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Closing Data Gaps and Paving the Way for Pan-European Fire Safety Efforts: Part I—Overview of Current Practices for Fire Statistics

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Abstract. The analysis of the current state of fire statistics and data collection in Europe and other countries is needed to increase awareness of how fire incidents affect buildings and to support pan-European fire prevention and fire mitigation measures. The terminology and data collected regarding fire incidents in buildings in the EU Member States were mapped to obtain meaningful datasets to determine common terminology, collection methodology, and data interpretation system. An extensive literature review showed that fire data collection systems have been instrumental in informing firefighting strategies, evidence-based planning, prevention, and educational programmes. Differences and similarities between fire data collection systems were also investigated. The amount and quality of the information in fire statistical recording systems appear to be influenced by the complexity and structure with which the data are collected. The analysis also examined the existing fire statistics in the EU Member States and a few other countries. Finally, a detailed investigation of the number of fires, fire deaths, and injuries from 2009 to 2018 in several countries was examined based on data from a report by CTIF. The trends showed differences attributable to the existing fire statistical practices in terms of terminology and data collection, and interpretation. Part II proposes a common terminology for selected fire statistical variables. The results provide relevant information regarding fire safety at the European level and should be used to guide the development of more uniform fire statistics across Europe.

Keywords: Fire statistics, Fire incidents, Fire statistical variables, Terminology, Data collection, Data interpretation

1. Introduction

The nature and format of the collected input data for fire statistics vary significantly across the European Member States and internationally. Naturally, this poses an obstacle to data accuracy and elaboration and thereby to effectively assessing potential best practices and successful safety approaches. Moreover, when fire data are plotted over time, the changes in trends are difficult to be attributed to the efficacy of the introduction of fire safety measures and prevention regulations [1] if a comprehensive understanding of the fire statistics is missing. Therefore, the various methods and descriptions of terms used need to be more uniform to allow meaningful pan-country policy and guidance to reduce fire risk and enhance the safety of occupants. Differences in the fire statistics practice are difficult to capture without a detailed evaluation and assessment focused on terminology, collection and identification of the fire statistical variables recorded.

Most national fire statistics are centralized and presented as one unique dataset. However, in some countries such as France [2], and Spain [3], due to the lack of

official definitions and national fire statistical collection, differences may exist in the terminology adopted by the various fire departments when the data are gathered after attending fire events. While fire departments usually are responsible for entering the fire incident data, volunteers and other professionals also participate in filling in fire incident reports. The data elaboration and accuracy could assume different levels of approaches. In Sweden [4], a systematic assessment of errors and missing data is applied while other countries do not adopt a specific methodology. At the same time, fire statistical variables are generally referred to as the evaluation of the number of fire incidents, deaths and injuries while other information and analysis on building performance, effectiveness and operation of fire safety systems, and quantification of property damage could support a complete description of fire incidents, which is the case in the UK and USA [5, 6].

Therefore, it is clear that the variety of fire statistics available in several countries, as well as differences in current practice and terminology, must be assessed to effectively evaluate the complexity of the fire safety issue affecting various property types.

It is in this light that fire statistics of 27 EU Member States and eight other countries (Australia, Canada, New Zealand, Norway, Russia, Switzerland, UK, and the USA) for a total of 35 countries, were examined to understand and evaluate the differences in practice and move towards an enhanced awareness of fire statistical data. The adopted terminology in fire statistics was evaluated and compared with other domains within the country and internationally, for example considering the terminology provided by the World Health Organization's (WHO) 10th Edition of the International Classification of Disease (ICD-10) [7] when examining fire deaths. Moreover, the fire incident datasets were assessed in terms of responsibility for collection and elaboration as well as identification of missing data and potential uncertainties. Furthermore, the terminology could also influence the aspects covered by the available variables in the fire statistics that can vary in terms of adopted definitions and be referred to different pre, post-fire conditions, fire characteristics, fire safety measures in place and life safety.

Finally, an analysis of data and variables available in the fire statistical datasets was necessary for a quantified assessment of the evolution of fire incidents, deaths, and injuries over time in several countries. Therefore, this paper summarises the state of the art of the current fire practices in the investigated countries and underlines some potential issues that should be improved in the future. Consequently, Part II [8] proposes a common methodology for data collection and terminology for selected fire statistical variables. The method used to identify the needed data is also described in detail in the same paper. Moreover, the evaluations of quality level is reported in the EU FireStat reports [9–11]. Such evaluations assume relevant importance within the fire safety community to determine fire risk and areas of concern, and more broadly for national and international authorities to identify prevention campaigns and strengthen fire resilience for people, buildings, and communities.

Therefore, this research aims to overview the existing fire statistics and collection methodologies and identify potential issues to provide preparatory studies to create EU actions able to improve fire safety in buildings and move towards a

harmonized fire statistic at the EU level. The research presented was part of the EU FireStat project [12–14].

Lessons from the research are intended to inform the European Commission and Parliament, national and local authorities, regulators, policymakers, fire and rescue services, the international fire safety community, and the general public by providing an in-depth description of existing fire statistics, quantification of fire statistical variables over time and evaluation of potential future improvements to better understand fire risk and consequences for property and lives. The research developed in this research arises from the necessity of evaluating the current state of the European fire statistics and proposing a thorough collection methodology in the future as discussed in Sect. 1. Section 2 presents the adopted methodology for evaluating the existing fire statistics in the 27 EU Member States and other eight countries (Australia, Canada, New Zealand, Norway, Russia, Switzerland, UK, and the USA). This evaluation focuses on identifying the practice of fire statistics, the adopted terminology, the collection methodology, the responsible authorities, and the comparison of practices between countries. Section 3 provides an extended literature review focused on identifying the learnings from relevant research studies and publications developed by several international organizations. Section 4 highlights potential issues in comparing the fire statistics among various countries related to the used terminology both in fire statistics or other domains, along with the collection and interpretation issues. Section 5 presents an overview of the current state of the collected variables in fire statistics for the investigated countries. Section 6 introduces a detailed analysis of fires, fire deaths and injuries from 2009 to 2018, based on the CTIF reports [15] and finally, Sect. 7 summarises the conclusions of this study.

2. Methodology

The research was focused on the creation of a detailed assessment of the available fire statistics from 27 EU Member States and eight other countries (Australia, Canada, New Zealand, Norway, Russia, Switzerland, the UK, and the USA) with the goals to provide a comprehensive overview of the current practice of fire statistics, identify the adopted terminology, collection methodology, responsible authority, data elaboration and fire statistical variables, and highlights differences and similarities. Moreover, the analysis of fire statistical data referred to fire incidents, deaths and injuries appears fundamental to determine how their evolution in time could vary according to examined countries, geographical locations, and fire safety policies.

The structure followed to develop the research is composed of a literature review of previous studies and publications focused on national and international fire statistics. A qualitative investigation of current fire statistical practice as well as quantitative analysis of recorded fire statistical variables was created for European and other countries, followed by an evolution of data related to fires, deaths and injuries from 2009 to 2018. While the literature review represents a fundamental step to increase awareness of previous studies, the complementary qualitative

and quantitative analysis of international fire statistics provides a comprehensive assessment supported by the evaluation of the variation of fires, deaths and injuries over time. The literature review evaluated national fire statistics and international studies based on a review of publications of international organizations such as the World Health Organization (WHO) [16], International Organization for Standardization (ISO) [17, 18], and the International Association of Fire & Rescue Services CTIF [15] as the baseline of available international fire statistics. The analysis of the literature review highlighted the differences among fire statistic practices and the need to investigate each country in detail in order to be able to evaluate terminology, collection methodology, and available fire statistical variables.

The research also qualitatively investigated current national fire data collection systems, focusing on the collection sources, organizations responsible for collecting and analysing the datasets, available data, and adopted terminology. A review of the quality assurance processes in these systems was developed to identify best practices. In addition, common issues and limitations of each method were identified. The study on the current definitions adopted in the fire statistical variables will be the base for a creation of a harmonised terminology developed in other studies [8].

Therefore, the analysis then quantified the available fire statistical variables collected in the fire statistics. Pre- and post-fire conditions of fire incidents in buildings were defined and classified according to ten categories of interest. Each of them has various subcategories and the relevant authorities indicated the variables in their fire statistics. While 35 countries were covered in the description of current fire statistics, for the analysis of the available variables, a total of 21 EU Member States (missing Greece, Lithuania, Luxemburg, Malta, Portugal, and Spain) and eight other countries were investigated.

Finally, the definition and analysis of the available fire statistical variables were then followed by the evaluation of such data based on the number of fires, fire deaths, and injuries per 100,000 inhabitants for several countries obtained by the CTIF reports [15]. The trends showed differences attributable to the existing fire statistical practices.

The most challenging aspects of the research stem from language barriers, confidentiality policies, private databases, and non-response to requests for information. Where necessary, an attempt to deal with the latter issue was represented by requesting information directly from the relevant fire statistical authorities.

3. Literature Review of Studies Focused on Fire Statistics

A comprehensive literature review on fire data collection was undertaken and organized into studies based on fire incidents as well as learnings from international organizations investigating fire statistics. The literature review had the aim to focus on building fires mainly targeting fires, fatalities and injuries, fire safety measures and data quality according to studies examining a single country or a comparison between several nations. The research produced by international orga-

nizations is also necessary to understand the work developed by several institutions at the international level and the current driving interest in a comprehensive evaluation of fire incident data and their correct interpretation.

The sources investigated can be dated back to early 2000 as the most recent studies were the target of the literature review with some exceptions where relevant work was necessary to support the following analyses. Moreover, the studies selected in the literature review were described with the aim to highlight the complexity of creating a comprehensive assessment of current fire statistical practices, internationally. It is in this light that variations in data focused on similar fire statistical fields provided by single countries or international comparisons are introduced highlighting the differences that inevitably arise supporting the need to move towards harmonised fire statistics at national and international levels. The literature review in the following sections represents the first step to evaluate previous studies on fire statistics and understand the best approach to follow for the analysis developed in this research.

3.1. Literature Based on Fire Incident Data

Data collection should be guided by the practical goal of gathering useful information that can be applied to actions. In the literature review, several studies were identified highlighting the vital importance that information on fire incidents has for efforts to improve fire safety and guide interventions that reduce the human and economic cost of fire. Sections 3.1.1 and 3.1.2 provide an overview of studies based on fire incident data from several countries and comparative use of national fire data.

3.1.1. Literature Based on Fire Incident Data in Specific Countries The data on fatalities and injuries due to fire incidents represent important aspects related to life safety and can be found in the studies developed for several nations where the causes, as well as information on the affected people, are usually presented. However, the data collected can vary according to the investigated fire statistics and different fire statistical variables can be available and referred to different aspects. For example, for the analysis of the factors influencing fire deaths, a 2003 study of fire deaths in Ireland from 2001 to 2002 evaluated at-risk individuals and behaviours linked to death and injury [19]. The research, drawing from multiple data sources, found that most fatalities (67%) occurred in house fires and that almost half (46%) occurred in two- or three-story dwellings. Most victims were male (65%) and alcohol was a factor in 39% of fire deaths. Victims most often lived in urban locations. Fires occurring between 12 pm and 6 am, usually on early Sunday morning, accounted for most fire deaths. There was no working smoke alarm in 82% of fatal fires.

Another aspect related to life safety is supported by the fact that a high number of fatalities were also found to be significantly influenced by the victim's condition, location, and activity at the time of ignition. It is in this light that a research from Australia in 2015 by Xiong et al. [20] examined risk factors related to surviving or dying in residential fires. The study used the Victoria University Fire Fatal-

ity Coronial Database, which includes fatalities from the states of Victoria, New South Wales, and Queensland, to identify fire deaths. Survivors of residential fires were drawn from the Victoria University Residential Fire Survivor Database, which includes data on fire survivors from the state of Victoria. Researchers removed deaths due to suicide, murder, deliberate fires, undetermined cause, fires on non-residential premises, or incidents with more than one victim, creating a database of 177 single-fatality fire deaths. The database of survivors included 183 survivors following the removal of missing data. The leading risk factors associated with fatal fires were psychotropic and sedative drug intake, discarded cigarettes, living alone, being over seventy years of age, being asleep, location in the room of fire origin at the time of ignition, and alcohol intake. Risk factors most significantly associated with surviving fires included cooking fires, electrical fires, involvement of stove in the ignition, and fire occurrence in a one- or two-family dwelling. Fire survivors were more likely to wake up to non-smoke alarm cues, such as smoke or breaking glass, than a cue from a smoke alarm.

