Design fire of passenger vehicles – how to decide about it?

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ABSTRACT:

Passenger vehicle fires present a significant fire hazard in enclosed car parks. Accordingly, this hazard is often used as a design fire scenario for the application of fire protection systems. Specific fire protection standards, like NFPA 88A:2019 and NFPA 502:2020 in the US, or BS 7346-7:2013, NBN 21-208-2:2014, VDI 6019-1:2006, NEN 6098:2010 and ITB 493:2015 in Europe provide varying requirements for car park fire protection. Car parks fire strategies, especially when smoke control systems are used, often make use of performance-based methods, in which fire growth (HRR) plays a fundamental role. The chosen HRR can influence the specification of car park construction and on smoke control system calculations. This article presents a review of 44 full scale car fire tests together with Polish and British passenger car fire statistics from the last 8 years. Based on the collected data and the averaged tests, HRR values provided in this article could assist local authorities and stakeholders determine optimal fire safety design criteria for car parks.

KEYWORDS: car park fire, vehicle fire, statistics, heat release rate (HRR);

1. INTRODUCTION

The intention of this article is to illustrate how the chosen car design fire size (HRR) can be influential for the application of fire safety and protection systems in an underground car park. This choice could be based upon the available standards recommendations, statistical data or experimental results. The problem is that the range of the attainable data is extensive whilst, at the same time, the parameter is necessary in determining the most effective fire safety strategy. There are several methods used for choosing design fire size for fire safety systems parameters calculations. Very often, the most conservative and risk averse decisions are made, underscored by fears for a designer's reputation or local authorities' opinions. However, it is believed that the situation does not typically provide for a sufficiently consistent and fully considered solution, especially in the todays tendency for sustainability and optimisation. This paper presents a combination of existing statistics of Fire and Rescue Services (FRSs) intervention time, together with an averaged HRR taken from experimental data. The conclusions could provide a new proposal for the optimal design fire size for vehicles. This could then assist in the specification of the most appropriate forms and arrangements for car park fire protection systems, adapted to local requirements and conditions.

2. CAR PARKS FIRES IN STANDARDS AND STATISTICS

A wide research on vehicle fire statistics and available fire tests was described by Brzezinska at. al in 2020 [1]. In this paper the most significant findings of this research are presented.

It was found that passenger vehicle fire development has been the subject of several experimental programmes over previous years [2-39]. The experiments taken into account here were representative for potential fires that could occur in a car park. These varied from simulated openly ventilated above-ground car parks, to underground facilities, with the addition of car stacking systems to better utilise space. Furthermore, different car models and sizes were used. These represented production models from the 1970's to the 2000's, with a corresponding increase in fire load [6]. The main goal of the tests was in the determination of the vehicles' fire heat release rate (HRR). A selection of standards and guides for car park fire protection systems design were used, where the HRR was published [40-50]. The standards represent local fire requirements from countries where they are utilised, and it is significant that their design assumptions and requirements vary considerably. Fig. 1 presents design fire heat release rate curves recommended by the given references [40, 42, 47-50]. The variation in these curves illustrates the issues faced by fire engineers when developing their designs. The most contentious seems to be the HRR value taken after 15 min from fire ignition, a period that covers fire service intervention time for around 90% of cases [54, 55], which varies from 1.5 MW to around 10 MW (Fig. 1), however the values after this period are also given.

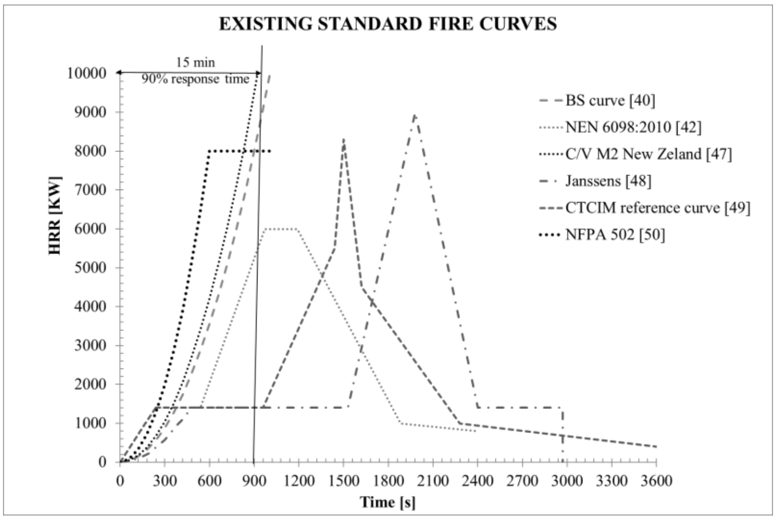


Fig. 1. Illustration of varying standards for fire heat release curves.

