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A Critical Evaluation of BS PD 7974-7 Structural Fire Response Data Based on USA Fire Statistics

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Abstract. Probabilistic techniques deal with the randomness of variables and reliability of safety system but their application in fire safety engineering is limited due to the lack of data related to real structures subjected to real fires. This can be overcome by analysis of national fire statistics provided by fire departments. Fire statistics databases are a collection of data from real structures subjected to real fires and provides an understanding of real effectiveness of different fire safety measures (i.e. compartmentation) which influence the spread and growth of fire, and ultimately their monetary consequence. The ability to understand the realistic responses of buildings in fire is the fundamental basis of British Standards PD 7974-7, which provides data to perform probabilistic risk assessments for fire. However, the current data presented by BS PD 7974-7:2003 (referred to as PD 7974-7 within this paper) was developed between 1966 and 1987. This research has used the USA fire statistic database of 2014 to recreate the tables present in the PD 7974-7, compare the results, and understand their evolution in time. The comparison between PD 7974-7 and the USA fire statistics introduced in this paper shows that modern fire frequency can be up to more than 10 times smaller than presented in PD 7974-7; area damage in m^2 and spread of fire are linked to automatic extinguish systems effectiveness and greater in the USA fire statistics than predicted by PD 7974-7. This clearly demonstrate the need of updates to PD 7974-7 and feeds towards a better understanding of the robustness, and potentially the resilience, of real structures in fire.

Keywords: Probabilistic risk assessment, Fire statistics, Fire frequency, Fire damage, Fire safety systems, Fire financial loss, Performance based-design

1. Introduction

Fire design codes and regulations are transitioning from a prescriptive basis to more of a performance-based design paradigm. This is due to perceived lack of regular updates within the codes, limiting the creation of innovative and diverse design solutions [1]. The fundamentals of performance-based design (PBD) are to ‘enable improvement of structural fire safety in fire, to increase the design flexibility, and reduce the costs of fire protection to structures’ [2]. One of the methods

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available to be used by engineers is to adopt a probabilistic assessment of the fire and its consequences on the structure, and within the UK there are codes (PD 7974 parts 7 and 8) that provide data and methods to assess the risks of fire and their impact [3, 4]. However, like their prescriptive counterparts, data within the probabilistic codes (i.e. [3]) are often decades old, and as such they add an extra level of uncertainty about their validity to be used in the current context.

Governments regulations aim to ensure life safety (i.e. means of warning and escape in the Approved Document B for dwellings [5] and buildings other than dwelling houses [6] in England), and provisions of prescriptive codes (i.e. [7]) assume that the intended life safety fire performance criteria are implicitly satisfied by meeting the minimum code requirements for design and detailing of structural and non-structural components [8]. In the USA, life safety goals are covered by the fact that every new and existing building shall comply with the NFPA 1: Fire Code and NFPA 101 [9, 10]. These life safety goals have been shown to be more and more well satisfied since the early 2000s; the number of primary fires (i.e. in structures rather than outdoor or vehicular) in the UK has decreased from a peak of 178,000, in 2003/2004 to 75,000 in 2016/2017, with fire related deaths in the UK reduced from around 454 in 2003/2004 to 261 in 2016/2017 [11]. A similar picture also emerges from the USA where in 2003 520,000 structure fires caused 3385 deaths compared to 475,500 structure fires with 2950 deaths in 2016 [12]. However, whilst life safety goals are improving, the economic cost of fire remains high with economic losses due to fire in the USA in 2011 being at an estimated \$14.9 Bn (\$13.3 Bn direct, \$1.6 Bn indirect losses such as business interruption), a value that has not varied greatly over the past 30 years [13].

Risk and consequence of fires have received a lot of academic inquiry, with the majority interrogating the probability of failure in terms of structural collapse and/or life safety [14], however, very few explicitly consider damage and thus the potential reinstatement and re-use of the property [15]. Property protection is an essential part of business continuity and forms a major part of the resilience of the business [4], where resilience is the ability of a system to absorb, and recover from, disruptions (fires in this context) to normal functionality. Whilst there is no unique definition yet of fire resilience, there are three main principles that sit beneath it: life safety, property protection and business continuity [16, 17].

As in any built environment discipline, there are natural variabilities and uncertainties which are dealt through design codes, for instance Eurocode 1991-1-2 [18] provides details on the actions on structures with respect to fire effects, describing how (if permitted by national authorities, as is the case in the UK) the inclusion of different fire safety measures, the fuel load, and thus the effective worst case severity of a fire, can be reduced. However, due to the complexity of fires with multiple interactions occurring between different materials, ventilations, safety systems, and/or structural systems, uncertainties will emerge in all aspects of reported national and international fire statistics. The concept of safety itself is one of the uncertainties, there is no such thing as absolute safety [19].

It is in this uncertain context that probabilistic techniques, which deal with the randomness of variables and reliability of safety system, have become available [3], however their application is limited due to the lack of contemporary data

(data in BS PD 7974-7:2003 from 1966 to 1987) related to real structures subjected to real fires. Provisions of prescriptive codes [7] assume that the intended life safety fire performance criteria are implicitly satisfied by meeting the minimum code requirements for design and detailing of structural and non-structural components. This represents an expectation and not necessarily the reality since the complexity of actual fires and the interaction with structures is difficult to predict accurately. Structural fire engineering knowledge, for instance, is predominantly based on the response of single elements to a standard time temperature curve, under idealised furnace conditions, and assessing the response to a binary, pass/-fail criterion [20]. However, these idealised furnace conditions are not real fires, which may or may not cause a failure but will produce some level of damage. Previous experiments conducted on full structural frames, and sub-frames [21], have provided valuable data for modelling and design code enhancements, nevertheless, due to their expense, they are limited in numbers so the relevance of any data is confined to the specific experimental building characteristics. Therefore, fire statistics, when coupled with appropriate and valid modelling scenarios, could provide the necessary means to assess and design real structures in real fires for different performance criteria.

Performance-based design is used to explicitly demonstrate, using pre-identified performance objectives, that the same level of life safety can be provided with enhanced property protection. However, models used for these demonstrations are rarely validated or benchmarked due to a lack of relevant experimental data and can also be limited in their ability to describe structural behaviour close to the point of failure. Probabilistic performance-based design [22], attempts to overcome this, however, again, lack of validation data for these models limits their application in practice. For this reason, statistical data on existing structures in the aftermath of an event can be instrumental in defining the real impact effects on structures and the quantification of damage. Therefore, fire statistics can be used to understand the real relation between fire occurrences, fire size, damage caused by fire and interventions to extinguish the fire.

This paper presents an assessment and comparison of the current PD 7974-7 Probabilistic Risk Assessment for fire with fire statistics from the USA, and where able with statistics from the UK. Tables within PD 7974-7 [3] document present frequency of fire and fire damage classifications according to sprinklered and un-sprinklered buildings. However, at the start of analysis procedure, data regarding sprinklers were not available for the UK, while these were comprehensively and readily available for fires within the USA, and thus the focus of this paper. New UK fire statistics released in September 2017 [23], will allow further comparisons between PD 7974-7 data and the UK fire statistics.

This paper aims to recreate the tables (specifically Tables A.1, A.2, A.4, A.5, A.6, A.7, A.8, and A.12) presented in the PD 7974-7 using contemporary fire statistics from the USA, and compare the results, allowing engineers to understand pre-fire conditions, fire growth and post-fire conditions, according to data obtained on real structures subjected to real fires, and reduce the uncertainties that inevitably arise in fire safety design.

2. Historical Development of PD 7974-7

In 1907, von Sawitsh expressed that fire insurance claims frequency had a linear relationship with volume, or value, at risk. In 1937, Berge demonstrated, on the basis of Swedish dwellings, how the claims frequency and the fire loss ratio increase with the size of the house. D'Addario [24] followed in 1940 by expressing claims frequency, $f(s)$, of the Swedish statistics explained by Berge, as a function of the size (s , sum insured) as:

$$f(s) = As^\alpha \quad (1)$$

where A and α are empirically fitted coefficients. This power law model is currently in use in PD 7974-7.

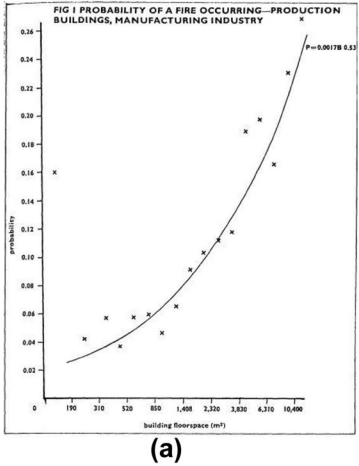
In 1968, Ramachandran combined national fire statistics, developed by local authority fire brigades, with financial loss data from British Insurance Association. Ramachandran estimated, for different occupancy types, the total number of fires and total cost in thousands of pounds [25] for large fires (defined as requiring five or more jets). In 1969, Ramachandran assessed large fires from 1965 to 1968, again considering the total number of fires and total cost in thousands of pounds for different occupancy types, as well as, fire frequency, place of origin, source of ignition, material first ignited, age of the building, number of storeys, spread of fire, attendance time and fire protection devices [26]. In 1970, Ramachandran produced fire loss indexes defined as loss per ft² of floor area or loss per hundred pounds of value at risk [27].

In 1979, Rutstein [28] affirmed that fire risk (probability of fire and its consequence) can only be expressed in probabilistic terms and can be estimated by examining past fire incidence data. Furthermore, Rutstein determined the probability of fire by comparing the number of fires reported by the fire brigades divided by the total amount of property at risk, determined from 1977 Home Office survey data of UK manufacturing industry. The fire probability, F , is described with a power law according to the total area of the building A :

$$F = aA^b \quad (2)$$

where a and b are empirical constants determined according to the different occupancy types. In particular, a defines the ratio between total number of fires and total number of buildings at risk, while b defines the total number of fires divided by the building maximum floor area.

The analysis interrogated only industrial buildings leaving a wide margin of uncertainties for the other occupancy types [28]. The 1977 Home Office survey enumerated the number and floor space of each building occupied by firms. Information relating to 6000 separate buildings was then used to estimate the total number of buildings of each size in each industry in UK. Consequently, plotting the data according to building floor space in m² (x-axis) and probability of fire (y-axis), a nonlinear function was estimated (Fig. 1a) where the non-linearity could be attributed to two potential reasons. The first, that *there may be a genuine scale*



INDUSTRY (SIC Order)	ALL BUILDINGS		PRODUCTION BUILDINGS	
	Probability function	Probability of fire in 1500m ² building	Probability function	Probability of fire in 1500m ² building
Food, Drink and Tobacco (III)	0.0054 B ⁻¹³	0.058	0.0011 B ⁻⁶⁰	0.086
Chemical and Allied (V)	0.017 B ⁻²⁷	0.12	0.0069 B ⁻⁴⁰	0.21
Metal Manufacture (VI)	0.011 B ⁻³⁶	0.14	*	*
Mechanical Engineering (VII)**	0.00036 B ⁻⁵⁹	0.027	0.00011 B ⁻⁷⁵	0.027
Instrument Engineering (VIII)	0.000027 B ⁻⁹⁶	0.031	*	*
Electrical Engineering (IX)	0.0011 B ⁻⁴⁹	0.040	0.00061 B ⁻⁵⁹	0.046
Shipbuilding (X)	0.0062 B ⁻³⁸	0.055	*	*
Vehicles (XI)	0.00030 B ⁻⁷⁴	0.065	0.00012 B ⁻⁸⁶	0.062
Metal Goods not elsewhere specified (XII)**	0.0027 B ⁻⁴⁶	0.078	0.00158 B ⁻⁵⁴	0.082
Textiles (XIII)	0.0036 B ⁻⁴²	0.079	0.0075 B ⁻³⁵	0.097
Clothing and Footwear (XV)	0.0017 B ⁻⁴⁹	0.032	*	*
Bricks, Pottery, Glass, etc. (XVI)	0.0013 B ⁻⁵⁴	0.067	*	*
Timber, Furniture, etc. (XVII)	0.00074 B ⁻⁶⁴	0.077	0.00037 B ⁻⁷⁷	0.10
Paper, printing, publishing (XVIII)	0.00010 B ⁻⁸⁵	0.052	0.000069 B ⁻⁹¹	0.054
Other Manufacturing Industries (XIX)	0.0023 B ⁻⁵⁴	0.12	0.0084 B ⁻⁴¹	0.17
All Manufacturing Industry (III-XIX)	0.0019 B ⁻⁵⁹	0.072	0.0017 B ⁻⁵³	0.083

* The sample was too small to allow a separate probability estimate for the production buildings.
 ** Some of the fires which should properly be classified as "mechanical engineering" may have been included with "metal goods n.e.s.". This would cause an underestimate of the probability in mechanical engineering and an overestimate in metal goods n.e.s. If the two groups, mechanical engineering and metal goods n.e.s are combined the probability function for all buildings is 0.00056 B⁻⁵⁶ and for production buildings 0.00086 B⁻⁵⁶.

(b)

Figure 1. (a) Probability of fire occurring (Production building, manufacturing industry) and (b) The estimated probability of fire in different industries [28].

effect: if a building is enlarged to double its original size, not all the services would double in size or in fire risk so that the risk of fire in a larger building would be less than twice than that of the original building; the second, the composition of the sample: larger buildings may have different processes, fire prevention management or first aid-firefighting capability. They may have lower fire risk than the small ones.

Initially, Rutstein estimated the probability of a fire considering all buildings within each industry together, where most of them were used for production and a smaller number for storage, office and other buildings. In a second instance, the probability of fire was calculated for those buildings primarily used for production as showed in Fig. 1b. Rutstein's functions are always power laws with positive exponents, therefore the probability of fire increases non-linearly with the increase of the dimension of the buildings. Coefficients *a* and *b* according to different industry types but solely for production buildings are those reported in Table A.1 of the PD 7974-7 [3], completely neglecting the coefficients for the class of all buildings.

The studies of D'Addario, Ramachandran and Rutstein have converged into PD 7974-7, which sets out the general principles and techniques of risk analysis that can be used in fire safety, outlines the circumstances where this approach is appropriate and gives example illustrating their use. It also includes data for probabilistic risk assessment and criteria for assessment that cover life safety and property protection in both absolute and comparative terms (*Absolute terms*: performance of one situation against predetermined criteria; *Comparative terms*: reliability analysis between two or more competing solutions) [3].

Despite being an essential guide for engineers to express a reasoned judgement based on local conditions, data within PD 7974-7 range from 1966 to 1987 (except

Table A.16 with data from 1995) and may no longer represent the current situation regarding its fire statistics. Therefore, there is a pressing need to re-examine these relationships using current fire statistics.

3. Fire Statistics and Building Stock Databases

Different countries have developed their own fire statistic databases using on-line forms completed after an incident by fire departments. Current research [16, 17] has started to analyse fire statistics databases from different nations including the Incident Reporting System (IRS, UK) [29] and the National Fire Incidents Reporting System (NFIRS, USA—covering more in-depth data provided to the authors on request from FEMA) [30]. These national statistical estimates have common mandatory fields that can be divided in major groups: causes of fire, factors contributing to ignition, response time from fire departments, start-stop time, building status and structural damage. Further fields question the intensity, powering factors and fire spread. Fire spread includes the area damaged in m² in the horizontal and vertical direction in UK and a percentage of area damage in USA. Additional information is also requested on the effectiveness of alarm and safety systems based on type, location and reasons why they did not operate as intended. The coalescing of this data will provide a quantification of the size and scale of damage with respect to different intervention strategies and are subdivided by building type (dwellings and other buildings) and use.

Below is a summary of: (a) the data being interrogated from the National Fire Incident Reporting System (NFIRS), which reports all the information with respect to the fire incidents that have occurred; and (b) the determination of the building stock from the US Energy Information Administration (EIA), specifically the Commercial buildings energy consumption survey (CBECS) and the Manufacturing energy consumption survey (MECS). Domestic building stock is determined from the Residential energy consumption survey (RECS).