Fatalities and casualties are also studied in terms of their relationship with fire characteristics. For example, another research on fatalities and injuries in building fires was developed in the United States in 2006 with data on building fires in 1993 from the National Fire Incident Reporting System (NFIRS) [21]. The research found that the number of injuries and deaths and proportion of deaths depends mainly on the extent of fire damage, area of fire origin, material ignited, and ignition factor, while the absolute number of fatalities depended upon the material ignited and form of the heat of ignition.

In addition, a short communication analysed in 2017 the data collected by the Laboratoire central de la Police Prefecture in Paris (LCPP) concerning fires that caused casualties deceased on the spot in the years 2012, 2013, and 2014 [22]. The geographic sector includes Paris and its surrounding counties, constituting more than 10% of the French population but exclusively dense urban areas. As this database is filled in by trained fire investigators that is called systematically when a fire causes one or several casualties, these data constitute one of the most reliable analyses in France, despite being limited to Paris and its suburbs. Again, for the fires involving fatalities, 91% of fires causes one death and the remaining 9% caused multiple deaths. Out of the 108 fires with fatalities, the origin of the fire could be determined in 90 cases out of 108 (83%). In residential buildings, for 88 fires having caused 100 deaths, 26 fires caused 37 deaths (35% of the recorded deaths). In four of the fires having caused seven deaths, the flashover also reached the building staircase. In 43 fires having caused 44 deaths (41% of the total number of deaths registered), the fire was limited to the room where the fire started: most often in a bedroom (20 fires having caused 20 deaths), then the living room and the lounge (10 fires having caused 10 deaths), last in the kitchen (nine fires having caused nine deaths). The origin of the alarm was registered for 92% of the fires analysed: the alert was given by someone who neither was a victim nor lived on the premises in 90% of the cases registered; it was given by a victim or a resident in 7% of cases; smoke detectors gave the alarm in only 3% of the cases. Moreover, the time of the day or night could influence human response. A significant number of deaths occurs during the day, when people are not usually asleep,

with 44% of death from 9 am to 9 pm. The gender of the deceased is unknown for eight victims. Males represent 58% of the deceased of known gender, females 42%. In line with the previous studies focused on fatalities and casualties, it is clear that the available fire statistical variables vary according to the investigated fire statistics in several countries. This variation in data has an inevitable implication for the analyses and potential comparisons among countries developed by this research.

Where data on fire protection measures are available, they are investigated to understand their operation and effectiveness in reducing fires. A study from Sweden in 2012 elaborated an approach to understand deficiencies in fire protection by drawing upon both statistical data and more qualitative data from case studies of school fire incidents in Sweden [23]. The study used Swedish fire statistics on fire cause, the extent of the fire, and room of fire origin to identify the types of fires that produced the greatest damage in Swedish school buildings. Data indicated that the most destructive school fires were those that were deliberately set during the evening and night-time hours. Fire investigation reports of these fires showed that an absence of fire detection and insufficient fire separation contributed to the ability of fire to spread along the façades and into the attic space of school buildings. All case reports showed that the fire was very difficult to extinguish without causing substantial damage to the building once it spread into the attic space.

While the previous study is focused on schools, in some countries it is possible to determine the building types and building locations in terms of frequency and distribution of fires. A study from Poland in 2014 examined residential fires to assess safety levels for the country and the city of Warsaw from 2000 to 2012 [24]. Residential building fire incidents were geocoded and mapped on a 25-km cartography grid for national incidents and a one-kilometre grid for the city of Warsaw. Administrative Districts were ranked to show the highest and lowest number of residential fires. Fire causes were divided into three categories: human factor, technical and unknown. Human factors accounted for 60% percent of residential building fires at the national level and 73% in Warsaw. Technical factors were attributed to 19% of national incidents and 11% of incidents in Warsaw, while 21% of national incidents and 16% of Warsaw incidents were due to other factors.

As highlighted previously, several countries developed analyses focused on different fields related to fire incidents in buildings. Even if similar aspects could be found, they assume relevant differences in terms of recorded data, fire statistical classification, and practice to collect the information with implications on the obtained results. Furthermore, the terminology for each fire statistical variable should be established to guarantee correctness and data quality. Nevertheless, two studies presented in [19] and [20] underlined that alcohol is an important factor that leads to fire fatalities and injuries. It was also concluded that the majority of the victims are males, as shown in [19] and [22]. Same studies have different conclusions regarding the fire times. While in [19] it was concluded that the fires mainly occur in the interval from 12 pm to 6 am (especially on Sundays), in [22], the majority of fire incidents were recorded in the interval from 9 am to 9 pm. In

[20], it is mentioned that the survivors are more likely to wake up to other cues than the ones from the smoke alarm (e.g. smoke or breaking glass), while in [22], it is concluded that the smoke detectors operated only in a very small percentage of cases (3%).

It is in this light that several studies were identified that examined data quality issues with the US National Fire Incident Reporting System (NFIRS) [25]. A 2012 study by Butry and Thomas [26] evaluated the ability of NFIRS data to depict fire activity in non-reporting US cities, to test differences between those cities that reported fire incident data and those which did not, and to discuss how findings could be used to weight NFIRS-based statistics to produce more accurate national estimates. A second study of NFIRS data by the National Association of State Fire Marshals [27] examined the problem of unknown data to better understand why NFIRS data elements for the area of origin and causal information were frequently reported as undetermined, unreported, or inappropriately coded as "none". A 2016 study of NFIRS data by Kinsey and Ahrens [28] examined the NFIRS three-digit coding system for types of fire incidents. A series of coding exercises testing reliability were conducted and reliability was generally low at the detailed code level, and showed marked improvements when incident types were grouped into smaller numbers of categories. It is in this light that a more recent study by the U.S. Fire Administration from 2017 assessed data quality and data usability for required data elements in NFIRS reports [29].

The studies presented in this section provide an overview of the variety of fire statistical variables that could be available in European and other countries as well as the differences that could be found in terms of available data and obtained results. In the following section, studies focused on the fire incidents data comparisons among countries are discussed.

3.1.2. Literature Based on Fire Incident Data Comparing Several Countries In countries with fire statistical variables addressing similar fields related to fire incidents, several studies were identified focused on fire incidence or fire-related outcomes highlighting potential factors that influence disparities or trends.

For the analysis of fire fatalities and casualties, several studies are comparing the USA with various countries. In 1994, a comparative analysis of fire risk in the USA, Japan, and the UK was developed [30]. The research utilized data on the causes of residential fires and deaths, fire death trends, fire death rates by age group, and victim location to compare risk indices. The USA was found to have higher fire death rates than the UK and Japan in almost every age group. Japan experienced the highest death rates among those 80 years or older, and older victims or victims with disabilities tended to be closer to the area of fire origin, suggesting that early detection was insufficient for such victims as evacuation probably had a key role. Common patterns for fire risk were shown in the UK and Japan.

In 2011, the United States Fire Administration examined fire death rate trends in the USA and 23 other industrialized countries [31]. The research found that although the USA had made substantial progress in reducing fire deaths since the 1970s, its fire death rate was the tenth highest among the 24 industrialized nations

in 2007. Fire death rates per million inhabitants consistently fell throughout the industrialized world from 1979 to 2007 but fell faster in North America and Eastern European regions than in other regions. From 1979 to 2007, the fire death rate in the USA declined by 66 per cent. Fire death rates in Japan showed a slight worsening over the study period. A variety of factors contributing to differences in fire death rates were identified, including differences in fire prevention practices and education, building practices and regulations, differences in lifestyles and cultural attitudes, and the proportion of senior citizens in the population. One of the difficulties in determining the cause of different fire death rates in different countries is a lack of available data.

A 2016 study used fire statistics from the USA, the UK, Japan, and Finland for the 2002–2012 period to compare the number of deaths and injuries from structure fires started by a small open flame ignition source to those from fires started by smoking materials [32]. Japan had substantially more fires ignited by smoking materials than the other countries, but not more fatalities from these fires, while the problem of deaths from fires started by smoking materials was the greatest in the UK. A more detailed quantitative analysis compared the relative contributions of low-energy ignition sources (match, lighter, space heater, etc.) to ignitions by smoking materials ignition to the USA fire problem. The analysis found that fires ignited by smoking materials more commonly resulted in fatalities than low-energy ignition fires, while the overall volume of low-energy ignition fires and corresponding losses and injuries are greater. Finally, a logistic regression model indicated that older persons were at greater risk of death from fires ignited by smoking materials than by low-energy ignition sources.

In Sweden, in 2016, Lund University sought to understand why more people were killed in residential fires per inhabitant in Finland than in Sweden [33]. Using reports and fire databases, the research found that fire victims in Finland were more likely to be male and that they were often single. A higher share of victims in Finland was under the influence of alcohol or drugs than in Sweden. Research of possible risk factors for fire death found that alcohol consumption, tobacco use, and the proportion of the population living alone were all higher in Finland than in Sweden and were seen as potentially contributing to disparities in the death rates in building fires between the two countries.

Another 2016 study from Sweden reviewed fire fatality data from 42 countries, using data from World Fire Statistics reports and the International Association of Fire and Rescue Services [34]. Reported rates of fire fatality experienced a decrease in most countries and were particularly significant in Estonia, Germany, Great Britain, Latvia, Russia, and the United States. Fire safety interventions that contributed to the decrease in deaths included increased use of smoke alarms and sprinkler systems and fire regulations for children's sleepwear and furniture and furnishings. Differences in how data is collected or how deaths due to fire are defined could explain differences in death rates between countries. However, the focus of the study was on trends within countries rather than a direct comparison between them to overcome differences in fire statistics reporting when trying to identify successful fire safety measures.

The previously discussed studies on fire fatalities provide examples of the differences that could be attributable to each fire statistic and the difficulties in gathering the data and creating appropriate comparisons. Moreover, the trends obtained are strongly influenced by the adopted datasets and the period considered for the analysis.

When causes of fires are examined, a 2009 study conducted by researchers from the Netherlands Institute for Safety (IFV) [35] examined fire statistics in European countries and researched on fire causes and development obtaining that domestic fires were more often caused by human behaviour than by technical failure. The most common causes of fires involved smoking materials or cooking, while the presence of upholstered furniture or textiles was also a contributing factor to fire development. The research also emphasized the need to exercise caution in drawing comparisons between countries based on fire statistics due to the absence of European standards for gathering, analysing, and publicizing data on fire statistics. The report also cautioned that national fire data only include information reported to the responsible data bodies for data collection and are likely to substantially undercount the actual number of domestic fires.

Finally, the Department for Communities and Local Government in the United Kingdom commissioned a study in 2011 with the European Union Fire Safety Network to examine and better understand fire data in member states of the European Union [36]. The research team relied upon an extensive literature review, telephone interviews with key stakeholders, and an online survey of national organizations collecting fire statistics in European Union states, as well as Norway and Iceland. The research found fire data to be collected at national and state levels to track and inform policy measures, raise awareness about fire risk, evaluate the number of fires and deaths, and develop interventions. However, substantial differences were confirmed between countries in numerous aspects of fire data collection. Countries used different ways of recording in-scope fires and fire-related deaths and injuries. While most countries recorded such key points as the number of fires or deaths, the recording of other critical factors, such as type of injury, information about fire safety systems, and size of the fire, was much more mixed and infrequent. Such differences were recognized as complicating the ability to make comparisons in several key variables of interest. The research determined that reconciling data between countries in its current form would be a significant task. Common datasets would facilitate comparisons that could be used to inform the development and effectiveness of fire safety interventions.

The study presented in [33] had similar conclusions as the one presented in [19, 20] and [22] regarding the most common factor in fire fatalities and injuries (the drug and alcohol intake) and the most common victims (males). It was also shown that the USA has a significant number of fire fatalities compared to other countries, as described in [30, 31] and [32].

