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Assessing fire frequency and structural fire behaviour of England statistics according to BS PD 7974-7

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ABSTRACT

Contemporary structural fire statistics are fundamental in engineering design practice to evaluate likelihood and consequence of fire for different property types, and to investigate how different safety measures impact fire spread. British Standard PD 7974-7:2003 has recently been updated using USA fire statistics; this paper compares PD 7974-7:2003 to current England statistics (named UK statistics) using one public and one Home Office dataset. PD 7974-7:2003 overestimates fire frequency with values up to 5 times greater than the ones found in UK and USA. When fire frequency is plotted against total floor space, for different property types, power laws with positive or negative exponent and polynomial functions provide better approximations of the data than the current codes. Average area damage from PD 7974-7:2003 has been compared to *fire* and *total* damage from UK datasets where fire size is usually well confined to room of origin at 20% of fires based on the publicly available dataset. When fires exceeding specific areas of damage are considered, PD 7974-7:2003 usually overestimates *fire damage* and underestimates *total damage,* with more damage evident when sprinklers are absent compared to when they are present.

1. Introduction

The Building Regulations introduced in 1985 in England and Wales established the use of performance- or functional-based building codes [1]. This allowed a change from prescription to performance-based design, and can be interpreted as a reaction to the limits that a prescriptive design framework can provide. As stated in the PSA 911:2007 [2], even if prescriptive guidelines are easy to apply and provide a consistent approach and output, they appear to be inflexible, do not necessary lead to an optimum solution, and are not representative of current design and practice. Instead, performance-based approaches can be created on specific property needs, allowing innovations and flexibility [3]. Moreover, with appropriate design, holistic approaches can be developed albeit with potential higher initial costs [2]. Regardless of the cost, functional objectives of buildings must consider life safety, property protection, business continuity and environmental impacts [4].

The criteria against which the functional objectives must be met could be set as deterministic or probabilistic. Deterministic criteria are generally validated using experiments involving the response of single elements [5] or using full-scale test [6] which could be expensive, time consuming and not always able to recreate all the possible fire scenarios. Probabilistic risk criteria are generally based on statistical data [7]. In order to have a representative dataset, statistical analyses of real building fires are usually produced. Previous studies have considered national fire statistics of UK, USA and New Zealand which have common mandatory fields investigating pre and post-fire conditions [8] as well as direct financial losses [9]. Statistical analyses convert fire data into information useful to predict the likelihood of occurrence and consequences [10] where quantitative risk assessments are adopted to recreate fire scenarios, system failure modes and provide insights about physical phenomena and human behaviour facilitating risk treatment and management [11].

The British Standard PD 7974-7:2003 [12] provides a useful methodology and techniques to develop probabilistic risk assessment (PRA). This document, updated in 2019, presents flowcharts to evaluate risk assessment and reasons for acceptable criteria. However, no absolute risk criteria are included where the evaluation of risk does not affect risk management [13]. The tolerability limit is the combinations of possible consequences and associated occurrence frequencies and it refers to societal and individual tolerability [14]. If statistical analyses are assumed, data of real fire incidents in buildings are required and elaborated to evaluate likelihood and consequences as specified in the data

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collection section of the PD 7974-7:2019. In Annex B of the PD 7974-7:2019, some informative indicative probabilities are presented related to: the reliability and effectiveness of sprinklers in the USA and New Zealand, respectively; fire growth rate distributions; occupancy dependant fire load energy densities; and extent of damage in USA fire incidents from 1989 to 1994. Table B.3 of PD 7974-7:2019 presents the overall probability of fire starting in various types of occupancy and it has been created by a study of 2018 in which the PD 7974-7:2003 was compared to USA fire statistics [15]. Therefore, Annex B presents some examples for PRA but the PD 7974-7:2019 document is entirely informative and it is not imposed on engineering practice. Previous fire safety data of PD 7974-7:2003 taken between 1968 and 1987 provide more detailed fields covering probability of fire starting, fire frequency, fire spread, frequency distribution of area damage according to presence or absence of safety systems, average loss per fire and discovery time and fatal casualties in various occupancy types. These data from PD 7974-7:2003 could be used as inputs data for PRA, however they are outdated. Therefore, this study redevelops the PD 7974-7:2003 tables using contemporary fire statistics, for potential use in PRA presented in PD 7974-7:2019.

The Home Office's fire statistics report for England from April 2017 to March 2018 showed that the total number of fires attended by fire and rescue services decreased from around 474,000 in 2003/04 to 154,000 in 2012/13. Since then, the total number of fires has increased from approximately 162,000 in 2016/17 to 167,000 in 2017/18 [16]. At the same time, the average area of damage of dwellings (excluding those over 5000 m^2) in England decreased by 5% from 17.1 m^2 in the previous year to 16.2 m^2 [17]. In the USA, in 2017, fires in structures are estimated to have increased by 5% to 499,000 compared to 2016 and an increase in estimated property loss of 35% [18]. Individuals, organizations and Government have clear responsibilities to manage and control fire risks where safety increases if the risk is reduced [19].

This paper compares trends found in the England fire statistics to those of PD 7974-7:2003 (hereafter called UK statistics and PD 7974-7, respectively) and those from the USA fire statistics with clear references to the research developed by Manes and Rush in 2018 [15]. The data of PD 7974-7:2019 are only used for comparison for the overall probability of fire starting. Several countries have different fire safety policies and mitigation systems and the analysis presented herein evaluates analogies and differences seen. Moreover, the fire safety data described in PD 7974-7 will be compared to current fire statistics to evaluate if their predictions are applicable to the current building stock affected by fire incidents. In current fire design practice, it is fundamental to have fire safety data able to represent the current behaviour of buildings subjected to fires considering the effect of safety systems and quantifying structural consequences. All the updated data could be used in the evaluation of fire frequency in different property types, effectiveness of active safety systems, compartmentation in fire spread reduction and business impact analysis or continuity plans to determine possible strategies to improve prevention, absorption and recovery after a fire incident [20,21]. Furthermore, this paper provides contemporary fire statistical data that could be adopted within the updated framework and data collection methods for PRA described in PD 7974-7:2019.

2. Fire statistics and building stock

The Home Office Incident Recording System (IRS) by the Home Office in UK collects information on every incident attended by the fire and rescue services (FRSs) in England, Wales and Scotland. The web-based forms are pre-populated with information from the Command and Control systems, and are then completed and submitted by those present at the time of the incident [22]. The Home Office publishes a quarterly release on Fire and rescue service statistics which is a collection of national statistics on fires, casualties, false alarms and non-fire incidents attended by the fire and rescue service in England and annual releases with more-detailed analyses and non-fire incidents [23]. The Home Office works with the FRSs to ensure the quality of data but the datasets may present a small number of unidentified inconsistencies [22].