3.1. National Fire Incident Reporting System (NFIRS)

In the USA, the National Fire Incident Reporting System (NFIRS—established in 1976) collects approximately 600,000 fire incident data each year from all 50 States and more than 40 major metropolitan areas [30]. NFIRS is a voluntary system so not all fire departments decide to participate, however the majority do [30].

NFIRS reports cause, heat source, item and material first ignited or contributing most to flame, factors contributing to ignition and fire spread. Response time is expressed not only considering the time from alarm to arrival of fire service but also in terms of time from alarm to last unit cleared or from arrival to last unit cleared. Detector type, operation and failure are reported, and aspects related to the automatic extinguish systems, including number of sprinklers, are available. With respect to damage, NFIRS defines the damage as a percentage of number of stories damaged by flame (excluding damage by heat, smoke and water), using four main categories as shown in Table 1.

Table 1
Damage, Fire Spread and Property Use Classifications in the NFIRS Database and Total Floor Space Bands in CBECS

NFIRS	
Damage classes	
Damage	Percentage of number of stories damaged
Minor damage	1% to 24%
Significantly damage	25% to 49%
Heavy damage	50% to 74%
Extreme damage	75% to 100%
Property use	Fire spread
Assembly	Confined to object of origin
Educational	Confined to room of origin
Health care, detention and correction	Confined to floor of origin
Residential	Confined to building of origin
Mercantile, business	Beyond building of origin
Industrial, utility, defence, agriculture, and mining	Automatic extinguishing system
Manufacturing, processing	Present
Storage	Partial system present
Outside or special property	None
CBECS floor area bands	
Building floor space (ft ²)	
1001 ft ² to 5000 ft ²	50,001 ft ² to 100,000 ft ²
5001 ft ² to 10,000 ft ²	100,001 ft ² to 200,000 ft ²
10,001 ft ² to 25,000 ft ²	200,001 ft ² to 500,000 ft ²
25,001 ft ² to 50,000 ft ²	Over 500,000 ft ²

NFIRS also reports the number of floors of building below and above the fire floor and the average floor area. This allows an evaluation of the total floor area of the building in ft² (consequently converted into m² for comparison to UK data).

Additionally, NFIRS reports fire loss data, as defined by the U.S. Fire Administration: *Fire loss is an estimation of the total loss to the structure and contents in terms of replacement in like kind and quantity. This estimation of fire loss includes contents damaged by fire, smoke, water and overhaul. It does not include indirect loss, such as business interruption.* The estimated dollar losses are divided into property and contents losses to assess a magnitude of the fire problem. This is fundamental to define fire prevention programs where high monetary losses are expected. Fire departments also estimate the pre-incident value of the property and the dollar loss caused by the event which are assessed thanks to the International Code Council's Building Valuation Data (BVD) formula [31] using average square foot construction costs provided by the BVD:

$$\text{\$ loss} = \text{Total square feet of damage} \times \text{Square foot construction cost} \quad (3)$$

where the square foot construction cost is specified according to the different property types.

3.2. Number of Buildings at Risk

To determine the frequency of fire the total number of buildings at risk is required with respect to the specific country and also subdivided by total area. This research uses data from the US Energy Information Administration (EIA) [32] namely: Commercial buildings energy consumption survey (CBECS) [33] and Manufacturing energy consumption survey (MECS) [34].

Both the CBECS and MECS are national sample surveys that collect information on U.S. commercial and manufacturing buildings stock, including their energy-related data. CBECS databases classify buildings into total floor space bands ranging from 1001 ft² at the lowest end, to over 500,000 ft² at the top (Table 1). In the MECS databases, the average floor space (in ft²) has been evaluated considering the average enclosed floor space per establishment divided by the average number of buildings onsite per establishment. Values obtained have been consequently classified according to the floor space bands in the CBECS databases.

The most recent CBECS data are from 2012 [33] assessing commercial buildings and estimate that there were 5.6 million commercial buildings in the U.S. in 2012. The Energy Information Administration (EIA), used a stratified statistical sample of just over 12,000 buildings completed surveys designed to represent the entire population. The sampling technique ensures that all types and sizes of commercial buildings have a chance of selection where ft² is highly correlated with energy consumption and variance was minimised as much as possible given time and budget constraints.

The 2014 MECS sample size of approximately 15,000 establishments was drawn from a nationally representative sample representing 97% to 98% of the manufacturing payroll. This sample allows EIA to report separate estimates of energy use for 21 3-digit industry subsectors, and 50 industry groups and industries according to the North American Industry Classification System [35].

It should be noted that in the analysis presented later in this paper, a choice has been made to present the fire frequencies at a point of the bands evaluated as an average of the total floor space for that band divided by the total number of buildings. In this way, it is not considered the average of the general floor space band but the average floor space of all the buildings attributable to that band. This will have subsequent impact on developed relationships.

The data from CBECS and MECS determine the number of non-residential buildings in USA classified according to the different building sizes. The different classes of buildings present in the two surveys have then been grouped according to the USA NFIRS classifications to have a straight comparison between numbers of fires per type of buildings according to the building size.

The use of the fire incidents data and the building stock data will allow further interrogations on the influence of occupancy types on fire frequency and the relationship between fire frequency and total floor space, damage, spread of fire, efficiency of sprinkler systems, and cost of fire.

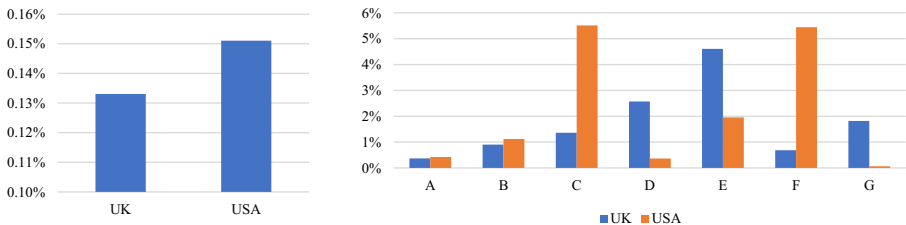
4. Overall Probability of Fire Starting in Various Types of Occupancy

Fire frequency is an important input factor in any probabilistic analysis and has therefore been studied well within the academic literature around the world [36–38]; future studies should compare these various sources of data to provide a more global analysis of fire frequency. In this paper, USA and UK fire frequencies will be compared with current data provided in PD 7974-7, namely Table A.2 which presents the overall probability of fire starting in various types of occupancy. No references are presented for Table A.2, so fire frequency has been obtained by dividing the number of fires by the total number of buildings at risk.

Fires per occupancy type have been determined from the IRS [29] and NFIRS [30] for the UK and USA, respectively, whilst residential and other non-residential building stock for the UK have been obtained from the DCLG English housing survey [39] and the Valuation office agency [40], respectively, and for the USA from the US Census Bureau [41], and the CBECS and MECS, for residential and non-residential buildings correspondingly. All the information for residential and non-residential buildings is referred to the 2014–2015 with the only exception of the total number of USA non-residential buildings, which were collected in 2012; therefore, all data presented are on a per annum basis unless otherwise stated.

Some building classifications within the UK and USA fire statistics have been rearranged and grouped together to create a direct comparison between UK and USA. The results can be seen in Fig. 2a, b. For residential buildings, the probability of a fire starting never exceeds the 0.3% stated in PD 7974-7 (Table A.2) but is equal to 0.133% and 0.151% for the UK and USA, respectively (Fig. 2a). This represents a potential factor of safety of over 2 when considering the probabilistic assessment of dwelling fires.

In non-residential buildings, fires are more frequent in *Food and drinks premises; Hotels and Communal living* (4.61%) in the UK; and in the USA fires are more usual in *Educational premises* (5.51%) and *Entertainment, culture and sport spaces*



A. Offices and call centres, Retail premises; B. Industrial premises; C. Education premises; D. Hospital and medical care; E. Food and drink premises; Hotels, boarding houses, hostels etc.; Communal living; F. Entertainment, culture and sport; G. Other public buildings and services.

(a)

(b)

Figure 2. Fire frequency in (a) residential buildings in UK and USA and (b) non-residential buildings in UK and USA.

(5.45%). Analysing the NFIRS in the USA fire statistics, is possible to attribute the high fire usual in *Educational premises* to open flames (potentially due to arson) with related high financial losses. The lowest percentages in Fig. 2b are in *Offices and call centres*; *Retail premises* (0.37%) in UK and *Other public buildings and services* (0.06%) in USA.

Table 2 compares fire frequency between more recent USA and UK fire statistics and the frequencies presented in Table A.2 of PD 7974-7 [3]. For the *Storage* and *Assembly non-residential* classes, it has not been possible to recreate the frequency due to limited information within the databases being examined. *Offices* in Table A.2 of PD 7974-7 has been compared to the classes of *Offices and call centres* and *Retail premises*. In general, fire frequencies are in the same order of magnitude with the exceptions of *Assembly entertainment* (5.446×10^{-2}) and *Schools* (5.512×10^{-2}) in USA which present a higher peak than the ones for the UK (0.687×10^{-2} and 1.362×10^{-2} , respectively), and fires in *Hospitals* (2.571×10^{-2}) within the UK which are seven times more frequent than in the USA (0.363×10^{-2}).

Frequencies in PD 7974-7 are in general always higher than the ones obtained from the current analysis. Frequencies for *Assembly entertainment* (12×10^{-2}) and *Hospitals* (30×10^{-2}) in PD 7974-7 seem to be very conservative with values 17 and 11 times greater, respectively, than those obtained in the current analysis of the UK data, and 2 and 82 times greater, respectively, than the USA data. The *Industrial*, *Offices*, *Schools*, and *Dwellings* classes are all 2 to 4 times greater in PD 7974-7 than determined in the current analysis (except for *Schools* (5.512×10^{-2}) in USA data which is 1.4 times greater).

Table 2
Table A.2 Overall Probability of Fire Starting in Various Types of Occupancy in PD 7974-7, UK and USA Fire Statistics

Occupancy	PD 7974-7	UK	USA
Probability of fire starting (10^{-2})			
Industrial	4.4	0.903	1.121
Storage	1.3	N/A	N/A
Offices	0.62	0.369	0.423
Assembly entertainment	12	0.687	5.446
Assembly non-residential	2.0	N/A	N/A
Hospitals	30	2.571	0.363
Schools	4.0	1.362	5.512
Dwellings	0.3	0.133	0.151
Food and drinks premises; hotels, hostels; communal living	N/A	4.609	1.954
Other public buildings and services	N/A	1.818	0.063
Agricultural premises	N/A	N/A	1.229

5. PD 7974-7 vs USA Fire Statistics 2014

5.1. Probability of Fire Starting

Frequency of ignition with respect to floor area is often used in probabilistic risk assessments due to fact that it is a fundamental input for event tree or fault tree analyses. Table A.1 in PD 7974-7 presents the probability of fire starting F as a function of the total area of the building according to Eq. (2) and is repeated here for convenience:

$$F = aA^b \quad (4)$$

where a and b are coefficients obtained with the method explained in Sect. 2.

The following analysis takes the number of fires from the NFIRS fire database, and the number of buildings at risk from the CBECS and MECS. The fire events have been sub-divided by property use, whilst NFIRS data of building floors above and below ground level, and the average size of the floor are used to understand the total area of the buildings. The property types are presented in Table 1.

The evaluation of the total size of the building has been calculated summing the building below and the building above to obtain the total number of floors and then multiplying the total number of floors by the average size of floor. Since the value is in ft², this has consequently been converted in m² to provide a direct comparison to the results in PD 7974-7 [3].

The probability of fire has been obtained by dividing the total number of fires for each property use by the number of buildings at risk. The results of the analysis have been repeated for each building type and potential relationships are examined and compared to the power law [Eq. (4)] used in PD 7974-7 [3]. Table A.1 is composed of two main parts: one for industrial and manufacturing buildings and one for other occupancies excluding residential buildings. In the PD 7974-7 document, the frequency period is not specified; in this paper a yearly frequency is assumed.

Parameters a and b have been derived, to recreate the law present in PD 7974-7, in the light of their definitions (Sect. 2) using USA fire statistics with respect to the different property types (i.e. a is the ratio between total number of fires and total number of buildings at risk from MECS and CBECS, and b is given by the total number of fires divided by the building maximum floor area). Table 3 shows the parameters a and b obtained for the USA fire statistics, where the related function is called [*Power (USA-Rutstein)*], and compares them to those provided in the PD 7974-7 Table A.1. Unfortunately, due to differences in the reported building types between PD 7974-7, NFIRS, CBECS and MECS, not every industry or manufacturing subclass has been compared. For industry and manufacturing categories this results in five comparisons using the same method as Rutstein based on the USA data, whilst for other occupancies, *Shops* and *Offices* in PD 7974-7 have been represented as *Mercantile*, *Business* in the USA data, and *Hospitals* in PD 7974-7 by *Health care*, *Detention and Correction*. Whilst these representations are not perfect, the authors believe that they are appropriate for comparison.

Table 3
Probability of Fire Starting in Different Occupancy Types

	PD 7974-7				USA fire statistics			
	Power law		Power law (+ve b)		Power law		According to dots graph probability of fire—tot floor space	
	a	b	a	b	a	b	Law	R ²
Industrial buildings	[Power (PD)]		[Power (USA-Rutstein)]		[Power (USA-Improved)]		[Poly (USA-Improved)]	
Trend in Figs. 3, 4 below	a	b	a	b	a	b	Law	R ²
Overall Industry and Manufacturing	0.0017	0.53	0.003920	0.1464	1.7584	- 0.831	N/A	N/A
Food, drink and tobacco	0.0011	0.60	Not applicable					
Chemical and allied	0.0069	0.46	0.000249	0.0028	0.00003	0.2447	N/A	N/A
Mechanical engineering and other metal goods	0.00086	0.56	0.000245	0.0027	Only 2 points			
Electrical engineering	0.0061	0.59	0.002537	0.0041	Only 2 points			
Vehicles	0.00012	0.86	Not applicable					
Textiles	0.0075	0.35	Not applicable					
Timber, Furniture	0.00037	0.77	Only 1 point					
Paper, printing and publishing	0.000069	0.91	Not applicable					
Other manufacturing	0.0084	0.41	0.012748	0.0474	0.0018	0.1523	2.28 × 10 ⁻⁹ A ² - 1.95 × 10 ⁻⁵ A + 4.23 × 10 ⁻²	1

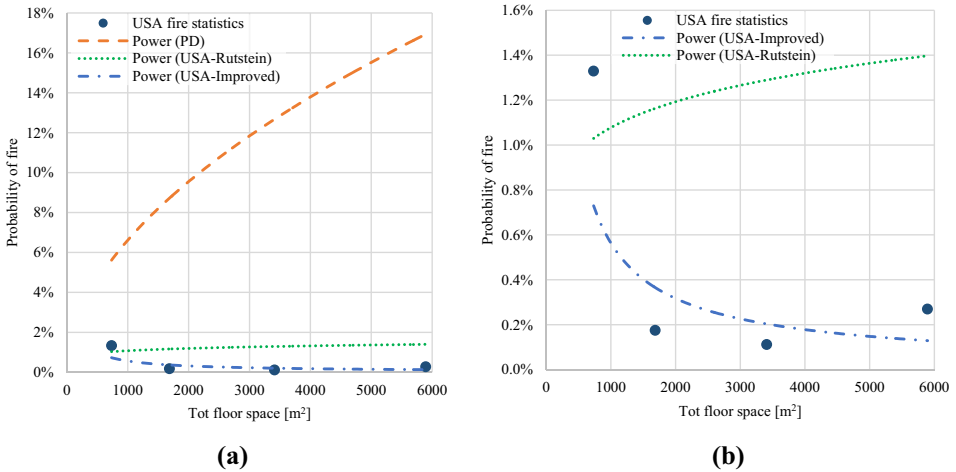


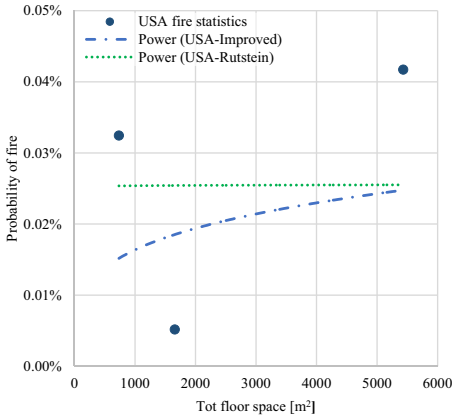
Figure 3. Probability of fire starting in Industry and manufacturing (a) comparing PD 7974-7 and USA fire frequency relationships and (b) looking solely at the USA fire frequency relationships.

