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Charging of electric cars in parking garages

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Abstract

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There has been a huge increase in the number of electric cars over the last few years, as of the 1st of September 2019 a total of 247,565 electric cars were registered in Norway. There is a clear political incentive to facilitate the charging of electric cars in parking garages in Norway. This has resulted in a public inquiry regarding a proposed amendment to the Norwegian Planning and Building Act (Planning and Building Act, the Norwegian Act relating to owner-tenant sections and the Norwegian Housing Cooperatives Act). The inquiry proposes that housing cooperative owners be given the right to install chargers for electric cars. The inquiry has resulted in a consultation paper in which the uncertainties regarding fire safety during electric car charging in confined spaces were highlighted.

The study examined whether the charging of electric cars in parking garages results in unacceptable risk of fire and, if so, what sort of measures would be required to ensure acceptable risk levels.

One of the objectives of the study was to identify the required measures to ensure acceptable safety levels when parking and charging electric cars in parking garages.

This was done through the use of a comprehensive evaluation of the risk of fire in electric cars while charging, the risk of fire in electrical installations in parking garages during charging and also the layout of the parking garage and the possibility for active firefighting or extinguishing using sprinklers and water mist systems.

It also investigated the relevant measures that could be taken to prevent increased fire risk arising from the installation of charging points for electric cars.

Conclusions

Based on the findings from statistics and a literature review, there were no indications that charging of electric cars in parking garages would result in an increased probability of fire. The regulations regarding charging points for electric cars seem to be adequate for ensuring that the risk of fire arising due to the charging of electric cars in parking garages is acceptable. This requires that the charging points are in accordance with the regulations and that the recommendations from the car manufacturers and the producers of the charging points are followed. It is important to avoid the use of power sockets not intended for the charging of vehicles and also to avoid the use of extension leads. Based on this, the need for fixed water-based firefighting systems in parking garages is no higher for parking garages with the possibility of charging of electric cars than in other parking garages.

There are still unknown factors with regard to both the development of fire in parking garages in general and also regarding potential fire propagation to the battery pack specifically. More knowledge is needed in order to increase the accuracy of evaluations and recommendations.

Keywords: Electric car, charging, fire development, extinguishing, regulations, statistics

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Summary

Background

There has been a large increase in the number of pure electric cars in recent years and, as of 1 September 2019, a total of 247,565 pure electric cars were registered in Norway. There is a clear political incentive for the facilitation of electric car charging in parking garages in Norway. This has resulted in a public inquiry regarding a proposed amendment to the Norwegian Planning and Building Act, the Norwegian Act relating to owner-tenant sections and the Norwegian Housing Cooperatives Act. The inquiry proposes that housing cooperative owners be given the right to install chargers for electric cars. The inquiry has resulted in a consultation paper in which the uncertainties regarding fire safety during electric car charging in confined spaces were highlighted.

The study examined whether the charging of electric cars in parking garages results in unacceptable risk of fire and, if so, what sort of measures would be required to ensure acceptable risk levels.

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One of the objectives of the study was to identify the required measures to ensure acceptable safety levels when parking and charging electric cars in parking garages.

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There are still many unknown factors with regard to both the development of fire in parking garages in general and also regarding potential fire propagation to the battery pack specifically. These are areas where knowledge is needed in order to increase the accuracy of evaluations and recommendations.

1 Introduction

1.1 Background

There has been a large increase in the number of electric cars in recent years. As of 1 September 2019 a total of 247,565 pure electric cars were registered in Norway [1], compared to 97,532 registered electric cars at the end of 2016 [2]. Proper safety measures must be taken to facilitate the parking and charging of these electric cars in parking garages. This study considers pure electric cars only, i.e. cars that use electricity as their sole source of power. Hybrid cars are not included in the study. Chargeable hybrid cars traditionally use lower charging energy, which means that the risk of overheating is somewhat smaller. Other than that, the same risk assessments will apply to chargeable hybrids as for pure electric cars.

In 2016, RISE Fire Research (RISE) completed a study [3] in which the conclusion stated "Until there is more information about extinguishing times and rescue efforts in connection with electric car fires in parking garages, sprinkler/water mist systems should be a minimum requirement for permitting the parking of electric cars." The background for the conclusion was inadequate statistics and research on the risk of ignition in electric cars during charging. However, this would result in a large financial burden for all new and existing parking garages. It is therefore desirable to investigate the extent to which charging and parking of electric cars in parking garages affect the risk situation and whether there may be other measures that must be implemented in order to achieve a satisfactory safety level. This will be a prerequisite for achieving the goal of phasing out vehicles that run on fossil fuels.

There is a clear political incentive for the facilitation of charging of electric cars in parking garages. This was described in a parliamentary motion to the Norwegian parliament in March 2017, *Document 8:70 S (2016-2017)*, which states "...ensuring that everyone in housing cooperatives and co-ownership has the opportunity to charge their electric cars..." [4]. Parliamentary resolution 717 based on the proposal states

"The Norwegian parliament asks the government to consider how to introduce requirements for new buildings and buildings subject to major reconstruction to be charging-prepared buildings."

The *Recommendation to the Norwegian parliament from the Energy and Environment Committee (Recommendation 315 S (2016-2017))* proposes "charging rights for residents in housing cooperatives and co-ownerships" [5]. This resulted in a consultation on proposals for amendments to the Norwegian Planning and Building Act, the Norwegian Act relating to owner-tenant sections and the Norwegian Housing Cooperatives Act [6]. The inquiry proposes that housing cooperative owners be given the right to install chargers for electric cars. The consultation paper highlighted the uncertainties relating to fire safety based on, among other things, the RISE Report from 2016 [3].