The next important assumption is to determine the number of vehicles expected to be involved in a fire. Tests conducted by Schleich showed that, in most cases, a time of 12 minutes was required for the fire to spread to a neighbouring car. A third car would ignite at about 24 minutes after the point where the first car was entering its decay stage [6]. Similar results, but with even longer average times (10 min in one test and 20 min in two other tests) were confirmed by BRI [3]. The BRANZ report [6] suggests the creation of a multiple car fire curve by the successive addition of single car fire curves, with a time step of 12 min. Such a method could be especially useful in unsprinklered car parks. In sprinklered car parks, the research show that only one car fire can be assumed to be involved in a fire [3, 6].

In summary, the existing knowledge about design fires in car parks is as follows:

- There are many different standards around the world providing varying requirements for fire protection methods in car parks and different recommendations for the heat release rate value, this being the main design parameter; The HRR recommended by the standards and illustrated in Fig. 1 is based upon representative singular fire tests [42, 49] or on average [48] or t-square curves [40, 47];
- Fire can spread between cars after around 12 mins from ignition (if the cars are parked in adjoining bays and not above or below the other);
- Modern vehicles can create an increased fire hazard as they incorporate higher fire loads. Note that the full-scale fire test were undertaken over a decade ago, and used vehicles available at that time;
- Car fires behavior should be taken from the most recent statistical data;

The actual fire size recommended as the design HRR could be verified on the basis of existing fire tests data, to increase objectivity and consistency across national guidance.

The research presented in this article is to provide additional knowledge and to fill knowledge gaps on design fires for car parks.

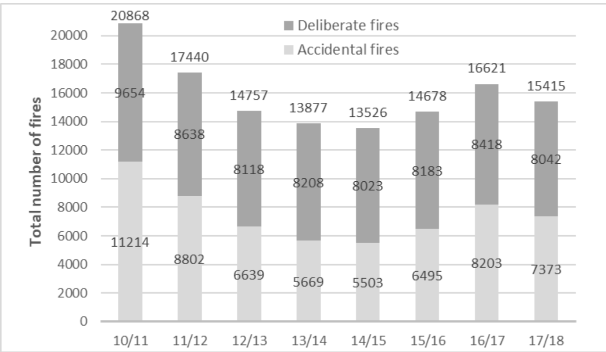
3. MATERIAL AND METHODS

This paper focuses on fires involving cars that were reported and used to provide statistical data in the United Kingdom (UK) from 2010 to 2018 [54, 57, 58]. The presented statistics do not identify the exact place of the incident. However, road traffic incidents were excluded, leaving consideration of all other car fire incidents as representing fires involved with parked vehicles, and how such incidents also relate to the underground structures, being the subject of the article. This analysis focuses on fires in two types of road vehicles, which are typically parked in enclosed car parks: passenger cars and vans. Data for all other vehicle types like agricultural, motorcycles, lorries, tankers, buses, caravans, etc., were excluded. Moreover, for reference purposes, the British statistics follow the UK financial year, which run from 1 April to 31 March. This is used for the study period from April 2010 and to March 2018. Some of the British data presented here was compared with Polish statistical data [55] from the same period.

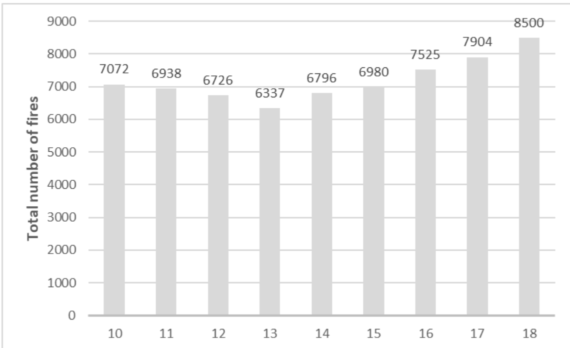
The second part of the presented research focused on fire tests as presented in published literature. Several passenger car fires have been tested around the world and the tests results were published over the last 12 years. The objective was to collect all available heat release rate data of car fires and determine their average value and statistical distribution. The 44 fire tests conducted between 1994 and 2008 were collected and taken here into account.