In this research, the *Other building* fires dataset has been adopted for the study and data are collected from 2010/11 to 2016/17 including 121,558 fire incidents [24]. This dataset has been used for all the analyses present in this paper except for the evaluation of fire frequency in relation to the total floor space of the building. This is due to the published dataset not including the total floor area of the building. For this reason, the Home Office provided the authors with an additional dataset which includes information about the building dimension. In this database, only the data of 2014/15 have been investigated to recreate a direct comparison with the previous research developed for PD 7974-7 and USA statistics [15]. In order to guarantee a data quality, the authors have removed entries in which the building room or floor of origin are equal to 0 m^2, the number of floors above or below ground/main level are recorded as 99 or 999, and fires where the fire damage is greater than the total damage. Therefore, the *Other building* fires dataset has been reduced by around a quarter from 15,561 to 11,168 fire incidents. The National Fire Incident Reporting System has been considered for the USA fire statistics for the 2014/15 provided by the US Fire Administration which collects approximately 600,000 fire incident data each year from all 50 States and more than 40 major metropolitan areas [25].

For the building stock classified according to the total floor space of the building, UK Valuation Office Agency (VOA) of the 2017 rating list compiled on April 2017 for England and Wales has been investigated. Every entry in the rating list includes a rateable value where 80% are supported by regular site and building survey while 20% by specialised surveys or based on construction costs or annual accounts. Bulk class properties are collected as particular use of the property at the time of the valuation [26]. Only records still valid and with a rateable value greater than zero have been considered and bulk class buildings distributed according to specific total space. For USA building stock, US Energy Information Administration (EIA) [27] have been adopted according to the Commercial buildings energy consumption survey (CBECS) [28] and the Manufacturing energy consumption survey (MECS) [29].

3. Methodology

This paper recreates the tables present in Annex A of the PD 7974-7:2003 (Tables A.1, A.2, A.4, A.5, A.6, A.7, A.8), adopting UK fire statistics. In PD 7974-7, the methodology with which the fire safety data have been obtained is not explicitly described. However, research of D'Addario in 1940 about the claims in frequency as a function of the sum insured [30], Ramachandran in 1970 with the analysis of large fires for different occupancy types [31], Rutstein in 1979 using fires reported by fire brigade [32] and others converged into the PD 7974-7 defining the principles and methodology able to create direct comparisons with current fire statistics.

Rutstein affirms that the fire probability is described by a power law according to the total space of the building with two empirical coefficients a and b, where a is defined as the ratio between the total number of fires and total number of building at risks, while b as the total number of fires divided by the building maximum floor space [32]:

$$F = aA^b \tag{1}$$

This law is adopted for Table A.1 of the PD 7974-7 and has been recreated considering the UK IRS for the number of fires and the VOA building stock for the number of buildings according to specific ranges of floor space. In the USA statistics, the areas of total floor space are limited to the ones that are present in the NFIRS, whereas the IRS does not have this reported publicly, therefore, the authors have obtained data from the Home Office for the year 2014/15 to develop the necessary relationships with more classes of building area (from up to 50 m^2 to over

50,000 m^2) than those found in the USA statistics. This is the only analysis developed with the bespoke fire statistics dataset for 2014/15 while all the other PD 7974-7 tables are generated using the *Other building* fires dataset published in 2017 with data from 2010/11 to 2016/17 [24].

The power law in Table A.1 of PD 7974-7 has always positive exponent, however analysis of USA statistics [15] showed that these trends could assume also a negative exponent and that a polynomial relationship better approximates the observed trends. Rutstein defined a power law with positive exponent to calculate the frequency of ignition only based on the total number of fires, floor area and buildings at risk. However, other potential factors could cause ignition as activities, amount and distribution of fuel loads, number of occupants, area of the building and others. This could be the reason why other functions are nowadays able to better describe the fire statistical distributions. Therefore, the UK fire data are plotted considering three trends: power law with positive exponent called [Power(UK-Rutstein)] based on Eq. (1) and two other laws (with the related R^2) named [Power (UK-Improved)] for the power law with positive or negative exponent and [Poly.(UK-Improved)] for the polynomial relationship. The same analysis in USA have been previously developed considering the total number of fires in NFIRS and the building stock provided by the CBECS [28] and MECS [29].

Furthermore, Rutstein defines the probability of fire as the number of fire incidents attended by the fire brigade divided by the total number of buildings at risk [32]. This consideration is at the base of the recreated yearly frequency of Table A.2 in which the total number of fires is obtained by the IRS for the year 2014/15, where the year is chosen to compare the results with the USA ones, and the total number of building at risk by the number of rateable properties as at 31st March 2016 of the 2010 Local rating List [26] in England and Wales.

All the other PD 7974-7 tables have been produced using the publicly available *Other building* fires datasets from 2010/11 to 2016/17. The fields considered are presented in Table 1 and involved fire spread, safety systems and fire and total damage.

4. Overall probability of fire starting in various type of occupancy

The overall probability of fire starting in various occupancy types present in Table A.2 of the PD 7974-7:2003 have been compared to 2014/15 UK and USA statistics evaluating the percentages as the total number of fires divided by the total number of buildings at risk where the values for the denominators have been found in the VOA [26] for UK and in the US Census Bureau [33] for the USA. The updated values are shown in Table 2 for non-residential buildings and the classes investigated are the ones presented in the PD 7974-7 but for *Storage* in UK and *Assembly non-residential* in UK and USA a direct comparison has not been possible.

Values for PD 7974-7:2003 seem to overestimate contemporary fire statistics for the UK and USA, in particular for *Industrial* when it appears to be 4 times, *Assembly entertainment* approximately 2 times and *Hospitals* 5 times greater than the maximum value in the other two statistics. PD 7974-7 only underestimates the probability in *Schools* where in USA statistics 5.512×10^{-2} is found while in UK this is given by 1.362×10^{-2} as shown in Table 2.

The probabilities of fire starting in UK assume slightly different values than those in the updated PD 7974-7:2019 for two property types: in *Offices* where PD 7974-7:2019 classification also includes retail premises and in *Hospitals* where the new analysis adopts the *Other buildings* dataset which was not available previously. In general, trends appear uniform where PD 7974-7 generally overestimates the overall probability of fire starting showing a reduction of fires in current fire statistics probably due to an improvement of fire safety measures in buildings.