1.2 Objectives

One of the objectives of the study was to identify measures that could ensure acceptable safety levels in connection with the parking and charging of electric cars in parking garages.

This was done through a comprehensive evaluation of the risk of fire in electric cars while charging, the risk of fire in electrical installations in parking garages during charging and also the layout of the parking garage and the possibility for active firefighting or extinguishing using sprinklers and water mist systems.

It also investigated the relevant measures that could be taken to prevent increased fire risk arising from the installation of charging points for electric cars.

1.3 Scope and limitations

The report evaluates the risk situation in connection with the charging of pure electric cars in parking garages.

The risk associated with charging in automatic parking facilities has not been assessed. These are facilities where cars are delivered and built-in mechanical systems move the cars to vacant spaces. Such facilities are currently not widespread and most are not set up for the charging of electric cars. A separate investigation must be carried out if this becomes a relevant issue in future.

1.4 Methodology

The information for this report has been obtained through:

- Searching literature and news articles.
- Reviewing national standards and regulations.
- Reviewing a selection of international standards and regulations.
- Case studies with inspections in a parking garage that has been upgraded for the purpose of charging electric cars.
- Interviews.

2 Literature review

2.1 Fires in parking garages

Thankfully, parking garage fires are rare, but if a fire were to occur, it would have the potential to develop into a serious fire.

Historically, the risk of fires spreading between vehicles has been considered limited and it has been assumed that most fires in parking garages will involve one or a maximum of two vehicles [7]. Several fires in recent years have shown that this is no longer the case and that a fire can spread and potentially involve all of the cars in the parking garage [7,8]. One of the latest examples of this was the fire at King's Dock car park in Liverpool, England, on New Year's Eve 2017, where a fire broke out in a parked vehicle. The fire spread to a total of 1,200 cars across seven floors [9].

There are several reasons why the potential for fire spreading is greater today than it was in the 1960s and 1970s [10]. One of the reasons is that there is significantly more combustible plastic and composite materials in modern cars. It has been estimated that by the year 2020, the volume of plastic in cars will generally have increased to 350 kg compared to 200 kg in 2014 [11]. Plastic also has new uses and it has been estimated that 85% of new cars have fuel tanks manufactured from plastic [7], which could influence the spread of fire if the fuel tank melts and the petrol or diesel leaks out, as it did in the King's Dock car park fire. Additionally, there is a trend for increasing numbers of wide cars such as SUVs, which means that the distance between parked cars is reduced. These two factors mean that there is potential for fires to develop more quickly and more extensively than before. The probability of a fire in a parking garage involving more than one car therefore becomes large.

The changed fire developments in modern vehicles and the increased risk of multiple cars being involved in a fire also results in greater requirements in terms of fire ventilation in parking garages. Adequate fire ventilation may prevent the accumulation of hot fumes that could contribute to escalating fire development.

One report claims that fire and explosion in connection with the ignition of flammable electrolyte fluids used in Li-ion battery packs is comparable to or less serious than fire and explosion in diesel and petrol cars [12]. One study also shows that fire in the battery pack does not result in any significant increase in heat release compared to diesel and petrol cars [13]. A study conducted in Sweden also supports these conclusions [14].

2.2 Extinguishing fires in parking garages

The extinguishing of electric car fires is said to be extremely challenging, both with regard to water consumption and the efforts of the fire service. In this context, it is important to differentiate between fire in an electric car and fire in the battery pack of an electric car. The former would be comparable with a fire in a car using fossil fuel and the extinguishing efforts would therefore be comparable with traditional efforts against car fires.

If a fire in an electric car starts somewhere other than the battery, some time would pass before the battery heats up to a temperature at which *thermal runaway* occurs. Thermal runaway is an uncontrolled chemical heat production inside the battery and can occur if the temperature in the battery exceeds a given threshold (in the range 130–200°C). This means that early extinguishing efforts or other technical measures such as automatic extinguishing systems can be used to manage the fire in the same way as regular car fires.

Extinguishing becomes challenging if the fire occurs in the battery pack or if the battery has been exposed to adequate heat for a sufficient period of time for the fire to spread to the battery pack. The battery packs are usually well protected and situated in or under the car, making them difficult to access from the outside. Additionally, the battery itself is well protected against water ingress and pollution and this also makes it difficult to attack the fire directly. According to current knowledge, cooling is the only way in which to stop a fire inside a battery pack without physically opening the battery itself. This means that the battery must be cooled enough to stop the chemical reaction that creates thermal runaway. This requires large quantities of water. If the temperature inside the battery is not adequately reduced, the fire could flare up again even if it appears to have been extinguished. However, experiments show that an undamaged electric car battery requires extensive external heating before it is adequately heated to cause thermal runaway [15].

In order to check the temperature in the battery, it is possible to use a thermal camera, provided there is unrestricted visibility to the battery pack. It is important to note that the thermal camera can only detect the temperature at the surface of the battery. It is therefore necessary to pause the cooling and wait for a period of time in order to check whether the surface temperature increases again.

The optimal scenario would be to initially extinguish the fire at the location where the car is parked, before transporting the car out in a safe manner even if the temperature in the battery remains high. It would then be possible to either allow the car to burn out at a safe location or continue cooling the battery pack until the temperature of the entire battery is adequately low. Whether this would be possible would depend on e.g. the layout of the parking garage, the availability of equipment for transporting the vehicle out and the training of the fire service personnel who would be performing the task.