3.1. STATISTICAL DATA ANALYSIS

From 2010 to 2018, the British Incident Recording System (IRS), used by FRS's, recorded 127,182 fires involving passenger vehicles [54]. In the same period, the National Headquarters of the State Fire Service (KG PSP) of Poland recorded 64,778 passenger vehicles fires [55]. Fig. 2 shows the total number of vehicle fires in UK and Poland from 2010 to 2018. The analysed British data shows an average of 15 898 car fires per year pointing to an annual average of 0.47‰ of all registered cars burned when the Polish data shows an average of 7,197 car fires per year, equating to 0.35‰ of all registered cars burned. It is also interesting that almost half (47.1%) of fires recorded in the period in UK were classified as a deliberate fire. All other fires (52.9%) were classified as accidental fires (including cases with motive unknown). Fig. 2a presents specific number of accidental and deliberate vehicle fires per financial year in UK. Unfortunately, Polish statistical data doesn't offer such detailed information.



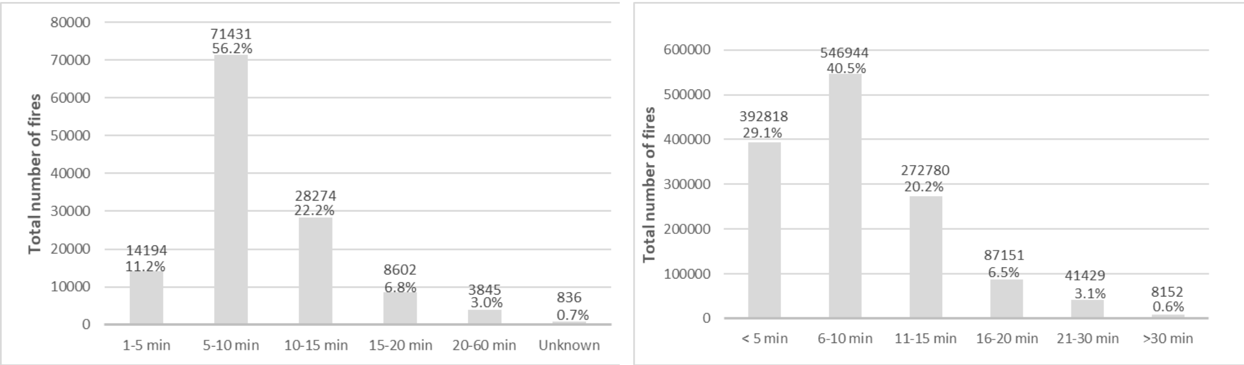
a)



b)

Fig. 2. The total number of vehicle fires in the UK (a) and Poland (b) from 2010 to 2018.

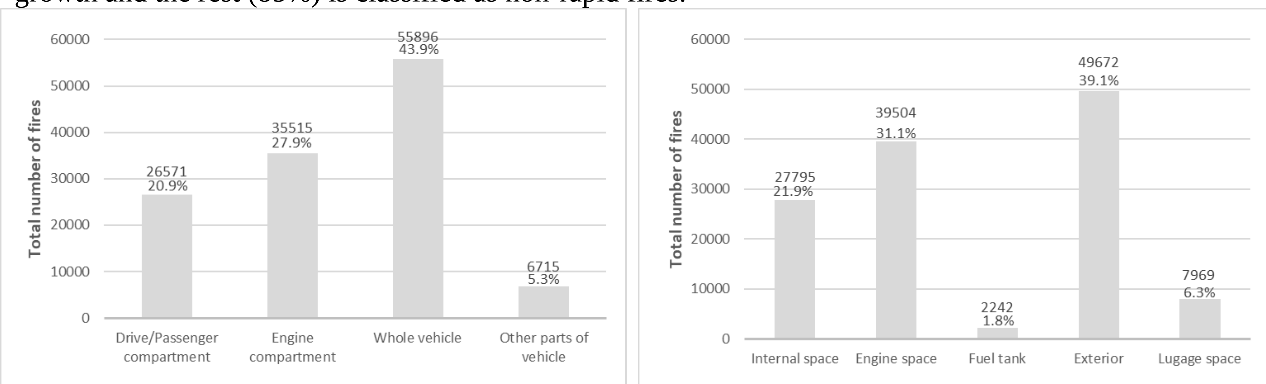
The next significant consideration is the response time of FRS's. The response time is taken as the period between the alarm call being made and the first fire vehicle attendance at site. In this respect, British and Polish statistics are very similar, and their results are shown in Fig. 3. In most cases, the response time is between 5 and 10 mins. However, in Poland, it is often below 5 mins. In both cases, the FRS's attendance time to a fire should be taken as being within 15 mins (~ 90% cases of vehicle fire accidents). This time of 15 mins is taken later in the article as an exemplar, most typical time of fire brigades response and is used in point 3 for presentation of the proposed idea of the vehicle design HRR optimization.



