Meta-analysis of response times and safety systems to the fire size, growth and damage, based on UK, USA and New Zealand fire statistics databases.

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# Abstract

National fire statistic databases provide the opportunity to assess the response of real fires in real structures. Different countries have developed their own databases using on-line forms completed after an event by fire departments. Common mandatory fields include response times, area of damage, size of fire at arrival and after extinguishment. This paper analyses three such fire statistics from the IRS, UK; NFIRS, USA and the New Zealand Fire Service. These national statistical estimates also acknowledge the resilience of structures to fire shocks. During reporting structural fire events, departments must detail the ignition of the fire, the type and status of the building, the response times of fire services and, as a consequence, the frequency of fires can be deduced. Further fields question the intensity, powering factors, and spread (both on arrival of services and extent at extinguishment) of the fire. Fire spread includes the area damaged in square meters in both the horizontal and vertical direction in UK and a percentage of area damaged in USA, while in New Zealand flame, smoke and water damage are also reported. 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 coalescence of this data will provide a quantification of the size and scale of damage with respect to different intervention strategies and can (given well-defined statistics) be subdivided by building type and use. A comparison between the different countries is essential to highlight how each of them approaches the problem and the data available, and will allow an assessment of the ability to create a benchmark able to improve the understanding on the safe and resilient design of structures.

# nomenclature

IRS: Incident Reporting System

NFIRS: National Fire Incident Reporting System

# 1. Introduction

Fire performance of real structures subjected to real fires has always been a topic of interest within the structural engineering community. Many of the performance criteria are related to life safety goals rather than other drivers such as property protection, or limiting direct and indirect losses. Resilience optimization of structures for fire identifies and mitigates fire-induced risks to enable swift recovery in the aftermath of an event. It is very difficult to give a unique definition so it will be described through the whole fields that are covered under its range. Life safety, property and business continuity are three big categories to consider, able to guarantee the fundamental principles at the base of fire safety [1]. Structural fire engineering knowledge 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 [2]. Structural frames, however are known to show better performance compared to individual element when subjected to fire, due to a beneficial effect of the connection between beam and column [3] [4]. Previsions of prescriptive code [5] assume that the intended life safety fire performance criteria is 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. Previous experiments conducted on full structural frames, and sub-frames [6], have provided valuable data for modelling and design code enhancements, however, due to their expense, the relevance of any data can be limited to the specific building characteristics. Additionally, there are many known complexities with respect to the fire and its interaction with the structure, and therefore it is impossible to fully develop the probabilistic data and understanding through experimentation alone. 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. This is possible through advanced computer simulations using 3D models. However, these models are rarely validated or benchmarked due to a lack of relevant data and can also be limited in their ability to describe structural behaviour close to the point of failure. To overcome this, much research has been in the field of probabilistic performance-based design [7]. Again, lack of validation data for these models limits their application in practice. For this reason, 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, the use of fire statistics can be used to understand the real relationships between fire occurrences, fire size, damage caused by fire and interventions to extinguish the fire.

Different countries have developed their own databases using on-line forms completed after an incident by fire departments. This paper analyses three fire statistics databases from the IRS, UK [8]; NFIRS, USA (including more in-depth data provided to the authors on request from FEMA) [9] and the New Zealand Fire Service database (provided to the authors on request from the NZ fire service). 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, status of the building and structural damage. Further fields question the intensity, powering factors, and spread of the fire. Fire spread includes the area damaged in square meters in both the horizontal and vertical direction in UK and a percentage of area damage in USA, while in New Zealand, flame, smoke and water damages are reported and can be compared to the total area of the structure in consideration. 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 coalescence of this data will provide a quantification of the size and scale of damage with respect to different intervention strategies and can be subdivided by building type (dwellings and other buildings) and use. Moreover, the data can form some of the inputs parameters required to conduct performance-based design analyses where the resilience of structures to fire shocks can be estimated. Direct monetary losses will not be analysed in this paper but their estimation is present in the NFIRS, applying the BVD (Building Validation Data) method [10], and in the New Zealand database where, unfortunately, how they have been calculated is not specified. A comparison between the different countries is essential to highlight how each of them approaches the problem, the data available and which are the aspects that should be improved in term of fire science but also fire safety. Further developments will allow the creation of a benchmark in order to improve the design of real structures subjected to real fire.