5. Frequency of fire starting in various occupancy types

Table A.1 in PD 7974-7:2003 has been recreated as suggested by Rutstein [32] and described in Section 3. Rutstein in his research [32] possibly assumed the frequentistic definition where probability is defined as the relative frequency of occurrence of an event given by the number of times that it occurs divided by the number of experiments and it is obtained with the limit of the relative frequency if the number of experiments approaches infinity [34]. Therefore, the values obtained in the analysis are relative frequencies. Since increasing but finite total floor spaces are evaluated, the term frequency appears more appropriate than probability in Table A.1. In Table 3, the UK fire statistics are evaluated based on the bespoke Home Office datasets while the USA statistics [15] are provided for comparison. According to area ranges from up to 50 m^2 to over 50,000 m^2, 12 data points are obtained for *Shops* and *Offices*, 11 for *Industry and manufacturing* and *Miscellaneous*, 10 for *Storage*, *Schools* and *Leisure* and 9 for *Hospitals*. Due to high degrees of uncertainties, *Vehicle*, *Other manufacturing* and *Hotels* are not considered.

The Spearman's correlation [35] between total floor areas and fire frequencies is examined and values vary from 0.503 to 0.930 in the various property types proving a positive correlation. Instead, negative values of −0.209, −0.248 and −0.164 are obtained in *Industry and manufacturing*, *Storage* and *Miscellaneous*, respectively. The residuals [36] are evaluated for the two (UK-Improved) laws usually assuming random distribution showing that the model fits the data well.

In *Industry and manufacturing*, PD 7974-7 appears to overestimate the trends obtained in the UK and USA statistics and if a power law is applied it shows a negative exponent instead of a positive one with a R^2 equals to 0.055 in UK and to 0.482 in USA (Table 3). The law which

Table 1
UK fire statistics fields investigated.

Spread of fire	Safety systems	Fire and total damage [m^2]
No fire damage	Sprinklers presented, raised alarm	0
Limited to item 1st ignited	Sprinklers operated, no alarm	Up to 5
Limited to room of origin	Sprinklers present, did not operate	6 to 10
Limited to floor of origin	Other System presented, raised alarm	11 to 20
Limited to two floors	Other System operated, no alarm	21 to 50
Whole building or more than two floors	Other System present, did not operate	51 to 100
Roofs/Roof spaces	No Safety System	101 to 200
		201 to 500
		501 to 1000
		Over 1000

Table 2
Table A.2 in PD 7974-7, USA and UK statistics.

Occupancy types	PD 7974-7:2003	PD 7974-7:2019	USA	UK
Industrial	4.4×10^{-2}	0.9×10^{-2}	1.121×10^{-2}	0.953×10^{-2}
Storage	1.3×10^{-2}	N/A	N/A	0.132×10^{-2}
Offices	0.62×10^{-2}	0.4×10^{-2}	0.423×10^{-2}	0.166×10^{-2}
Assembly entertainment	12×10^{-2}	0.7×10^{-2}	5.446×10^{-2}	0.868×10^{-2}
Assembly non-residential	2.0×10^{-2}	N/A	N/A	N/A
Hospitals	30×10^{-2}	2.6×10^{-2}	0.363×10^{-2}	5.856×10^{-2}
Schools	4.0×10^{-2}	1.4×10^{-2}	5.512×10^{-2}	1.362×10^{-2}

better describes the trend in UK, although still poorly, is a polynomial of third order ($R^2 = 0.155$) (Fig. 1). In *Storage*, the highest curve is represented by the [Power(UK-Rutstein)] obtained considering a positive exponent but PD 7974-7 assumes higher values than the ones described in UK statistics where a second order polynomial function best approximates the data ($R^2 = 0.205$) (Fig. 2). In USA, the third order polynomial function ($R^2 = 0.993$) well describes the distribution (Table 3).

The frequency of fire in *Shops* according to PD 7974-7 is equal to 100% for a total floor space greater than 15,000 m^2 and when the UK statistics trends are drawn, they usually have percentages lower than 2%. In particular, the functions which better describe the data are the power law with positive exponent ($R^2 = 0.262$) and a second order polynomial ($R^2 = 0.449$) (Fig. 3) where the building stock is concentrated up to 10,000 m^2 building total floor space. In *Offices*, considerations are as similar as the ones already expressed for *Shops* where the PD 7974-7 power law presents a frequency of fire greater than 70% for a total floor space of 35,000 m^2. The only difference in this property type is that the function which better describes the UK statistics is a power law ($R^2 = 0.835$) while the second order polynomial is less accurate ($R^2 = 0.588$). As shown in Fig. 4, the power law derived considering only a positive exponent [Power(UK-Rutstein)] always has values lower than 0.2% and it is not representative of the data. In USA, these two property types have been recreated according to the one of *Mercantile, Business* present in the USA statistics where the power law ($R^2 = 0.927$) and a third order polynomial function ($R^2 = 0.997$) provide very good approximations (Table 3). Again, PD 7974-7 seems to be very conservative.

While in the majority of the property types PD 7974-7 overestimates contemporary UK statistics, in *Hospitals* this overestimation is not as obvious, as shown in Fig. 5. When the UK statistics trends are plotted, it appears that the best fit is a third order polynomial ($R^2 = 0.999$) followed by a power law with positive exponent ($R^2 = 0.442$) which shows a systematic pattern of the residuals and fits the data poorly. In USA, the class of *Hospitals* has been compared to the one of *Health care, Detention and Correction* where even in this statistics, a power law and a second order polynomial function well approximate the distributions ($R^2 = 0.839$, and $R^2 = 0.742$, respectively) as shown in Table 3. Finally, as in *Hospitals*, the UK statistics for *Schools* again is similar to PD 7974-7 trends especially for the frequency of fire up to 2000 m^2 as shown in Fig. 6 (a). In Fig. 6 (b), a polynomial law of third order approximates the data with R^2 equals to 0.718, similar to USA where a cubic function presents a R^2 of 0.983 and a power law a R^2 of 0.768 (Table 3). The residuals for the improved laws of *Hospitals* and *Schools* in UK show a pattern and the models appear as poor fit.

According to the analyses for UK and USA statistics, PD 7974-7 generally overestimates fire trends. A power law with positive exponent is not always the best approximation of the distributions, as in *Industrial manufacturing* where it assumes a negative exponent in both UK and USA and in *Storage* in UK statistics. However, as seen with the USA data, the polynomial fitted relationships of second or third order, tend to be more accurate (Table 3). This could be due to the common distribution form found in the two statistics, where the frequency usually decreases to a minimum, then gradually increases again, or to different regulatory requirements as the size of building increases. Only few of the exponential or polynomial relationships in UK have R^2 greater than 0.85, with several lower than 0.4 in UK due to smaller area classes considered. This is markedly different from the results of USA fire statistics, where R^2 was often above 0.99. A non-uniform data scatter is generally present and the extreme data points are less dense. Therefore, data need to be used carefully and with consideration of the uncertainties within the data and the fitted curves.