The variety of fire statistical variables and current fire statistical practices described in this section proved the need for common datasets of fire statistics supported by the analysis of current practices and adopted terminology. Based on the literature review, it is, therefore, clear the need to move toward a harmonised data collection methodology able to create appropriate comparisons among simi-

lar variables and provide useful tools to evaluate and improve fire safety based on a deep analysis of current practice.

3.2. Learnings from International Organizations Investigating Fire Statistics

While Sect. 3.1 was focused on studies based on available fire statistics, the literature review presented in this section targeted the research developed by international organizations with the aim to highlight the complexity of creating a comprehensive assessment of current practice and data interpretation, internationally.

Several reports on the World Fire Statistics (WFS) from the Geneva Association provided basic recent indices of the fire experience at the international level [37], 38. These reports also offered important insight into how currently available data on fire incidents are used, as well as its potential limitations.

The WFS's information bulletin from 2011 reported findings from the United Nations that are based on a percentage of gross domestic product (GDP) calculations. Direct losses from fires for the 2006–2008 period were generally stable, with most countries experiencing a slight decrease or holding steady [37]. Minor increases were observed in the USA, Finland, France, the Netherlands, and Poland. Western and Central European countries were reported to compare well against the average situation in Eastern Europe and Central Asia/Eurasian countries in terms of the number of fire deaths per 100,000 inhabitants. Variance observed in the cost of fire service organizations between similar countries was attributed to different ratios of public, private, and volunteer organizations. Notable differences were observed in the costs of fire protection for buildings between countries, reflecting varying requirements for different types and sizes of buildings. The high fire death rates in Russia, Ukraine, Belarus, Moldova, and the Baltic states were in decline, though still very high. The high variance in fire deaths was attributed to inadequate fire protection services, poor building construction, and maintenance, and a high level of cigarette and alcohol consumption. Some of the Eastern and Eurasian countries were not members of the European Union and had not benefited from the possible advisory regulatory harmonization. The report emphasized that substantial differences in how fire data are collected and interpreted posed a critical challenge in using world fire statistics.

Findings from the United Nations for the 2007–2009 period were reported in the WFS bulletin on world fire statistics in 2012, with fire deaths in Eastern Europe and Eurasia reported for 2001–2009 [39]. Direct losses due to fires showed that most countries had very minor decreases or increases in their losses as a percentage of GDP. Italy was an exception and experienced the largest increase. Proportional costs for funding fire service organizations remained largely stable, with only minor variances over the previous year's report, and the absolute costs also saw relatively minor changes which generally took the form of small increases. Many countries continued to experience improved long-term trends in fire deaths, while Singapore showed the lowest proportion of fire deaths. Germany and Sweden experienced slight increases in death figures for the three years of the report. The fire mortality rates in Eastern Europe and Eurasia showed improvement since

2000 but remained significantly higher compared to the Western and Central European states. In Estonia, Latvia, Lithuania, and the Russian Federation, the reductions in mortality rates throughout the entire reporting period were dramatic, ranging from a low of 20% in the Russian Federation to a high of 42% in Estonia.

The WFS's 2014 report of fire analysis findings from the United Nations covered the period from 2008 to 2010 [38]. GDP calculations for direct losses were again reported to be stable or show a slight decrease while presenting decreasing costs in absolute figures. Scandinavian countries suffered above-average fire losses, seen as possibly a result of the harsh climate and higher percentage of buildings containing wood. Most countries experienced small to noticeable decreases in per capita mortality due to fire for the reporting period, coinciding with decreases in deaths due to fires in 2010. The proportional costs of funding fire service organizations were again reported to be generally stable, with minor variances from the prior year's report, with the greatest variance being a noticeable decrease in costs in Japan. Absolute costs also saw relatively minor changes and frequently involved comparatively small increases, except for the USA, which showed a noticeable cost increase in 2010. Cost of fire protection presented significantly higher cost estimates for various types of buildings than earlier reports and raised important questions about appropriate methods of calculations. The wide variation in building fire protection costs to some extent reflects differences in estimation assumptions and methods, but also differences in rates of construction activity within the larger economy.

Finally, the International Association of Fire and Rescue Service (CTIF) publishes annual fire statistics from several countries in the "World Fire Statistics" reports [15]. These publications will be discussed and analysed in Sect. 6 of this paper.

As seen in the literature review, the variation obtained in the comparison of fire statistical data in several countries could be attributable to various factors that can be determined only by an extensive evaluation of specific fire statistics of each nation. Such evaluations could highlight the adopted practice in collecting the data and the variables available for comparison. The remainder of this paper focuses on a review of the current fire statistics in European and other countries in terms of terminology, collection, and interpretation issues.

4. Potential Issues in the Comparison of Fire Statistics from Different Countries

4.1. Terminology Issues in Fire Statistics

Most fire services in the investigated countries centralise their data into one unique database. At least, that is the case for Bulgaria, Croatia, Czech Republic, Denmark, France, Greece, Hungary, Italy, Luxembourg, Norway, Poland, Romania, Russia, Slovakia, and Spain. However, in France, Spain, and other countries, due to the lack of official definitions and national fire statistical collection, differences may exist in the terminology adopted by the various fire departments when

the data are gathered after attending fire incidents. Other countries display differences concerning how data are collected and maintained, which data elements are recorded, and how variables are coded in different regions, states, or even within a state, as is the case in Australia, Austria, Canada, Germany, and the Netherlands.

In Sweden, the Civil Contingencies Agency (MSB) developed documentation and an online education program to support individual fire and rescue services and personnel in their reporting responsibilities [40]. Prior to 2018, there were three systems (Alarmos, Core, or Daedalos) used by the fire and rescue services when reporting incidents. A unique system is now used by all fire and rescue services in Sweden.

In the UK, fire safety data are separately maintained for England, Northern Ireland, Scotland, and Wales. English statistics appears to provide the highest number of variables publicly available. Finally, Northern Ireland Fire and Rescue Service statistics do not use the Incident Recording System (IRS) [41] and do not publish comparable statistics.

In the USA, incident reports [25] and data elements are standardized and can be found online [42]. However, the completeness of data in incident reports may vary locally, creating differences in interpretation. For example, ''Burnt food'' may be considered a fire, excessive heat, a smoke scare, or a false alarm. Similarly, many non-fatal civilian injuries are not captured by the fire service [43]. It is estimated that in the USA 21,174 of 48,202 civilian non-arson fire injuries resulted from residential or consumer-product fires attended by fire departments from 1 July 2002 to 30 June 2003. NFPA estimated totals of 18,425 civilian injuries in 2002, and 18,125 in 2003, including injuries caused by arson. This means that some of the injured may have left the scene before the fire department arrived or been transported by a non-fire emergency service or civilians.

In Switzerland, in addition to the fire service database, the Public Insurance for Real Estate (PIRE) collects fire data using a specific codification. Data from 19 out of 26 Cantons are then gathered and analysed by the national insurance association (APIRE) [44] covering 80% of the country's buildings. However, insurers of buildings in the seven remaining cantons do not use this code.

4.2. Terminology Issues Compared with Other Domains

In general, there are four main sources of fire databases in most countries, originating from fire services, medical organizations, insurance providers, and police departments, and there are likely to be differences in their terminology and data definitions. Regarding the fire service data, in some countries like France, and Germany, due to the current lack of official definitions of terms and fire statistics, it is most likely that differences and contradictions with the various domains exist. In particular, classifications in fire statistics from insurance companies do not correspond to those used by the fire and rescue services. For example, one fire incident according to the fire services could result in multiple fire claims. Finally, there are discrepancies between fire service data and the medical data, which is usually based on the International Classification of Disease (ICD) coding of death certificates.

The World Health Organization's (WHO) 10th Edition of the International Classification of Disease (ICD-10) [7] is used by healthcare systems and coroners for medical records, billing, and death certificates. ICD is a global classification system and tool for different diagnoses. The primary purpose of ICD is to enable the classification and statistical description of diseases and other health problems that result in human death or contact with the health care system in a country. In addition to traditional diagnoses, the classification includes a range of symptoms, abnormal findings, and social conditions.

The coding for lethality due to exposure to smoke, fire, and flames is included in Chapter 20 of the 2016 edition of ICD-10 [7] and is expressed with the codes X00-X09 (Table 1). External causes of injury codes on death certificates can be used to obtain fire death data. Separate categorizations are used for unintentional, intentional self-harm, assault, and undetermined intent. It is important to separate this coding from section X10-X19, which is related to contact with heat and hot substances that are not related to smoke, fire, and flames. It is also important to note that Chapter 20 in ICD-10 is intended to be used as secondary to a code from another chapter, indicating the nature of the condition. Most often, the condition will be classifiable according to Chapter 19, ''Injury, poisoning and certain other consequences of external causes''. Except for X00 and X02, it is not easy to separate building fires from non-building fires, since X04-X09 do not distinguish if the exposure occurs indoors or outdoors.

In a Swedish study [45], three different sources of information on fire fatalities were compared, and in one of these sources, the cause of death register, uses the ICD-10 coding system. The results showed that the cause of death registry underestimates the number of fire fatalities by about 25%, and the authors argue that none of the single sources is sufficient to assess how many people die in fires.

Since the introduction of the ICD system, classifications have been changed several times and this needs to be considered when comparing data over extended periods. Jonsson et al. [46] have used the ICD data for Sweden to conduct this type of study of temporal trends.

Finally, there are discrepancies between fire service data and the ICD-10 coding of death certificates. For instance, NFPA counted the fatalities in the World Trade Centre and Pentagon attacks as fire deaths, while the death certificates identified them as terrorism-related deaths [47]. It can also be difficult with ICD-10 codes to determine when vehicle fire deaths should be counted as transportation events rather than fires. There are other cases where ICD-10 codes do not show if the fire is the cause of injury, such as defenestration, suicide, and collapses or collisions by a falling object. While ICD codes have their issues and limitations, they are widely used by national statistic institutes. A way to determine the reliability of fire service data is to compare the data with those of the ICD-10.

4.3. Collection and Interpretation Issues

4.3.1. Responsibility for Fire Statistics In some countries, fire departments are responsible for entering data not only for fires, but also for emergency medical services, severe weather and natural disasters, and other incidents. Reports are

Table 1
Sub-Sections for Lethality Due to Exposure to Smoke, Fire, and Flames in ICD-10 by WHO

Code	Description
X00	Exposure to uncontrolled fire in building or structure
X01	Exposure to uncontrolled fire, not in building or structure
X02	Exposure to controlled fire in building or structure
X03	Exposure to controlled fire, not in building or structure
X04	Exposure to ignition of highly flammable material
X05	Exposure to ignition or melting of nightwear
X06	Exposure to ignition or melting of other clothing and apparel
X08	Exposure to other specified smoke, fire, and flames
X09	Exposure to unspecified smoke, fire, and flames
	Subsection for other intents
X76	Intentional self-harm by smoke, fire, and flames
X97	Assault by smoke, fire, and flames
Y26	Exposure to smoke, fire, and flames, undetermined intent

filed for incidents and, if applicable, fatalities and casualties. Firefighter casualties and civilian casualties generally adopt separate reports. Fire departments are in most cases composed of professional firefighters and volunteer firefighters while in others military firefighter units can be responsible for cities or areas.

Volunteers, professionals, military, and a mix of the previously mentioned group categories could usually participate in filling in fire incident reports while in some countries, such as in the USA, only local fire departments collect the fire data. In particular, they are filled in and signed by the firefighter in charge of the operation. In many countries, the information is then collected by the fire department and sent to the regional or national body where data are compiled.

In the USA, states with fewer resources may rely upon a single person, while other state programs might include full- or part-time research analysts or rely upon administrators, information technology staff, or investigators to run their programs. The UK (Wales, Scotland, England, and Northern Ireland) has different organizations elaborating the data according to their specific fire statistics datasets. Even Sweden and Russia have several organisations interpreting the statistics.

Many differences exist concerning who is interpreting the fire statistics, and this is also depending on the purpose of the data investigation. Organizations responsible for interpreting the statistics are insurance associations, governmental organizations, universities, research institutes, individual municipalities represented through the local fire and rescue service, departments of State fire service, scientific and educational organizations, Ministries, General Inspectorate for Emergency Situations, Directorate for Civil Protection, the fire corps, first responders and technical experts.