a) b)

Fig. 3. Response time during vehicle fires in UK (a) and Poland (b) from 2010 to 2018.

The statistical data given also provides details of vehicle fire size. In Poland, 99.9% of such fires are classified as a "small fire" and the remainder, 0.1% as a "medium fire". Only 3 accidents were classified as a "large fire" and none as a "huge fire". A "small fire" typically relates to a fire of area <70 m^2, a "medium fire" to an area from 70 m^2 to 300 m^2, a "large fire" to an area from 301 m^2 to 1000 m^2 and "huge fire" – above 1000 m^2 [55]. The British data is more detailed and presents damage with a description of the extent of flame and heat damage at the conclusion of the incident, the area affected by fire, the FRS's arrival time and the fire growth. This only includes flame and heat damage; it does not include damage by smoke or water (for example). Moreover, where more than one area of the vehicle was damaged, it was recorded as the "whole vehicle" [57] (Fig. 4). Additionally, the British stats demonstrate that only 15% of the car fires are reported as rapid fire growth and the rest (85%) is classified as non-rapid fires.



a) b)

Fig.4. Vehicle fires in UK from 2010 to 2018: damage restricted to description (a), area affected by a fire on fire brigade arrival time (b).

3.2 Fire test data

The second part of the research was focused on the results of fire tests provided by published literature. Research on the fire development of passenger vehicles has been studied by various institutes around the world, such as the CTICM (Centre Technique Industrial de la Construction Métallique) in France [1, 9, 10] , the Building Research Institution in Japan [29], the VTT Technical Research Centre of Finland [14], the NRIPS (National Research Institute of Police Science) in Japan [18, 19], the FM Research Centre in USA [20-28], the British Building Research Establishment [3, 30], the MPA in German [32], the TNO (Netherlands Organisation for Applied Scientific Research) [37], the SP Technical Research Institute of Sweden [13], and the TU Braunschweig in Germany [33].

A number of large-scale experiments have been carried out and information from 44 experiments have been collected and presented in Fig. 5. All the presented data represents a singular car fire curve. When the original HRR values of each test were presented in the same graph and in the same time scale, all the individual HRR values of each test were averaged over time. The tests considered various ignition source locations:

- under gear box,
- on or under front or back seats,
- engine compartment or under the engine,
- wheel,
- around battery and power distributor housing,
- in air cleaner housing in engine compartment,
- windshield washer fluid reservoir.

Note also that the tests used a range of cars sizes, and scenarios such as the filling of the fuel tank or opening of the windows during the fire.

On the basis of the fire test curves, the average HRR rates from ignition and their standard deviation were calculated. The curves representing the average HRR within 2,400 s of the test fires, together with the positive standard deviation numbers, are also presented in Fig. 5. The test parameters given above were not individually considered given that actual car fires vary considerably in terms of the ignition of car materials and the fire location. Consequently, all the curves were averaged at each time period in order to provide a realistic usable design fire heat release rate curve. Moreover, the scenarios where the fire that had burned out before 2,400 s were averaged up to the point of extinction.