6. Area damage and percentage of fires

Table A.4 and Table A.5 of PD 7974-7 describe the area damage in m^2 according to a specific class of fire spread and the related percentage of fires respectively in *Textile industry* and *Pubs, clubs and restaurant* with different fire origin locations. These tables have been updated using the *Other buildings* dataset published by the Home Office, considering *Industrial manufacturing* (not including Factory) for Table A.4 and *Pub, wine bar, bar; Casino, club, nightclub; Restaurant, cafe and Takeaway, fast food* for Table A.5. In Table A.4, the fire origin locations investigated in UK statistics are: Production areas as Process/Production room; Storage areas as Store room/Laundry room/Cloakroom, Refuse store; Other areas as all the other fire origin locations.

The two PD 7974-7 tables are analysed for the presence or absence of sprinklers and the area damage has been further classified in UK statistics according to *fire* and *total damage*; where *fire damage* is defined as the total horizontal area damaged by the flame and heat in m^2 at the stop of the fire; and *total damage* as the area damaged by the flame, heat, smoke and water in m^2. In USA, only *fire damage* is recorded which does not include areas receiving only heat, smoke, or water damage. Table 5 presents the legend for Table 4, Table 6 and Table 7. The fire spread classes in PD 7974-7 have a distinction when the fire confined to the

Table 3
Frequency of fire starting in different occupancy types in PD 7974-7, UK and USA fire statistics.

Occupancy types	UK fire statistics								
	According to data points frequency of fire – total floor space								
	[Power (PD)]		[Power (UK-Rutstein)]		[Power (UK-Improved)]			[Poly (UK-Improved)]	
	a	b	a	b	a	b	R^2	Law	R^2
Industry manufacturing	0.0017	0.53	0.0029	0.0736	0.0044	−0.137	0.055	$4 \times 10^{-15}A^3\text{-}9 \times 10^{-11}A^2+3 \times 10^{-7}A+0.003$	0.155
Storage	0.00067	0.5	0.0253	0.3187	0.0439	−0.237	0.101	$-7 \times 10^{-10}A^2+3 \times 10^{-6}A+0.0177$	0.205
Shops	0.000066	1	0.0027	0.0515	0.0014	0.164	0.262	$1 \times 10^{-11}A^2\text{-}2 \times 10^{-7}A+0.0049$	0.449
Offices	0.000059	0.9	0.0009	0.0128	0.00007	0.518	0.835	$-2 \times 10^{-11}A^2+1 \times 10^{-6}A+0.0017$	0.588
Hospitals	0.0007	0.75	0.0117	0.1183	0.0002	0.764	0.442	$-4 \times 10^{-12}A^3+8 \times 10^{-8}A^2\text{-}5 \times 10^{-5}A+0.0157$	0.999
Schools	0.0002	0.75	0.0246	0.0544	0.0047	0.340	0.178	$-5 \times 10^{-12}A^3+4 \times 10^{-8}A^2\text{-}4 \times 10^{-5}A+0.0473$	0.718
Leisure	N/A	N/A	0.0079	0.0563	0.0012	0.321	0.228	$-3 \times 10^{-13}A^3+2 \times 10^{-9}A^2+5 \times 10^{-6}A+0.0059$	0.861
Miscellaneous	N/A	N/A	0.068	0.068	0.053	−0.01	0.0005	$-2 \times 10^{-10}A^2+9 \times 10^{-7}A+0.0684$	0.068
Occupancy types	USA fire statistics								
	a	b	a	b	a	b	R^2	Law	R^2
Industry manufacturing	0.0017	0.53	0.0039	0.1464	1.7584	−0.831	0.482	N/A	N/A
Storage	0.00067	0.5	0.0023	0.0392	0.0001	0.349	0.405	$-3.75 \times 10^{-17}A^3+7.26 \times 10^{-12}A^2\text{-}9.90 \times 10^{-8}A+0.0019$	0.993
Shops	0.000066	1	0.001	0.0589	0.00005	0.451	0.927	$4.88 \times 10^{-17}A^3\text{-}4.61 \times 10^{-12}A^2+2.25 \times 10^{-7}A+0.0008$	0.997
Offices	0.000059	0.9							
Hospitals	0.0007	0.75	0.0029	0.0115	0.0001	0.487	0.839	$-2.37 \times 10^{-12}A^2+4.71 \times 10^{-7}A+0.004$	0.742
Schools	0.0002	0.75	0.0012	0.0101	0.0002	0.218	0.768	$2.92 \times 10^{-16}A^3\text{-}7.76 \times 10^{-12}A^2+1.04 \times 10^{-7}A+0.0010$	0.983

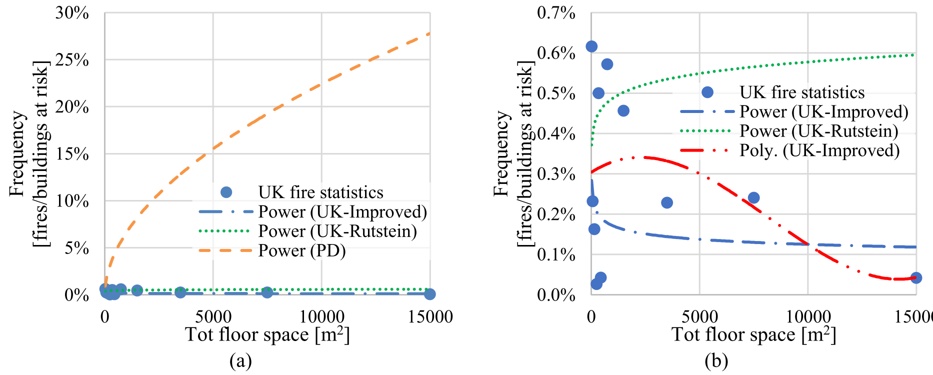


Fig. 1. Frequency of fire starting *Industry and manufacturing* (a) PD 7974-7 and UK statistics, (b) only UK.

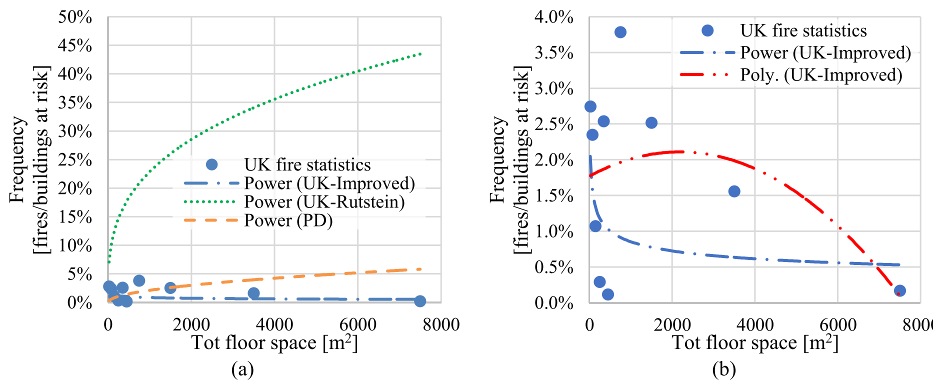


Fig. 2. Frequency of fire starting *Storage* (a) PD 7974-7 and UK statistics, (b) only UK.