It is notable that in smaller countries in terms of the number of buildings and population, the interpretation of the collected statistics is done by a single institute

or multiple organizations such as in the Netherlands, Switzerland, Denmark, and Hungary. In Austria, the purpose is to provide data for research and scientific reasons as well as for performance-based fire prevention measures.

Since information on fire incidents is collected at local levels which vary by resources, staffing, and leadership, there are substantial opportunities for disparities between jurisdictions related to the completeness and accuracy of data. Moreover, different fire departments provide different levels of quality control. The differences in the level of training for reporting could result in different data quality. The coexistence of several organizations interpreting the data leads to difficulties in comparing fire statistics considering different interests and objectives and based on their adopted analysis, definitions, and terminologies (Table 2).

4.3.2. Missing Data in the Fire Statistics Missing data in the analysis of fire statistics datasets can compromise the quality and completeness of the fire incident assessment and provide a skewed evaluation of specific fire safety variables.

In the USA, the variables in the National Fire Incident Reporting System (NFIRS) [25] frequently include several code choices that represent unknown data. In addition to the variables that contain missing values, NFIRS includes code choices that indicate that the requested values are undetermined, unknown, or under investigation. NFPA treats variables with unknown values and those with missing values in the same way and applies a procedure that redistributes unknown values to produce an estimate of the true values. NFPA allocates unknown data proportionally among known data by calculating percentages based on the known data and then multiplying the totals by the percentages known. Based on this approach if the missing data are known, they would be distributed in the same manner as the known data. NFPA also applies additional adjustments to several fields.

In England, statisticians at the Home Office carry out a monthly monitoring process that looks for unusual patterns in the data and examines data gaps and conducts variance checks to identify entries that seem unusually large or small if compared to figures for the same month in the prior year [48]. Missing data are reported as unknown, and no imputation or other estimation methods are used to deal with such item-level missingness. In Wales, statisticians occasionally record data as missing and seek to impute data if there are time and resource constraints with the submission of incident reports [49]. Data providers are informed of any imputation or changes to data and are provided with an opportunity to challenge or comment upon the changes. This is considered a compromise to resolve validation issues and to minimally impact the usability of the dataset.

France uses a weighted average to deal with unit-level missing data in the number of fire interventions reported by fire departments [2]. When data on fire interventions are not reported by a fire department, the Ministry of Interior calculates the weighted average number of interventions by fire departments protecting populations of similar size and applies that number to the data for the non-reporting fire department.

The Swedish Civil Contingencies Agency (MSB) has a national system for collecting data from incident reports that are recorded by local fire departments in

Table 2
Authorities Responsible for the Data Collection and Interpretation

Data collection	Data interpretation
Fire departments	Fire and Rescue Services
Emergency medical services/medical institutes	Governmental organizations
Volunteers and military	National and local bodies
Fire investigators	Research institutes
Insurance companies	Insurance companies and/or associations

their own records management systems [40]. A procedure was introduced in 2018 to identify underreporting at the central level. Every month MSB sends feedback to fire departments on reports that have been initiated but remain uncompleted in the national dataset. When publishing statistics, MSB has never developed estimates to mitigate missing data. MSB believes that it is better to accept this loss of precision in the statistics, rather than having the risk of introducing bias in the material. The approach adopted is in line with the practice for European statistical authorities as formulated by Eurostat, where the data quality is described in a quality declaration. The user of the statistics must decide how to deal with missing data from underreporting or other shortcomings in data quality. However, the amount of missing data is very low in Sweden.

The Austrian Fire Prevention Associations collect data from the police stations and insurers for each federal state (except Vienna) and publish them yearly [50]. Several fire statistics are gathered by the Upper Austrian Fire Prevention Association for creating and yearly publishing of the Austrian Fire Statistic. In the years 2014 to 2017, a group of experts in fire investigation created a database system to collect fire data in a structured way (Datenmanagement in der Brandursachenermittlung—DMBUE). Six of nine Austrian federal states participate in this data management system up to now. It is estimated that Austria provides data with a high confidence level due to the existing definitions, important covered areas and collected terms, and existing quality safeguards [51].

No other countries appear to adopt a methodology for dealing with missing data, although some countries do acknowledge that missing data is a potential problem that compromises data quality. Once the fire statistics in several countries were described in terms of terminology, collection, and interpretation issues, the fire statistical variables in the European and other countries are discussed.

5. Overview of the Variables Collected in the Fire Statistics

The analysis of the available fire statistical variables in the EU and other countries (Australia, Canada, New Zealand, Norway, Russia, Switzerland, the UK, and the USA) is supported by the necessity to better investigate existing fire statistics to be able to increase awareness on current fire incidents in various building

types, develop appropriate comparisons amongst countries and evaluate future actions to improve fire safety. However, these need to be complemented with the analysis of the potential issues in terms of terminology, collection and interpretation presented in Sect. 4.

While 35 countries were covered in the description of current fire statistics, for the analysis of the available variables, a total of 21 EU Member States (missing Greece, Lithuania, Luxemburg, Malta, Portugal, and Spain) and eight other countries were investigated as they provided information about the variables covered by their fire statistics. The eight other countries were selected based on their experience with data collection and their detailed systems for recording the information of the fire incidents and extensive datasets, which tend to have a greater number of variables than those provided by the EU Member States. The analysis focuses on the available variables collected in the fire statistics classified according to ten categories of interest such as fire incident, building description, fire causes, fire consequences, fatalities, casualties, fire safety measures, fire response, fire costs, and fire prevention with various subclasses. The categories of interest were selected based on the analysis of structured fire statistics currently adopted in the UK and USA as their extensive practices comprehensively describe the fire incidents. The provided categories based on the fire statistical variables available in structured fire statistics are able to provide a complete assessment of fire incidents in buildings and the existing fire statistical fields collected in the EU and other countries are summarized in Tables 4 and 5 in the Appendix. The existing definitions related to the categories of interest compared to those available in the ISO/TS 17755–2 [18] can be found for each of the examined countries in the report published by the EU FireStat [14] and further discussed in the analysis developed in Part II [8].

The incident time, date, and location are recorded in almost all countries (Figure 1) and this could be attributable to systems that automatically record the time of the fire call or equipment placed in the fire vehicle able to monitor its position. False alarms are recorded in 14 EU and four other countries while the distinction between intentional and accidental fires is less frequent being recorded in more than nine and five EU and other countries, respectively.

The classification of the building into residential and non-residential properties is usually available in the 17 EU and seven other countries where the building type is usually further classified into various sub-property types. The property type appears to be recorded in most of the examined countries and this is relevant in the light of the differences in fire safety measures and approaches in residential and non-residential buildings. The variables related to the construction type is often available in six other countries and four EU countries. The number of floors, origin floor, and total building dimension are recorded for a maximum of eight EU countries and most of the other countries investigated (Figure 2).

Analysing the variables related to pre-fire conditions, fire causes are available in the fire statistics of 15 EU and five other countries. The factors contributing to ignition, source of ignition (in nine EU and six other countries), fire room of origin (in nine EU and six other countries), item first ignited (in 10 EU and six other countries), material first ignited (in six EU and six other countries) and material

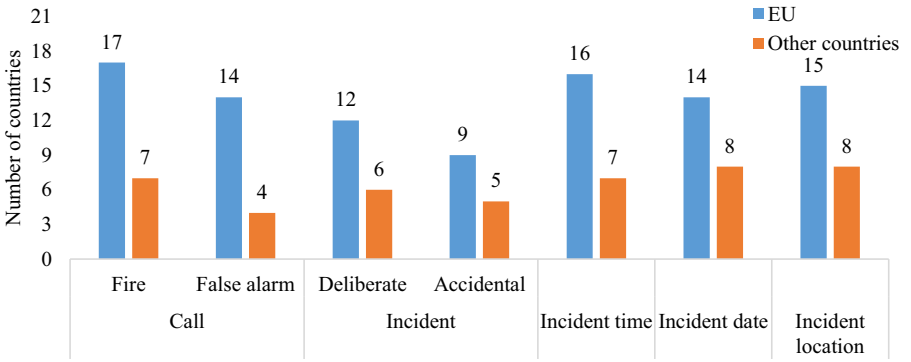

Figure 1. Variables recorded for the description of fire incidents in 21 EU and the eight other countries.

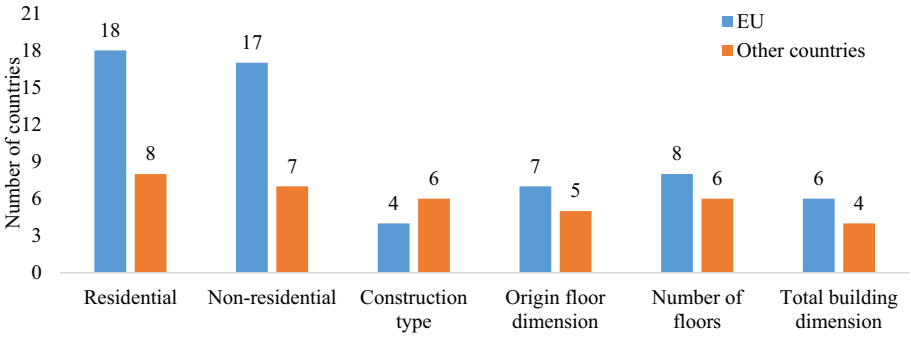

Figure 2. Variables recorded for the building description in 21 EU and the eight other countries.

mainly responsible for the fire development (in five EU and other countries) are available (Figure 3).

Fire statistics also include variables related to post-fire conditions and such analysis was divided into the evaluation of fire spread, investigation, and quantification of damage. As shown in Figure 4, fire spread was recorded in seven EU countries where six of them also provide a distinction between horizontal and vertical fire spread. In six other countries, fire spread was generally referred to as horizontal spread even if the vertical spread is recorded.

From the analyses behind the data in Figures 3 and 4, it was found that the description of pre-fire conditions such as fire cause and item first ignited was recorded more often than the evaluation of post-fire conditions related to fire spread. Despite the evaluation of property damage appears to be challenging, it provides important information for the fire safety community to determine the fire consequences and how this could be mitigated when active and passive fire safety measures are present in the building. The property damage is also further exam-

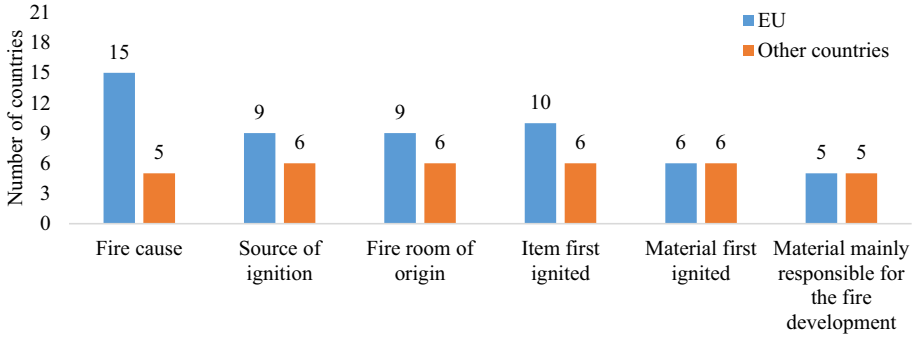

Figure 3. Variables recorded for the fire causes in 21 EU and the eight other countries.

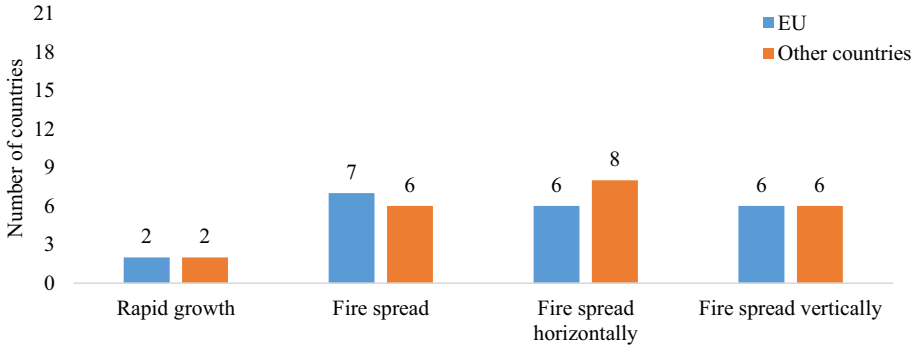

Figure 4. Variables recorded for the fire consequences focused on the fire spread in 21 EU and the eight other countries.

ined in some countries in terms of evaluation of the damage and damage quantification as illustrated in Figure 5.