Table 3 shows that when applying the same positive exponent restriction on the parameter b as suggested by Rutstein, the USA fire statistics trends are always lower (and thus conservative) than those reported in PD 7974-7. These positive exponent power laws do not show good agreement with the datasets created, therefore, further analysis of potential better fitting relationships for the USA fire statistics are required and described as [*Power (USA-improved)*] and [*Poly (USA-improved)*] (Table 3).

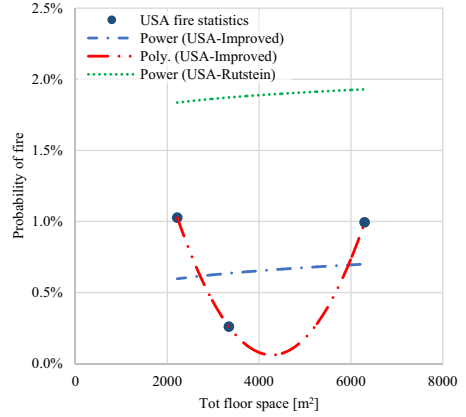
Grouping the fires by occupancy type and floor area bands of the building in which they occurred and relating them to the respective probability (fire divided by total number of buildings at risk per floor area band), new fire frequency relationships are obtained ([*Power (USA-improved)*] and [*Poly (USA-improved)*]) based on the dot plots deduced by the analysis. Floor area bands (Table 1) and number of buildings within each band are determined from the MECS and CBECS databases. The probability of fire has then been plotted according to its respective floor area, and trends drawn to represent the data, with associated R^2 values to understand how well the trends are approximating the fire incident dataset. It should be noted, that due to the way the building area is represented in the MECS and CBECS databases, with buildings being classified within area bands (i.e. between 5001 ft² and 10,000 ft²) some of the improved relationships within the industrial subcategories cannot be fitted due to having fewer than 3 floor area bands (*Mechanical engineering and other metal goods* and *Electrical engineering*).

Figure 3a shows the fire frequency relationship for **Overall Industry and Manufacturing** according to the USA positive exponent function [*Power (USA-Rutstein)*], the function presented in PD 7974-7 [*Power (PD)*], and a new function based on fires per area band [*Power (USA-improved)*]. Whilst Fig. 3b presents a closer look of the USA functions and data. Figure 3 clearly shows that the posi-

A Critical Evaluation of BS PD 7974-7 Structural Fire Response Data

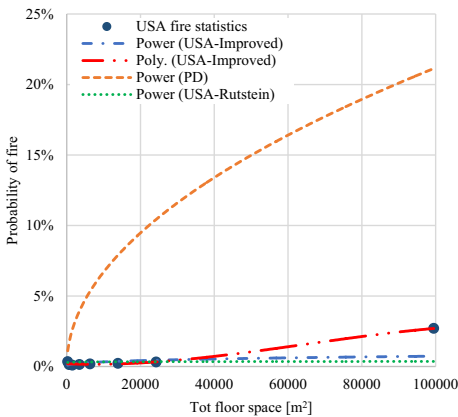


(a)

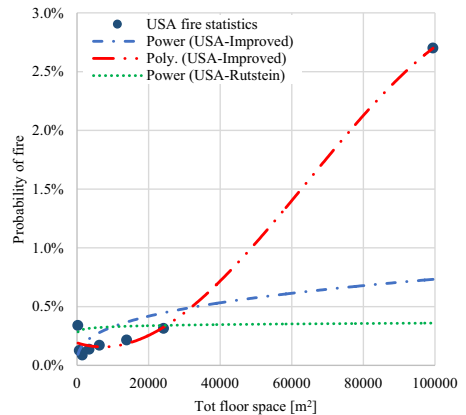


(b)

Figure 4. Probability of fire starting from USA fire statistics in (a) chemical and allied industry and (b) other manufacturing.



(a)

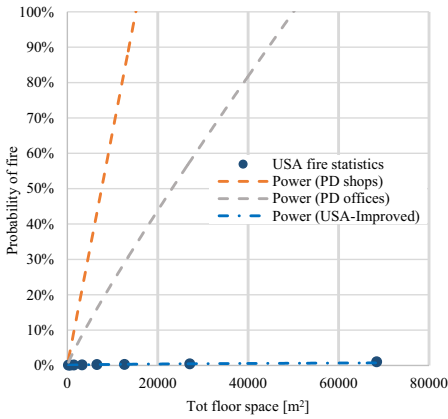


(b)

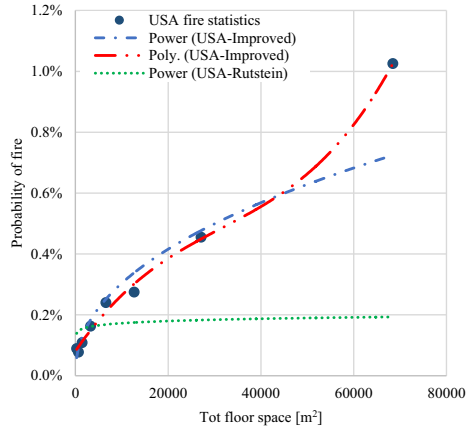
Figure 5. Probability of fire starting in Storage (a) comparing PD 7974-7 and USA fire statistics and (b) focussing on USA fire statistics.

tive exponent power law from PD 7974-7 and the law generated using the USA data with the positive exponent constraint, do not represent the data at all well. There is a trend in the data for a reduction in fire frequency as the total floor area increases, i.e. a negative exponent. This could be due to the fact that larger buildings present better fire safety measures that should prevent the origin of fires or detect them in their early stages. It should also be noted however, that for small floor areas a negative exponent will produce high fire frequencies. For instance, a floor area of 10 m² using *Power (USA-improved)* would have a fire probability of

26%. Therefore, there is a need to identify the potential limits of the relationships, and how to incorporate small building areas into the analysis. Figure 3 clearly shows that the *Power (PD)* relationship is very conservative, and it may therefore cause structures to be overly protected and thus increase the fire safety related costs.

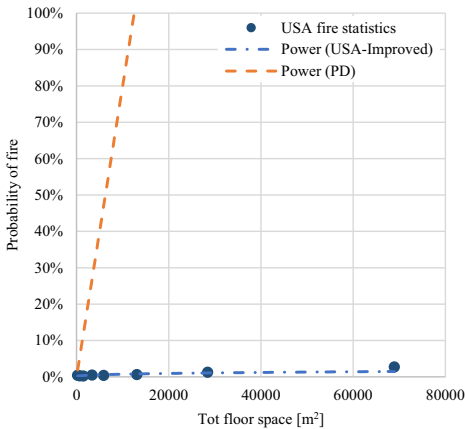


(a)

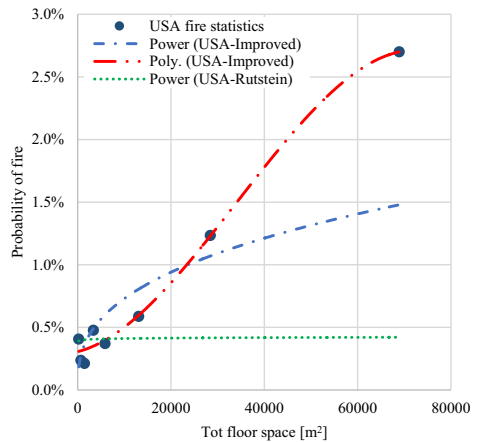


(b)

Figure 6. Probability of fire starting in Shops and Offices (Mercantile, Business) (a) comparing PD 7974-7 and USA fire statistics and (b) focussing on USA fire statistics.



(a)



(b)

Figure 7. Probability of fire starting in Hotels (a) comparing PD 7974-7 and USA fire statistics and (b) focussing on USA fire statistics.

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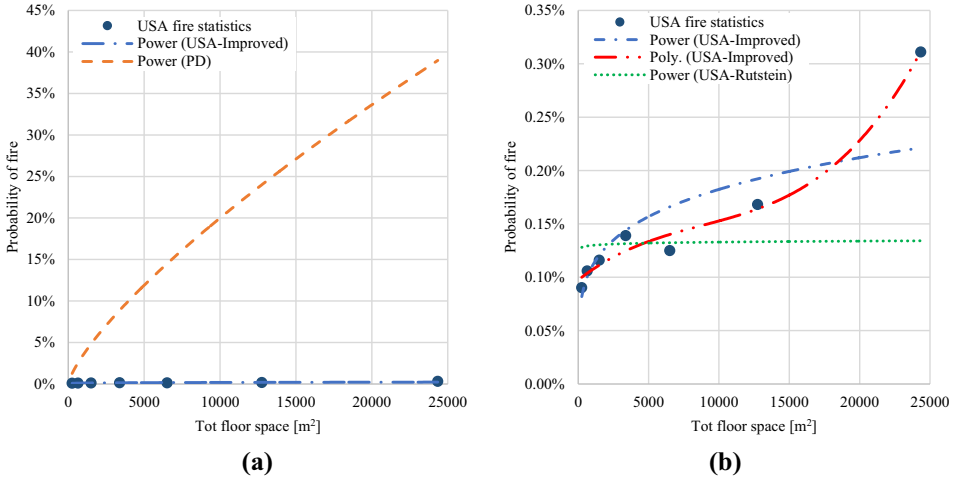


Figure 8. Probability of fire starting in Schools (a) comparing PD 7974-7 and USA fire statistics and (b) focussing on USA fire statistics.

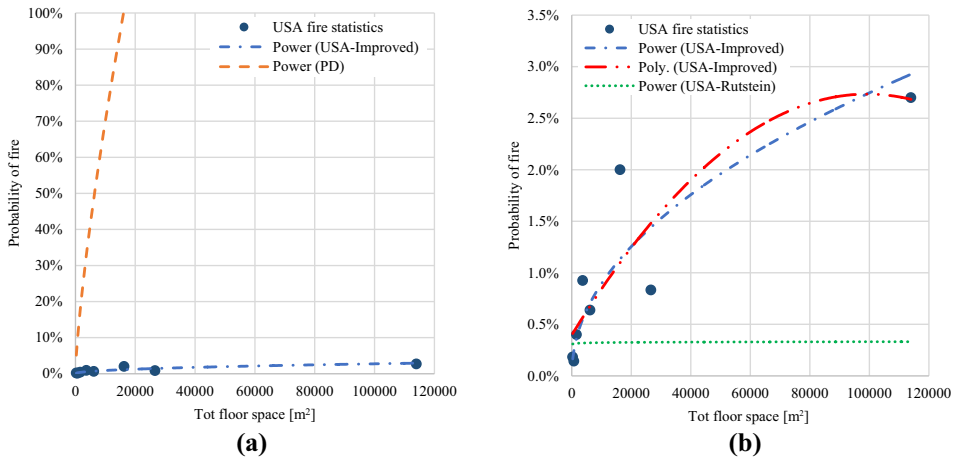


Figure 9. Probability of fire starting (a) comparing PD 7974-7 Hospitals and USA fire statistics Health Care, Detention and Correction and (b) focussing on USA Health Care, Detention and Correction fire statistics.

Buildings at risks for *Chemical and allied* are distributed from 464.4 to 9290.3 total floor space in m² with zero structures in the range between 2323 m² and 4645 m²; this data point has been neglected in subsequent analyses. Figure 4a, shows the power law *Power (USA-improved)* and the general function *Power (USA-Rutstein)* obtained just evaluating the two coefficients *a* and *b*. Neither of the laws are accurate due to a large dispersion in data, however, Fig. 4a, shows

that the fire frequency according to the building area with the power law gives a positive exponent as in the PD 7974-7; an opposite trend to that of *Overall Industry and Manufacturing*.

Other manufacturing, again a positive exponent *Power (USA-improved)* relationship is present as shown in Fig. 4b based on the USA fire statistics data. However, as for *Chemical and Allied industries*, there is a great dispersion in the data leading to a very low correlation ($R^2 = 0.010$). This could be in part due to how buildings have been grouped by areas, and limited variety in area ranges, therefore a higher fidelity in the building stock data for the specific types of industrial buildings is required to improve these relationships further.

The second part of Table A.1 is related to **Other Occupancies** excluding residential buildings. For this analysis, the number of buildings at risk for each category has been found in the CBECS, again banded by area from a total building area below 1000 ft² to over 500,000 ft² (below 92.03 m² to over 46,451.59 m²). In general, there is a consistency in the results presented in these classes, with fire frequency increasing with floor area as noted by Rutstein, however, Rutstein's method is poor. The *Power (USA-Rutstein)* relationship, evaluated calculating the two coefficients a and b , seems to consistently and significantly underestimate the tendency of fire frequency according to the building size (Figs. 5, 6, 7, 8, 9). Therefore, a change in the analysis of the data is required.

Curve fitting power laws with respect to the banded area data points, in general, provide better relationships for all the different occupancy types with R^2 values between 0.405 and 0.927. Across several different classes of occupancy, the most consistently accurate forms examined for the relationship were cubic polynomials which regularly produced R^2 values close to unity (0.742 to 0.997), however this may not be a physically representative relationship and is difficult to justify. This could be an influence of how the codes used to design structures have different criteria as buildings get larger/taller, where the cubic function may be capturing this aspect; future research will investigate a possible explanation.

Figure 5 presents the PD 7974-7 relationship, the *USA-Rutstein*, and the *USA-Improved* relationships, for **Storage** buildings with a total area of greater than 92.99 m², and shows that PD 7974-7 adopts a highly conservative approach compared to the trends seen from NFIRS data. However, in Fig. 5b the positive exponent power law does describe the increasing fire frequency with increasing total building area, even if the correlation is low ($R^2 = 0.405$). It is also possible to represent the trend using a cubic polynomial increasing the R^2 correlation value to 0.993, however, as mentioned above this is hard to justify.

In PD 7974-7 **Shops and Offices** are two separate categories and have separated fire frequency relationships. However, their nearest comparators, *Mercantile, Business*, are grouped in a single class in the NFIRS; these groups are compared in Fig. 6. Figure 6a shows that the power laws for *Shops* and *Offices* in PD 7974-7 are considerably greater than those found in the USA fire statistics. The PD 7974-7 laws estimate that you will have one fire per year in your *Shop* or *Office*, if they are greater than 15,000 m² and 50,000 m², respectively. This is very conservative when compared to the USA data analysis. The fire frequency for *Mercantile, Business*, as for *Storage*, increased with floor area. A power law, when based on area

bands, provides a very good approximation of the data, with an R^2 value of 0.927. The accuracy can be further improved using again a cubic polynomial approximation, with an R^2 value of 0.997.

Similar analyses were performed for *Hotels*, *Schools*, and *Hospitals*, and similar trends were found. For **Hotels**, the PD 7974-7 law gives a probability of fire equal to 100% for total area greater than 12,500 m², which when compared to the USA data analysis, is evidently wrong, with the probability of fire starting approximately 0.6%. Again, for *Hotels*, Table 3 and Fig. 7 show that as the floor area increases the fire frequency increases, and a positive exponent law based on floor area (USA-Improved) provides a moderate level of accuracy ($R^2 = 0.673$), which can be further improved using a cubic function ($R^2 = 0.991$). For **Schools**, PD 7974-7 is again very conservative if compared to the one obtained according to the USA fire statistics (Fig. 8). Going deeper in details, both the power law and a cubic function for fire frequency according to building size, have an acceptable R^2 values of 0.768 and 0.983, respectively, as can be seen in Fig. 8.