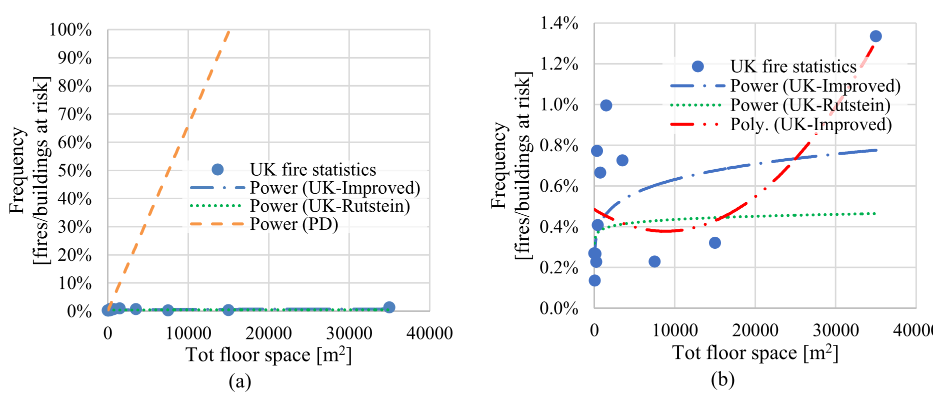


Fig. 3. Frequency of fire starting *Shops* (a) PD 7974-7 and UK statistics, (b) only UK.

room of origin affects only the contents or involves the structure whereas current fire statistics have a detailed classification if the fire spreads beyond the room of origin (e.g. confined to the origin floor, to two floors, involve the whole building/more than two floors or roofs/ roof spaces). Unfortunately, total number of fires in PD 7974-7 is not provided for Table A.4 and Table A.5.

Tables 4 and 6, present respectively the area damage and frequency for *Industrial manufacturing*. In Production areas, the total number of fires for sprinklers is 198, while for no sprinklers 2124 in UK. The average area damaged in Table 4 for PD 7974-7 when sprinklers are present is 40 m^2 and is similar to the UK statistics for *fire damage* of 29 m^2, while no sprinklers in PD 7974-7 presents a typo: 153 instead of 152 m^2. When the spread affects the whole building in UK, one fire with 1000 m^2 is recorded and may not represent the real scenario for presence of sprinklers. In Table 6, fire frequency appears confined up to the room of origin for more than 80% for both sprinklered and non-sprinklered production areas.

In Storage areas, 11 fires are reported for the presence of sprinklers and 172 for the absence in UK fire statistics, thus the focus will be on those fires where no sprinklers are present. [NB: In PD 7974-7 for presence of sprinklers and fire confined to room of origin, the area damage of 19 m^2 and fire frequency of 24% are corrected values not repeated twice as in PD 7974-7 [15]]. The average area damage in PD 7974-7 for absence of sprinklers is equal to 533 m^2 (not 539 m^2 as wrongly evaluated in Table A.4) and it appears approximately four times greater than the one obtained for *total damage* in UK given by 137.97 m^2 (Table 4). Fire frequency in UK statistics with no sprinklers is confined to the room of origin in 65% of cases with a 13.95% affecting the whole building (Table 6).

In Table 4, when Other areas are evaluated, 94 fires are reported for

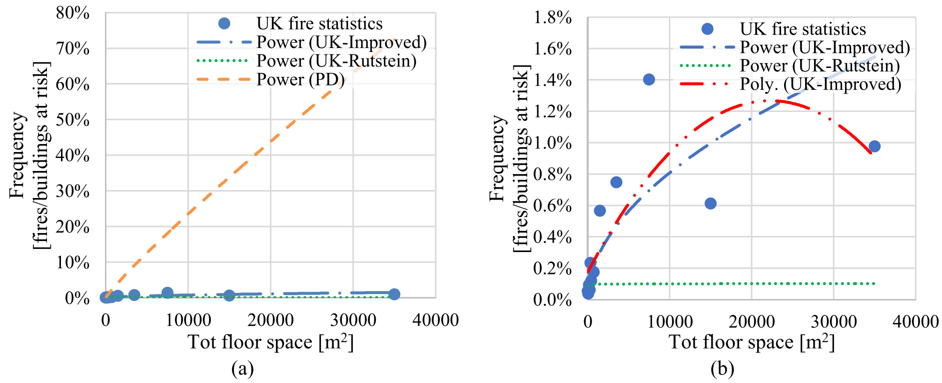


Fig. 4. Frequency of fire starting *Offices* (a) PD 7974-7 and UK statistics, (b) only UK.

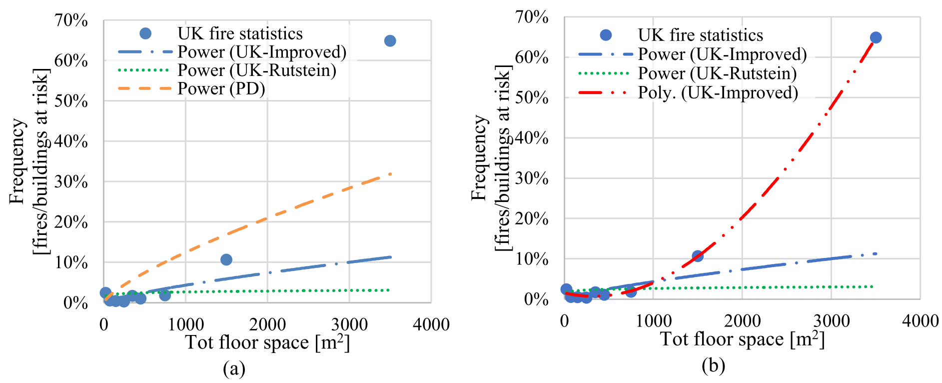


Fig. 5. Frequency of fire starting *Hospitals* (a) PD 7974-7 and UK statistics, (b) only UK.