The distinction between fire and total damage appears in seven EU countries and three other countries, where damage is usually linked only to fire damage except in two other countries in which the subdivision of damage in fire, flame, smoke, and water damage is available. As shown in Figure 5, it appears that fire damage is quantified based on the area (m^2) and the percentage of property damage in five and three EU countries while both quantifications are in three other countries.

Other important variables are those linked to fire safety measures. Fire safety measures are here subdivided into alarms, automatic extinguishing systems (Figure 6), and other safety measures such as compartmentation, smoke extractors, and others (Figure 7). In the EU Member States, the presence and operation of alarms are generally more often recorded in 11 and nine countries than the type in seven countries while effectiveness and failure of the alarm are recorded in six countries. For the automatic extinguishing systems, the presence in a building is

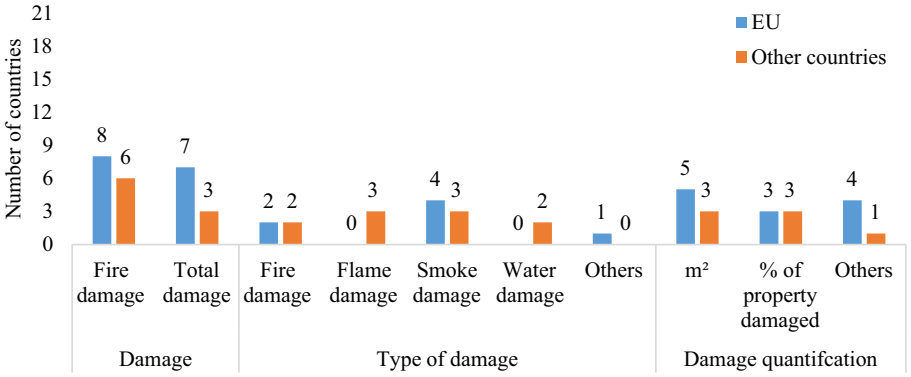

Figure 5. Variables recorded for the fire consequences focused on the evaluation of damage in 21 EU and the eight other countries.

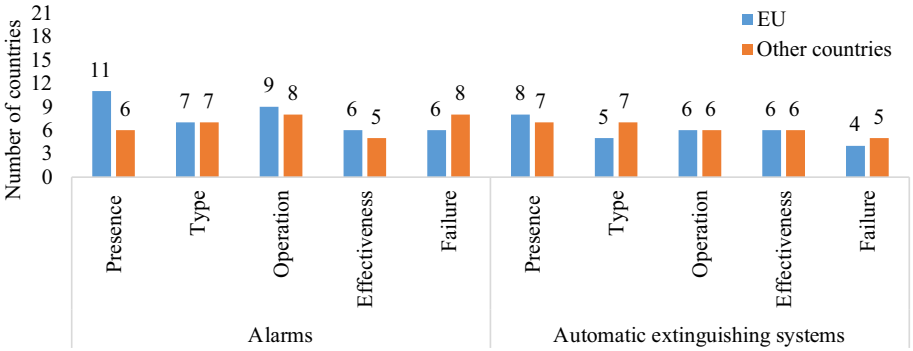

Figure 6. Variables recorded for fire safety measures focused on alarms and automatic extinguishing systems in 21 EU and the eight other countries.

generally recorded in eight, followed by operation and effectiveness in six, type in five, and failure in four EU countries. If the analysis for alarms is applied to the other countries, the variables recorded are operation and failure in eight countries, type in seven, presence in six and effectiveness in five countries while for the automatic extinguishing systems the presence and type are available in seven countries, operation and effectiveness in six, and failure in five countries (Figure 6).

Figure 7 shows that evacuation is recorded in eight EU and four other countries, the presence of fire brigade on site in seven EU and four other countries, smoke extractors in six EU and two other countries, and compartmentation in five and three EU and other countries. Fire barriers are available in four EU and one other country, escape routes less often in three EU and two other countries while information on safe areas is available only in two EU countries.

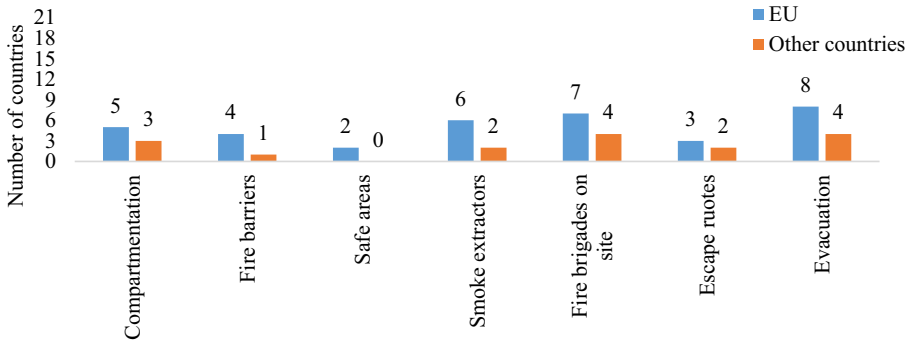

Figure 7. Variables recorded for other fire safety measures in 21 EU and the eight other countries.

It is, therefore, clear that the fire statistical variables related to fire safety measures in various countries are mainly referred to as active safety measures while passive safety measures are identified only with the variables related to compartmentation and fire barriers recorded only in a few countries. This consideration could provide potential implementations and optimizations for the development of fire statistics to effectively assess the performance and operation of various fire safety measures and their effectiveness in reducing fire consequences.

The response time is divided into the response of occupants and firefighters, as illustrated in Figure 8. The response time of occupants is also subdivided into the time between ignition to discovery and between discovery to call, which are variables available in the fire statistics of four and seven EU countries and both time intervals in two other countries. The response time of the fire brigades is usually defined as the time between the notification of the fire incident and the arrival of the fire brigade at the fire scene and is comprised of five steps: notification, dispatch, preparation, travel time, and set up time. Between eight and 12 EU countries and between one and eight other countries collect the above-mentioned time steps where the notification time is the variable usually available in the fire statistics. The time intervals related to the response time for the occupant rescue and fire extinguishment are presented only in four and five EU countries and one and two other countries, respectively. The response time of occupants and fire brigades could be seen in terms of how these aspects could influence the reduction of fire fatalities and casualties. The evaluation of the time needed for the fire vehicle to attend the fire scene and the number of fire incidents could also support the fire brigades in effectively allocating and optimising resources and equipment.

Fatalities and non-fatal casualties were investigated separately and include information for both occupants and firefighters. For fatalities in the EU countries (Figure 9), the number of victims is available in 20 countries, age in 14, and gender in 10 countries, followed by cause of fatality in eight countries, type of fatality in six and disability in seven countries. In the other countries, all the variables investigated for the description of fatalities are available for a minimum of six countries, except disability and profession recorded in four and two countries,

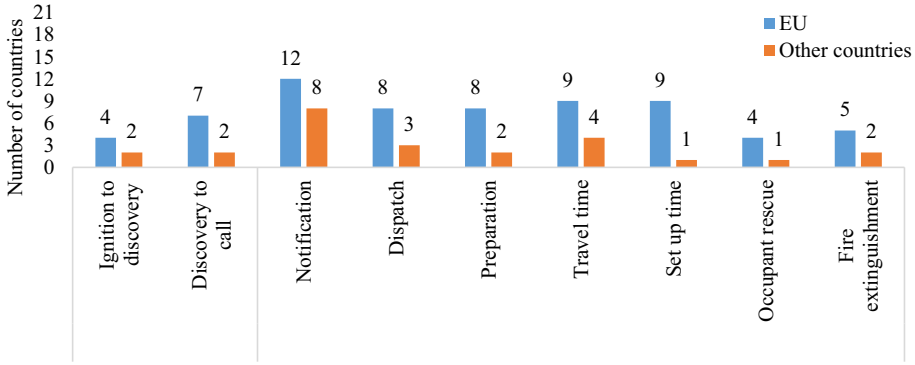

Figure 8. Variables recorded for the fire response time of occupants and fire brigades in 21 EU and the eight other countries.

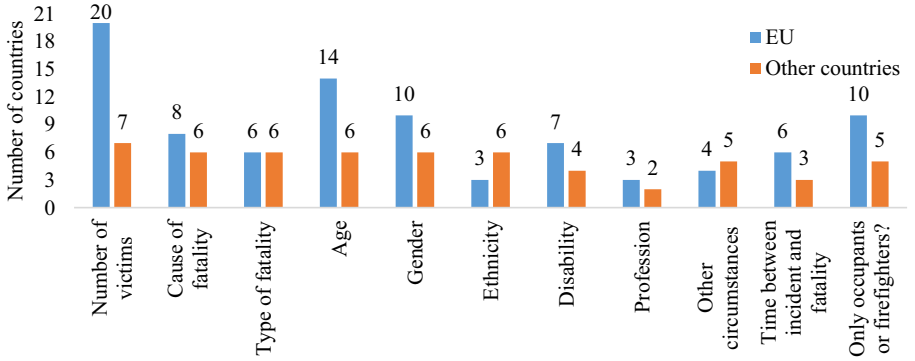

Figure 9. Variables recorded for fatalities in 21 EU and the eight other countries.

respectively. The time between the incident and the fatality is available only in six EU and three other countries. The distinction of victims between occupants and firefighters is determined in 10 and five EU and other countries, respectively.

From the analysis, it appears that non-fatal casualties are recorded less often than fatalities. In the data collection systems investigated in this research, the obtained information on non-fatal casualties included: in EU countries, the number of injured people recorded in 15 countries, age in 11, type of injury in eight, gender in seven, and cause of injury in five countries while in the other countries, the number of injured people is available in seven countries, cause of injury, age, gender, and disability in six and type of injury in five countries. Furthermore, the time between the incident and the injury is recorded only in two EU and other countries. The distinction of the injured people in occupants or firefighters is present in the fire statistics of seven EU and five other countries (Figure 10).

When the analyses presented in Figures 9 and 10 are compared to the other fire statistical variables illustrated in this section, it appears clear how the evaluation

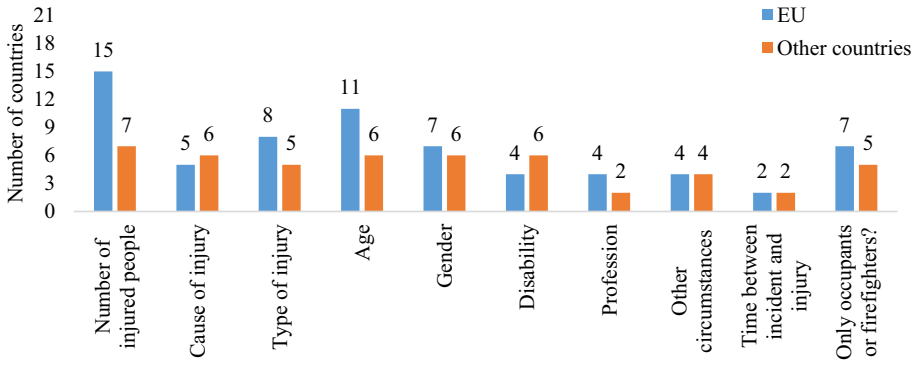

Figure 10. Variables recorded for casualties in 21 EU and the eight other countries.

of fatalities and casualties are generally recorded in the fire statistics of the examined countries showing the relevance given to the evaluation of the impact of fire incidents to life safety.

Finally, the evaluation of the financial costs due to fire incidents usually includes direct and indirect financial losses. As described in Figure 11, the methodology for the evaluation of direct costs is usually collected in five EU and four other countries. Information on direct costs includes property in nine EU and five other countries and medical care in one and three EU and other countries. For the indirect costs, temporal shelter and medical care are available in Denmark and Norway.