Hospitals, are compared to *Health Care*, *Detention and Correction* from the NFIRS as its nearest comparator. PD 7974-7 assumes a fire will occur every year if your hospital is greater than 16,000 m² in floor area (Fig. 9). Again this seems overly conservative and not supported by the data, where, for a similar area in all *Health Care*, *Detention and Correction*, the fire frequency is approximately 2%. Plotting the *USA-Improved* functions is not easy since there is a great dispersion of data. This could be due to the mixed classification within NFIRS, where certain facility types have a greater fire frequency, and these facilities are generally of a specific size. However, both a power law and a second order function seem to present a good R^2 of 0.839 and 0.742, respectively.

It can be seen from the analysis, that the relationships within PD 7974-7 are extremely conservative in all cases when compared to analysis of frequencies using data from the USA NFIRS, and CBECS and MECS databases. This could result in expensive and overly conservative designs.

6. Area Damage and Percentage of Fires for Each Category of Fire Spread

The area damage in PD 7974-7 [3] is expressed according to various classes of spread of fire where the correspondent m² of damage and related percentage of fires is provided. A distinction is given between sprinklered and un-sprinklered buildings and two different property types are analysed: in Table A.4 textile industry subdivided in Production area, Storage area and Other areas while in Table A.5 pubs, clubs, restaurants—all areas. The data of which these two classes are composed are referred to the UK Fire Statistics of 1984–1986. Tables A.4 and A.5 from PD 7974-7 are recreated using fire incident data from NFIRS including: property use, fire spread, number of floors below and above ground floor, average size of floor, percentage of area damaged, and presence of automatic extinguish systems.

All classes of property use have been analysed and in the USA fire statistics database, fire spread is classified according to the five different classes stated in Table 1 above. This subdivision for fire spread is similar to PD 7974-7 with some differences. PD 7974-7 fire spread confined to room of origin further specifies if the spread is confined to contents only or if the structure is involved; this is not present in the NFIRS. In the USA fire statistics when fire spreads beyond the room of origin, other specific classes than the simple one referred to the spread beyond the room of origin, are introduced (confined to floor, confined to building and beyond building of origin).

In the USA fire statistics, the damage represents the number of stories damaged by flame spread. Flame damage is the area actually burned or charred and does not include areas receiving only heat, smoke, or water damage. Damage is expressed as banded percentage ranges of area instead of unique m² of area damage. Since these percentage bands present a range and not a unique value or percentage, the median of each band has been presented with error bars for the upper and lower bands (i.e. for Minor damage, median is 12% damaged area, with lower and upper bounds of 0% and 24%, respectively).

The total weighted area damaged is determined from the number of stories damaged, average floor area, and damage class involved per building. Damage and fire spread are also analysed in this paper related to the presence or absence of automatic extinguishing systems. Finally, the fire frequency for each fire spread classification has been evaluated with the distinction in fires and unclassified events.

6.1. Area Damage and Percentage of Fires in the Property Uses of the USA Fire Statistics

In general, the influence of sprinklers not only reduces the fire spread with fires 10% to 30% more likely to be confined to object or room of origin, but sprinklers also limits the damage from a fire, with higher percentages seen in the Minor and Significantly damage bands, rather than the Heavy and Extreme. It should be noted however that there are several fires within the NFIRS databases that have an assigned level of fire spread, however, they have no assigned damage class. These have been represented as unclassified (U) in Tables 5, 6, 7 and Tables 12, 13, 14, 15, 16 in Appendix (legend present in Table 4). The aforementioned tables also show the number of fires for each fire spread level for each damage class, percentages of fire spread per damage class (%F-S, percentages sum horizontally for the specific spread class) and percentages of damage per spread class (%F-D, percentages sum vertically for the specific damage class). The direction to follow to evaluate the two percentages are specified by the arrows in the aforementioned tables.

The property types for which sprinklers are effective and their action limits fire and spread, are *Educational; Health care, Detention and Correction; Industrial, Utility, Defence, Agricultural, Mining; and Storage*. Table 5 and Fig. 10 show, for **Educational** buildings, that the presence of sprinkler systems have significant impact on the spread of fire and the amount of damage these fires cause, with

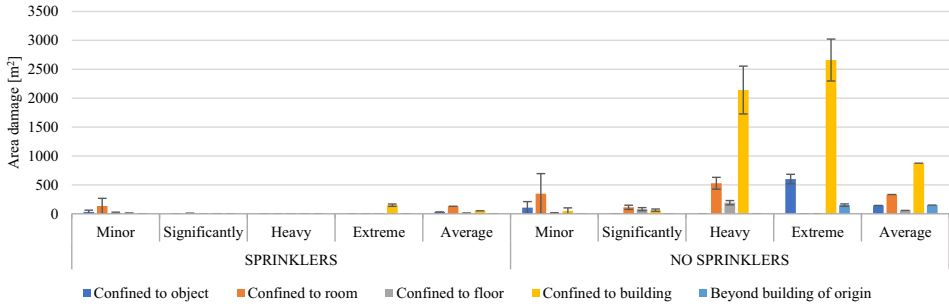


Figure 10. Area damage in Educational for different spread of fire and damage classes, including weighted average area damage.

approximately 85% of these fires being confined to the room of origin, with a predominantly class of minor damage. When no sprinklers are present the fire has a more than 30% chance of spreading beyond the room of origin. No fires were reported, in the NFIRS data, to fire spread beyond the building of origin in sprinklered buildings, whereas this occurred in 3% of the fires for un-sprinklered educational buildings. The average area damaged for sprinklered buildings across all the four fire spread classifications is of almost 87 m², compared to approximately 390 m² across five class of spread when no sprinklers are present. Un-sprinklered educational buildings are also more likely to experience extreme damage compared to sprinklered buildings with 2660 m² of damage confined to building.

Similar considerations as found for Educational buildings can be applied to **Health Care, Detention and Correction**. Sprinklers, again are shown to reduce the area damaged with average damage being 70.70 m² and 94.51 m² for sprinklered and un-sprinklered buildings, respectively (Figure 16 and Table 12 in Appendix). [NB: one fire incident has not been considered where the fire spread was confined to object first ignited however, it had a median area damaged of 89,186 m²].

Industrial, Utility, Defence, Agricultural, Mining as well as **Storage** buildings have limited data for sprinkler systems so a rigorous analysis is not possible but similar comments can be deduced for both property types where for un-sprinklered buildings, in more than 50% of cases the fire affects the whole buildings (Fig. 17, 18 and Tables 13 and 14 in Appendix).

Sprinklers limit the damage but not the spread in *Assembly; Residential; and Mercantile, Business* showing similar trends. Starting with **Assembly**, a single fire (no sprinklers, confined to floor, significant damage) has been removed from the analysis as the area damaged (in the range of 145,161 to 284,516 m²; 25% to 49% respectively) is significantly higher than others in the same class, and thus skews the data to unrepresentative values.

Table 6 and Fig. 11 show that, when sprinklers are present in *Assembly* in the USA, damage is predominantly *Minor Damage*, whereas in un-sprinklered buildings damage is predominantly *extreme damage*. This consideration supports the idea that automatic extinguish systems can reduce fire spread and can be demonstrated by the values of %F-S. When the fire spreads beyond the room of origin,

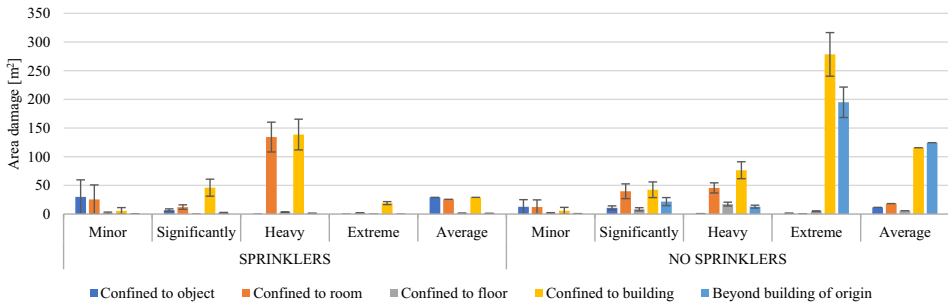


Figure 11. Area damage in Assembly for different spread of fire and damage classes, including weighted average area damage.

un-sprinklered structures experience much higher damage and the frequency of fire spread beyond room of origin in un-sprinklered buildings is more than 50% of fires, compared to more than 25% in the sprinklered case. On average, a sprinklered and un-sprinklered *Assembly* building will experience 25.96 m² and 59.50 m² of damage, respectively. Fires are frequently confined within the room of origin for around 70% in sprinklered and 50% in un-sprinklered buildings. The data also indicates that if the fire does go beyond the room of origin, then it is likely to spread to the whole building, rather than being confined to the floor of origin, with sprinklered and no automatic extinguishing systems, having 24.61% and 43.85% of their fire spread, respectively, spreading past the floor of origin (Table 6 and Fig. 11).

Similar comments can describe **Residential** and **Mercantile, Business** with average damage being 4.92 m² and 48.58 m² for sprinklered compared to 35.69 m² and 97.34 m² for un-sprinklered, respectively (Figs. 19, 20 and Tables 15, 16 in Appendix).

In **Manufacturing, Processing**, sprinklers seem to limit the spread but not the fire damage. Indeed, 69% of fires are confined in the room of origin when sprinklers are present and 37% for un-sprinklered buildings (Table 7 and Fig. 12). For both sprinklered and un-sprinklered buildings the damage class is usually minor, however peaks are seen for both with significantly damage of 2856.61 m² of area damage confined to building for sprinklers, and 2007.78 m² confined to building for extreme damage for un-sprinklered buildings. Table 7 and Fig. 12 also show that for both sprinklered and un-sprinklered buildings the highest average area damage is reached for spread confined to building with 843.41 m² and 839.56 m², respectively.

It is evident from the analysis of these data that sprinklers can significantly reduce both the spread of fire and the associated damage of the fire. However, the NFIRS database presented the damage by flame only, and there is no indication within the data about the damage that may or may not be caused by the sprinkler systems, or by smoke.

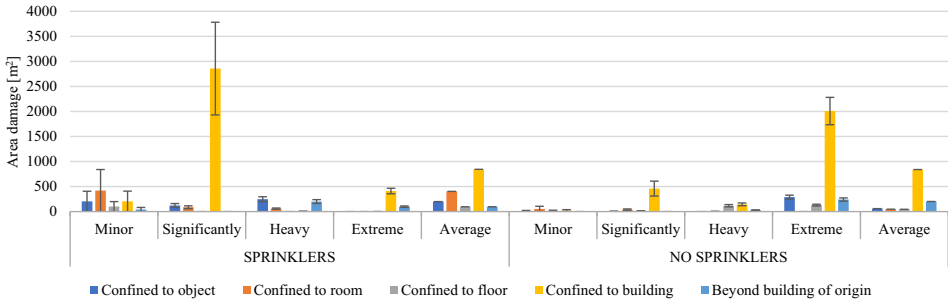


Figure 12. Area damage in Manufacturing, Processing for different spread of fire and damage classes, including weighted average area damage.

6.2. Area Damage and Percentage of Fire Spread in PD 7974-7 vs USA Fire Statistics

6.2.1. *Textile Industry* Table A.4 in PD 7974-7 summarizes the area damage in m² and percentage of fires for each category of fire spread in textile industry. Since the exact comparison to the textile industry was not possible with the USA fire statistics, comparisons are made instead to *Manufacturing, Processing*. Table A.4 is divided into three different fire locations, which have been reproduced in the USA fire statistics as follow in the NFIRS: Production area—Processing/manufacturing area, workroom, assembly area; Storage area—Storage Areas; Other areas—all the other fire origin locations excluding those previously considered.

The method explained in Sect. 6, has been adopted with the only difference that a further classification has been applied regarding fire locations. The influence of sprinkler systems on the response is also considered. The average area damage within Table 8 (last row) is obtained by multiplying the area damage for the related frequency for each class of fire spread, summing all values and dividing by the total frequency.

In recreating Table A.4 for **Production area** using NFIRS data, for sprinklered buildings, 7 fire incidents have been recorded for spread confined to floor, 14 for spread confined to building and 2 for the one beyond building. For un-sprinklered buildings, only 4 incidents related to fire confined to floor and 2 for spreads beyond the building of origin. One sprinklered building damage value (spread confined to building) has been ignored value in the dataset as the median damage is 85,935 m², which is not comparable with other values.

Frequency of fire, in Table A.4 of PD 7974-7, not confined to the room of origin is equal to 4% for sprinklered and 12% for un-sprinklered, indicating good compartmentation. However, in the NFIRS, the spread beyond the room of origin is much greater at 24.07% for sprinklered and 51.73% for un-sprinklered (Table 8). When considering damage, PD 7974-7 has identical areas of damage for sprinklered and un-sprinklered buildings, whereas in the NFIRS analysis the damage for sprinklered buildings is always greater than for un-sprinklered. This is

believed to be due to the small number of fire recorded in the case of sprinklered buildings.

For **Storage areas**, in the PD 7974-7 table, there are two mistakes: firstly the area damage confined to room, for *contents only* and for *structure involved* in sprinklered buildings, both have identical values of 19 m² and 24% of frequency. If these values were real for both classes, then the cumulative frequency would exceed 100%. In this paper, we have combined the two classes and assigned them the 19 m² and 24% damage and frequency, respectively. The second mistake is that the average area damage for buildings without automatic extinguish systems is wrongly evaluated since it should be equal to 533 m² while in the PD 7974-7 table is 539 m².

In the USA fire statistics analysis, one fire has been neglected as its median area damaged is too high compared to the others 16,350 m². In the NFIRS, there is no data for fire spread beyond the building of origin for sprinklered buildings, and limited fires for confined to floor, only 5, and confined to building there are only 7. Moreover, fire departments have attended an overall of 50 fires associated with buildings without sprinklers. The results should therefore be taken with caution. In Table A.4 of PD 7974-7, fire frequency decreases as the fire spread class, and damage, increase. In the USA fire statistics, the fire frequency for spread within room of origin is 68.97% for sprinklered and 19.35% for un-sprinklered buildings (Table 8). There is also a significant 58.06% of fires confined to building of origin in un-sprinklered buildings. In general, as seen in Sect. 6.1, the presence of sprinklers decreases the damage and spread of fire as can be seen in Table 8 where for sprinklered see 31% of fires spread beyond room of origin compared to 80% for un-sprinklered buildings. This results in the average damage in un-sprinklered buildings being more that 1.49% of sprinklered buildings.

Last part of Table A.4 regards **Other areas**. In the PD 7974-7 table, fire frequency and area damage have the same trend as for Storage areas: fire frequency decreases with the increase of the spread of fire class while the area damage increases with the increase of the extension of fire (Table 8). In the NFIRS, for sprinklered building, only 6 fire incidents are recorded for fire beyond the building of origin. In the USA fire analysis, the spread within the room of origin is equals to 66.67% and 40.19% respectively for sprinklered and un-sprinklered buildings.