The most important thing is to ensure that the efforts start as early as possible and that the focus is on preventing the fire from spreading to more vehicles than the one in which the fire originated. This is specified in the report from the fire at King's Dock Car park [9].

We also know that there are challenges associated with fires in parking garages and that fire has the potential to develop more quickly, become larger and involve more vehicles now than before. We therefore recommend considering installing automatic extinguishing systems to reduce the risk of fire spreading where this is practically and financially sound, even if there are no explicit requirements set down in regulations.

In order for the fire service to carry out effective extinguishing of fires in a parking basement, the fire service needs to be familiar with the new challenges relating to fire development and the risk of spreading. Additionally, tactics and techniques must be established to manage fire in battery packs in electric cars.

2.3 Statistics

2.3.1 Statistics from Norway

Even if, in recent times, there has been a substantial increase in the number of electric cars both in Norway and abroad, there are no available statistics that are good enough when it comes to fires in electric cars. This applies, among other things, to the identification of causes of electric car fires or whether the batteries were involved in the fire. In Norway, DSB has developed the reporting system BRIS, which collects and systematises information about the tasks managed by the fire and rescue service [16]. A total of 998 fires in car parks and garages were recorded in BRIS during the period 2016-2018. Of these, 109 fires were recorded with the cause listed as electrical equipment and 65 fires started in vehicles, of which two were electric cars. Whether these two cars were charging at the time or not was not recorded.

Of the 998 total fires, seven were recorded as being in car parks. One of these was recorded as having an electrical cause with smoke development in a switchboard room, four were recorded as arson, and the final two were not recorded with a cause. None of the car park fires were recorded with the cause originating in a vehicle, but there could be some uncertainty here as 60% of the fires were recorded as cause unknown or not recorded. A summary of the various fire causes can be found in Table 2-1.

Table 2-1 Causes of fires in parking garages for the period 2016 – 2018, recorded in BRIS.

Cause of fire	**Number**
Unknown	522
Electrical	137
Other	68
Open fire	158
Self-ignition	26
Natural phenomena	10
Cause not recorded	77
Total	**998**

A total of 82 fires in electric cars were also recorded in BRIS during the same period. 45 of these were in passenger cars, but none of these were recorded in parking garages. Only in one of these events was the battery recorded as having been involved in the fire. None of these fires resulted in personal injury.

It has been difficult to find reliable international statistics for fires in electric vehicles in general and for fires associated with charging electric cars in particular.

According to the DSB report “Project Statistics from BRIS, first half of 2018,” 445 fires were recorded in passenger cars during the first half of 2018 [17]. The report does not specify the fuel type or cause of fire, but, according to the data from the BRIS database from the same period, only three of the fires involved electric cars.

Even though BRIS is a great tool for collecting and retrieving information about incidents, the information is inadequate for the assessment of fire risk associated with the charging of electric cars. Whether the car was charging at the time of the incident is, among other things, not recorded, nor is whether the battery pack was involved in the fire or where in the car the fire is assumed to have started.

2.3.2 International statistics

Studies from the USA looking at fires in cars on motorways show that the vast majority of car fires are due to mechanical faults in the engine, brakes or drive train (45%), followed by faults in the general electrical system (29%) [18].

In a list of 13 known fires in electric cars of the make Tesla for the 2013 – 2018 period, only one fire was associated with charging, the remaining fires were the results of accidents [19]. There were also two incidents in Norway (2016 [20] and 2018 [21]) and one incident in Belgium (2019 [22]), as well as one in Shanghai (2017 [23]), in which fires arose in connection with the charging of electric cars. In three of these fires, the car was connected to a so-called fast charger. In the last case, the fire occurred in an extension lead used in connection with charging.

The websites “Undecided with Matt Farrell” [24] and “CNN Business” [25] estimate that there are five fires each billion miles driven (1.6 billion kilometres) for electric cars, compared to 55 fires for each billion miles driven (1.6 billion kilometres) for petrol cars. Nevertheless, these figures do not take into account the age of the cars, which means that there is a larger proportion of older fossil fuel cars in the statistics and the reliability of this type of statistics is therefore limited. However, the information could provide an indication that there is not a significantly greater risk of fire when using electric cars compared with the use of traditional cars, even though the statistics are somewhat uncertain.

2.4 Regulations

We have chosen to examine the regulations applicable to Norway, the United Kingdom and North America. The United Kingdom was chosen to look at how the regulations have been adapted in a country where the proportion of electric cars is substantially smaller than in Norway. North America was chosen because it has extensive regulations applicable to electric cars. Additionally, there is a high number of electric cars in North America, even if the proportion of electric cars in the total car fleet is not so large.

2.4.1 Norwegian regulations

The Norwegian requirements for the actual construction of parking garages are described in the Regulations on technical requirements for construction works (TEK 17) [26]. In the guidance to *Section 11-2. Risk Classification* in TEK 17, car parks and parking garages with two or more floors or levels as well as parking basements and underground garages are classified as risk class 2. The guidance to Section 11-12, subsection 2, litra a states the following for risk class 2. *Measures to influence escape and rescue times:*

> For parking garages, car parks and parking basements, the requirement for fire alarm systems shall apply when the total gross area is greater than 1,200 m^2. Alternatively, an automatic sprinkler system may be installed. Car parks with more than 1/3 of the wall surfaces on each level open to the outside above fully levelled ground and the topmost parking surface less than 16 metres above the average ground level can still be constructed without fire alarm systems or automatic sprinkler systems if the openings are positioned in such a way that good ventilation is achieved.

