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The Statistical Effectiveness of Fire Protection Measures: Learning from Real Fires in Germany

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Abstract. Fire protection measures are taken to prevent fires or to keep the resulting damage as low as possible. The statistical effectiveness of fire protection measures can be derived from a large number of fires that have already occurred. With the research paper presented here, such proof of effectiveness is rendered for certain specific fire protection measures, such as installed fire detection and fire alarm systems, fire extinguishing systems, smoke and heat exhaust systems, as well as according to the type of fire service. The investigation is based on a systematically collected database of 5,016 building fire interventions with 1,216 real fires by 29 fire services across Germany. The results can be used by applying engineering methods for quantitative risk analyses, within the scope of the risk-based performance level oriented planning of object-specific protection strategies. In this way, the performance level can be achieved effectively, flexibly and economically.

Keywords: Effectiveness, Risk analysis, Fire protection systems, Fire detection and fire alarm system, Fire extinguishing systems, Smoke and heat exhaust systems, Fire services, Fire statistics, Fire loss statistics

1. Introduction: Objective, Benefit and Target Group

By investigating real fires, valuable findings for future protection strategies can be obtained. This approach can also be used statistically. With statistical methods, key risk factors, trends and cause-effect relationships can be identified across all types of fire services and, finally, the effectiveness of fire protection measures can be assessed. This has already been realised some time ago (cf. [1–6]), but only a few approaches with meaningful statistics have prevailed until today.

Within the scope of the research project "Fire Loss Statistics" of the German Fire protection Association, VFDB (cf. [7, 8]), a proprietary systematic database was developed on the basis of uniformly collected data on fire service interventions in the event of building fires. On this basis, the effectiveness of installed fire detection and fire alarm systems, fire extinguishing systems, smoke and heat

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exhaust systems in particular as well as the effectiveness of fire services depending on the type of fire service (cf. [9, 10]) were investigated.

Typical fires and damage symptoms can be assessed as to the required use of fire protection measures and the influence of these measures on the fire development. The data about the effectiveness make a performance-based design more acceptable and the risk-based performance level can be achieved effectively, flexibly and economically. By applying those data, the acceptance of compensation measures can be increased if, as a result of this, deviations from building legislation are verified and construction projects are made more flexible or changes in the building use are approved more easily. Such flexible protection strategies—without reducing the performance level—are useful if qualified personnel [11] and building areas [12] are lacking and the fire protection measures must be compensated by specific and verified measures.

The statistical proof of effectiveness is of interest to fire services, engineers and specialist planners in the field of fire protection, building authorities, insurance companies, manufacturers and providers of fire protection systems as well as to researchers [7].

With this article, the results for the risk-based effectiveness analyses of installed fire detection and fire alarm systems, fire extinguishing systems, smoke and heat exhaust systems as well as according to the type of fire service are published internationally for the first time. This paper aims to fill an important gap in knowledge concerning the verified performance of fire protection systems in achieving fire safety and loss control objectives. With respect to their statement, the results comply with the previous publications (cf. [10, 13, 14]) which are based on certain specific fire protection measures and on lower case numbers on the basis of a partial data pool.

2. Methodology

The investigation of the ‘‘Fire Loss Statistic'' is based on a systematically collected database of fire service interventions using a standardised survey sheet of currently 5,016 building fire interventions [N = 5,016] with 1,216 real fires [n_{Fire} = 1,216]. These survey sheets were filled in by 29 fire services, either by the officer-in-charge or another person being familiar with the intervention conditions [7]. The survey period of the involvement in the project was kept open. This means that fire services were involved in the project with individual survey sheets up to the complete registration of all of their building fire interventions over a period of up to one year. The standardiSed survey sheet includes 20 survey blocks with 149 survey criteria, see Table 1.