# 2. FIRE STATISTICS DATABASES

The nationally reported fire statistics assessed in this paper are a collection of data due to real incidents and usually include false alarms, fire and non-fire incidents reported by the Fire and Rescue Services. Each country has its own database and at the end of the year, a report is generally published to show the trend of casualties, fatalities and fires and compare them with the other data available for the previous years. After an incident, Fire and Rescue Services fill an online form, which presents questions about the causes and frequency of fires, response time, description of the type of property, damage of structure, dollar losses (in the case of NZ and US database) as well as people involved. While each national form is different, as not all the same information is required in the different forms or within the same categories, the databases are similar enough to be comparable even if it is unavoidable that some errors appear due to the lack of data, as the presence of empty boxes, and errors in the answers. These annual reports are a significant source of data of real incidents.

This paper analyses the UK, USA, and New Zealand databases from April 2014 to March 2015. The Incidents Reporting System (IRS) database in UK has been divided in four main regions: England, Northern Ireland, Scotland and Wales. The IRS is composed of around 150 questions, which cover the whole description of the incident from property to people injured. This paper considers only the data published for England [8] since they are the most complete with relevant and comparable information than the other databases. It should also be noted that within the England fire statistics, properties are divided in dwellings and other buildings (i.e. offices and call centers, retail premises, industrial premises, etc). Causes of fire, source of ignition, item and material first ignited are the aspects related to the origin of fire. Frequency of fire is expressed through the response time from the call to the arrival of the fire department in the building. Moreover, damage is expressed in average area damaged (m2) and presence, operation and failure of smoke alarms are described specifying a distinction between dwellings and other buildings.

In the USA, the National Fire Incident Reporting System (NFIRS) has been established since 1976 with the aim to collect data on fires [9]. On a yearly basis, approximately 600,000 fire incidents and more than 5 million non-fire incidents are added in the database by the Fire and Rescue Service of all the 50 States and more than 40 major metropolitan areas. NFIRS is a voluntary system so not all States and fire departments decide to participate, however the majority do [9]. The NFIRS reports causes, 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 the alarm to the arrival of fire service but also in term of time from alarm to last unit cleared or from arrival to last unit cleared. Even in this database, detector type, operation and failure are reported with the only difference that the aspects related to the automatic extinguish systems, including the number of sprinklers, are available while in the other databases they are missing. Additionally, with respect to damage, the NFIRS define the damage as a percentage of number of stories damaged by flame, using four main categories; Minor Damage (from 1 to 24%); Significant Damage (25 to 49%); Heavy Damage (50 to 74%); Extreme Damage (75 to 100%.).

The New Zealand Fire Service Incident database, as in the other cases, is filled in the aftermath of an event. Only relevant information is reported and in general, the Incident, General, Equipment and Response groups are always available. The response time includes start-stop and en route-arrival time. Furthermore, causes, heat source, object ignited first and material most flamed are available in the database. In the reports, the percentage of property saved is reported (i.e. the inverse of property damaged), and damage is not explicitly expressed, but is instead considered in terms of the area damaged involved by flame, smoke and water. Since the total area of structures is present, it has been possible to compare the area damaged with the total structures in term of percentage for each of the previous classes. The New Zealand Fire Service does not publish an annual report and data are presented for single incidents. The work of this paper has been first the collection of all the information for the period of interest and then the reclassification according to different categories for each major class. Within the three databases, there are small differences in the nomenclature adopted; however, buildings are generally categorized in dwellings and other buildings, with similar subclasses.

# 3. ANALYSIS of individual reporting areas

## 3.1 FIRE frequency and ORIGIN

From April 2014 to March 2015, all the 496,051 incidents attended by the Fire and Rescue Service in England, are divided in three big categories with the following percentage: 31.2% of total fires, 43.5% of fire false alarms and 25.2% of non-fire incidents. IRS subdivides the Total Fires into primary fires and secondary fires, which include just small outdoor fires not involving people or property, and chimney fires. Within the Primary Fires (71,089 fires), there are fires in dwellings (31,329 fires), other buildings (15,548 fires), road vehicle (19,464 fires) and other outdoor fires (4,748 fires) with the distribution for the year in consideration. The total number of fires in the USA, in the same period, was 479,000; 79.2% were residential fires and 20.8 % non-residential fires. In New Zealand for 2014/2015, 65.6% (3,586/5,466) of fires were in dwellings compared with 33.3% (1,833/5,466) in other buildings (Figure 1).