Based on the results obtained from the analysis of 21 EU and eight other countries, the findings indicate that the fire statistics of the other countries appear more detailed, especially for the quantification of damage, the presence, operation, and effectiveness of fire safety measures, and information on fatalities and non-fatal casualties. In the following section, a quantified analysis of specific fire statistical variables per 100,000 inhabitants from 2009 to 2018 for several countries is provided to illustrate the uses of fire statistical data.

6. Detailed Analysis of Fires, Fire Deaths, and Injuries from 2009 to 2018

Once the need for accurate investigations of fire statistics was examined in terms of terminology, collection and interpretation issues and the available variables in the EU and other countries presented, the analyses developed in this section provide some examples of how data can be used to determine trends over periods and highlight data that requires actions and future optimizations.

A comparison was developed based on data extracted from the ''World Fire Statistics'' reports [15], which are published annually by the International Association of Fire and Rescue Service (CTIF). Data were compiled and analysed for the years between 2009 and 2018 for European countries and selected other countries

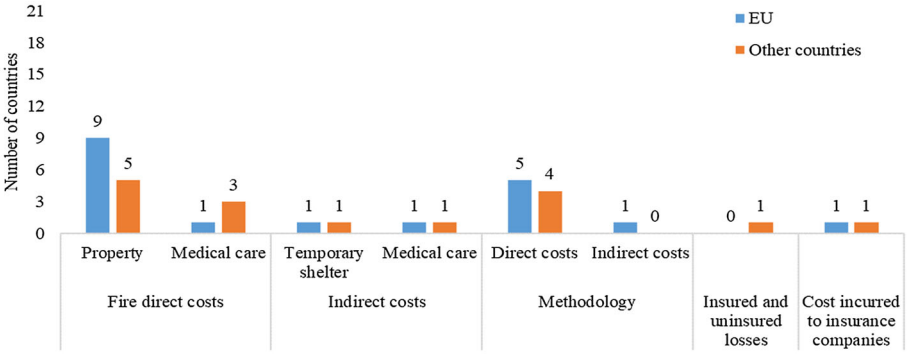

Figure 11. Variables recorded for the fire financial costs in 21 EU and the eight other countries.

included in the research pool. CTIF collects (annual numbers) data from each country voluntarily. Data are usually provided by Fire and Rescue Services or firefighter associations. In some cases, data are provided by two institutions, such as firefighters and national institutes providing data that may differ for the same country. In general, the differences reported by the two main institutions range between 5 and 10%. There are also possibilities where countries do not provide data and gaps were filled in where possible. Some countries only provide structure fires, while others data for structure fires, vehicle fires, and wildfires.

In the analysis developed in this research, the number of fires, fire deaths, and fire injuries was divided by the average population for each country into categories as shown in Table 3, and Figures 22, 23 and 24 in the Appendix. The average population was calculated from the population numbers reported by CTIF over the period from 2009 to 2018. CTIF recommends analysing data by decades (e.g. sequential average over 10 years) and not by year to capture proper trends and adequately consider potential outliers that may be present in the data. If the data are analysed by year, then exceptional fire events would cause some spikes in the trends. Moreover, countries are divided into categories based on the average numbers over ten years. This classification is developed only for better visualization and does not affect the conclusions. Since there is no common terminology among the countries, the figures presented in this section are mainly offering information about the existing trends in the investigated countries.

Figures 12, 13 and 14 present the average number of fires per 100,000 inhabitants from 2009 to 2018 as classified in Table 3 into categories 1, 2 and 3, respectively. Note that the y-axis scale is different in these remaining sets of figures. Despite the classification into the various categories, it can generally be observed that the number of fires is relatively constant or slightly decreasing over time. Most spikes in the graphs are related to extraordinary fire events. Moreover, when fire incidents among the countries of a specific category are examined, the changes in trends can be determined within data ranges in which the data variation can be identified. In detail, the number of fires per 100,000 inhabitants from 2009 to 2018

Table 3
Categories of Number of Fires, Fire Deaths and Injuries per 100,000 Inhabitants

Category	Number of fires per 100,000 inhabitants	Countries
1	> 400	Austria, Bulgaria, Cyprus, Estonia, France, Ireland, Latvia, Lithuania, USA
2	200–400	Croatia, Finland, Germany, Great Britain, Greece, Hungary, Italy, Luxembourg, New Zealand, Poland, Portugal, Serbia, Slovakia, Spain, Sweden
3	< 200	Belarus, Czech Republic, Moldova, Norway, Romania, Russia, Switzerland, Ukraine
Category	**Number of fire deaths per 100,000 inhabitants**	**Countries**
1	> 2	Belarus, Estonia, Latvia, Lithuania, Moldova, Russia, Ukraine
2	1–2	Bulgaria, Czech Republic, Denmark, Finland, Hungary, Poland, Romania, Serbia, Sweden, USA
3	0.5–1	Croatia, Cyprus, France, Great Britain, Greece, Ireland, Norway, Slovakia
4	< 0.5	Austria, Canada, Germany, Iceland, Italy, Netherlands, New Zealand, Slovenia, Spain, Liechtenstein, Luxemburg, Portugal
Category	**Number of injuries per 100,000 inhabitants**	**Countries**
1	> 10	Czech Rep, Finland, France, Great Britain, Latvia, Lithuania, Portugal, Slovenia, Sweden
2	6–10	Estonia, Hungary, New Zealand, Norway, Russia
3	< 6	Belarus, Bulgaria, Croatia, Greece, Italy, Moldova, Romania, Serbia, Slovakia, Ukraine, USA

in Category 1 varies between approximately 400 and 700 fires, in Category 2 between 200 and 400 fires, and in Category 3 between 50 and 200 fires.

The countries are also divided into four categories to represent the number of fire deaths per 100,000 inhabitants, as shown in Table 3. A noteworthy observation from the data is that a high number of deaths are reported in some countries with fewer fires including Belarus, Czech Republic, Moldova, Norway, Romania, Russia, and Ukraine, raising potential questions about how the number of fires and fire deaths are defined and counted.

Figures 15, 16, 17 and 18 present the number of fire deaths per 100,000 inhabitants from 2009 to 2018 for the four defined categories, respectively. In general, it can be observed that the number of fire deaths is decreasing for Category 1 countries while remaining relatively constant for Category 2 and 3 countries. All the

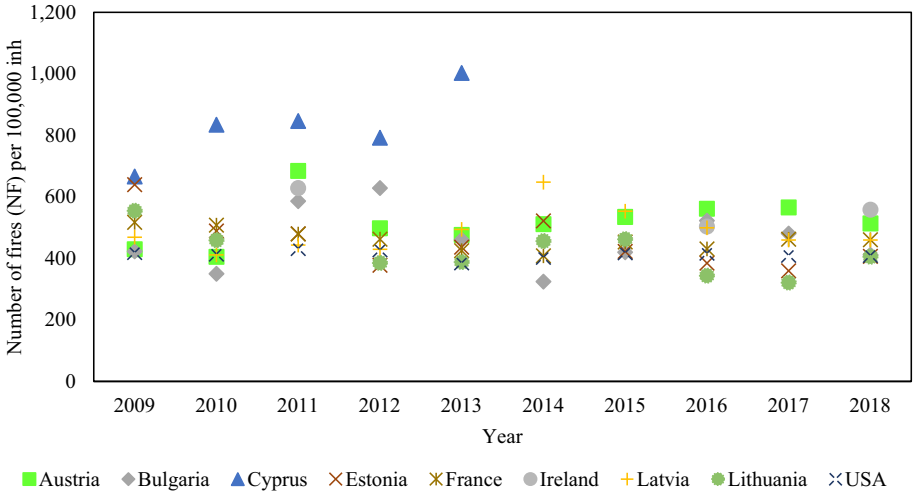

Figure 12. Number of fires per 100,000 inhabitants from 2009 to 2018—Category 1.

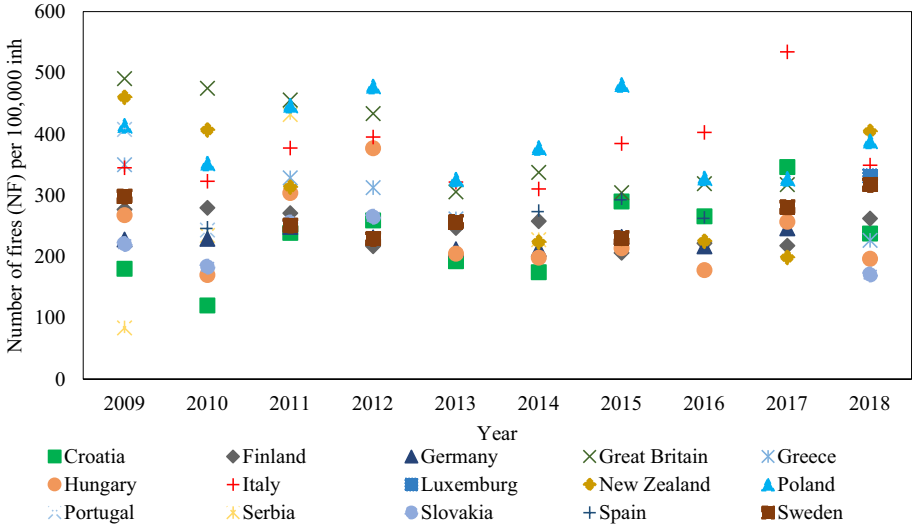

Figure 13. Number of fires per 100,000 inhabitants from 2009 to 2018—Category 2.

spikes in the graphs suggest that an extraordinary event (major fire incident) occurred, such as the 2015 Colectiv nightclub fire in Romania. These spikes are most noticeable in countries with smaller populations.

All analyses of fire deaths should be carefully considered since the exact definition of fire death is rarely specified. Countries take different approaches in defining the time elapsed between a fire incident and the time a fire fatality is recorded.

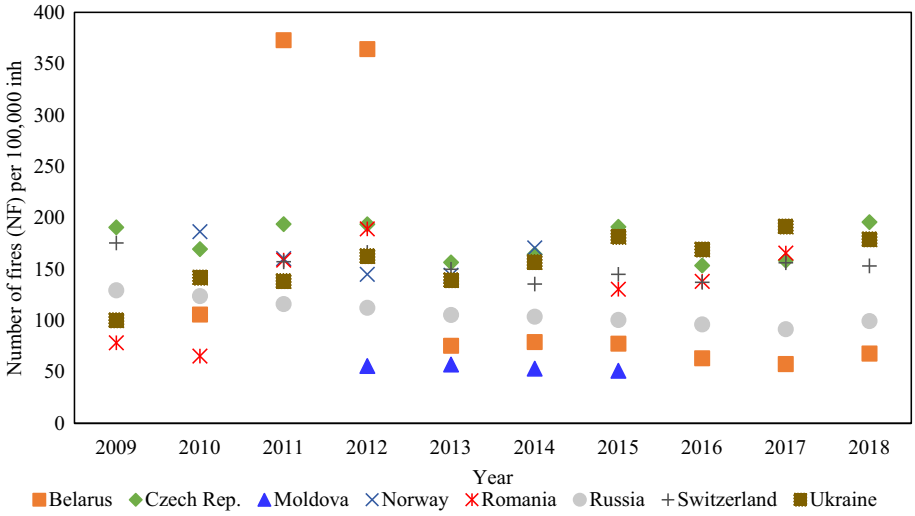

Figure 14. Number of fires per 100,000 inhabitants from 2009 to 2018—Category 3.

Many countries, such as Australia, France, Russia, and the UK, do not specify any time limit for recording a fire death. Canada counts a fire fatality for injuries leading to death within 1 year and 1 day after the fire incident. In other countries, "death within 48 h after the fire" is regarded as a fire death. Additionally, some countries do not include fire deaths resulting from arson. France and Switzerland only report fire fatalities at the location of the fire—either those discovered by rescuers or those declared dead after unsuccessful resuscitation attempts. Therefore, the French and Swiss official databases do not consider fire fatalities that occurred at the hospital or during the transport of casualties to the hospital. This helps to explain why the number of fire deaths in France was six deaths per million inhabitants in 2008, while figures derived from the French Institute National de la Santé et de la Recherche Médicale (INSERM) data are higher (nine deaths per million inhabitants in 2008) because they also include victims who died in the hospital [22, 52–55]. This is not the case in other countries such as Germany, the UK, and Spain.

