fire Safety Department (with permission)	Used	© City of London Corporation Fire Safety Department	Consent provided
Figure 12	The system components of an EV [adapted from [86]]	Adapted	U.S Department of Energy [86]	Permission received

Figure	Figure Title	Adapted/ Used	Rights Holder / Reference	Consent
Figure 13	Typical location of charge ports on EV [adapted from [79]]	Adapted	IET [79]	Permission received
Figure 14	Typical housing types for lithium-ion battery cells	Arup produced	Arup	N/A
Figure 15	Structure of a lithium-ion battery (cylindrical cell) [adapted from [87]	Adapted	Sage [87] Swiss Federal Laboratories for Materials Science and Technology (EMPA) [9]	Gratis consent Permission received
Figure 16	EV battery pack elements [adapted from [20][20]]	Adapted	RISE Research Institutes of Sweden [20]	Permission received
Figure 17	Mode 1 Charging: Vehicle to standard (domestic) socket-outlet and 3-pin plug using a simple charging cable (no in-cable control box)	Adapted	IET [79]	Permission received
Figure 18	Mode 1: Wall - mounted charge point	Adapted	IET [79]	Permission received
Figure 19	Mode 2 Charging: Vehicle to standard domestic or dedicated EV socket-outlet and plug using a charging cable with an in-cable control box incorporating RCD (residual current device)	Adapted	IET [79]	Permission received
Figure 20	Mode 2: Wall - mounted charge point with 3-pin plug (LHS) and dedicated EV plug (RHS)	Adapted	IET [79]	Permission received
Figure 21	Mode 3 Charging: Vehicle to dedicated socket-outlet and plug using a charging cable	Adapted	IET [79]	Permission received
Figure 22	Mode 3 Charging: Vehicle to dedicated socket-outlet and plug using a tethered charging cable	Adapted	IET [79]	Permission received

Figure	Figure Title	Adapted/ Used	Rights Holder / Reference	Consent
Figure 23	Mode 3: Standalone AC chargepoint	Adapted	IET [79]	Permission received
Figure 24	Mode 4 Charging: Vehicle to dedicated socket-outlet and plug using a tethered charging cable	Adapted	IET [79]	Permission received
Figure 25	Mode 4: Rapid DC chargepoint	Adapted	IET [79]	Permission received
Figure 26	HRR for ICEV and EV fire tests (including a 2MW burner contribution)	Used	Cecilia Lam et. al [42]	Permission received