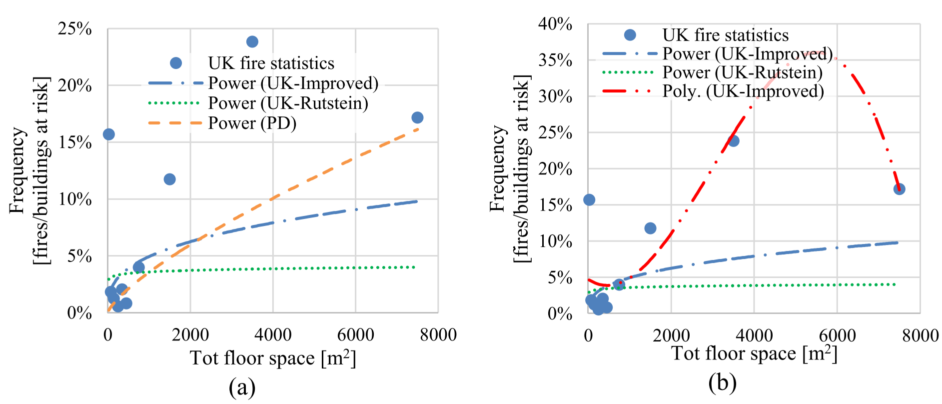


Fig. 6. Frequency of fire starting *Schools* (a) PD 7974-7 and UK statistics, (b) only UK.

sprinklers and 1800 for no sprinklers in UK. In the latter case, the average area damage in PD 7974-7 is two times bigger than the one of *total damage* in UK (77.86 m^2) with frequency confined within room of origin for 70% of cases and 13.72% confined to floor of origin in UK fire statistics (Table 6).

In *Pubs, clubs, restaurants*, all fire origin locations are considered and in UK, 96 fires are reported when sprinklers are present and 11,429 when they are absent. Again, considerations on fires with presence of sprinklers will be avoided. In Table 7, both area damaged and frequency are described for PD 7974-7 and UK statistics. In this property type, in the absence of sprinklers, the average area damaged for PD 7974-7 (24 m^2) is almost half of the value found for the *total damage* (41.25 m^2). *Total damage* for absence of sprinklers appears approximately three times greater than *fire damage* in the various classes of fire spread that could indicate firefighting activities to extinguish the fire having an impact on the damage of the building. Fire frequency which spreads beyond the room of origin in absence of sprinklers is equal to 17% and 21.5% for PD 7974-7 and UK statistics, respectively; and it is approximately 30% confined to item first ignited and 25% for no fire damage in UK fire statistics for both presence and absence of sprinklers showing similar trends in fire frequency despite the difference in number of fires (Table 7).

In UK statistics, fires when sprinklers are reported are very limited in number if compared to the ones for un-sprinklered buildings. Therefore, general comments on the fire spread when sprinklers are present are difficult to deduce but, as found in the analysis with the USA statistics [15], the average damage for presence of safety systems is in general less than the one for their absence. Moreover, the area damage in UK and USA statistics [15] increases with the increase of the spread of fire with *total damage* usually greater than the *fire damage*. Fire frequency

Table 4
Area damage for *Industrial manufacturing* in different fire origin locations in PD 7974-7 and UK statistics [F=Fire, T = Total].

		Area damage [m^2]					
		Production areas					
		Sprinklers			No Sprinklers		
		PD	UK F	UK T	PD	UK F	UK T
A		/	2.91	12.28	/	9.16	23.90
B		5	7.26	45.06	5	3.37	33.07
C	C1	13	39.67	163.34	17	21.24	98.65
	C2	113			475		
D	D1	694	15.79	185.32	694	80.04	163.25
	D2		97.50	207.50		87.80	228.11
	D3		1000.00	1000.00		350.23	401.41
	D4		212.30	225.80		38.89	46.75
Average		40	29	100.20	153	29	72.43
Total fires			198	198		2124	2124

		Storage areas					
		Sprinklers			No Sprinklers		
		PD	UK F	UK T	PD	UK F	UK T
A		/	0.00	0.00	/	4.65	18.50
B		4	4.33	129.50	10	2.53	12.25
C	C1	19	39.00	176.50	17	16.58	36.23
	C2				262		
D	D1	1712	21.75	79.25	1712	80.83	171.36
	D2		75.50	150.50		199.25	301.75
	D3		750.50	750.50		420.85	457.54
	D4		/	/		328.15	455.10
Average		76	87	163.73	533	101	137.97
Total fires			11	11		172	172

		Other areas					
		Sprinklers			No Sprinklers		
		PD	UK F	UK T	PD	UK F	UK T
A		/	2.43	4.65	/	4.64	16.57
B		2	2.64	6.44	2	5.43	16.67
C	C1	11	7.18	33.20	4	17.84	59.85
	C2	68			68		
D	D1	1007	45.50	130.94	1007	53.41	136.20
	D2		35.50	55.50		86.54	156.43
	D3		504.00	504.00		354.41	389.03
	D4		37.83	62.83		69.12	92.33
Average		49	21	39.89	165	47	77.86
Total fires			94	94		1800	1800

Table 5
Legend for Table 4, Tables 6 and 7

Legend for spread and damage classes			
A. No fire damage	C1. Contents only	D1. Confined to origin floor	D4. Roofs/Roof spaces
B. Confined to item ignited	C2. Structure involved	D2. Confined to two floors	F. Fire Damage
C. Confined to origin room	D. Spread beyond room	D3. Whole building	T. Total Damage

generally presents the highest values of spread within the room of origin for both countries with some peaks found for fires affecting the whole building. The room of origin usually represents a compartment and the analysis developed shows that compartmentation is effective.

7. Frequency distribution of area damage

Tables A.6, A.7 and A.8 in PD 7974-7:2003 are related to the frequency distribution of area damage in terms of number of fires in *Office buildings, Retail premises* and *Hotels* respectively recreated considering *Other buildings* dataset as Offices and call centres, Retail and Hotel/Motel. Since in UK fire statistics there is a further distinction in *fire* and *total damage*, the analysis has been developed considering both of them and plotting the results against PD 7974-7 and USA trends [15]. Unfortunately, it is not clear if the area damage of PD 7974-7 is referred to the fire or total one. Presence and absence of sprinklers have also been investigated.

In *Office buildings*, three different fire origin locations are present in Table A.6 and these have been compared as follows: Office rooms as Meeting room/Office and Other rooms as all the other fire origin locations. In Office rooms, the fires reported in PD 7974-7 are 18 and 1860 while in UK statistics 15 and 1342 respectively for presence and absence of sprinklers. In Other rooms, PD 7974-7 reports 127 and 4369 while UK statistics 64 and 3051 for sprinklers and no sprinklers. Based on Fig. 7, it can be seen that the PD 7974-7 data are usually located between the UK *fire damage* and *total damage,* where the frequency of exceeding the damage bands upper limit is always less than 30% when sprinklers are present. The trends found for PD 7974-7 and UK statistics are relatively close and whose percentages are considerably less when compared to USA statistics.