The overarching requirements for electrical installations are set down in the "Regulations on electrical low voltage installations" [27] and the "Regulations on electrical supply systems", including guidance [28, 29], while specific recommendations for the installation of charging stations are described in the standard NEK 400:2018 Electrical low voltage installations [30]. In this latest version of NEK 400, effective from 1 July 2018, certain specifications and amendments have been made with regard to the charging of electric cars to enhance safety. In the sub-standard 7-722, the requirements for power supply and outlets for the charging of electric vehicles are defined. Some of the amendments and specifications made are:

- Generally available public charging outlets must be type 2 plug/outlet.
    - Industrial plugs and ordinary earthed plugs (Schuko) are no longer permitted.
- Requirement that the connection point must have surge protection.
- Requirements concerning dedicated circuits have been continued but some amendments have been made with regard to the installation of new charging points in existing circuits.
- Charging using ordinary earthed sockets (defined as Schuko [31]) are permitted for personal use but there must be a dedicated circuit protected with 10 A surge protection and earth fault protection relay type B.
- Extension leads must not be used.
- Various adapters may not be used unless they comply with the recommendations from the manufacturer of the electrical equipment or electric vehicle.

Additionally, DSB has published guidance [32] that provides a detailed specification of what must be facilitated in order to perform the charging of electric cars in a safe manner. Chapter 3 of this provides an unambiguous clarification:

> The charging cable must not be extended using extension leads due to the risk of damage and overheating.

This must also be clearly described in the user manual for the electric car.

2.4.2 US regulations

In the USA, the National Fire Protection Association has published the standard *NFPA 88A, Standard for Parking Structures* [33]. The standard differentiates between open parking garages, garages with at least two open sides and closed parking garages. There are requirements for sprinkler systems in closed parking garages, while the natural ventilation of fire gases in open structures is deemed adequate for reducing the risk of the fire spreading.

References to sprinkler systems in closed parking garages refer to NFPA, 13, *Standard for the Installation of Sprinkler Systems* [34]. The standard defines parking garages as "Ordinary Hazard, Group I," which is defined as an area with a moderate amount of fuel providing a low energy volume. This is intended for areas where relatively minor fires may normally occur.

The requirements for the electrical system and charging points applicable to North America are set down in the standard *NFPA 70 National Electrical Code* [35] in which technical details associated with the installation of charging stations for electric cars are described in *Article 625 – Electric Vehicle Charging System.* This has been broken down into four different categories for charging:

- Mode 1 – Standard 120 V American plug
- Mode 2 – Standard 240 V American plug with special charging cable
- Mode 3 – Charging via specialist plug with built-in control and safety functions (Type 1 plug)
- Mode 4 – Fast charger.

This corresponds to the requirements set down in NEK 400, sub-standard 722 as these are based on the same IEC standard. Nevertheless, there may be some national variations.

The standard *J1772 SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler* [36] describes the requirements for the design (dimensions and lengths) of charging plugs. This was issued by NEC based on the IEC 62196 series and describes the requirements for Type 1 plugs.

Neither NFPA 88A, NFPA 70 nor J1775 describe any specific conditions applicable to the charging of electric cars in parking garages.

2.4.3 British regulations

The construction regulations for garage facilities in the United Kingdom are specified in *Approved Document B, Volume 2 – Buildings other than dwelling houses* [37]. Generally, there are no requirements concerning sprinkler systems for parking garages, but there is a requirement that the structure must be constructed using non-combustible materials. The fire requirements are largely based around ventilation to reduce the build-up of hot smoke, thereby reducing the risk of the fire spreading. The regulations differentiate between three ventilation configurations for parking garages: open, natural ventilation and mechanical ventilation.

In 2018, new legislation was introduced concerning the charging of electric cars, the *Automated and Electric Vehicles Act 2018* [38]. This act describes the requirements concerning the organisation of infrastructure for public charging stations but not the technical requirements for the charging station itself.

A specification of the technical requirements for the installation of charging stations for electric cars is described in the standard *BS 7671:2018 Requirements for Electric Installations, Section 722 Electric vehicle charging installation* [39].

None of these documents provide any specification of special conditions applicable to the charging of electric cars in parking garages.

2.4.4 General guidelines for the EU

In the EU, there is great focus on facilitating an increase in the proportion of electric cars. This is, among other things, clear from DIRECTIVE 2014/94/EU [40], wherein Section 24 states:

> Member States should ensure that publicly accessible infrastructure for the supply of electricity to motor vehicles is built up. To define an appropriate number of recharging points accessible to the public in their national policy framework, it should be possible for Member States to take into consideration the number of existing recharging points accessible to the public on their territory and their specifications, and to decide whether to concentrate deployment efforts on normal or high power recharging points.

The design of charging plugs and sockets is standardised through EN 62196-1 *General requirements [41] (safety requirements), EN 62196-2 Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories* [42] (Type 1 and Type 2 plugs) and EN 62196-3 *Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers* [43] (European fast charging plug).

These standards allow for the use of the same charging system across all of Europe without requiring separate adapters for each country.

3 Case study: Facilitation of the charging of electric cars in garages

The use and installation of wall-mounted chargers is recommended for the charging of electric cars. Such charging units have built-in safety functions, can be equipped with systems for the distribution of available power and have the option to include payment solutions. Normally, the chargers are protected using 16 A or 32 A fuses but can also be used for semi-fast charging at 63 A if there is power available. The charging unit provides the best safety, charges quickly and has great flexibility compared with ordinary power sockets [32]. NEK 400 provides guidance as to how to meet the requirements for satisfactory electrical safety in low voltage installations, including garages [30].