Surprisingly, there is no correlation in the countries grouped in the categories when the number of fires and number of fire deaths are analysed. For instance, Russia, Belarus, and Ukraine belong to Category 3 for the number of fires with less than 200 fires per 100,000 inhabitants but are listed in Category 1 for fire deaths with more than 2 fire deaths per 100,000 inhabitants. That suggests that fires in these countries are less frequent but deadlier or could instead be due to different definitions of fires, as previously mentioned.

For the number of fire injuries, the countries are divided into three categories based on the average number of fire injuries per 100,000 inhabitants, as shown in Table 3. Fewer countries reported the number of fire injuries than the number of fires and fire deaths. In addition, the term "fire injury" can be difficult to define,

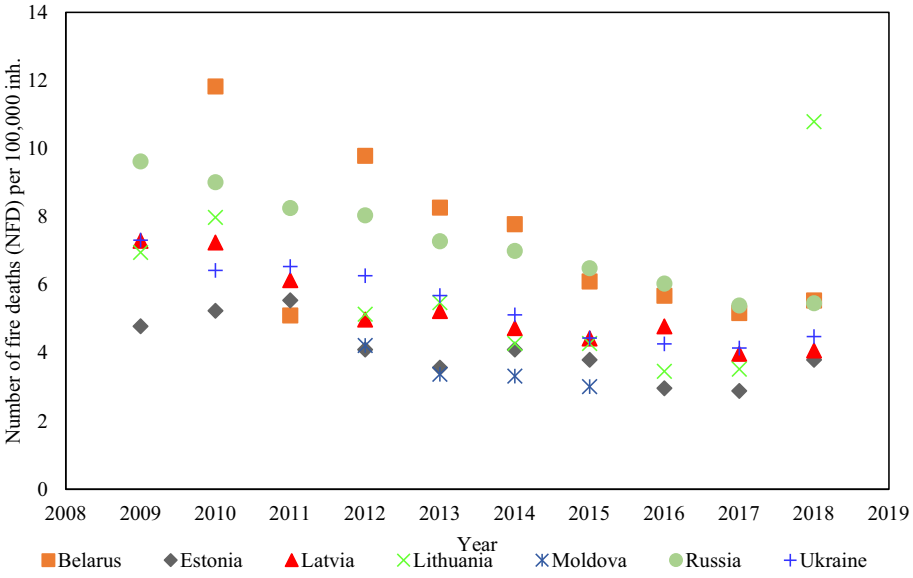

Figure 15. Number of fire deaths per 100,000 inhabitants from 2009 to 2019—Category 1.

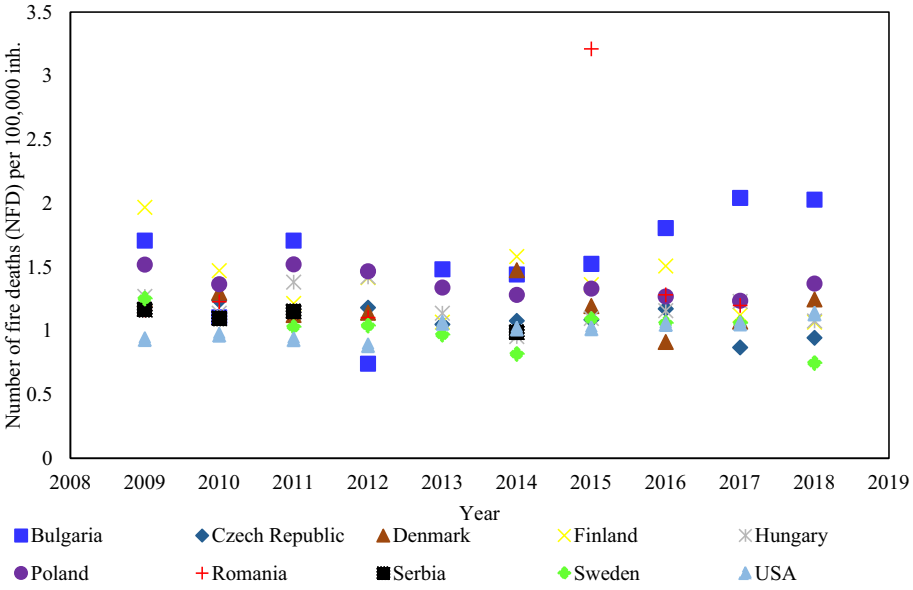

Figure 16. Number of fire deaths per 100,000 inhabitants from 2009 to 2019—Category 2.

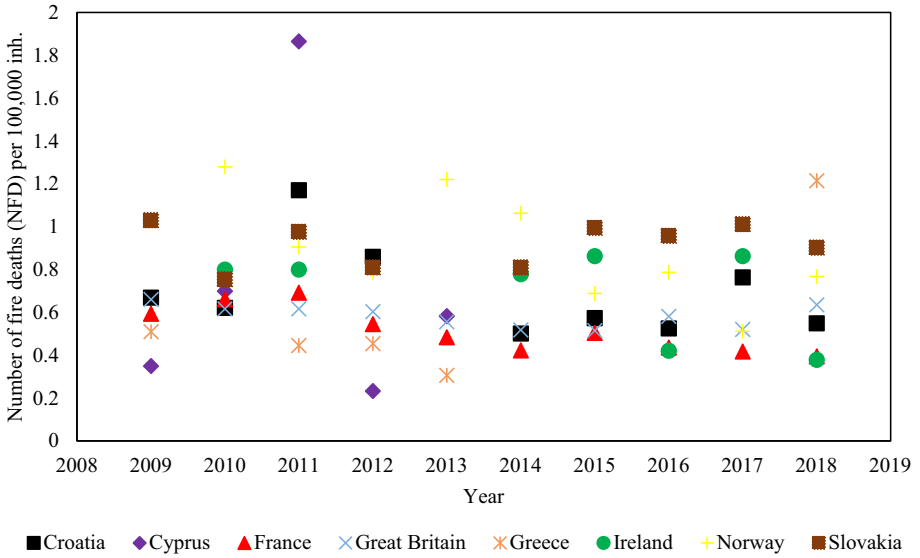

Figure 17. Number of fire deaths per 100,000 inhabitants from 2009 to 2019—Category 3.

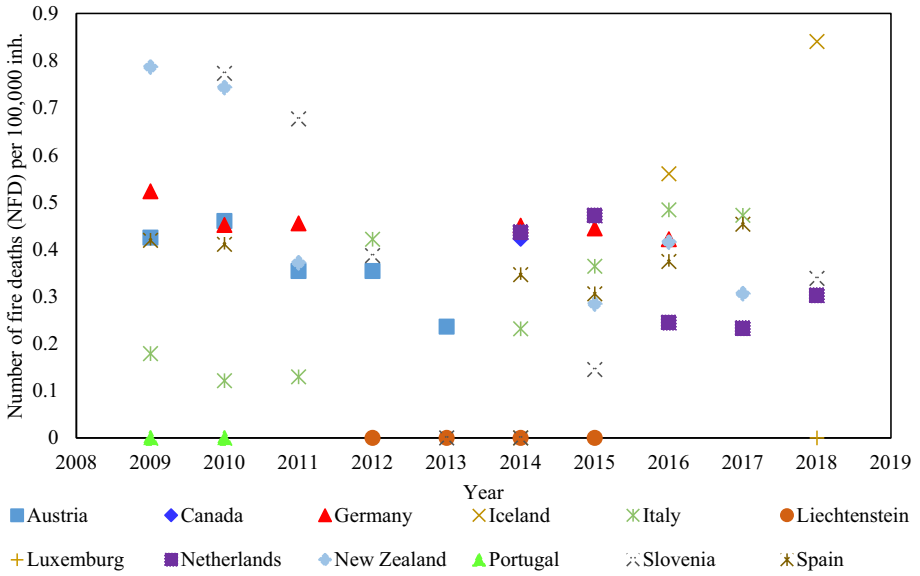

Figure 18. Number of fire deaths per 100,000 inhabitants from 2009 to 2019—Category 4.

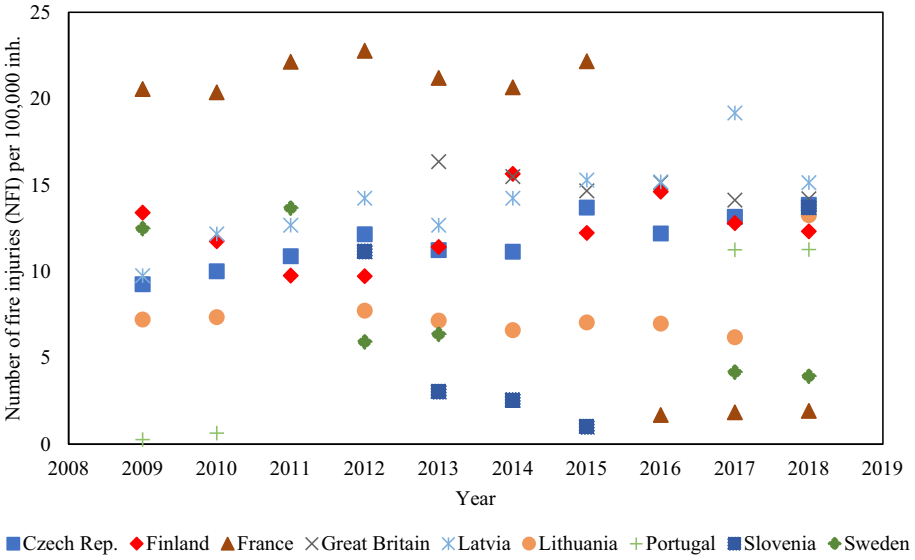

Figure 19. Number of fire injuries per 100,000 inhabitants from 2009 to 2018—Category 1.

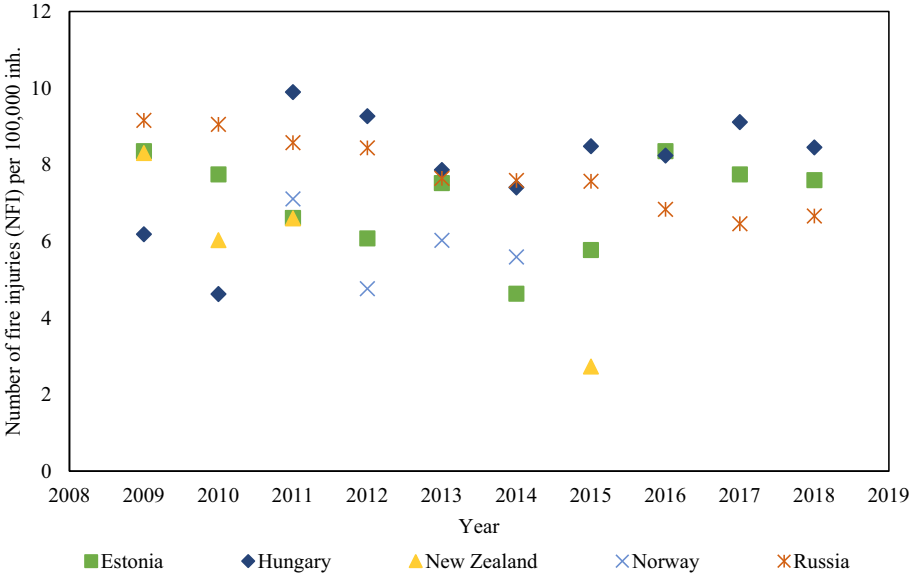

Figure 20. Number of fire injuries per 100,000 inhabitants from 2009 to 2018—Category 2.