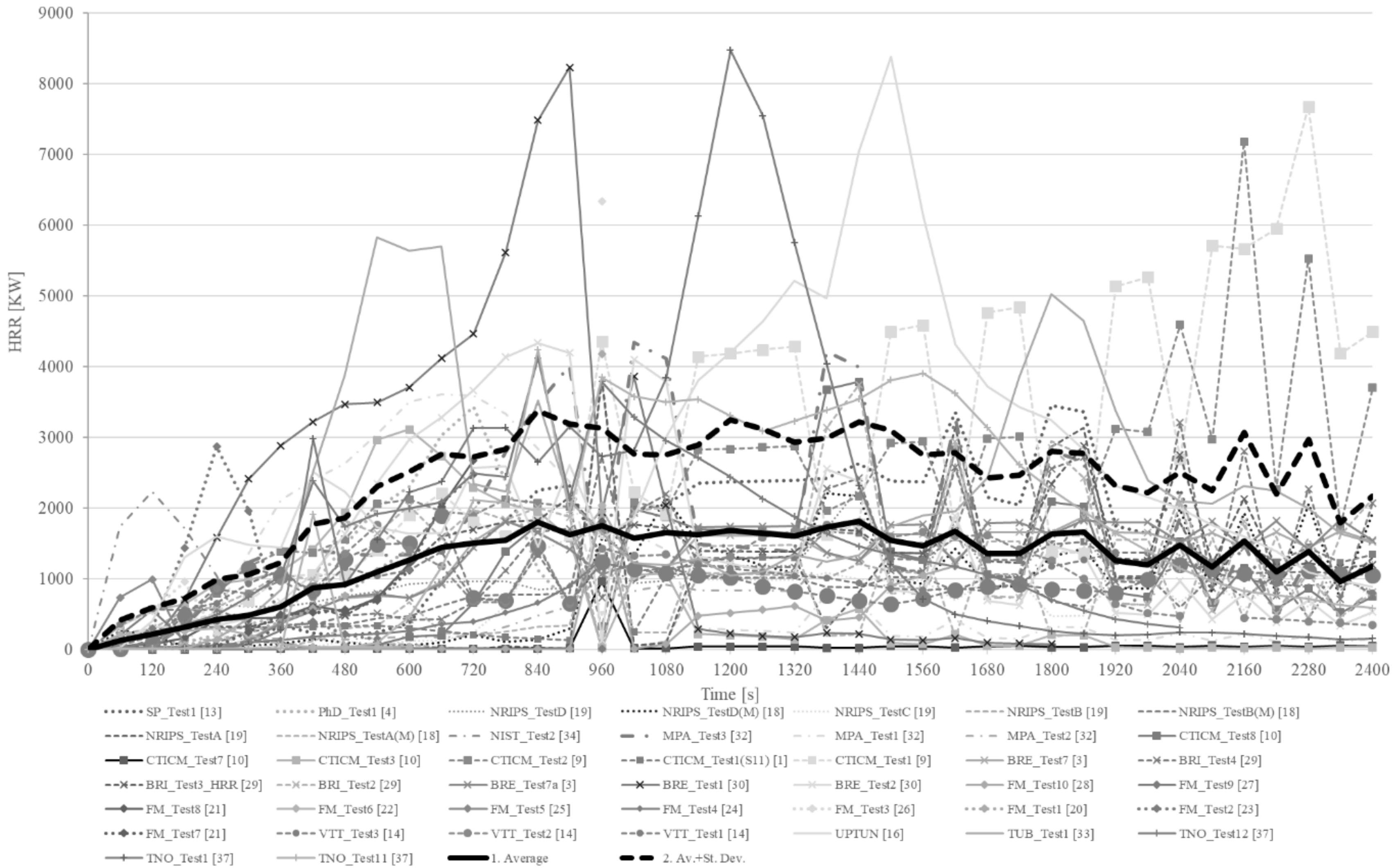


Fig. 5. Heat release rate curves of 44 real scale fire tests with their average curve and its positive standard deviation.

4. THE AVERAGE DESIGN FIRE HEAT RELEASE RATE CURVES

The research results consist of a combination of literature review, rescue service response time statistical analysis as presented in clause 4.1, with fire tests data analysis presented in clause 4.2. The following conclusions were made:

- The fire and rescue service response time could be determined for the analysed car park (for this paper purposes it is assumed as 15 mins from the notification of the fire);
- The fire tests provide a better representation of fire spread of deliberate fires than of accidental cases;
- Typically, a period of 12 minutes can be used for a fire to spread to a neighbouring car.
- In sprinklered car parks, it can be assumed that the spread of fire can be restricted to the car on fire.