Few older garages have tailored solutions for the charging of electric and hybrid cars. This case study describes how an existing communal garage in Trondheim, Norway has been adapted for an increasing proportion of electric cars. The garage and the upgrade were covered by the media and it was selected as an example of how a garage can be adapted for charging electric cars. In the case study, we did not consider whether this is the best way in which to carry out such adaptations.

The garage in the case study belongs to a housing cooperative that took the initiative to carry out an upgrade in order to facilitate the charging of electric cars [44]. The garage is free-standing and consists of two floors with a total of 120 parking spaces for passenger cars. There is also visitor parking available on the garage roof. The residents have allocated parking spaces. Pictures of the garage can be seen in Figure 3-1 to Figure 3-3.

Figure 3-1 Communal garage over two levels with visitor parking on the roof. The garage is free-standing.

Figure 3-2 The first level of the communal garage with two gates for entry and exit.

Figure 3-3 The communal garage has space for 120 passenger cars. Residents have allocated parking spaces.

3.1 From power sockets to charging units

Prior to the upgrade, power sockets intended for engine heaters were used to charge electric cars in the garage, see Figure 3-4. Extension leads were also often used in connection with charging. An increasing proportion of electric cars being charged in this way resulted in the housing cooperative, due to the regulations on electrical low voltage installations [27] and safety in the garage, deciding to initiate the upgrade of the electrical installation. When a burnt engine heater circuit was also detected in the fuse box, it became even more clear that something had to be done to increase fire safety in the garage.

In connection with a conference arranged by the housing development company TOBB, the housing cooperative became aware of a grant scheme via the Municipality of Trondheim that provided funding for charging infrastructure for electric cars in housing cooperatives [45]. The purpose of the scheme was to stimulate safe and simple home charging for electric and hybrid cars. The housing cooperative submitted an application and was awarded funds from the scheme.

Figure 3-4 Prior to the installation of charging units, power sockets intended for engine heaters were used to charge electric cars. Following the installation of the charging system, a ban has been placed on the charging of cars via power sockets.

The initial consideration was to establish new power sockets on separate circuits. This solution was disregarded, as the number of parking spaces with new power sockets would have been limited due to the power capacity of the garage. It would also have become expensive due to the internal administration costs and fees associated with the redistribution of parking spaces.

Instead, the housing cooperative wanted a more future-oriented charging solution in which all residents would have access to safely charge their electric cars.

3.2 Installation of dynamic charging system

In order to take into account the increasing proportion of electric cars and the subsequent need for charging, a dynamic energy management system was installed. In connection with the upgrade, the interior of a 40-year old fuse box was replaced and renewed. Two 63A power cables were laid in the ceiling of each level. From these main cables, power is drawn to each parking space where a charging unit is installed, see Figure 3-5.

Figure 3-5 Two main cables on each floor supply power to the charging units (flat cable in the ceiling, middle of picture). Cables are laid from the main cable to the charging units. The electrical system has capacity for all of the parking spaces to be connected to the charging system. Car owners are free to choose whether they want to connect to the system, but need to connect to the system if they wish to charge a vehicle in the garage.

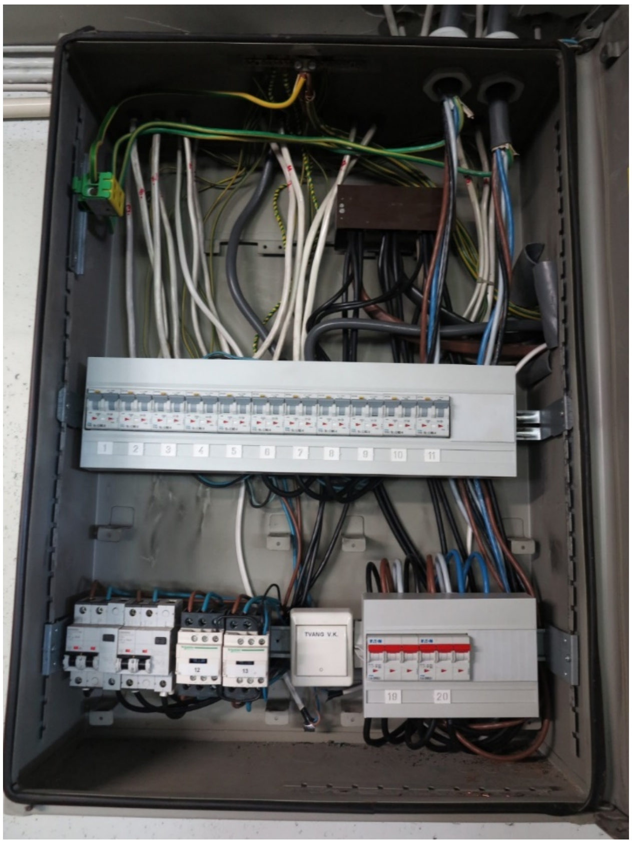

Figure 3-6 Old fuses and earth fault switches were replaced in connection with the upgrade.

Car owners are free to choose whether they want to connect to the system, but need to use the system if they wish to charge a vehicle in the garage. Car owners are responsible for the costs associated with the charging unit. The charging units are connected to the main cable as and when a car owner requests access to a charging station. The electrical system has capacity for all of the parking spaces to be connected to the charging system. All charging units can supply up to 13 kW. A wireless network has been installed in the garage, allowing all of the charging points to communicate with one another, as a so-called dynamic charging system. The system distributes power between the cars currently charging. The power supply for the main functions of the garage is prioritised at all times. The remaining power is distributed as needed to the cars that are charging. An almost fully charged car will be allocated less power when a car with a greater power requirement connects to the network. The owners of the charging units can monitor the charging status via the network and are thereby updated as to how much charge the car has.