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| Fig. 1 Fire incidents in residential and non-residential buildings in UK, USA and NZ 2014/2015 |

In UK, the cause of a fire in dwellings predominantly comes from misuses of equipment or appliances (25.8%, C) while in other buildings the highest percentages are reached with 7.4% and 7.8% respectively for faulty appliances and leads (B) and other accidental (H) (Figure 2a). In USA, cooking (E) is the major cause both in dwellings with 39.6% and in other buildings with 6.1%. This is followed by 9.9% in heating (D) for dwellings and for the 2.1% in careless (N) for other buildings (Figure 2b). Fire or heat source (26.6%, F) and Electrical failure (22.1%, G) are the biggest classes of causes for New Zealand (Figure 2c).

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| (a) |
| **A**. Faulty fuel supplies; **B**. Faulty appliances and leads; **C**. Misuse of equipment or appliances; **D**. Chip/fat pan fires; **E**. Playing with fire; **F**. Careless handling of fire or hot substances; **G**. Placing articles too close to heat; **H**. Other accidental; **I**. Unspecified |
|  (b) |
| **A**. Intentional; **B**. Playing with Heat Source; **C**. Smoking; **D**. Heating; **E**. Cooking; **F**. Electrical Malfunction; **G**. Appliances; **H**. Open Flame; **I**. Other Heat; **J**. Other Equipment; **K**. Natural; **L**. Exposure; **M**. Equipment Malfunction; **N**. Other Unintentional, Careless; **O**. Cause under Investigation |
| (c) |
| **A**. Careless; **B**. Design, construction and maintenance; **C**. Equipment; **D**. Flammable material; **E**. Improper actions; **F**. Fire or heat source; **G**. Electrical failure; **H**. Reckless; **I**. People; **J**. Others; **K**. Unknown |
| Figure 2. Fire causes in a) UK, b) USA and c) NZ in 2014/2015 |

In both the UK and New Zealand, the items first ignited are food (A) with 25.5% and 21.3%, respectively, followed by textiles, upholstery and furnishings (B) - 23.7% and 17% - and by structure and fittings (D) - 20.8% and 17.5% - respectively, with a not negligible 24.8% due to “other materials” in New Zealand (Figure 3a). In USA, the 21.6% of item ignited is given by organic materials (G) with the 12.4% of general materials (H). No other classes exceed 6% with an exception regarding the 48.3% of other items first ignited (I) (Figure 3b).

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| (a) |
| **A**. Food; **B**. Textiles, upholstery and furnishings; **C**. Paper, cardboard; **D**. Structure and fittings; **E**. Agricultural and forestry product; **F**. Explosive Gases & Chemical; **G**. Rubbish/Waste/Recycling; **H**. Other materials; **I**. Not known; **J**. None; **K**. Unspecified |
|  (b) |
| **A**. Structural Component, Finish; **B**. Furniture, Utensils. Includes built-in furniture; **C**. Soft Goods, Wearing Apparel; **D**. Adornment, Recreational Material, Signs; **E**. Storage Supplies; **F**. Liquids, Piping, Filters; **G**. Organic Materials; **H**. General Materials; **I**. Other Items First Ignited |
| Figure 3 Item first ignited in a) UK and NZ and b) USA in 2014/2015 |

Considering a probabilistic framework, causes of ignition and the likely items to be first ignited can be used in determining the likelihood of significant fires occurring. The analysis presented in Figures 2-3 define the range of the most common scenarios in which fires occur allowing means to prevent fires being ignited (i.e. PAT testing in UK to check for faulty electrical appliances), understand the materials which first ignite and thus improve the resilience of our built environment to fire.

## 3.2 DETECTORS

Information about detectors are given in the three different databases regarding their type, operation and failure. In IRS, the percentage of households owning a smoke alarm or working smoke alarms is 88%, while in NFIRS, 39.7% of cases smoke alarms are present, 32.9% not present and undetermined 27.5%. In UK, detector types are divided in two major groups: 55.2% battery powered and 43.2% mains powered (Figure 4a), but no further delineation is given. Within the NFIRS, 76.1% of the detectors are smoke detectors (A) followed by 6.4% for combined of smoke and heat in a single unit (C) and a non-negligible 10.3% of undetermined detectors (Figure 4b). Domestic smoke alarms (21.7%, D), smoke detector system (monitored) (11.9%, L) and smoke detector /security alarm system (3.1% M) are the three most prevalent types of detector in New Zealand, however it should be noted that data are not recorded for 56.6% of cases (Figure 4c).