Table 4
Legend to be Referred to Tables 5, 6, 7 and Tables 12, 13, 14, 15 and 16 in Appendix

Legend	
U: unclassified fires	1: Spread confined to object of origin
F: fires	2: Spread confined to room of origin
S: spread	3: Spread confined to floor of origin
D: damage	4: Spread confined to building of origin
Av: average area damage	5: Spread beyond building of origin
±: Standard deviation	

Table 5
Educational: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

Sprinklers - Area damage m ²																								
U		Minor				Significantly				Heavy				Extreme				Weighted area damage m ²		F		F+U		
		% F		Av. m ²		% F		Av. m ²		% F		Av. m ²		% F		Av. m ²		± m ²	%	Cum	%	Cum		
		S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓									
1	40	19	100.00%	31.15%	31.10	31.10	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	0.00	0.00%	0.00%	29.23%	29.23%	32.00%	32.00%	32.00%
2	73	35	97.22%	57.38%	133.90	133.90	1	2.78%	50.00%	6.92	2.24	0	0.00%	0.00%	0.00	0.00	0.00	0.00%	0.00%	55.38%	84.62%	58.40%	90.40%	90.40%
3	4	4	100.00%	6.56%	13.53	13.53	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	0.00	0.00%	0.00%	6.15%	90.77%	3.20%	93.60%	93.60%
4	8	3	50.00%	4.92%	6.45	6.45	1	16.67%	50.00%	0.65	0.21	0	0.00%	0.00%	0.00	0.00	0.00	33.33%	100.00%	9.23%	100.00%	6.40%	100.00%	100.00%
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total weighted area damage																		87.01						
No Sprinklers - Area damage m ²																								
U		Minor				Significantly				Heavy				Extreme				Weighted area damage m ²		F		F+U		
		% F		Av. m ²		% F		Av. m ²		% F		Av. m ²		% F		Av. m ²		± m ²	%	Cum	%	Cum		
		S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓									
1	47	32	88.89%	31.07%	105.44	105.44	1	2.78%	6.25%	0.98	0.32	0	0.00%	0.00%	0.00	0.00	0.00	8.33%	18.75%	25.53%	25.53%	31.13%	31.13%	31.13%
2	73	52	88.14%	50.49%	347.17	347.17	5	8.47%	31.25%	112.37	36.44	2	3.39%	33.33%	528.00	102.19	0	0.00%	0.00%	41.84%	67.38%	48.34%	79.47%	79.47%
3	4	4	50.00%	3.88%	8.94	8.94	3	37.50%	18.75%	79.81	25.88	1	12.50%	16.67%	192.00	37.16	0	0.00%	0.00%	5.67%	73.05%	2.65%	82.12%	82.12%
4	23	15	45.45%	14.56%	50.65	50.65	7	21.21%	43.75%	62.68	20.33	3	9.09%	50.00%	2140.80	414.35	8	24.24%	50.00%	23.40%	96.45%	15.23%	97.35%	97.35%
5	4	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	0	100.00%	31.25%	3.55%	100.00%	2.65%	100.00%	100.00%
Total weighted area damage																		389.87						

Table 6
Assembly: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

U		Sprinklers - Area damage m ²						Weighted area damage m ²						F+U									
		Minor		Significantly		Heavy		Significantly		Heavy		Extreme		F		F+U							
F	% F	Av. m ²	± m ²	F	% F	Av. m ²	± m ²	F	% F	Av. m ²	± m ²	F	% F	Av. m ²	± m ²	%	Cum	%	Cum				
S →	D ↓			S →	D ↓			S →	D ↓			S →	D ↓										
1	65	97.01%	29.41%	29.86	2	2.99%	11.11%	6.84	2.22	0	0.00%	0.00%	0	0.00%	0.00%	26.59%	26.59%	34.85%	34.85%				
2	245	106	94.64%	47.96%	25.38	4	3.57%	22.22%	12.11	3.93	1	0.89%	33.33%	1.88	0.26	44.44%	71.03%	50.52%	85.36%				
3	16	10	90.91%	4.52%	1.69	0	0.00%	0.00%	0.00	1	9.09%	10.00%	3.29	0.64	0	4.37%	75.40%	3.30%	88.66%				
4	50	39	67.24%	17.65%	5.57	10	17.24%	55.56%	45.99	14.92	7	12.07%	70.00%	138.65	26.84	2	23.02%	98.41%	10.31%	98.97%			
5	5	1	25.00%	0.45%	0.13	2	50.00%	11.11%	2.09	0.68	1	25.00%	10.00%	1.15	0.22	0	1.59%	100.00%	1.03%	100.00%			
Total weighted area damage																25.96							
U		No Sprinklers - Area damage m ²						Weighted area damage m ²						F+U									
		Minor		Significantly		Heavy		Significantly		Heavy		Extreme		F		F+U							
F	% F	Av. m ²	± m ²	F	% F	Av. m ²	± m ²	F	% F	Av. m ²	± m ²	F	% F	Av. m ²	± m ²	%	Cum	%	Cum				
S →	D ↓			S →	D ↓			S →	D ↓			S →	D ↓										
1	111	75	83.33%	28.30%	12.53	9	10.00%	14.75%	10.73	3.48	1	1.11%	2.13%	0.66	0.13	5	5.56%	5.56%	11.59	19.44%	19.44%	25.52%	25.52%
2	185	106	77.37%	40.00%	12.31	20	14.60%	32.79%	39.73	12.89	9	6.57%	19.15%	45.63	8.83	2	1.46%	2.22%	18.32	29.59%	49.03%	42.53%	68.05%
3	22	17	51.52%	6.42%	1.18	6	18.18%	9.84%	8.32	2.70	6	18.18%	12.77%	17.30	3.35	4	12.12%	4.44%	5.87	7.13%	56.16%	5.06%	73.10%
4	109	58	34.52%	21.89%	5.79	24	14.29%	39.34%	42.36	13.74	29	17.26%	61.70%	76.31	14.77	57	33.93%	63.33%	115.71	36.29%	92.44%	25.06%	98.16%
5	8	9	25.71%	3.40%	0.37	2	5.71%	3.28%	21.63	7.01	2	5.71%	4.26%	12.92	2.50	22	63.86%	24.44%	124.60	7.56%	100.00%	1.84%	100.00%
Total weighted area damage																59.50							

Table 7
Manufacturing, Processing: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

		Sprinklers - Area damage m ²																									
U	F	Minor			Significantly			Heavy			Extreme			Weighted area damage m ²		F		F+U									
		%F		Av. m ²	%F		Av. m ²	%F		Av. m ²	%F		Av. m ²	± m ²	%	Cum	%	Cum									
		S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓																		
1	146	54	93.10%	29.51%	203.12	203.12	3	5.17%	20.00%	120.31	39.02	1	1.72%	25.00%	248.68	48.13	0	0.00%	0.00%	0.00	0.00	199.62	28.02%	28.02%	44.11%	44.11%	
2	138	81	95.29%	44.26%	420.41	420.41	3	3.53%	20.00%	86.25	27.97	1	1.18%	25.00%	60.10	11.63	0	0.00%	0.00%	0.00	0.00	404.38	41.06%	69.08%	41.69%	85.80%	
3	15	21	95.45%	11.48%	100.03	100.03	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	1	4.55%	20.00%	2.23	0.30	95.58	10.63%	79.71%	4.53%	90.33%	
4	28	25	65.79%	13.66%	204.15	204.15	9	23.68%	60.00%	2856.61	926.47	1	2.63%	25.00%	4.86	0.94	3	7.89%	60.00%	410.57	55.99	843.41	18.36%	98.07%	8.46%	98.79%	
5	4	2	50.00%	1.09%	41.62	41.62	0	0.00%	0.00%	0.00	0.00	1	25.00%	25.00%	200.35	38.78	1	25.00%	20.00%	98.11	13.38	95.42	1.93%	100.00%	1.21%	100.00%	
												Total weighted area damage												388.81			
		No Sprinklers - Area damage m ²																									
U	F	Minor			Significantly			Heavy			Extreme			Weighted area damage m ²		F		F+U									
		%F		Av. m ²	%F		Av. m ²	%F		Av. m ²	%F		Av. m ²	± m ²	%	Cum	%	Cum									
		S →	D ↓	S →	D ↓	S →	D ↓	S →	D ↓																		
1	29	18	78.26%	21.69%	10.93	10.93	1	4.35%	4.00%	4.69	1.52	0	0.00%	0.00%	0.00	0.00	4	17.39%	9.52%	288.07	39.28	58.86	13.69%	13.69%	19.59%	19.59%	
2	69	32	80.00%	38.55%	52.92	52.92	6	15.00%	24.00%	39.61	12.85	2	5.00%	11.11%	3.01	0.58	0	0.00%	0.00%	0.00	0.00	48.42	23.81%	37.50%	46.62%	66.22%	
3	8	9	56.25%	10.84%	13.57	13.57	2	12.50%	8.00%	11.72	3.80	4	25.00%	22.22%	116.75	22.60	1	6.25%	2.38%	129.14	17.61	46.36	9.52%	47.02%	5.41%	71.62%	
4	36	24	30.77%	28.92%	19.65	19.65	16	20.51%	64.00%	459.44	149.01	10	12.82%	55.56%	144.50	27.97	28	35.90%	66.67%	2007.78	273.79	839.56	46.43%	93.45%	24.32%	95.95%	
5	6	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	2	18.18%	11.11%	29.43	5.70	9	81.82%	21.43%	240.45	32.79	202.08	6.55%	100.00%	4.05%	100.00%	
												Total weighted area damage												427.03			

**Table 8
Table A.4 Area Damage and Percentage of Fire for Each Category of Fire Spread in Textile Industry, PD
7974-7 vs USA Fire Statistics**

	Production area						Storage area						Other areas										
	Area damage m ²			Frequency			Area damage m ²			Frequency			Area damage m ²			Frequency							
	Sprinklers	No Sprinklers		Sprinklers	No Sprinklers		Sprinklers	No Sprinklers		Sprinklers	No Sprinklers		Sprinklers	No Sprinklers		Sprinklers	No Sprinklers						
PD	USA	PD	USA	PD	USA	PD	USA	PD	USA	PD	USA	PD	USA	PD	USA	PD	USA	PD					
Confined to object	5	292.13	5	22.38	72%	22.22%	43%	13.79%	4	38.32	10	3.62	72%	20.69%	19%	6.45%	2	99.35	66%	32.52%	42%	15.89%	
Confined to room	Contents only	13	499.52	17	18%	53.70%	32%	34.48%	19	170.71	17	16.41	24%	48.28%	18%	12.90%	11	4	22%	22%	25%	24.30%	
	Structure involved	113		475	6%		13%				262				38%		68	68	8%	8%	18%		
Spread beyond room	Confined to floor		198.32			7.41%		3.45%		75.45		84.89		13.79%		16.13%		62.64		31.91		9.35%	
	Beyond building	694	429.16	694	4%	14.81%	12%	41.38%	1712	137.05	1712	161.70	4%	17.24%	25%	58.06%	1007	472.93	1004.24	4%	19.51%	43.93%	
Average		768.00		164.68		1.85%		6.90%		-		1176.10		0.00%		6.45%		89.72		86.14		2.44%	6.54%
		40	425.67	153	177.62				76	124.38	533	185.81					49	322.24	165	482.80			

There is also a 43.93% for fires confined to building of origin for un-sprinklered buildings. The average damage caused by the fire in the USA analysis is slightly lower in sprinklered than in un-sprinklered fires. The reason(s) behind this needs further investigation, but it is possible to say that sprinklers in other areas do limit the spread of fire as seen by the spread beyond room values of 33.33% and 59.82% for sprinklered and un-sprinklered structures, respectively.

6.2.2. Pubs, Clubs and Restaurants Table A.5 is focused on pubs, clubs and restaurants and in order to recreate a direct comparison with the USA fire statistics, within the property type of assembly, the following subclasses have been considered and the results for each of them summed together: Athletic or health club (includes YMCA or YWCA, lodge, swimming, and baths); Clubhouse associated with country club that includes golf, tennis, hunting, fishing, and riding activities; Yacht club (includes boating and yacht club facilities; excludes marinas, boat mooring facilities; boat repair/refuelling facilities; or boat sales, services, and repairs); Casino, gambling clubs (includes bingo halls—use only where primary use is for gambling); Clubs, others; Restaurant or cafeteria, places specializing in on-premises consumption of food (includes carryout and drive-through restaurants); Bar, nightclub, saloon, tavern, pub; Eating, drinking places, others.

As for Table A.4, Table A.5 presents fire frequency decreasing with increasing fire spread classes and increasing area damaged. In USA fire statistics, in presence of sprinklers, only 7 fires occurred for the class of fire beyond the building of origin. Fire frequency, from the USA statistics, of spread confined to the room of origin is 70.23% and 50.38% for sprinklered and un-sprinklered buildings, respectively (Table 9). Average area damage for both countries present lower values when buildings are equipped with sprinklers, and is significantly less when considering damage beyond room of origin.

The data recreated for Tables A.4 and A.5 show that the PD 7974-7 statistics may be no longer representative of the damage and frequency of fires as observed in fire statistics from the USA.

7. Frequency Distribution of Area Damage in Terms of Number of Fires

Tables A.6, A.7 and A.8 in PD 7974-7 describe the frequency distribution of area damage in terms of number of fires and fire origins for *Offices, Retail premises* and *Hotels*, respectively, with area damage ranging from '1 and under' to '1000 and above' m². For each area class, the number of fires and the percentage of fires exceeding the upper limit of the range are given. A distinction is present between sprinklered and un-sprinklered buildings. The data used in Tables A.6 to A.8 of PD 7974-7 are from UK Fire Statistics from 1979 and 1984 to 1987 and it is not clear if they are grouped for the 5 years or not. Fire size has been investigated more recently considering London Fire Brigade's real fire library in dwellings and other buildings [42], where the probability of fire exceeding specific classes of fire damage area is investigated.

Table 9
Table A.5 Area Damage and Percentage of Fire for Each Category of Fire Spread in Pubs, Clubs and Restaurants, PD 7974-7 vs USA Fire Statistics

	Area damage m ²				Frequency			
	Sprinklers		No Sprinklers		Sprinklers		No Sprinklers	
	PD	USA	PD	USA	PD	USA	PD	USA
Confined to object	1	31.30	1	4.19	59%	25.58%	26%	20.38%
<i>Confined to room</i>		24.11		13.81		44.65%		30.00%
Contents only	1		2		15%		12%	
Structure involved	4		15		19%		45%	
<i>Spread beyond room</i>	50		101		7%		17%	
Confined to floor		2.18		8.20		4.19%		7.69%
Confined to building		11.95		126.67		24.19%		37.31%
Beyond building of origin		1.02		79.05		1.40%		4.62%
Average	5	21.77	24	56.54				

Again, Table 1 summarizes the data used to recreate these tables using the NFIRS data, and classifying the fires with respect to the area damaged bands, sprinklered or un-sprinklered properties, and locations of ignition presented in Tables A.6, A.7, and A.8 of PD 7974-7.

7.1. Office Buildings

Table A.6 in PD 7974-7 has been recreated according to the class of *Business office* of the NFIRS database. Table 10 compares the data from Table A.6 to the analysis using the USA fire statistics, where for fire origin, the fire locations in Table A.6 (underlined) are represented as follows in the NFIRS: Office rooms—Office; Other rooms—all other areas of origin excluding those previously considered.

Sprinklered Office room fires are low in number both in the PD 7974-7 and the USA fire statistics. The PD 7974-7 data indicate that the maximum fire damage that occur is limited to 19 m², whereas the analysis of USA fire statistics show that fires in office rooms have a 30% to 35% chance of exceeding 19 m² and an 8.7% chance of exceeding 999 m². The trends for the two countries start with quite similar values, however, in all the USA fire statistical analyses of damage and frequency, the trend only once reaches zero (Table 18 in Appendix—Assembly areas) within the 1000 m² set of ranges, and almost always presents higher frequencies of fires exceeding the upper limit with the increased damaged areas (Fig. 13a).

For *un-sprinklered Office rooms*, the total number of fire recorded for each country is very different: 1860 in UK and 42 in USA. For both fire statistics, however, fires exceeding the first class of damage are very similar with 51.2% in PD 7974-7 data and 54.76% in the USA analysis. Comparing sprinklered and un-sprinklered fires, un-sprinklered fires more frequently experience damage up to

Table 10
Table A.6 Frequency Distribution of Area Damage in Terms of Number of Fires in Office Buildings, PD 7974-7 vs USA Fire Statistics

Area damage (m ²)	Sprinklers				No sprinklers			
	PD 7974-7		USA data		PD 7974-7		USA data	
	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit
<i>Office rooms</i>								
1 and under	13	27.8	15	34.78	908	51.2	19	54.76
2 to 4	3	11.1	0	34.78	379	30.8	0	54.76
5 to 9	0	11.1	0	34.78	144	23.1	2	50.00
10 to 19	2	0.0	0	34.78	116	16.8	0	50.00
20 to 49	0	0.0	1	30.43	154	8.5	2	45.24
50 to 99	0	0.0	0	30.43	69	4.8	7	28.57
100 to 199	0	0.0	1	26.09	35	3.0	4	19.05
200 to 499	0	0.0	4	8.70	33	1.2	6	4.76
500 to 999	0	0.0	0	8.70	13	0.5	1	2.38
1000 and above	0	0.0	2	0.00	9	0.0	1	0.00
	18		23		1860		42	
<i>Other areas</i>								
1 and under	95	25.2	66	37.74	2588	40.8	126	48.36
2 to 4	17	11.8	0	37.74	902	20.1	1	47.95
5 to 9	9	4.7	2	35.85	303	13.2	5	45.90
10 to 19	2	3.1	2	33.96	199	8.6	6	43.44
20 to 49	3	0.8	1	33.02	180	4.5	18	36.07
50 to 99	1	0.0	3	30.19	75	2.8	29	24.18
100 to 199	0	0.0	6	24.53	53	1.6	25	13.93
200 to 499	0	0.0	10	15.09	40	0.7	19	6.15
500 to 999	0	0.0	3	12.26	18	0.3	11	1.64
1000 and above	0	0.0	13	0.00	11	0.00	4	0.00
	127		106		4369		244	

99 m². Figure 13 also shows that the frequency of exceeding the damage band upper limit in the USA is higher than seen in PD 7974-7. However, there are few data points for both sprinklered and un-sprinklered fires, and in future research, greater fidelity of these relationships is required.