Figure 3-7 All of the charging units in the garage are from the same supplier and form part of the dynamic charging system.

Figure 3-8 The wireless network ensures that the charging of cars can be managed by the dynamic charging systems.

The charging system design was created in consultation with a registered electrical installer. The electrical system and charging system in the garage were installed by electricians.

The electricity company was not involved in the upgrade. The main 315 A fuse was deemed to be adequate for the purpose, with ample capacity to supply power to the garage system. No changes were made to the power supply to the garage. The electricity company is assumed to have an overview of the overall load on the network and is able to adjust this as needed.

Following the upgrade, the charging of cars in the garage without using a charging unit has been banned.

Nine charging units had been installed per May 2019 and a tenth was being installed. Four units had been installed during spring 2019 alone. This shows an increasing interest in access to charge electric cars among the housing cooperative residents.

3.3 Fire safety and fire safety advice

The fire risk associated with the charging of electric cars in the garage has not been assessed by a fire safety advisor. A fire safety advisor has made an assessment of the fire risk in the garage, but this took place immediately prior to the upgrades and independent of the charging of electric cars. The assessment that was made focused on the labelling of escape routes and fire extinguishing equipment. The housing cooperative has implemented measures in accordance with the assessment that was made. There are now four portable fire extinguishers (6 kg, CO2) available on each level and portable fire extinguishers and escape routes are well marked. The fire safety adviser was contacted as part of the housing cooperative’s HSE follow-up, in which fire prevention in communal areas is included.

Installing a sprinkler system in connection with the garage upgrade was found to be too costly. At the same time, it was also found to be unnecessary, as the distance to any nearby structures was deemed to be large enough with regard to fire spread and because the garage is free-standing and situated away from any residences.

Figure 3-9 The labelling of escape routes and fire extinguishers was improved following a previous fire safety inspection. There are four portable fire extinguishers available on each level.

Figure 3-10 Escape routes are marked in several places in the garage.

3.4 Future investments

The housing cooperative intends to introduce a payment scheme based on the kWh price for the users of the charging system. The income will be used to pay back the investment that has been made and for the maintenance of the charging system. There are external payment services available that the housing cooperative and joint owners can use for this purpose.

Furthermore, the housing cooperative also plans to establish a charging system for the roof parking. The intention is to install four electric car charging stations for the visitor parking. This will be realised only after gathering experience from the current system.

Several parties, including other housing cooperatives, have contacted the housing cooperative to ask for tours and to learn about the experiences it gained from establishing the charging system. This shows that there is increasing interest in the facilitation of charging of electric cars in existing garage facilities.

With the proposed amendment to the regulations giving housing cooperative shareholders the right to install charging points for electric cars [6], the number of housing cooperatives facilitating charging in garages could be expected to rise in the coming period.

4 Discussion

Even though this report focuses on the charging of electric cars and the associated risk of fire, it is a fact that fires can also start elsewhere in cars, regardless of whether or not the car is electric. This could include overheating in the brakes or other electrical faults resulting in the car catching fire even if parked. If this were to happen in an electric car, the fire would initially develop similarly to a fire in a conventional petrol or diesel car.

The statistics described in Chapter 2.3 show that there is nothing to indicate that there is a significant risk of fire when charging electric cars. This is subject to compliance with the regulations for charging points [30] and the car not having any damage or faults that could affect charging.

Some concerns have been expressed with regard to the possibility of batteries in electric cars incurring mechanical damage during driving without the driver noticing and that this could cause thermal runaway in the battery even after the car has been parked [25]. There have been isolated cases in which the batteries in electric cars have started burning when parked, the latest fire was in China during April 2019 [46]. However, these cases appear to be individual cases and not a widespread problem with electric cars in general. However, it is still important that if a driver suspects that the battery may be damaged in some way, it is checked by an authorised professional. It is also important, in such a case, to not park the car in a parking garage until the battery pack has been checked. A challenge arises if the car owner is unaware of the status and a check is therefore not carried out. The battery often needs to be replaced in the event of damage.

The greatest challenge associated with charging of electric cars in general and in parking garages especially is when the regulations and recommendations for charging are not followed. The risk of fire increases in connection with the use of power sockets not intended for this kind of load and when using extension leads.

There are several publications that describe and specify how to charge correctly and safely, from interest groups [47], manufacturers [48], road authorities [49], insurance providers [50], electricity suppliers [51] and the DSB authorities [52]. All of these highlight the risk of using the wrong charging point and in particular the use of extension leads when charging electric cars. This was also noted as one of the motivations behind the upgrade during the inspection of the upgraded parking garage described in Chapter 3. This shows that extension leads and non-dedicated power sockets are used in parking garages that have not been adapted to include dedicated charging points. Based on this, it is important to note that there is still a need to provide information to owners and users of electric cars about how to perform proper charging and the risks associated with non-compliance with the regulations and recommendations for safe charging.

If a fire were to arise in a parking garage where electric cars are parked, it is crucial that the fire service is familiar with the procedures to manage the challenges associated with battery fire in electric cars. This requires the fire service to have undergone training in the tactics and techniques to manage this sort of scenario. They must also have received training in assessing whether a fire has spread to the battery or whether there is a risk of the fire spreading to the battery, as well as any measures that may be implemented to prevent the battery packs from being affected by the fire. If it is found that there is no risk of the battery packs of electric cars being affected by the fire, the fire can be managed as an ordinary car fire.