Table A.7 for *Retail premises* considers three different fire origin locations: Assembly areas as Meeting room/Office and Corridor/Hall/Open Plan Area/Reception area; Storage areas as Store room/Laundry room/Cloakroom and Refuse store; Other areas as all the other fire origin locations. For the presence of sprinklers the fires recorded are 223 and 37 in Assembly areas, 354 and 55 in Storage areas and 183 and 322 in Other areas, respectively for PD 7974-7 and UK fire statistics. When building fires with no sprinklers are considered, fires are 8207 and 851 in Assembly areas, 5144 and 1672 in Storage areas and 7194 and 9378 for Other areas in PD 7974-7 and UK statistics, respectively. In Fig. 8, similar comments can be deduced for the three fire origins where the trends for sprinklers have lower values than the ones for no sprinklers except for *total damage* which assumes an opposite trend with percentages of fires exceeding 20 m^2 usually greater than 10%. Furthermore, PD 7974-7 values are generally greater than the ones for UK *fire damage* but less than the one of UK *total damage*. USA statistics presents values greater than UK where despite the initial peaks for no safety systems, trends show a less rapid decrease for sprinklers.

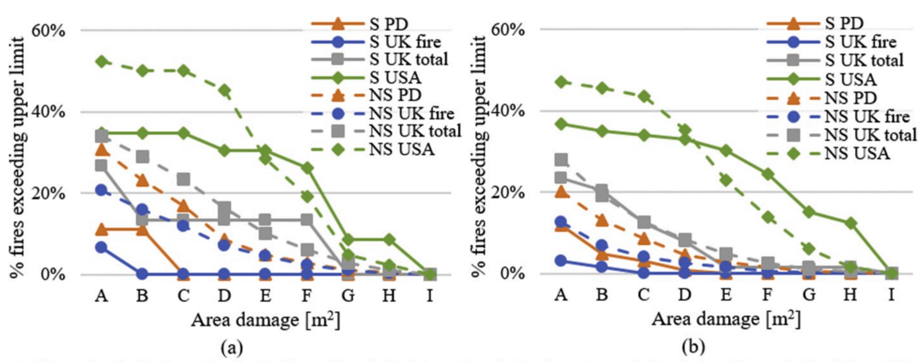
Finally, for *Hotels*, three different fire origin locations are assessed: Storage and other areas as Store room/Laundry room/Cloakroom and Refuse store; Assembly areas as Corridor/Hall/Open Plan Area/Reception Area and Meeting Room/Office; Bedrooms as Bedroom/Bedsitting room. In Assembly areas and Bedrooms only fires in buildings without sprinklers are considered while for Storage and other areas, presence and absence of safety systems are evaluated in PD 7974-7. When fires in

Table 6
Percentages of fires for *Industrial manufacturing* in PD 7974-7 and UK statistics related to Table 4.

		Frequency											
		Production areas				Storage areas				Other areas			
		Sprinklers		No Sprinklers		Sprinklers		No Sprinklers		Sprinklers		No Sprinklers	
		PD	UK	PD	UK	PD	UK	PD	UK	PD	UK	PD	UK
A		/	19.70%	/	24.86%	/	18.18%	/	20.93%	/	24.47%	/	22.50%
B		72%	35.86%	43%	38.94%	72%	27.27%	19%	17.44%	66%	26.60%	42%	30.61%
C	C1	18%	29.29%	32%	22.36%	24%	18.18%	18%	26.74%	22%	31.91%	25%	18.50%
	C2	6%		13%				38%		8%		18%	
D	D1	4%	9.60%	12%	8.00%	4%	18.18%	25%	10.47%	4%	9.57%	15%	13.72%
	D2		2.53%		1.51%		9.09%		4.65%		2.13%		2.33%
	D3		0.51%		3.67%		9.09%		13.95%		2.13%		8.17%
	D4		2.53%		0.66%		0.00%		5.81%		3.19%		4.17%

Table 7
Area damage, percentages of fires for *Pubs, clubs, restaurants* in PD 7974-7 and UK statistics [F=Fire, T = Total].

		Area damaged [m^2]						Frequency			
		Sprinklers			No Sprinklers			Sprinklers		No Sprinklers	
		PD	UK F	UK T	PD	UK F	UK T	PD	UK	PD	UK
A		/	2.24	16.26	/	3.92	12.43	/	28.13%	/	22.85%
B		1	3.48	93.82	1	2.21	9.11	59%	31.25%	26%	32.71%
C	C1	1	7.27	34.50	2	8.08	44.50	15%	27.08%	12%	22.94%
	C2	4			15			19%		45%	
D	D1	50	1.88	188.88	101	25.72	73.53	7%	4.17%	17%	10.02%
	D2		12.13	388.00		52.24	121.93		4.17%		4.10%
	D3		255.50	255.50		181.01	237.27		3.13%		3.57%
	D4		41.75	93.00		69.07	114.97		2.08%		3.81%
Average		5	13	77.19	24	17	41.25				
Total fires			96	96		11429	11429				



A. Up to 5 m^2; **B**. 6 to 10 m^2; **C**. 11 to 20 m^2; **D**. 21 to 50 m^2; **E**. 51 to 100 m^2; **F**. 101 to 200 m^2; **G**. 201 to 500 m^2; **H**. 501 to 1000 m^2; **I**. Over 1000 m^2

Fig. 7. Frequency distribution of area damage in *Office buildings* in (a) Office rooms and (b) Other rooms [S=Sprinklers; NS=No sprinklers] for PD 7974-7, UK and USA statistics [15].

buildings with sprinklers are analysed, the total number recorded in Storage and other areas is 35 for PD 7974-7 and 10 for UK statistics and, due to the small sample, no comments are expressed. When sprinklers are absent, fires are 3821 and 304 in Storage and other areas, 518 and 167 in Assembly areas and 1205 and 366 in Bedrooms in PD 7974-7 and UK statistics, respectively. Even when *Hotels* are analysed, similar comments can be expressed as for the other two property types, with percentage of fire exceeding 100 m^2 damage approximately less than 10% in the three fire origin locations (Fig. 9). The only difference is found in Storage and other areas where percentages for sprinklers are higher than the ones for no sprinklers buildings for *total damage* possibly due to the limited number of fire recorded for presence of safety systems. Moreover, USA shows for these fire origin locations, percentages relatively similar to the ones found for *total damage* in UK (Fig. 9 (a)).

Similar results have been found for the analysis of three property types and different fire locations when PD 7974-7 is compared to UK and USA statistics. In general, PD 7974-7 seems to overestimate the *fire damage* and underestimate the *total damage* if compared to UK statistics but it is closer to UK predictions than those found using USA statistics [15].