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|  (a) |
| **A**. Battery Powered; **B**. Mains Powered; **C**. Other |
| (b) |
| **A**. Smoke; **B**. Heat; **C**. Combination smoke and heat in a single unit; **D**. Sprinkler, water flow detection; **E**. More than one type present; **F**. Detector type, other; **G**. Undetermined |
|  (c) |
| **A**. CO2; **B**. Deluge system; **C**. Domestic (Home) SPRINKLER; **D**. Domestic Smoke Alarms; **E**. Drencher system; **F**. Flame detector; **G**. Flammable vapour detector; **H**. Heat detector, Thermal detector; **I**. Inert gas (not CO2); **J**. Manual Fire Alarm; **K**. Residential sprinkler; **L**. Smoke Detector System (Monitored); **M**. Smoke Detector/Security Alarm System; **N**. Smoke sampling system; **O**. Sprinkler; **P**. Water spray projection system; **Q**. Unable to classify. |
| Figure 4. Detector types in a) UK, b) USA and c) NZ in 2014/2015 |

Another important aspect to consider is the operation of detectors. In the IRS database, four classes for detectors operation are presented and a further classification related to the use of property. Therefore, considering detectors respectively in dwellings and other buildings, they were present, operated and raised the alarm for 26.8% -11.8% (A), present, operated but did not raise the alarm for 7.1%-1.8% (B), present but did not operate for 13.2%-4.3% (C) and finally 19.8%-15.2% are the percentages related to the absence of detectors (D) (Figure 5a).

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| (a) |
| **A**. Present, operated & raised the alarm; **B**. Present, operated but did not raise the alarm; **C**. Present, but did not operate; **D**. Absent |
| (b) |
| **A**. Fire too small to activate detector; **B**. Detector operated; **C**. Detector failed to operate; **D**. Undetermined |
|  (c) |
| **A**. System operated and was effective; **B**. Alerted occupants - detector in room of origin; **C**. Alerted neighbour/passer-by - detector in room of origin; **D**. Fire too small to activate detector - detector in room of origin; **E**. Detector in Room operated and was effective; **F**. Did not operate - detector in room of origin; **G**. Detector in room of origin - not classified above; **H**. Alerted occupants - detector not in room of origin; **I**. Alerted neighbour/passer-by - detector not in room of origin; **J**. Detector Not in Room operated and was effective; **K**. Did not operate - detector not in room of origin; **L**. Detector not in room of origin - not classified above; **M**. Detector operated, but was not a factor in discovery of fire; **N**. Detector operated, but occupants failed to respond; **O**. Detector operated - not classified above; **P**. Unable to classify |
| Figure 5. Detector operation in a) UK, b) USA and c) NZ in 2014/2015 |

In USA, almost 60% of detectors operated (B) and only the 10.3% failed to operate (C) while in the 14.5% fires were too small to activate detectors (A) and there is 16.1% of undetermined operation (D) (Figure 5b). Classes related to detector operation in the New Zealand Fire Statistics never reach more than the 10%, as 56.7% of detector operation data was not recorded. However, 8.4% detector was in room of origin and alerted occupants (B), 6.7% system operated and was effective and 6.6% detector was not in the room of origin and did not operate (K) (Figure 5c). Grouping now the detector operation and not operation classes and neglecting data not recorded or occupant responses, respectively in the three different countries, USA presents 59.1% in which detector operated and 24.8% in which detector did not operate, UK has a percentage of 47.5%-17.5% and New Zealand of 30.1%-10.1% (note that 56.7% of unreported data).

As can be seen in Figure 6a, in UK detector failures have been divided for dwellings – battery powered, dwellings – mains powered and other buildings and for the three classes the highest percentages (44%, 47.7% and 47.5% respectively) are obtained when the cause of failure is due to fire products which did not reach detectors (D). Another major cause can be seen in a poor setting of detectors (E) and this is confirmed by the following values: 11.7% dwellings–battery powered, 13.8% dwellings–mains powered and 12.8% in other buildings. Unfortunately, these percentages are not obtained by the analysis shown in this paper but are directly provided by the IRS without the related totals or number of incidents. In NFIRS database, the main reasons for detector failures are given by battery missing or disconnected (25.1%, E) and by battery discharged or dead (14.3%, F). Moreover, not negligible are the undetermined failures, which are represented by the 42.3% (Figure 6b). Not recorded data for New Zealand detector failure are more than 80% and the major failure is given by defective discharge head or outlet with the 5.1% (D) but this consideration appears too general in the light of the lack of data presents for this particular aspect in this database (Figure 6c).