5 Conclusions

Based on the findings from statistics and a literature review, there were no indications that charging of electric cars in parking garages would result in an increased probability of fire. The regulations regarding charging points for electric cars seem to be adequate for ensuring that the risk of fire arising due to the charging of electric cars in parking garages is acceptable. This requires that the charging points are in accordance with the regulations and that the recommendations from the car manufacturers and the producers of the charging points are followed. It is important to avoid the use of wall outlets not intended for the charging of vehicles and also to avoid the use of extension leads. Based on this, the need for fixed water-based firefighting systems in parking garages is no higher for parking garages with the possibility of charging of electric cars than in other parking garages.

There are still many unknown factors with regard to both the development of fire in parking garages in general and also regarding potential fire propagation to the battery pack specifically. These are areas where knowledge is needed in order to increase the accuracy of evaluations and recommendations.

References

[1] 'Antallet elbiler og ladbare hybrider i Norge' (Number of electric cars and chargeable hybrids in Norway). [Online]. Available: https://elbil.no/elbilstatistikk/elbilbestand/.

[2] 'Bilparken etter type drivstoff' (Car fleet by fuel type), *Statistics Norway*. [Online]. Available: https://www.ssb.no/transport-og-reiseliv/statistikker/bilreg/aar. [Accessed: 22 May 2019].

[3] N. K. Reitan and A. Bøe, 'Brannsikkerhet og alternative energibærere: El- og gasskjøretøy i innelukkede rom' (Fire safety and alternative energy carriers: Electric and gas vehicles in enclosed spaces), SP Fire Research AS, Trondheim, Norway, A16 20096-1:1, February 2016.

[4] 'Parliamentary motion to ensure that everyone in housing cooperatives and joint ownership has the opportunity to charge electric cars and escalation plan for the sale of zero emission vehicles. Parliamentary resolution 717, Document 8:70 S (2016-2017)'. May 2017.

[5] Energy and Environment Committee, 'Recommendation 315 S to ensure that everyone in housing cooperatives and joint ownership has the opportunity to charge electric cars and escalation plan for the sale of zero emission vehicles. Parliamentary resolution 717, Document 8:70 S (2016-2017)'. 2017.

[6] Ministry of Local Government and Modernisation, 'Consultation Paper - Proposed amendments to the Norwegian Planning and Building Act, the Norwegian Act relating to owner-tenant sections and the Norwegian Housing Cooperatives Act. Ministry of Local Government and Modernisation, 5 March 2019.

[7] 'Fire spread in car parks', BRE, London, UK, BD2552, Dec. 2010.

[8] Dayan Li et al, 'Flame spread and smoke temperature of full-scale fire test of car fire', *Case Stud. Therm. Eng.*, Aug. 2017.

[9] 'Kings Dock car park fire - Protection report', Merseyside Fire & Rescue Service, Apr. 2018.

[10] Q. Dai, J. Kelly, and A. Elgowainy, 'Vehicle Materials: Material Composition of US Light-duty Vehicles', *Energy Syst. Div. Argonne Natl. Labs Chic. USA*, pp. 1–30, 2016.

[11] Plastics Today, 'Plastics use in vehicles to grow 75% by 2020, says industry watcher'. [Online]. Available: https://www.plasticstoday.com/automotive-and- mobility/plastics-use-vehicles-grow-75-2020-says-industry- watcher/63791493722019. [Accessed: 25 May. 2019].

[12] 'Lithium-Ion Battery Safety Issues for Electric and Plug-in Hybrid Vehicles', National Highway Traffic Safety Administation, DOT HS 812 418, Oct. 2017.

[13] C. Lam, 'Full-Scale Fire Testing of Electric and Internal Combustion Engine Vehicles'. Fourth International Conference on Fire in Vehicles, Oktober. 2016.

[14] Fredrik Larsson, 'Are Electric Vehicles Safer than Combustion Engine Vehicles?', RISE, 2014.

[15] A. S. Bøe, 'Fullskala branntest av elbil' (Full-scale fire testing of electric car), SP Fire Research, Trondheim, Norway, A17 20096:03-01, 2017.

[16] 'BRIS', *the Norwegian Directorate for Civil Protection.* [Online]. Available: https://www.dsb.no/lover/brannvern-brannvesen-nodnett/artikler/bris/. [Accessed: 31 May 2019].

[17] 'Project statistics from BRIS for the first half of 2018', Norwegian Directorate for Civil Protection, 2019.

[18] 'Highway Vehicle Fires (2014-2016)', *Topical Fire Report Series*, vol. Volume 19, no. Issue 2, 2019.

[19] 'A list of Tesla car fires since 2013', *AutoBlog*, 2018.