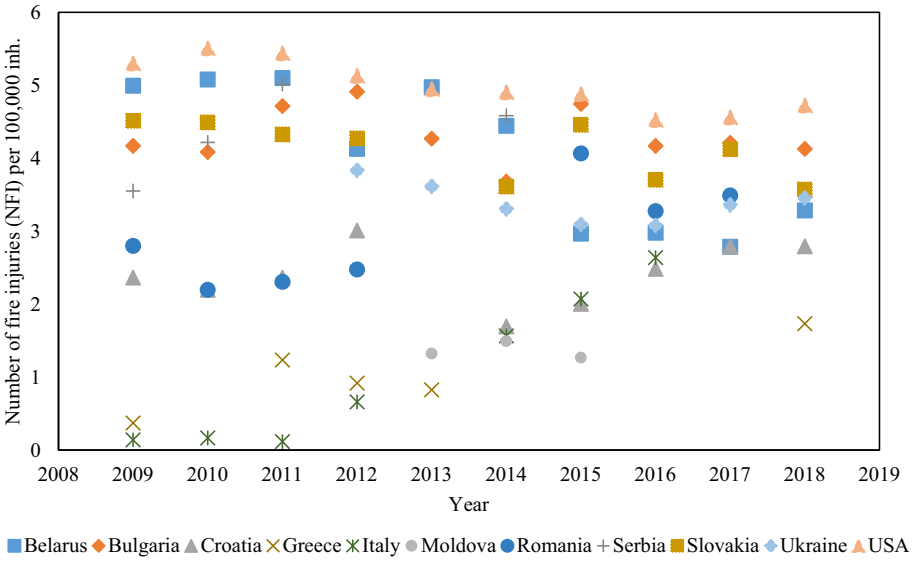

Figure 21. Number of fire injuries per 100,000 inhabitants from 2009 to 2018—Category 3.

and differences arise in how national data collection systems distinguish between "minor injury", "moderate injury" and "severe injury". With these caveats in mind, current fire statistics show important differences in trends between countries. Figures 19, 20, and 21 present the number of fire injuries per 100,000 inhabitants from 2009 to 2018 for the three defined categories. In general, it can be observed that the number of fire injuries is irregular in most countries. This variation can be real, but it can also be due to a lack of definition of an "injury", differences in collection methodology, or other parameters not identified.

For example, in France, there is a notable decline in the number of fire injuries between 2015 and 2016. When investigating the French annual reports [2], data for fire injuries prior to 2016 correspond to the number of injuries of "absolute emergency" and "relative emergency", the former meaning that the injured persons needed medical care, whereas the latter indicates that the injured person did not need medical care. After 2017, the number of injuries reported in the CTIF reports by French officials corresponds to the number of absolute emergencies only, which is likely to account for the observed decrease.

The analysis of fires, fire deaths, and injuries raises questions of statistical inference in drawing comparisons between fire trends in countries with small populations and those with larger datasets due to the difference in the statistical populations. Moreover, questions arise on the fire statistical variables recorded, terminology adopted, and data collection methodology. Despite similar nomenclature, the fire statistical variables plotted in the analyses can be associated with different definitions. Therefore, a comprehensive assessment of current practices in specific countries is necessary to have a complete understanding of the data trends.

7. Conclusions

A detailed assessment and overview of the available fire statistics of 27 EU Member States and eight other countries (Australia, Canada, New Zealand, Norway, Russia, Switzerland, the UK, and the USA) were carried out to provide a comprehensive description of the current practice of fire statistics and to identify potential issues in the comparison of fire statistics of different countries, recorded fire statistical variables in the EU Member States and other countries and analyses of the evolution of fire incidents, deaths and injuries based on the CTIF report [15].

Fire data collection systems can play an important role in reducing building fires and their associated fatalities, injuries, and economic damage. Data on fire incidents can inform firefighting strategies, building codes, educational and training programs, and technical innovations. However, when previous studies based on fire statistics are examined differences between fire data collection systems in various countries complicate the ability to make comparisons that could be useful in evidence-based planning and prevention efforts.

In the fire statistics of the 27 EU Member States and eight other countries, considerable variation in the type and scope of the information collected is found as well as the way that data elements are defined and the levels of detail and accuracy of the published datasets. Differences are also obtained if types of training and allocation of resources dedicated to collection efforts are examined. The amount and quality of the information in several data collection systems also appear to be influenced by whether they include information from sources outside the fire service, such as insurers or medical authorities, through data linkage or other means. In many respects, the issue of the fundamental information to collect and comprehensively assess a fire incident appears to be driven by available resources and training of personnel.

When the fire statistical variables were investigated in 21 EU Member States and eight other countries, the fire statistics in the other countries appear more detailed, especially for the quantification of damage, the presence, operation, and effectiveness of fire safety measures, and information on fatalities and non-fatal casualties while in the examined EU Member States, the fire statistical variables are mainly focused on the description of fire incidents and the assessment of fatalities and casualties. In particular, the incident time, date, and location are recorded in almost all countries, false alarms in 14 EU and four other countries while the distinction between intentional and accidental fires in more than nine and five EU and other countries, respectively. The building classification according to residential and non-residential properties is available in 17 EU and seven other countries. Furthermore, fire causes are recorded in the fire statistics of 15 EU and five other countries, the presence of alarms in 11 EU and six other countries and the number of victims in 20 EU and seven other countries. All the other fire statistical variables are not frequently available in the examined EU fire statistical data while they can be found more often in those of the examined other countries.

Fires, fire deaths, and injuries in several countries are plotted from 2008 to 2019 based on the CTIF reports. In the analysis developed in this research, the number of fires, fire deaths, and fire injuries was divided by the average population for

each country into categories as shown in Table 3. Rapid changes in values can be seen for specific years where these changes are likely influenced by variations in fire statistics terminology, collection methodologies, and data interpretation, rather than reflecting true changes in fire experiences. Despite the classification adopted to subdivide the countries according to the number of fire incidents, deaths, and injuries per 100,000 inhabitants, when trends are examined, it can be observed that the number of fires is relatively constant or slightly decreasing over time where most of the spikes are potentially attributable to major fire events. A relevant observation is that a high number of deaths are reported in some countries with fewer fires while fewer countries reported the number of fire injuries than the number of fires and fire deaths. In addition, the term "fire injury" can be difficult to define, and differences arise in how national data collection systems distinguish between minor, moderate and severe injuries.

In general, it appears that the fire data collection systems in most countries are presumed to provide an accurate representation of their respective experiences with fire incidents. However, information gathered through the research suggests that they may be unaware of important limitations of their data due to missing information, differences in the way terms are defined or interpreted, and other identified issues.

Current fire statistics of various countries present complex challenges when their data are compared. To provide relevant information regarding fire safety at the European level, future research should be considered in terms of detailed fire statistical recording system analysis, data evaluation and fire risk assessment in various property types as well as the reasons for the selection of certain data by each country, what policy decisions data can inform, and an analysis of the efficacy of the data in supporting the defined policy decisions. Future studies should also investigate the effect of calibrating the existing fire data with other relevant data sources, such as police, fire investigations and insurance reports. The outputs generated by this research will be used as preliminary groundwork for future improvements in fire statistics to move towards a harmonised terminology, common methodology, and data interpretation including uncertainty estimation and quality assurance process.

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Author Contributions

MM, RC, AS, MEH: Conceptualization, Writing original draft. EG, DR, GJ, AH, PA: Conceptualization, Review. PvH, PW, SS, FG, JV, MK, DO, NR: Conceptualization.

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Declarations

Competing interest The authors declare that they have no competing financial interests or personal relationships that could have influenced the work in this paper.

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Appendix

See Tables 4 and 5; Figures 22, 23, and 24.

Table 4
Overview of the Variables Collected in the Fire Statistics—Part 1/2

Fire statistical fields		EU	Other countries
Fire incident			
Call	Fire	17	7
	False alarm	14	4
Incident	Deliberate	12	6
	Accidental	9	5
Incident time		16	7
Incident date		14	8
Incident location		15	8
Building description			
Residential		18	8
Non-residential		17	7
Construction type		4	6
Origin floor dimension		7	5
Number of floors		8	6
Total building dimension		6	4
Fire causes			
Fire cause		15	5
Source of ignition		9	6
Fire room of origin		9	6
Item first ignited		10	6
Material first ignited		6	6
Material mainly responsible for the fire development		5	5
Fire consequences			
Rapid growth		2	2
Fire spread		7	6
Fire spread horizontally		6	8
Fire spread vertically		6	6
Damage	Fire damage	8	6
	Total damage	7	3
Type of damage	Fire damage	2	2
	Flame damage	0	3
	Smoke damage	4	3
	Water damage	0	2
	Others	1	0
Damage quantification	m^2	5	3
	% of property damaged	3	3
	Others	4	1
Fire safety measures			
Alarms	Presence	11	6
	Type	7	7
	Operation	9	8
	Effectiveness	6	5
	Failure	6	8
Automatic extinguishing systems	Presence	8	7
	Type	5	7
	Operation	6	6
	Effectiveness	6	6
	Failure	4	5

Table 4
continued

Fire statistical fields	EU	Other countries
Compartmentation	5	3
Fire barriers	4	1
Safe areas	2	0
Smoke extractors	6	2
Fire brigades on site	7	4
Escape routes	3	2
Evacuation	8	4

Table 5
Overview of the Variables Collected in the Fire Statistics—Part 2/2

Fire statistical fields		EU	Other countries
Fire response			
Occupant time	Ignition to discovery	4	2
	Discovery to call	7	2
Fire brigades	Notification	12	8
	Dispatch	8	3
	Preparation	8	2
	Travel time	9	4
	Set up time	9	1
	Occupant rescue	4	1
	Fire extinguishment	5	2
Fatalities			
Number of victims		20	7
Cause of fatality		8	6
Type of fatality		6	6
Age		14	6
Gender		10	6
Ethnicity		3	6
Disability		7	4
Profession		3	2
Other circumstances		4	5
Time between incident and fatality		6	3
Only occupants or firefighters?		10	5
Casualties			
Number of injured people		15	7
Cause of injury		5	6
Type of injury		8	5
Age		11	6
Gender		7	6
Disability		4	6
Profession		4	2

Table 5
continued

Fire statistical fields		EU	Other countries
Other circumstances		4	4
Time between incident and injury		2	2
Only occupants or firefighters?		7	5
Fire costs			
Fire direct costs	Property	9	5
	Medical care	1	3
Indirect costs	Temporary shelter	1	1
	Medical care	1	1
Methodology	Direct costs	5	4
	Indirect costs	1	0
Insured and uninsured losses		0	1
Cost incurred to insurance companies		1	1

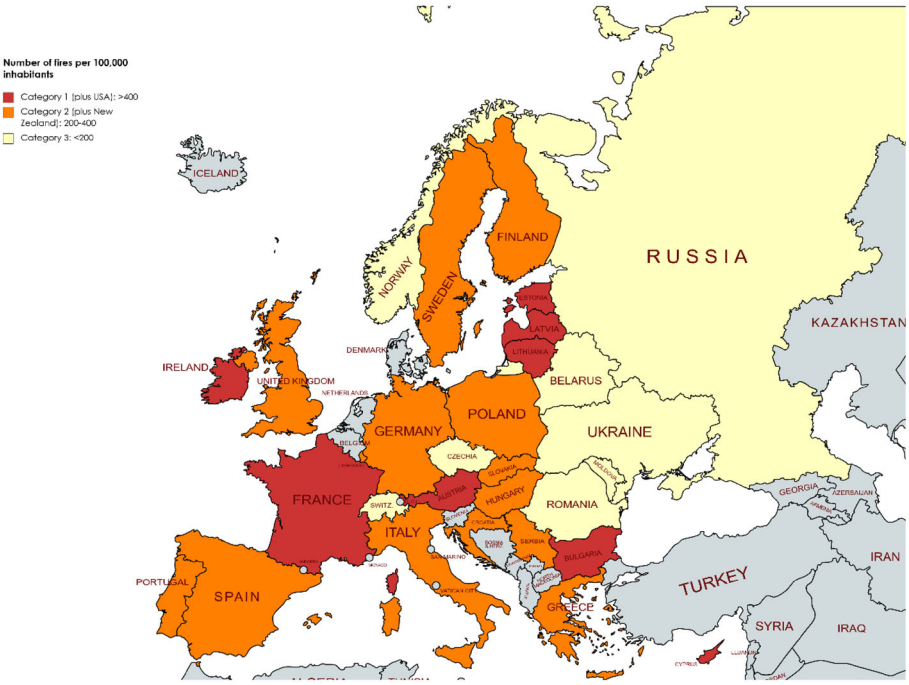

Figure 22. Categories of number of fires per 100,000 inhabitants (created with [56]).

Figure 23. Categories of number of fire deaths per 100,000 inhabitants (created with [56]).

Figure 24. Categories of number of injuries per 100,000 inhabitants (created with [56]).

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