8. Conclusions

This paper has presented a comparison of fire statistics, developed from the UK and USA fire incident reporting systems, with historical data that can be found within the recently superseded British Standard Published Document on probabilistic fire risk assessments (PD 7974-7:2003). It appears that some significant improvements of fire safety in UK have been introduced over the last 30–50 years. This could be due to the modern technologies in safety devices, new construction

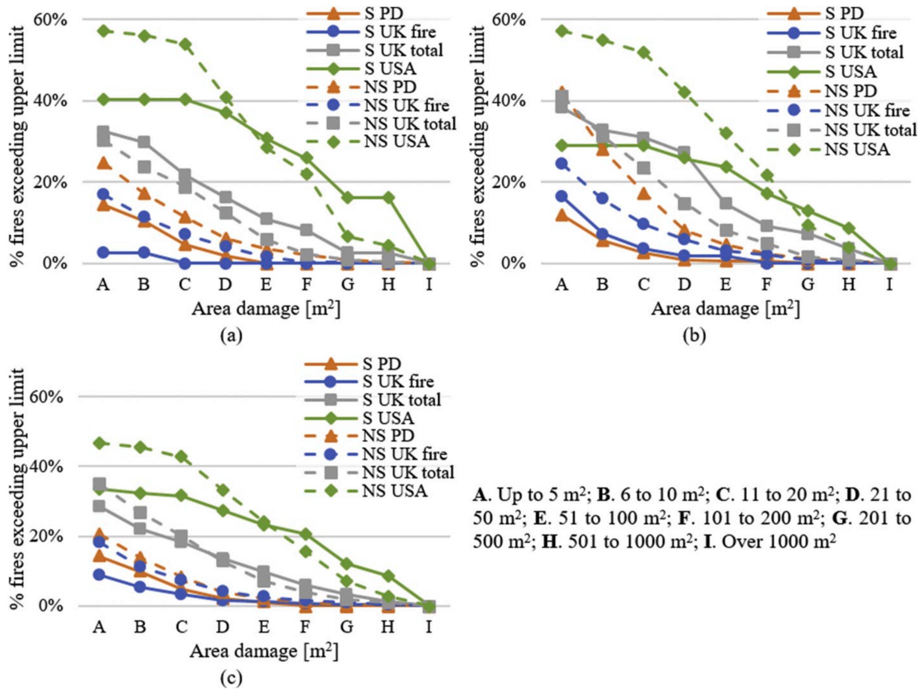


Fig. 8. Frequency distribution of area damage in *Retail premises* in (a) Assembly areas, (b) Storage areas and (c) Other areas [S=Sprinklers; NS=No sprinklers] for PD 7974-7, UK and USA statistics [15].

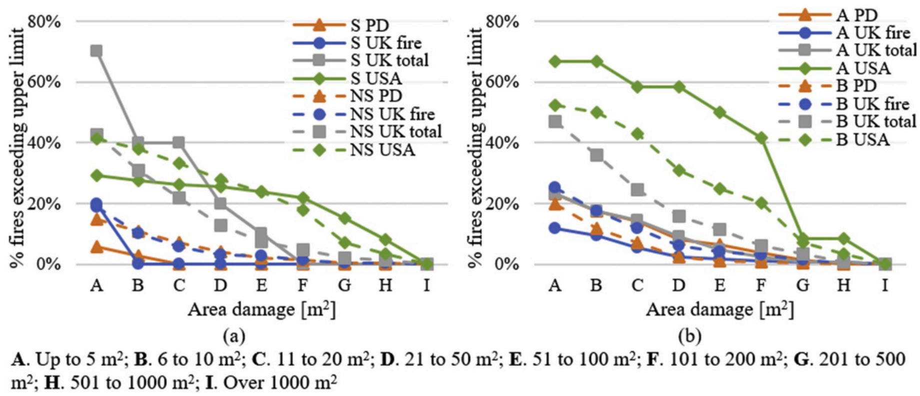


Fig. 9. Frequency distribution of area damage in *Hotels* in (a) Storage and other areas [S=Sprinklers, NS=No Sprinklers] and (b) Assembly areas (A) and Bedrooms (B) only for no sprinklers in PD 7974-7, UK and USA statistics [15].

techniques and materials or the application of performance based design approaches. However, it is difficult to define which of the above-mentioned factors have an implication because it would be necessary to investigate the evolution of yearly data and more detailed fields of fire statistics related to the fire safety design of the building affected by fire. Moreover, the IRS was only recently introduced and before 2008 a different methodology was adopted for the collection of data. The aim is to provide contemporary fire statistics for use with the new BS PD 7974-7:2019 and to comment on any differences between the datasets. From this work it is possible to conclude:

- PD 7974-7:2003 fire frequency usually overestimates the values of both UK and USA fire statistics in 2014/15 except for *Schools* in USA which assumes a value of 5.512×10^{-2} fires per year compared to 4.0×10^{-2} in PD 7974-7:2003.
- PD 7974-7:2019 fire frequency matches well with UK statistics data apart from for *Hospitals* where fires according to PD 7974-7:2019 are half as frequent as found from UK statistics, with a fire predicted every 18 years.
- When fire frequency is plotted against the total floor space, PD 7974-7:2003 positive exponent method is significantly different than the prediction provided by contemporary UK and USA statistics data.
- Polynomial relationships better represent fire frequency to floor space and are particularly accurate when assessing the USA data (R^2 values regularly greater than 0.98), however are less accurate when assessing the UK fire statistics (R^2 values regularly lower than 0.72). Despite the polynomial function well describes small total floor space, further investigations could consider a constant conservative value to address the scarce data present moving towards extreme total floor spaces.
- Analysing the area damage and percentage of fires for *Industrial manufacturing* and *Pubs, clubs, restaurants*, PD 7974-7:2003 is usually greater than data of UK fire statistics.
- In both PD 7974-7:2003 and UK statistics, fires are generally confined to the room of origin between 65 and 80% of the time depending on occupancy type.
- In general, in UK and USA the average area damage increases with the fire spread.

- For the frequency of fires exceeding an upper limit of area damage, the UK *fire damage* is in general, less than the frequencies presented in PD 7974-7:2003, whereas *total damage* is in general higher; the exception is in *Hotels* where *fire damage* and PD 7974-7 assume similar values.
- Comparing UK and USA data for the frequency of fires exceeding an upper limit of area damaged, there is always more damage recorded in the USA (apart from the sprinklered Storage and other areas in *Hotels* which suffer from a small UK dataset).

Further work will be focused on the application of fire safety data in the evaluation of probabilistic risk assessments and future fire statistics investigated to ensure that data are representative of fires and useful in the fire design of buildings in UK and USA.

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