In **Other rooms**, the total number of fires in the two countries for *sprinklered* fires is again similar (127 in UK and 106 in USA). According to Table 10, the fire is confined to damage of less than 1 m² in 74.8% in PD 7974-7 and 62.26% in the USA statistics. However, the main and significant difference is that in the NFIRS analysis 12.26% fires will exceed 1000 m² of damage, while in the UK fire statistics the maximum fire damage area is 99 m².

When *Other rooms* are *un-sprinklered*, there are significantly higher number of fires reported in the UK statistics compared to the USA statistics (4369 UK and 244 USA). Similar to Office rooms, both sets of data have a high percentage of fire experiences 1 m² of damage or less (59.2% UK and 51.64% USA), however, the USA fire statistics shows percentages exceeding the upper limit greater than 24.18% for area damage greater than 50 m² compared to 2.8% in PD 7974-7 (Fig. 13b). Figure 13, shows a significant difference in trends, which needs greater analysis.

7.2. Retail Premises

Table A.7 in the PD 7974-7 for retail premises has been recreated using the class of *Mercantile, Business*. The results are shown in Table 17 in the Appendix for the three fire locations in PD 7974-7 represented in the NFIRS data as follows: Assembly areas - Assembly or Sales Areas (Group of people); Storage areas - Storage Areas; Other areas - All the other areas excluding the two previously mentioned.

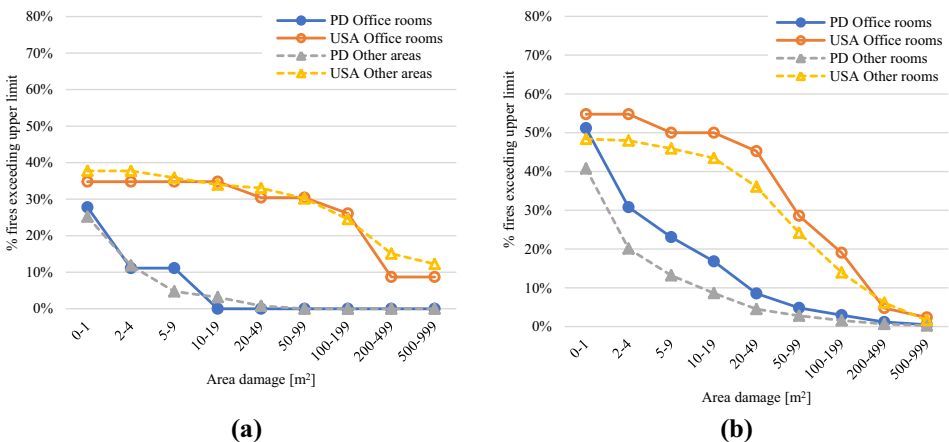


Figure 13. Frequency distribution of area damage in terms of number of fires in Office buildings (Office rooms and Other rooms) for (a) presence and (b) absence of automatic extinguishing systems.

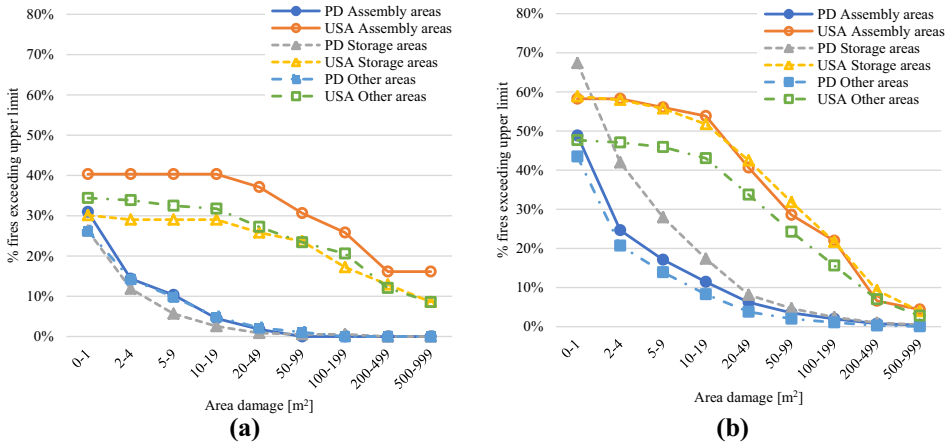


Figure 14. Frequency distribution of area damage in terms of number of fires in Retail premises (Assembly or Sales Areas (Group of people), Storage areas and Other areas) for (a) presence and (b) absence of automatic extinguishing systems.

In *sprinklered Assembly areas*, the total number of fires (223—not 224 as incorrectly stated in PD 7974-7) collected in the PD 7974-7 is almost 4 times bigger than the one in the USA fire statistics (62). In both the UK and USA fire statistics, it can be seen that a large proportion of the fires are limited to less than 1 m² of damage, specifically 69.1% for UK and 59.68% in the USA fire statistics. However, in the NFIRS data, it can be seen that fires create greater areas of damage than detailed in the PD 7974-7 data, with 16.13% of fires causing 1000 m² of damage or more. In comparison, PD 7974-7, has an upper limit of damaged area of 99 m² (Fig. 14a and Table 17 in Appendix).

In *un-sprinklered Assembly areas*, over 8000 more fires were reported in the UK statistics compared to the USA statistics, however, the distributions appear comparable. Both sets of results show that damage of lower than 1 m² is frequent with 51.1% UK, and 41.76% in USA. Figure 14b and Table 17, also show that in USA statistics there is a higher likelihood of experiencing greater areas of damage, where the percentage of fires exceeding the upper limit that spread beyond 50 m² is 28.57% (USA) compared to 3.5% in PD 7974-7.

The total number of *sprinklered Storage areas* fires collected in PD 7974-7 (354) are almost three times the one in the USA fire statistics (93). The distribution of fire frequency according to the area damage is similar as for previous trends, with a significant difference between the USA and PD relationships (Fig. 14a). One of the key issues, like previous areas, there is a significant number of fires exceeding 1000 m² of area damaged in the USA data, whereas the maximum area of damage predicted by PD 7974-7 is 499 m².

For *un-sprinklered Storage areas* fires, both UK and USA data show that more than 50% of fires will cause more than 1 m² of damage, however, in the UK this quickly diminishes to 17.4% of fires causing more than 20 m² of damage, and to less than 5% for area damage between 50 and 99 m², compared to 51.77% of fires

in the USA causing more than 20 m² of damage, and 31.86% for area damage between 50 and 99 m² (Fig. 14b). When considering larger damaged area fires, 3.98% and 0.5% of fires in the USA and UK databases, respectively, cause more than 1000 m² of damage. These are significant differences when considering the design of storage areas of retail premises.

In **Other areas**, when *sprinklers* are present, the total number of fires collected this time is greater in USA (573) than in PD 7974-7 (183). Again, the trends for frequencies in the two countries are comparable to the ones found in the other scenarios with relatively small frequencies exceeding the damage upper limit of 1 m² (Fig. 14a). USA fires have a higher proportion of fires causing greater areas of damage with 8.6% of fires exceeding 1000 m² compared to PD 7974-7 having no fires exceeding 200 m² of damage. In *un-sprinklered Other areas*, the total number of fires collected in the UK (7194) is again greater than those collected in the USA fire statistics (1542). Trends between PD 7974-7 and USA are similar to the ones for presence of automatic extinguish systems with the only difference that the values of frequencies between the two countries present a higher gap and the percentages of fire exceeding the higher limit are greater (Fig. 14b).

For retail premises, the analysis presented shows that sprinklers are effective at limiting the frequency of small area damage fires, but do not necessarily limit the larger damaged area fire frequency; and that PD 7974-7 seems to underestimate these fire area damage and frequency.

7.3. Hotels

Table A.8 in the PD 7974-7 has been recreated (Table 18 in Appendix) according to the class of *Hotel/Motel*, commercial and Boarding/Rooming house (this includes residential hotels and shelters). For fire origin, the locations in Table A.8 have been represented as follows in the NFIRS: Assembly areas—Assembly or sales Areas (Group of people); Bedrooms—Bedroom for less than five people (includes jail or prison cells, lockups, patient rooms, sleeping areas) and Bedroom for more than five people (includes barracks, dormitories, patient wards); Storage and Other Areas—All the other areas excluding the two previously mentioned.

Only *un-sprinklered* fire comparisons have been made for *Assembly areas* and *Bedrooms* since no sprinklers fire data is present in Table A.8. In **Assembly areas**, the USA fire statistics only report 12 fires, so comparisons should be taken cautiously. However, it seems, according to Fig. 15b, that a similar trend can be seen as for other analyses in un-sprinklered areas, with the USA data showing that fires more often cause larger areas to be damaged than suggested by PD 7974-7. In **Bedrooms**, the un-sprinklered comparison is shown in Fig. 15b. Firstly, the total number of fires stated in Table A.8 is wrong and should be equal to 1196 and not 1205, and this is compared to 84 fires from the USA statistics. Again, both datasets have similar values for fires damaging less than 1 m², and that the USA data have more fires that cause greater damage, 3.6% of fires causing in excess of 1000 m² of damage.

In *sprinklered Storage areas and other areas*, more fire data were collected in the USA fire statistics (255 fires) compared to PD 7974-7 (35 fires). Figure 15a, shows

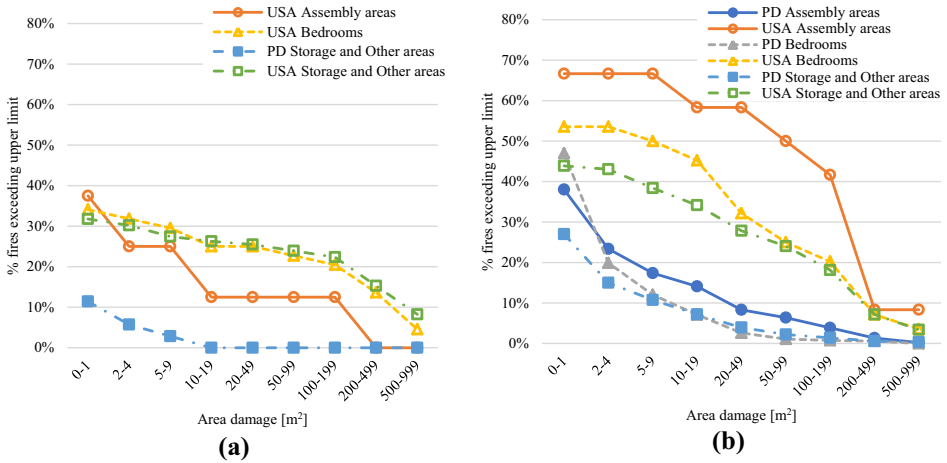


Figure 15. Frequency distribution of area damage in terms of number of fires in Hotels (Assembly areas, Bedrooms and Storage and Other areas) for (a) presence and (b) absence of automatic extinguishing systems.

that the upper damage limit in the UK data is 19 m² whereas, the USA data show that the probability of this value being exceeded is 26.27%, and that the area damaged will exceed 1000 m² on 8.24% of occasions. In *un-sprinklered Storage areas and other areas*, the USA data suggests that greater damage is to be expected than the UK data predict (Fig. 15b).

As can be seen from the above analyses, there seems to be a consistent and significant difference in the probability of area damaged, with the USA statistics presenting higher probabilities in every case compared to the data presented in Tables A.6, A.7 and A.8 of PD 7974-7 which should be revised using more current fire statistics.

8. Average Loss per Fire

Table A.12 presents the average loss per fire in 1966 for different property types. The conversion of 1966 GBP to 2014 GBP is calculated using Historical UK inflation rates and is equal to £1: £16.64 [43]. NFIRS fire loss data is calculated using Eq. (3) above in Sect. 3.1 and an average loss per fire can then be calculated for different property types. Table A.12 can therefore be expressed and compared to USA fire loss data, where the USD to GBP conversion is necessary to have the same currency and is based on December 2014 exchange rate [44] of 1 USD = 0.607353 GBP.

The different property types in Table A.12 of PD 7974-7 have no direct comparison in the NFIRS database, therefore some classes have been grouped together. Based on the classifications in Table A.12 the following classes have been adopted in the NFIRS: Wholesale distributive trades and Retail distributive trades

grouped together and considered as *Mercantile, Business*; Chemical and allied as the sum of: *Laboratory or science laboratory, Gas distribution, gas pipeline and Flammable liquid distribution system, flammable liquid pipeline*; Timber and furniture, Textiles and Paper, printing and publishing grouped together and considered as *Manufacturing, Processing*.

Table 11 presents the analysis for all the property types listed in Table A.12 as well as several others found in the NFIRS statistics (i.e. Educational). In general, the presence of sprinklers reduces the expected financial loss per fire. Clearly, there are also some exceptions for example in the NFIRS for single storey in Outside and special property (£11,916 sprinklered and £7918 in un-sprinklered) and for multi-storey in Industrial, Utility, Defence, Agricultural and Mining (£887,731 sprinklered and £45,585 un-sprinklered). All the financial losses for the NFIRS in Table 11 have been rounded to the nearest pound.

9. General Considerations and Conclusions

This paper has presented an in depth analysis and comparison of the PD 7974-7 Annex A Tables A.1, A.2, A.4, A.5, A.6, A.7, A.8, and A.12 to the NFIRS fire statistics from the USA (with selected comparisons to current UK data where available). This paper has also presented a brief history of where the current PD 7974-7 analyses and functions have been derived from and highlighted the need to update these with more recent fire statistics, as the data within PD 7974-7 Annex A can date back to 1966.

USA fire statistics were used for this comparison as necessary datasets were not available to the authors at the time of initial analyses. Comparing PD 7974-7 and USA fire statistics is clear to understand how common fire incidents fields are recorded by fire departments in the two countries and conversions have been developed to harmonize possible different values. The authors are aware of the differences in engineering culture, sets of codes and approach to fire safety within the two countries, however, the research has to be contextualized as the first attempt to improve a complex and fundamental data problem relating to the application of probabilistic techniques to fire safety.

The current Table A.2 over-estimates the frequency of fire in all areas, with residential fires in contemporary UK and USA statistics being half as frequent as stated in PD 7974-7, and 10 to 100 less frequent in hospitals as stated assuming frequency on a yearly basis.

When fire frequency is obtained with respect to building area (Table A.1 PD 7974-7) in the USA fire statistics following the approach used in PD 7974-7, very little correlation can be seen between old and new relationships. Two improved functions are proposed, a power law and a polynomial law, which provide better correlations, however the physical reality of these curves needs to be investigated further. Greater fidelity in building size is required to improve these relationships, which are limited in some cases (i.e. industrial structures) to the Rutstein's approach and not always present a positive exponent for the power law. Possible reasons could be due to the composition of the industrial buildings sample or to the nature of the function.