[20] H. Hattrem, 'Tesla-brannen: Kortslutning i bilen, men vet ikke hvorfor' (Tesla fire: Short-circuit in car, cause unknown), March 2016. [Online]. Available: https://www.vg.no/forbruker/bil-baat-og- motor/i/xnnmX/tesla-brannen-kortslutning-i-

bilen-men-vet-ikke-hvorfor. [Accessed: 2 June 2019].
[21] P. Solberg, 'Slik kan det gå om du lader elbilen i vanlig stikkontakt' (This could happen if you charge your electric car using an ordinary power socket), *Adresseavisen*, Trondheim, 14 December 2018.
[22] 'Tesla tok fyr under lading i Belgia' (Tesla catches fire while charging in Belgium), June 2019. [Online]. Available: https://e24.no/bil/tesla-motors/tesla-tok-fyr-under-lading-i-belgia/24633238. [Accessed: 2 June 2019].
[23] 'Tesla Model S caught on fire in Shanghai, company is investigating the cause', *Electrek*, 2017.
[24] 'Electric Cars: Myths vs Facts', *Undecided*, Jan. 2019. [Online]. Available: https://undecidedmf.com/episodes/2019/1/1/electric-cars-myths-vs-facts. [Accessed: 02 Jun. 2019].
[25] CNN Business, 'Are electric cars more likely to catch fire?' [Online]. Available: https://money.cnn.com/2018/05/17/news/companies/electric-car-fire- risk/index.html. [Accessed: 25 May. 2019].
[26] Ministry of Local Government and Modernisation, Regulation 19 June 2017 no. 840 on the technical requirements for structures (Regulations on technical requirements for construction works, TEK17). 2017.
[27] FOR-1998-11-06-1060. Regulations on electrical low voltage installations. 1998.
[28] Regulations on electrical supply systems, including guidance. 2006.
[29] *'Guidance to the Regulations on electrical supply systems.'* The Norwegian Directorate for Civil Protection (DSB), January 2006.
[30] 'NEK 400:2018 Elektriske lavspenningsinstallasjoner, Norsk elektroteknisk norm'. (Electrical low voltage installations, Norwegian Electrical Standard) Norwegian Electrotechnical Committee, 2018.
[31] Stian Mathisen, 'Hva er schuko?' (What is Schuko?), 16 December 2015. [Online]. Available: https://blogg.fortum.no/hva-er-schuko. [Accessed: 7 January 2019].
[32] The Norwegian Directorate for Civil Protection (DSB), 'Veiledning - Elbil - lading og sikkerhet' (Guidance - Electric car - charging and safety). 2017.
[33] 'NFPA 88A: 2019, Standard for Parking Structures'. National Fire Protection Association, 2019.
[34] 'NFPA 13: 2019, Standard for the Installation of Sprinkler Systems'. National Fire Protection Association, 2019.
[35] 'NFPA 70: 2017, National Electrical Code'. National Fire Protection Association, 2017.
[36] 'J1772: Surface Vehicle Standard. SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler'. SAE International, Oct. 2017.
[37] 'Approved Document B. Volume 2 - Buildings other than dwellinghouses. 2006 edition incorporating 2010 and 2013 amendments'. HM Government, UK, Apr. 2007.
[38] Automated and Electric Vehicles Act 2018. .
[39] 'BS 7671:2018 Requirements for Electrical Installations'. BSI, Jul. 2018.
[40] Official Journal of the European Communities, Directive 2014/96/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure. 2014.
[41] 'EN 62196-1:2014 - Plugs, socket outlets, vehicle connectors and vehicle inlets. - Conductive charging of electric vehicles. - Part 1:General requirements '. CEN-CENELEC, Brussels, 12 January 2014.
[42] 'EN 62196-2:2017 - Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories'. CEN-CENELEC, Brussels, 06 Jan. 2017.
[43] 'EN 62196-3:2014 - Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers'. CEN-CENELEC, Brussels, 12 Jan. 2014.

[44] B. Hegerberg, 'Omvisning Søndre Flatåsen borettslag' (Tour of Søndre Flatåsen housing cooperative), 16 May 2019.

[45] Environment Unit, Municipality of Trondheim, 'Tilskudd til ladeinfrastruktur i boligselskap' (Grants for charging infrastructure in housing cooperatives), 25 February 2019. [Online]. Available: https://www.trondheim.kommune.no/tilskudd/lading-elbiler/#heading-h2-3. [Accessed: 29 May 2019].

[46] Forbes, 'Tesla Looks Into Model S Fire Caught On Camera In China', 23 April 2019. [Online]. Available: https://www.forbes.com/sites/billroberson/2019/04/23/tesla-looks-into-model- 3-fire-caught-on-camera-in-china/#56ebf5d7bd91. [Accessed: 25 May 2019].

[47] 'Lade med vanlig stikkontakt' (Charging using ordinary power sockets), *elbil.no*, 2018. [Online]. Available: https://elbil.no/lading/lade-med-vanlig-stikkontakt/. [Accessed: 27 May 2019].

[48] 'Elbil like trygt og sikkert – dersom du lader riktig' (Electric cars are just as safe and secure, provided you charge correctly), *helgevold.com*, July 2018. [Online]. Available: https://helgevold.com/sikker-elbil-lading/. [Accessed: 27 May 2019].

[49] 'Til deg som eier en elbil' (For electric car owners), *vegvesen.no*. [Online]. Available: https://www.vegvesen.no/_attachment/356107/binary/1223379?fast_title=Til+deg+som+har+elbil.pdf. [Accessed: 5 June 2019].

[50] 'Brannfare ved feil lading av elbil' (Fire risks associated with improper charging of electric cars), *godtforberedt.no*, 7 December 2018. [Online]. Available: https://www.godtforberedt.no/brannfare-elbil-lading/. [Accessed: 27 May 2019].

[51] 'Trygg lading av elbil' (Safe charging of electric cars), *ladestasjoner.no*. [Online]. Available: https://www.ladestasjoner.no/lading/lading-av-elbil-og-sikkerhet/. [Accessed: 27 May 2019].

[52] 'Elsikkerhet 91'(Electrical Safety 91), DSB, Norwegian Directorate for Civil Protection, January 2019.

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