One of the difference between the NFIRS and the other databases, is that for USA there are also information related to automatic extinguish system but since extinguish systems appear not to be present for the 83.6% of cases, further investigation will be left to a new collection of data.

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| (a) |
| **A**. Missing Battery; **B**. Battery failure/flat; **C**. Other act preventing alarm from operating; **D**. Fire products did not reach detector(s); **E**. Poor sitting of detector(s); **F**. Faulty system / incorrectly installed; **G**. Other |
| (b) |
| **A**. Power failure or hardwired detector shut off or disconnected; **B**. Improper installation or placement of detector; **C**. Defective detector; **D**. Lack of maintenance. Includes not cleaning; **E**. Battery missing or disconnected; **F**. Battery discharged or dead; **G**. Detector failure reason, other; **H**. Undetermined |
|  (c) |
| **A**. Battery flat or removed; **B**. Defective detector; **C**. Defective discharge head or outlet; **D**. Detector not in room of origin; **E**. External Power supply failed; **F**. Extinguishing agent discharged but did not reach fire; **G**. Improper installation/Placement of detector; **H**. Inadequate maintenance; **I**. No discharge heads/detectors in room or space of fire origin; **J**. System shut down; **K**. System tampered; **L**. Unable to classify; **M**. Unknown |
| Figure 6. Detector failure in a) UK, b) USA and c) NZ in 2014/2015 |

## 3.3 RESPONSE TIME

In terms of response time to the fires, the IRS form states: “the response time measures the minutes and part minutes taken from time of call to time of arrival at scene of the first vehicle”. Comparing the response time with the relative number of incidents per years in England, it is possible to affirm that while the response time is increased from 6.1 minutes in 1994-95 to 8.7 minutes in 2014-2015 (Figure 7a), the number of incidents after an increment from 153,420 fires in 1994-1994 to 167,697 in 2003-2004, presents a decrement trend reaching 52,121 incidents in 2014-2014 (Figure 7b). As expressed in the IRS, “the difference in average response times between 2008-09 and 2009-10 is over half a minute. Part of this increase reflects a measurement discontinuity caused by a move from a paper-based to a more comprehensive online data collection tool in 2009, which means comparisons over this time should be treated with care”. However, according to the Fire and Rescue Operational Statistics Bulletin for England 2011-2012, the number of full-time equivalent (except retained duty system) firefighters has changed from 51,286 in 2007 to 48,944 in 2012 that is equivalent to a decrease of a -4.6% leading to a longer response time. [11]

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| (a) |
| (b) |
| Figure 7. a) Response times and b) number of incidents in England from 1994 to 2015 |

In the NFIRS, the actual month, day, year, and time of day (hour, minute, and - optional in on-line entry - seconds) are recorded for three different times: alarm, arrival, controlled and last unit cleared. Their definitions in the NFIRS form are the following: *alarm time* when the alarm was received by the fire department, *arrival time* when the first responding unit arrived at the incident scene, *controlled time* when the fire is brought under control or the incident is stabilized and does not require additional emergency resources (“Controlled” is the time when the incident commander determines that the fire will not escape from its containment perimeter) and *last unit cleared time* when the last unit cleared the incident scene. In New Zealand, four different times are recorded: *en route*, *arrival*, *start* and *stop time* but a clear definition for them is not given since an annual report is not published. Even in these two databases, response time has been obtained considering the time between the alarm (or en route for NZ) and the arrival at the incident scene. The average response time excluding more than 20 minutes response, in the USA database is equal to 8.5 minutes while in New Zealand to 5,0 minutes.

Comparing the response time in the three different countries with 1 minute bands from 0 up to more than 20 minutes, in UK the 17% of incidents have received the arrival of fire service between 6-7 minutes, 16% between 5-6 minutes and 13.8% between 7-8 minutes. All the other percentages are always equal or less than 10%. In USA, the response time for the 29.7% of incidents has obtained assistance within 2-3 minutes while the second highest peak is given by 24.7% for more than 20 minutes and this seems quite unexpected. In New Zealand, 3-4 minutes time of response have covered the 20.3% of fires immediately follow by 2-3 minutes with 18.2% and 4-5 minutes with 14.8% (Figure 8). In the light of this comparison, the fastest response time is given by USA, followed by NZ and UK. The percentage of more than 15 minutes response time for the three countries according to Figure 8, shows 2.9% in New Zealand, 5.3% in UK and a significantly high value of 42.7% in USA.