Table 11
Average Loss per Fire at 1966 for PD 7974-7 Converted into 2014 Prices in Order to Create a
Comparison with the USA Fire Statistics

N floors	PD 7974-7						USA data								
	Sprinklers			No sprinklers			Sprinklers			Partial systems			No sprinklers		
	Single	Multi		Single	Multi		Single	Multi		Single	Multi		Single	Multi	
A	/	/	/	/	/	/	£9381	£37,035	£17,882	£80,780	£45,145	£58,493			
B	/	/	/	/	/	/	£3717	£8197	£15,275	£0	£1,485,020	£24,579			
C	/	/	/	/	/	/	£1425	£6724	£197	£0	£20,999	£46,014			
D	/	/	/	/	/	/	£5067	£19,197	£27,564	£17,573	£13,702	£23,173			
E	/	/	/	/	/	/	£6795	£8986	£22,749	£154,237	£31,634	£60,274			
F	/	£78,208		£63,232	£156,416										
G	/	£23,296		£6656	£39,936										
H							£9431	£887,731	£607	£30,368	£43,718	£45,585			
I							£1397	£8098	–	–	£12,893	£1518			
J							£54,015	£23,969	£11,862	£611,406	£38,869	£107,086			
K	£19,968	£53,248		£39,936	£108,160										
L	£48,256	£58,240		£109,824	£419,328										
M	£86,528	£83,200		£118,144	£269,568										
N	/	/	/	/	/	/	£7792	£3155	£20,549	£1974	£11,661	£19,488			
O	/	/	/	/	/	/	£11,916	£89,266	£3037	£0	£7918	£251,523			

A Assembly; B Educational; C Health care, Detention and Correction; D Residential; E Mercantile, Business; F Wholesale and distributive trades; G Retail distributive trades; H Industrial, Utility, Defence, Agricultural and Mining; I Chemical and allied; J Manufacturing, Processing; K Timber and furniture; L Textiles; M Paper, printing and publishing; N Storage; O Outside or special property

The relationship of fire spread and damage has been examined in depth within this paper, where 8 different property types are examined from the NFIRS data. The results show that sprinkler systems can increase the likelihood of fires being contained to the object first ignited by between 10% and 30% depending on building type. Sprinklers can also reduce the degree of damage observed being limited to the class of minor damage and the spread to the room of origin. Moreover, sprinklers effectiveness can limit fire damage and spread, in 4 property types (*Educational; Health care, Detention and Correction; Industrial, Utility, Defence, Agricultural and Mining; Storage*) while in 3 of them only the area damage is reduced (*Assembly; Residential; Mercantile, Business*) and in *Manufacturing, Processing* only the fire spread and not the damage is confined.

PD 7974-7 data (Tables A.4 and A.5) predict less fire spread and damage than presented in the USA fire statistics. Both PD 7974-7 and USA fire statistics have fire frequencies being well confined to the room of origin, however, in the NFIRS there are non-negligible percentages of fires being confined to building or beyond.

The frequencies of area damaged in Tables A.6, A.7, and A.8 in PD 7974-7 Annex A, are un-conservative if compared to the analysis of the USA fire statistics which shows that fires more frequently cause greater damage. The form of the reducing frequency is very different to that presented in PD 7974-7, which has in general a zero value for more than 50 m² and neglects the tail of the NFIRS tendency.

Finally, analysing the direct financial loss, the average loss per fire was also compared between PD 7974-7 and the NFIRS data, and showed that sprinklered structures experienced less loss in general than un-sprinklered fires. These values are also on average less than those presented in PD 7974-7 where comparisons can be made.

One general consideration from this paper is that sprinkler systems can be a very effective means across all building types to reduce the severity of fire spread, damage (due to flame) and loss. However, the cost to benefit ratio of this needs to be explored in detail for each building type.

In conclusions, USA fire statistics have been investigated based on Rutstein's approach for the definition of fire frequency according to total building floor area (Table A.1) while the other tables in PD 7974-7 recreated grouping and elaborating the data in the NFIRS. Changes are attributable to updated values for the fields present in the current fire statistics and not to a different method of analysis. Differences need to be considered with a degree of caution since PD 7974-7 datasets, with which previous data have been obtained, are not available and USA fire statistics could report data with a certain degree of uncertainty. However, the quantity of fire incidents present in the NFIRS provides significant statistical distribution. Future works will investigate the improved frequency functions introduced in the paper and the new released UK fire statistics of 2017.

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Appendix

See Figs. 16, 17, 18, 19, 20 and Tables 12, 13, 14, 15, 16, 17, 18.

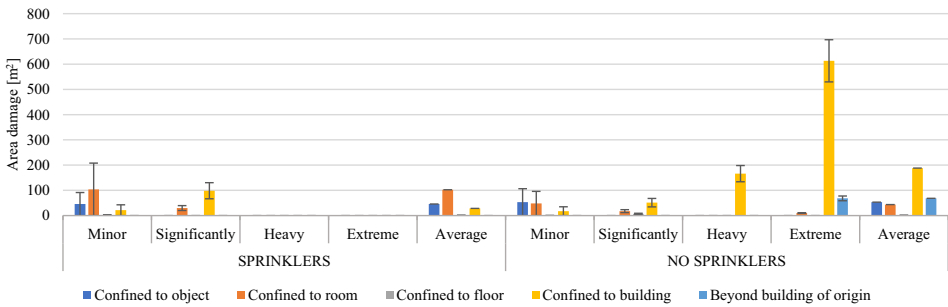


Figure 16. Area damage in Health Care, Detention and Correction for different spread of fire and damage classes, including weighted average area damage.

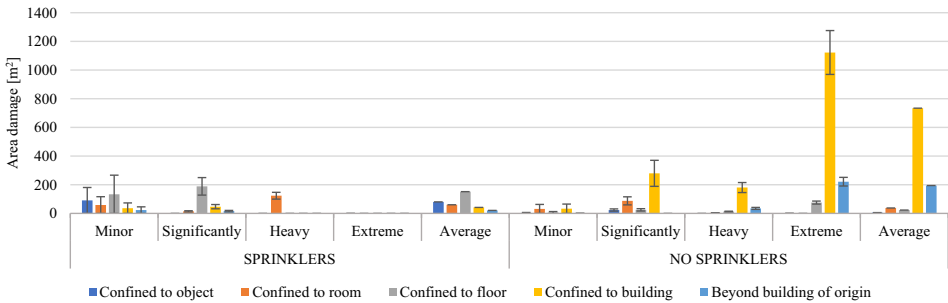


Figure 17. Area damage in Industrial, Utility, Defence, Agricultural, and Mining for different spread of fire and damage classes, including weighted average area damage.

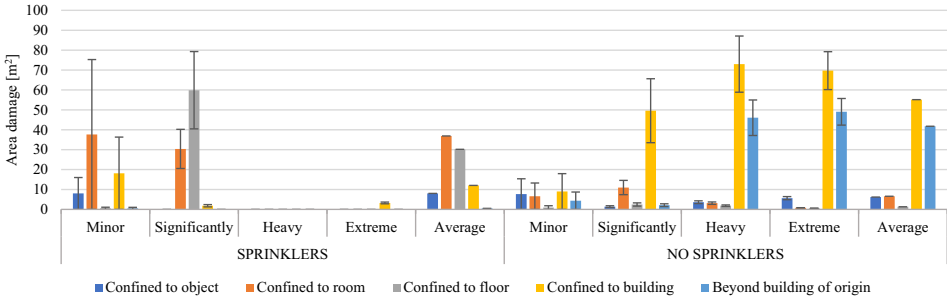


Figure 18. Area damage in Storage for different spread of fire and damage classes, including weighted average area damage.

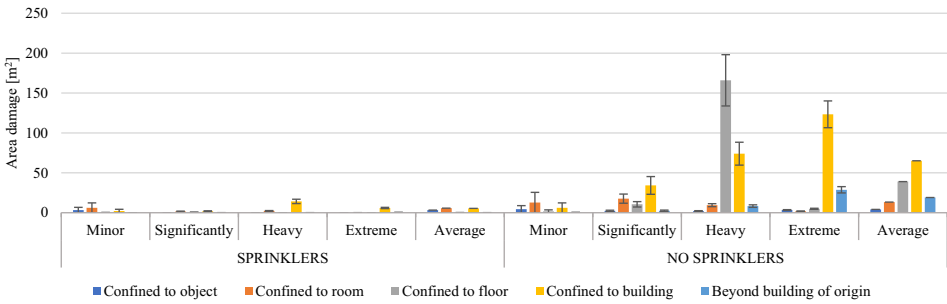


Figure 19. Area damage in Residential for different spread of fire and damage classes, including weighted average area damage.

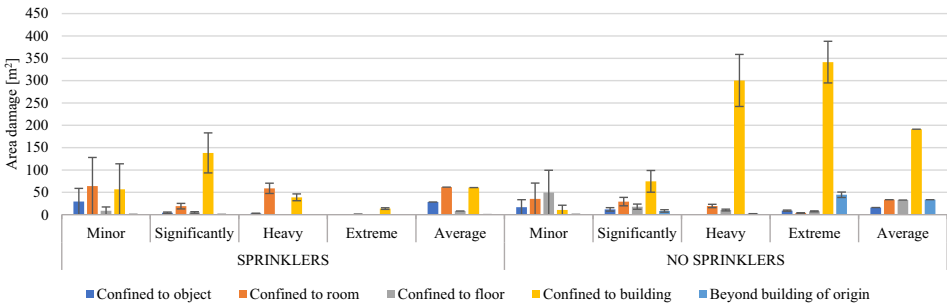


Figure 20. Area damage in Mercantile, Business for different spread of fire and damage classes, including weighted average area damage.

Table 12
Table A.7 Health care, Detention and Correction: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

<u>Sprinklers - Area damage m²</u>																									
U		Minor						Significantly						Heavy						F		F+U			
		% F		Av. m ²	± m ²	F	% F		Av. m ²	± m ²	F	% F		Av. m ²	± m ²	F	% F		Av. m ²					± m ²	
		S →	D ↓				S →	D ↓				S →	D ↓				S →	D ↓							
1	87	34	100.00%	37.36%	45.75	45.75	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	45.75	36.56%	36.56%	39.55%	39.55%
2	124	45	97.83%	49.45%	103.85	103.85	1	2.17%	50.00%	29.79	9.66	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	102.24	49.46%	86.02%	56.36%	95.91%
3	2	2	100.00%	2.20%	1.65	1.65	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	1.65	2.15%	88.17%	0.91%	96.82%
4	7	10	90.91%	10.99%	21.43	21.43	1	9.09%	50.00%	98.31	31.88	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	28.42	11.83%	100.00%	3.18%	100.00%
5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total weighted area damage																				70.70					
<u>No Sprinklers - Area damage m²</u>																									
U		Minor						Significantly						Heavy						F		F+U			
		% F		Av. m ²	± m ²	F	% F		Av. m ²	± m ²	F	% F		Av. m ²	± m ²	F	% F		Av. m ²					± m ²	
		S →	D ↓				S →	D ↓				S →	D ↓				S →	D ↓							
1	27	15	100.00%	25.00%	53.17	53.17	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	53.17	17.65%	17.65%	31.03%	31.03%
2	41	30	85.71%	50.00%	47.97	47.97	4	11.43%	36.36%	17.60	5.71	0	0.00%	0.00%	0.00	0	0.00%	11.11%	10.22	1.39	43.42	41.18%	58.82%	47.13%	78.16%
3	5	3	75.00%	5.00%	0.26	0.26	1	25.00%	9.09%	6.87	2.23	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	1.92	4.71%	63.53%	5.75%	83.91%
4	13	12	40.00%	20.00%	17.53	17.53	6	20.00%	54.55%	51.17	16.60	5	16.67%	100.00%	166.12	32.15	7	23.33%	77.78%	613.23	83.62	188.02	98.82%	14.94%	98.85%
5	1	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0	0.00%	11.11%	68.13	9.29	68.13	1.18%	100.00%	1.15%	100.00%
Total weighted area damage																				94.51					

Table 13
Table A.8 Industrial, Utility, Defence, Agricultural and Mining: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

		<u>Sprinklers - Area damage m²</u>																																
		<i>Minor</i>						<i>Significantly</i>						<i>Heavy</i>						<i>Extreme</i>			<i>Weighted area damage m²</i>		<i>F</i>		<i>F+U</i>							
<i>U</i>	<i>F</i>	% F		Av. m ²	± m ²	<i>F</i>	% F	S →	D ↓	Av. m ²	± m ²	<i>F</i>	% F	S →	D ↓	Av. m ²	± m ²	<i>F</i>	% F	S →	D ↓	Av. m ²	± m ²	% F	Cum	% Cum	% F	Cum	% F	Cum	% F	Cum		
		S →	D ↓																															
1	11	8	88.89%	32.00%	90.34	90.34	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	0.00	1	11.11%	100.00%	0.39	0.05	80.34	29.03%	29.03%	31.43%	31.43%	31.43%	31.43%	31.43%	31.43%	31.43%		
2	20	11	84.62%	44.00%	58.34	58.34	1	7.69%	25.00%	14.06	4.56	1	7.69%	100.00%	123.43	23.89	0	0.00%	0.00%	0.00%	0.00	0.00	59.94	41.94%	70.97%	57.14%	88.57%	88.57%	88.57%	88.57%	88.57%	88.57%		
3	1	2	66.67%	8.00%	133.30	133.30	1	33.33%	25.00%	188.63	61.18	0	0.00%	0.00%	0.00	0.00	0.00	0	0.00%	0.00%	0.00%	0.00	0.00	151.74	9.68%	80.65%	2.86%	91.43%	91.43%	91.43%	91.43%	91.43%	91.43%	
4	3	1	50.00%	4.00%	36.35	36.35	1	50.00%	25.00%	46.87	15.20	0	0.00%	0.00%	0.00	0.00	0.00	0	0.00%	0.00%	0.00%	0.00	0.00	41.61	6.45%	87.10%	8.57%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	
5	0	3	75.00%	12.00%	22.88	22.88	1	25.00%	25.00%	15.62	5.07	0	0.00%	0.00%	0.00	0.00	0.00	0	0.00%	0.00%	0.00%	0.00	0.00	21.07	12.90%	100.00%	0.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
		Total weighted area damage																					68.55											
		<u>No Sprinklers - Area damage m²</u>																																
		<i>Minor</i>						<i>Significantly</i>						<i>Heavy</i>						<i>Extreme</i>			<i>Weighted area damage m²</i>		<i>F</i>		<i>F+U</i>							
<i>U</i>	<i>F</i>	% F		Av. m ²	± m ²	<i>F</i>	% F	S →	D ↓	Av. m ²	± m ²	<i>F</i>	% F	S →	D ↓	Av. m ²	± m ²	<i>F</i>	% F	S →	D ↓	Av. m ²	± m ²	% F	Cum	% Cum	% F	Cum	% F	Cum	% F	Cum	% F	Cum
		S →	D ↓																															
1	34	10	71.43%	16.39%	2.97	2.97	2	14.29%	12.50%	23.50	7.62	0	0.00%	0.00%	0.00	0.00	2	14.29%	1.90%	1.55	0.21	5.70	6.97%	6.97%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%	24.82%
2	28	20	83.33%	32.79%	31.38	31.38	3	12.50%	18.75%	87.50	28.38	1	4.17%	5.26%	4.11	0.80	0	0.00%	0.00%	0.00%	0.00	0.00	37.26	11.94%	18.91%	20.44%	45.26%	45.26%	45.26%	45.26%	45.26%	45.26%	45.26%	45.26%
3	8	8	53.33%	13.11%	6.46	6.46	2	13.33%	12.50%	25.00	8.11	2	13.33%	10.53%	12.62	2.44	3	20.00%	2.86%	75.62	10.31	23.58	7.46%	26.37%	5.84%	51.09%	51.09%	51.09%	51.09%	51.09%	51.09%	51.09%	51.09%	51.09%
4	54	21	19.09%	34.43%	32.46	32.46	9	8.18%	56.25%	279.68	90.71	13	11.82%	68.42%	180.64	34.96	67	60.91%	63.81%	1122.31	153.04	734.02	54.73%	81.09%	39.42%	90.51%	90.51%	90.51%	90.51%	90.51%	90.51%	90.51%	90.51%	90.51%
5	13	2	5.26%	3.28%	0.32	0.32	0	0.00%	0.00%	0.00	0.00	3	7.89%	15.79%	34.81	6.74	33	86.84%	31.43%	220.97	30.13	194.66	18.91%	100.00%	9.49%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
		Total weighted area damage																					445.11											