The above conclusions, together with averaged fire tests data, were considered for the referenced car fire curves (Fig. 6), as provided in this article. The graph presents two options (curves no 1. And no 2.). The basic curve represents the average values of all fire tests taken for analysis and is presented in two options – for one car (curve no 1.) or for two cars (curve no 2.) The curve of the HRR of the two cars was created on the base of the curve for one car with an assumption that the second car starts to burn 12 mins after the first one, and from this moment the second car starts to burn following the same HRR as the first car before and the HRRs are added together. The additional curves (curves no 1a. and no 2a.) are more conservative and represent a combination of the average curves, together with a standard deviation allowance– for one (curve no 1a) and two car fires (curve no 2a.).

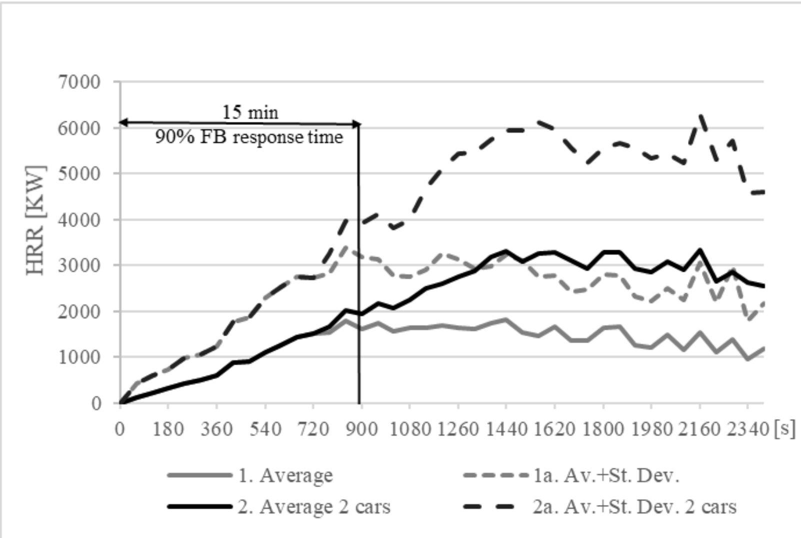


Fig 6. The average design fire heat release rate curves

The results show that the average HRR of two-car fire (curve no 2.) at the point when the fire and rescue services arrive (in this case taken as 15 mins), is around 2 MW. In the event of continued fire growth, the peek HRR could be taken as approximately 3 MW. A more conservative approach could increase these values to 4 MW and 6 MW respectively by adding the standard deviation values. In the case when only one car fire is considered (for example, in a sprinklered car park), Fig. 8 shows that the maximum design HRR values could be reduced to 1.8 MW and 3 MW, respectively. The choice of curve to be taken as design HRR should be made by local authorities or other responsible person(s). Furthermore, the most expected fire and rescue service response time of 15 min could be individually analysed for the specific car park and should be preceded by a fire detection time.

5. CONCLUSIONS AND FURTHER DISCUSSION

UK and Polish statistics show that car fires, annually, are in the thousands. Some of these incidents can be found in car parks, creating hazardous conditions for both persons involved and the car park structures. The heat release rate (HRR) of passenger vehicles plays a fundamental role in the car parks design process, especially in their use of smoke control systems. This article presents an analysis of British and Polish passenger car fire statistics over an eight-year period and of 44 actual car fire tests. Based on the analysis, a recommendation for a design HRR for enclosed car parks design is presented. The results show that the average HRR of two cars fire after 15 min from ignition is around 2 MW and grows to a maximum of around 3 MW. By taking a more conservative approach, whereby the HRR values represent a combination of the average values and the application of standard deviation criteria, the HRR increases to 4 MW and 6 MW respectively. In the case, when only one car fire is considered (for example, in a sprinklered car park), the maximum HRR values reduce to 1.5 MW and 3 MW respectively. When comparing the HRR values with the design car fire sizes recommended by national standards (Fig. 1), which assume up to 10 MW within the first 15 min of a car fire, it can be concluded that some of the standards and regulations probably rely on the peak values of the fire tests rather than on the averages.

The averaged HRR values from 44 real scale vehicle fire tests provided in this article, using statistical data and BS standard calculations, could help designers decide on an optimal car fire size, adapted to local requirements and conditions, especially for performance-based design analysis.. Additionally, the presented statistical analysis consider the location of fire ignition within a car, and the typical areas of fire loading first ignited for both accidental and deliberate vehicle fires. This information could be helpful for fire engineers when defining CFD fire source parameters.

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