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| Figure 8. Response time in UK, USA and NZ for 1 minute bands in 2014-2015 |

Response times are important when we consider the resilience of structures to fire, the intuitive view is that the longer the response time the greater the damage will be as the fire will, in general, be larger and thus take longer to extinguish, when fire service interventions start to occur.

## 3.4 FIRE GROWTH AND DAMAGE

All three databases present the material(s) mainly responsible for the fire growth and development. Data for UK and New Zealand have been grouped considering the same classes. As for the item first ignited food (A) and textiles, upholstery and furnishings (B) have the highest values respectively of 19.5% and 22.5% for UK, neglecting the 14% for none items and the 3.7% for not known. In New Zealand, however, the peaks are given in correspondence of agricultural and forestry product (E) and structures and fittings (D) with 19.1% and 8.0% if not considering the 50.8% reached for the not known materials and the 2.9% for unspecified (Figure 9a). New Zealand database presents also information regarding the material most smoked and still agricultural and forestry product and structures and fittings are the categories with the major number of items.

In the NFIRS, Wood or Paper - Processed (F) have the 38.4% and Fabric, Textiles, Fur (G) the 10.9%. In addition, even in this case, there is an unexpected 31.7% of other materials (I) not specified which does not fall in the other definitions applied (Figure 9b).

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|  (a) |
| **A**. Food; **B**. Textiles, upholstery and furnishings; **C**. Paper, cardboard; **D**. Structure and fittings; **E**. Agricultural and forestry product; **F**. Explosive Gases & Chemical; **G**. Rubbish/Waste/Recycling; **H**. Other materials |
| (b) |
| **A**. Flammable Gas; **B**. Flammable or Combustible Liquid; **C**. Volatile Solid or Chemical; **D**. Plastic; **E**. Natural Product; **F**. Wood or Paper – Processed; **G**. Fabric, Textiles, Fur; **H**. Material Compounded With Oil; **I**. Other Material |
| Figure 9. Material mainly responsible for the development of fire in a) UK and NZ and b) USA in 2014/2015 |

Analysing the spread of fire in UK, it is possible to affirm that the compartmentation works well both in dwellings and other buildings. This is evidenced for the two categories referring to the spread of fire limited to the item 1st ignited (A) or to the room of origin (B) with values of 29.2% and 24.8%, respectively. However, it should be noted that a not-insignificant amount, 8.8%, of the fires spread beyond the compartment; 6.8% limited to the floor of origin, 1.6% limited to 2 floors, and 0.4% to more than two floors. The whole building was damaged in 5.3% of occasions; however, some of these incidents include garden sheds and standalone garages (Figure 10a).

The IRS in England also reports an average area damaged in square meters. When comparing the areas between dwellings and other buildings, the average area damaged is considerably larger in other buildings, at 76.7 m2 compared with 18.5 m2. Furthermore, for other buildings, there are sub-divisions to exclude large floor area structures, i.e. those above 10,000 m2, 5,000 m2, 2,000 m2, and 1,000 m2, which reduces the area damaged to 59.9 m2, 52.7 m2, 38.4 m2, and 29.6 m2 respectively. This is still greater than the area damaged in dwellings of 18.5 m2 (Figure 10b) [1].

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| (a) |
| **A.** Limited to item 1st ignited; **B.** Limited to room of origin; **C.** Limited to floor of origin; **D.** Limited to 2 floors; **E.** Affecting more than 2 floors; **F.** Whole building; **G.** Roofs and roof spaces; **H.** No fire damage |
| (b) |
| **A.** Other Buildings; **B.** Other Buildings excluding 10,000+ m2; **C.** Other Buildings excluding 5,000+ m2; **D.** Other Buildings excluding 2,000+ m2; **E.** Other Buildings excluding 1,000+ m2; **F.** Dwellings |
| Figure 10. a) Fire spread and b) area damaged in square meters in UK 2014/2015 |