Table 14
Storage: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

Sprinklers - Area damage m ²																										
U	F	Minor			Significantly			Heavy			Extreme			Weighted area damage m ²			F		F+U							
		%F	Av. m ²	± m ²	%F	Av. m ²	± m ²	%F	Av. m ²	± m ²	%F	Av. m ²	± m ²	S →	D ↓	F	S →	D ↓	F	%	Cum	%	Cum			
																								F	%	Cum
1	24	13	100.00%	32.50%	8.01	8.01	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	0.00	0.00	27.08%	27.08%	28.57%	28.57%
2	45	18	90.00%	45.00%	37.65	37.65	2	10.00%	40.00%	30.37	9.85	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	0.00	0.00	41.67%	68.75%	53.57%	82.14%
3	3	2	50.00%	5.00%	0.54	0.54	2	50.00%	40.00%	59.86	19.41	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	0.00	0.00	8.33%	77.08%	3.57%	85.71%
4	11	6	60.00%	15.00%	18.15	18.15	1	10.00%	20.00%	1.82	0.59	0	0.00%	0.00%	0.00	3	30.00%	100.00%	3.23	0.44	0.44	0.44	20.83%	97.92%	13.10%	98.81%
5	1	1	100.00%	2.50%	0.50	0.50	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0	0.00%	0.00%	0.00	0.00	0.00	0.00	2.08%	100.00%	1.19%	100.00%
																			Total weighted area damage			22.59				
No Sprinklers - Area damage m ²																										
U	F	Minor			Significantly			Heavy			Extreme			Weighted area damage m ²			F		F+U							
		%F	Av. m ²	± m ²	%F	Av. m ²	± m ²	%F	Av. m ²	± m ²	%F	Av. m ²	± m ²	S →	D ↓	F	S →	D ↓	F	%	Cum	%	Cum			
																								F	%	Cum
1	171	106	46.49%	15.06%	7.69	7.69	14	6.14%	5.26%	1.39	0.45	14	6.14%	5.91%	3.60	0.70	94	41.23%	6.59%	5.64	0.77	6.21	8.66%	8.66%	9.53%	9.53%
2	234	196	73.13%	27.84%	6.61	6.61	39	14.55%	14.66%	10.98	3.56	8	2.99%	3.38%	3.14	0.61	25	9.33%	1.75%	0.77	0.11	6.60	10.18%	18.84%	13.04%	22.58%
3	50	38	59.38%	5.40%	0.92	0.92	13	20.31%	4.89%	2.48	0.80	8	12.50%	3.38%	1.86	0.36	5	7.81%	0.35%	0.54	0.07	1.33	2.43%	21.27%	2.79%	25.36%
4	986	293	20.71%	41.62%	8.98	8.98	168	11.87%	63.16%	49.58	16.08	166	11.73%	70.04%	72.97	14.12	788	55.69%	55.26%	69.72	9.51	55.14	53.74%	75.01%	54.96%	80.32%
5	353	71	10.79%	10.09%	4.35	4.35	32	4.86%	12.03%	2.13	0.69	41	6.23%	17.30%	46.07	8.92	514	78.12%	36.04%	49.03	6.69	41.75	24.99%	100.00%	19.68%	100.00%
																			Total weighted area damage			41.30				

Table 15
Residential: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

<u>Sprinklers - Area damage m²</u>																										
U	Minor			Significantly			Heavy			Extreme			Weighted area damage m ²		F		F+U									
	F	% F		F	% F		F	% F		F	% F		± m ²	± m ²	%	Cum	%	Cum								
		S →	D ↓		S →	D ↓		S →	D ↓		S →	D ↓														
1	404	163	98.79%	21.68%	3.35	3.35	1	0.61%	0.95%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	3.30	17.03%	17.03%	23.96%	23.96%					
2	1061	466	89.44%	61.97%	6.19	6.19	47	9.02%	44.76%	1.52	0.49	6	1.15%	9.09%	2.26	0.44	2	0.38%	4.35%	0.16	0.02	5.70	53.77%	70.79%	62.93%	86.89%
3	82	30	76.92%	3.99%	0.21	0.21	6	15.38%	5.71%	0.53	0.17	2	5.13%	3.03%	0.03	0.01	1	2.56%	2.17%	0.02	0.00	0.25	4.02%	74.82%	4.86%	91.76%
4	118	91	40.27%	12.10%	2.16	2.16	47	20.80%	44.76%	1.81	0.59	53	23.45%	80.30%	14.13	2.73	35	15.49%	76.09%	5.88	0.80	5.47	23.32%	98.14%	7.00%	98.75%
5	21	2	11.11%	0.27%	0.00	0.00	4	22.22%	3.81%	0.10	0.03	5	27.78%	7.58%	0.14	0.03	7	38.89%	15.22%	0.32	0.04	0.19	1.86%	100.00%	1.25%	100.00%
Total weighted area damage															4.92											
<u>No Sprinklers - Area damage m²</u>																										
U	Minor			Significantly			Heavy			Extreme			Weighted area damage m ²		F		F+U									
	F	% F		F	% F		F	% F		F	% F		± m ²	± m ²	%	Cum	%	Cum								
		S →	D ↓		S →	D ↓		S →	D ↓		S →	D ↓														
1	2902	2652	82.08%	18.74%	4.44	4.44	217	6.72%	4.35%	2.34	0.76	108	3.34%	2.98%	2.17	0.42	254	7.86%	4.73%	3.36	0.46	4.14	11.48%	11.48%	17.97%	17.97%
2	9574	7303	78.84%	51.60%	12.79	12.79	1535	16.57%	30.77%	17.65	5.72	344	3.71%	9.50%	9.45	1.83	81	0.87%	1.51%	1.87	0.25	13.38	32.92%	44.41%	44.10%	62.08%
3	1784	1056	39.62%	7.46%	1.75	1.75	842	31.59%	16.88%	10.54	3.42	556	20.86%	15.35%	166.01	32.13	211	7.92%	3.93%	4.92	0.67	39.05	9.47%	53.88%	8.22%	70.30%
4	5538	2883	25.76%	20.37%	6.19	6.19	2228	19.91%	44.66%	34.22	11.10	2341	20.91%	64.65%	74.02	14.33	3741	33.42%	69.66%	123.36	16.82	65.12	39.78%	93.67%	25.51%	95.81%
5	910	260	14.59%	1.84%	0.31	0.31	167	9.37%	3.35%	2.48	0.80	272	15.26%	7.51%	8.29	1.60	1083	60.77%	20.17%	28.74	3.92	19.01	6.33%	100.00%	4.19%	100.00%
Total weighted area damage															35.69											

Table 16
Mercantile, Business: Area Damage and Fire Spread According to Damage Class; Fire Frequency with Respect to Fire Spread in Presence and Absence of Automatic Extinguishing Systems, with Weighted area Damage, and Frequency for Fires and Unclassified Damage Fires in the USA Fire Statistics

<u>Sprinklers - Area damage m²</u>																										
U	F	Minor				Significantly				Heavy				Extreme				Weighted area damage m ²		F		F+U				
		% F		Av. m ²	± m ²	% F		Av. m ²	± m ²	% F		Av. m ²	± m ²	% F		Av. m ²	± m ²	%	Cum	%	Cum					
		S →	D ↓	F	D ↓	S →	D ↓	F	D ↓	S →	D ↓	F	D ↓													
1	165	68	95.77%	29.47	29.47	2	2.82%	13.33%	4.47	1.45	1	1.41%	16.67%	2.86	0.55	0	0.00%	0.00%	0.00	0.00	28.39	27.31%	27.31%	35.18%	35.18%	
2	228	115	93.50%	64.07	64.07	5	4.07%	33.33%	19.16	6.22	2	1.63%	33.33%	58.94	11.41	1	0.81%	20.00%	0.81	0.11	61.64	47.31%	74.62%	48.61%	83.80%	
3	19	13	86.67%	8.63	8.63	2	13.33%	13.33%	4.97	1.61	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	8.14	5.77%	80.38%	4.05%	87.85%	
4	51	36	75.00%	56.89	56.89	5	10.42%	33.33%	138.18	44.82	3	6.25%	50.00%	38.83	7.51	4	8.33%	80.00%	13.72	1.87	60.63	18.46%	98.85%	10.87%	98.72%	
5	6	2	66.67%	0.33	0.33	1	33.33%	6.67%	0.30	0.10	0	0.00%	0.00%	0.00	0.00	0	0.00%	0.00%	0.00	0.00	0.32	1.15%	100.00%	1.28%	100.00%	
																			Total weighted area damage		48.58					
<u>No Sprinklers - Area damage m²</u>																										
U	F	Minor				Significantly				Heavy				Extreme				Weighted area damage m ²		F		F+U				
		% F		Av. m ²	± m ²	% F		Av. m ²	± m ²	% F		Av. m ²	± m ²	% F		Av. m ²	± m ²	%	Cum	%	Cum					
		S →	D ↓	F	D ↓	S →	D ↓	F	D ↓	S →	D ↓	F	D ↓													
1	221	151	87.79%	27.66%	16.79	16.79	10	5.81%	7.25%	11.90	3.86	0	0.00%	0.00%	0.00	0.00	11	6.40%	5.70%	9.07	1.24	16.01	17.53%	17.53%	24.07%	24.07%
2	337	230	81.56%	42.12%	35.34	35.34	36	12.77%	26.09%	29.24	9.48	12	4.26%	11.54%	19.37	3.75	4	1.42%	2.07%	3.73	0.51	33.43	28.75%	46.28%	36.71%	60.78%
3	62	34	51.52%	6.23%	49.68	49.68	21	31.82%	15.22%	17.83	5.78	6	9.09%	5.77%	10.45	2.02	5	7.58%	2.59%	7.42	1.01	32.77	6.73%	53.01%	6.75%	67.54%
4	254	124	29.81%	22.71%	10.52	10.52	67	16.11%	48.55%	74.57	24.19	85	20.43%	81.73%	300.41	58.14	140	33.65%	72.54%	341.46	46.56	191.44	42.41%	95.41%	27.67%	95.21%
5	44	7	15.56%	1.28%	0.36	0.36	4	8.89%	2.90%	8.30	2.69	1	2.22%	0.96%	2.00	0.39	33	73.33%	17.10%	44.57	6.08	33.52	4.59%	100.00%	4.79%	100.00%
																			Total weighted area damage		97.34					

Table 17
Table A.7 Frequency Distribution of Area Damage in Terms of Number of Fires in Retail Premises, PD 7974-7 vs USA Fire Statistics

Area damage (m ²)	Sprinklers						No sprinklers					
	PD 7974-7			USA data			PD 7974-7			USA data		
	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit
<i>Assembly or sales areas (Group of people)</i>												
1 and under	154	30.9	37	40.32	4197	48.9	38	58.24				
2 to 4	37	14.3	0	40.32	1987	24.6	0	58.24				
5 to 9	9	10.3	0	40.32	619	17.1	2	56.04				
10 to 19	13	4.5	0	40.32	463	11.5	2	53.85				
20 to 49	6	1.8	2	37.10	430	6.2	12	40.66				
50 to 99	4	0.0	4	30.65	221	3.5	11	28.57				
100 to 199	0	0.0	3	25.81	127	2.0	6	21.98				
200 to 499	0	0.0	6	16.13	100	0.8	14	6.59				
500 to 999	0	0.0	0	16.13	29	0.4	2	4.40				
1000 and above	0	0.0	10	0.00	34	0.0	4	0.00				
	223		62		8207		91					
<i>Storage areas</i>												
1 and under	261	26.3	65	30.11	1679	67.4	93	58.85				
2 to 4	51	11.9	1	29.03	1306	42.0	2	57.96				
5 to 9	22	5.6	0	29.03	722	27.9	5	55.75				
10 to 19	11	2.5	0	29.03	543	17.4	9	51.77				
20 to 49	6	0.8	3	25.81	476	8.1	21	42.48				
50 to 99	1	0.6	2	23.66	177	4.7	24	31.86				
100 to 199	0	0.6	6	17.20	116	2.4	23	21.68				
200 to 499	2	0.0	4	12.90	74	1.0	28	9.29				
500 to 999	0	0.0	4	8.60	24	0.5	12	3.98				
1000 and above	0	0.0	8	0.00	27	0.0	9	0.00				
	354		93		5144		226					

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Table 17
continued

Area damage (m ²)	Sprinklers				No sprinklers			
	PD 7974-7		USA data		PD 7974-7		USA data	
	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit
<i>Other areas</i>								
1 and under	135	26.2	376	34.38	4066	43.5	807	47.67
2 to 4	22	14.2	3	33.86	1638	20.7	9	47.08
5 to 9	8	9.8	8	32.46	490	13.9	18	45.91
10 to 19	9	4.9	4	31.76	404	8.3	44	43.06
20 to 49	5	2.2	26	27.23	323	3.8	144	33.72
50 to 99	2	1.1	22	23.39	128	2.0	146	24.25
100 to 199	2	0.0	16	20.59	68	1.1	133	15.63
200 to 499	0	0.0	49	12.04	57	0.3	133	7.00
500 to 999	0	0.0	20	8.55	15	0.1	65	2.79
1000 and above	0	0.0	49	0.00	5	0.0	43	0.00
	183		573		7194		1542	

Table 18
Frequency Distribution of Area Damage in terms of Number of Fires in Hotels, PD 7974-7 vs USA Fire Statistics

Area damage (m ²)	Sprinklers						No sprinklers					
	PD 7974-7			USA data			PD 7974-7			USA data		
	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit
<i>Assembly or sales areas (Group of people)</i>												
1 and under	/	/	5	37.50	321	38.0	4	66.67				
2 to 4	/	/	1	25.00	76	23.4	0	66.67				
5 to 9	/	/	0	25.00	31	17.4	0	66.67				
10 to 19	/	/	1	12.50	17	14.1	1	58.33				
20 to 49	/	/	0	12.50	30	8.3	0	58.33				
50 to 99	/	/	0	12.50	10	6.4	1	50.00				
100 to 199	/	/	0	12.50	13	3.9	1	41.67				
200 to 499	/	/	1	0.00	13	1.4	4	8.33				
500 to 999	/	/	0	0.00	6	0.2	0	8.33				
1000 and above	/	/	0	0.00	1	0.0	1	0.00				
			8		518		12					
<i>Bedrooms</i>												
1 and under	/	/	29	34.09	634	47.0	39	53.57				
2 to 4	/	/	1	31.82	324	19.9	0	53.57				
5 to 9	/	/	1	29.55	94	12.0	3	50.00				
10 to 19	/	/	2	25.00	59	7.1	4	45.24				
20 to 49	/	/	0	25.00	54	2.6	11	32.14				
50 to 99	/	/	1	22.73	18	1.1	6	25.00				
100 to 199	/	/	1	20.45	4	0.8	4	20.24				
200 to 499	/	/	3	13.64	2	0.6	11	7.14				
500 to 999	/	/	4	4.55	7	0.0	3	3.57				
1000 and above	/	/	2	0.00	0	0.0	3	0.00				
			44		1196		84					

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**Table 18
continued**

Area damage (m ²)	Sprinklers						No sprinklers					
	PD 7974-7			USA data			PD 7974-7			USA data		
	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit	n of fires	% of fires exceeding the upper limit
<i>Storage areas and other areas</i>												
1 and under	31	11.4	174	31.76	2789	27.0	133	43.88				
2 to 4	2	5.7	4	30.20	459	15.0	2	43.04				
5 to 9	1	2.9	7	27.45	162	10.8	11	38.40				
10 to 19	1	0.0	3	26.27	136	7.2	10	34.18				
20 to 49	0	0.0	2	25.49	124	4.0	15	27.85				
50 to 99	0	0.0	4	23.92	67	2.2	9	24.05				
100 to 199	0	0.0	4	22.35	31	1.4	14	18.14				
200 to 499	0	0.0	18	15.29	31	0.6	26	7.17				
500 to 999	0	0.0	18	8.24	8	0.4	9	3.38				
1000 and above	0	0.0	21	0.00	14	0.0	8	0.00				
	35		255		3821		237					

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