In USA, the spread of fire is confined for the 16.7% to the object of origin (A) or for the 33.7% to the room of origin (B), for the 8.7% to the floor of origin (C), confined to the building of origin for 33.9% (D) and only for the 7.0% of incidents, fire appears to go beyond the building of origin (E) (Figure 11a). New Zealand Fire Service database shows spread not only for fire but also for flame, smoke and water. Fire damage is not present for 18.2% of fires, flame damage for 1.0%, smoke damage for 9.5% and water damage for 20.3% (A). For 10.4% fire damage is confined to structure of origin as well as smoke damage with 16% and water damage with 10.4% (G) while 15.2% of flame damage is confined to part of room or area of origin (D) (Figure 11b). Unfortunately, data are not recorded for 50.3% of incidents. Again, Figure 11 shows that, in general compartmentation works well. However, there are a significant number of fires that effect and cause damage outside the room of origin.

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|  (a) |
| **A**. Confined to object of origin; **B**. Confined to room of origin; **C**. Confined to floor of origin; **D**. Confined to building of origin; **E**. Beyond building of origin |
|  (b) |
| **A**. No damage of this type; **B**. Confined to fire cell of origin; **C**. Confined to object of origin; **D**. Confined to part of room or area of origin; **E**. Confined to room of origin; **F**. Confined to floor of origin; **G**. Confined to structure of origin; **H**. Extended beyond structure of origin;  |
| Figure 11. a) Fire spread in USA and b) Fire, Flame, Smoke and Water spread in NZ in 2014/2015 |

The USA data for area damaged is divided into four categories: minor, significant, heavy and extreme damaged. For each class, the fire departments must specify the number of floors subjected to fire and Figure 12a shows that 83.9% (D – heavy damage) to 96.2% (A – minor damage) of these fires are limited to a single floor. Predictably, the more damage seen, the more likely that the fire has spread to more than 1 floor, with heavy damage being experienced on 2 and 3 floors, 12.7% and 3.1% of the time respectively [1]. New Zealand database instead presents property saved and to create a comparison, the analysis of this paper has transformed the percentages of property saved in percentages of property damaged and grouped the values according to the four classes of damage presented in the NFIRS. Figure 12b presents the percentage of fires within these four categories in the two countries, and shows that 49.6% in USA and 80.5% in New Zealand of all fires cause only minor damage, with significant, heavy, and extreme damage being realized for 15.5%-3.4%, 11.4%-3.8% and 23.5%-10.9% respectively in USA and New Zealand.

|  |
| --- |
| (a) |
| (b) |
| **A**. Minor damage; **B**. Significantly damage; **C**. Heavy damage; **D**. Extreme damage |
| Figure 12. a) Floors involved per class of area damaged in USA and b) Percentage of fires per area damaged in USA and NZ in 2014/2015 |

# 4. Conclusions

This paper presents statistical data from three databases (IRS of the UK, NFIRS in USA and one produced by the New Zealand Fire Service) and shows important statistics on response times and safety systems to the fire size, growth and damage. From these statistics, we can conclude:

* Fire causes in UK and USA are divided in dwellings and other buildings. In the IRS, for dwellings the major cause is represented by misuse of equipment while for other building by faulty appliances and leads. In USA cooking is the major cause for both dwellings and other building while in New Zealand, fire or heat source is the class with the highest value. For what concerns the item first ignited, both in UK and New Zealand it is represented by food while in the NFIRS by organic material.
* In the three countries, the operation of detectors showed the highest peak when systems operated and were effective. For what concerns the failures in UK, they are divided by dwellings and other buildings but for both of them, the principal reason is due to fire products that did not reach detectors. In USA, failure can be seen in battery missing or disconnected. Data not recorded for New Zealand are more than 80% and this implies too general considerations for the other classes related to this aspect.
* In UK, number of incidents has decreased in years while the response time has increased and for the year in consideration is around 7 minutes. New Zealand is the one with the lower value of 5 minutes, followed by USA with 8.5 minutes and UK with 8.7 minutes. Considering 1 minute response bands, USA and New Zealand databases present a response time lower than UK and respectively equal to 2-3 minutes and 3-4 minutes.
* Material mainly responsible for the development of fire is given by food in the IRS database, by agricultural and forestry product in New Zealand and by wood and paper in the NFIRS. Fire spread is usually concentrated within the item first ignited or maximum within the area of the room of origin in all the databases. However, there are significant percentages of fires that spread beyond the room of origin, and beyond the floor of origin to more than a single floor.

The analysis presented will allow further developments of performance-based design approaches.

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