The survey sheet is used to collect information on building fire interventions by fire services from the place and time of the fire service intervention to the alerting of the fire service, the origin and spread of fire to the resulting damage as well as on the fire protection measures initiated. The use of survey sheets is one of the standardised methods of inquiring. In the present survey, standardised questions and standardised answers are used. Answer options are given for the survey

Table 1
Survey Blocks in the Uniform Survey Sheet of the ''Fire Loss Statistic'' Project

1. General information	11. Assumed location of fire outbreak
2. Fire service status	12. Assumed object of fire outbreak
3. Building type	13. Fire size on arrival of the fire service
4. Building use	14. Fire limited to (fire spread)
5. Emergency call/notification	15. Spread of smoke (arrival of the fire service)
6. Real fire/false alarm	16. Smoke layering
7. False alarm trigger	17. Usability of the escape route
8. Activated fire protection systems	18. Human lives saved/fatalities
9. Assumed cause of fire causes	19. Estimated material damage
10. Floor where the fire broke out	20. Use of fire fighting water

blocks and free text fields are used as far as possible. This ensures that the data are fully answered at the same level of detail. In addition to the fundamental limits of the survey methods as a scientific instrument (cf. [15, 16]), there are further limitations in the quality of the results in the present work. The data are collected by fire service personnel. The completeness and correctness of the information cannot be fully checked and is at least partially dependent on the person filling out the sheet. The command of intervention or another person, who is familiar with the conditions of the intervention, should fill out the data sheet immediately after the operations. This limits the uncertainties in the quality of the survey. The data were also checked for consistency in content by an expert, when they were entered into the database. Errors due to the transfer of the completed registration forms to the database and the evaluation can be excluded through targeted analyses and through replication tests on the results.

The documentation of a fire intervention is based on the applicable ''pre-determined attendance'' of the fire services. This specifies the number and type of units that are dispatched to a given alarm keyword. In this context, a distinction must be made between fire cases and fire interventions. The number of fire interventions are often considered in statistics. This means that the number of interventions of the fire services are counted. When deployed in association communities with several local communities and with supra-local help, the fire is rated multiple times in many cases. Then, statistically, there can be more fires than actually occurred. The cases analysed here have been recorded by different fire services and the number of interventions corresponds to the number of fires/false alarms. The location is identified on the survey sheet based on the ''community code'' and each assignment is clearly delimited based on the day and time and the details of the intervention. Interventions recorded twice (by several fire services) can be excluded from the database.

The effectiveness of certain specific fire protection measures is investigated by comparing the distribution of damage criteria of fires with these measures to fires in which no fire protection system was present—as reference scenarios (see [17, 18]). The effectiveness of firefighting by the fire service can be proven in a comparably differentiated manner according to volunteer, professional and private fire services by means of the distribution of damage criteria as well as by comparing them with one another.

When applying the values obtained, however, it must, according to [7], be checked on a case-by-case basis whether the data can be used appropriately. The following aspects must be taken into consideration when using effectiveness parameters of fire protection measures (here, due to the low case numbers for fire extinguishing systems in particular):

- Some (technical) measures are taken in buildings with a high value concentration and/or fire load, which usually results in a higher damage potential than that of the reference scenario.
- The effectiveness parameters do not provide information on the design criteria of the technical fire protection measure (e.g. fire extinguishing systems are also used to compensate for deviations in structural fire protection, which means that the protection goal may be to replace a fire wall and not to fight the fire within a fire compartment).
- No information is available on the specific fire protection measures (e.g. the standard according to which the systems are planned and set up).

Based on a pilot project [19], the data collection is subdivided into two survey phases. The survey phase I contains 2,775 survey sheets (building fire interventions) including 681 real fires reported by 18 fire services from 2013 to 2015 (cf. [10]) and the subsequent phase II over the years 2016 and 2017 with an additional 2,241 survey sheets including 535 real fire interventions reported by 11 fire services [7].

For the focus of the evaluation to be discussed in this article, the survey sheets of all fire services involved were anonymised and pooled in a central MySQL database. In addition to a number of research questions regarding the statistics of the fire phenomenon in Germany (e.g. distribution of the fires by means of the survey blocks and survey criteria, such as floors of a building or the suspected cause of fire), the investigation of the effectiveness of fire protection measures was the focus of the project [20]. For this purpose, defined criteria are used to compare the fire damage of fires with the investigated measure to fires in which this measure was not available by taking certain specific fire protection measures into consideration (e.g. installed fire detection and fire alarm systems, fire extinguishing systems, smoke and heat exhaust systems as well as type of fire service). The damage differences compared with reference scenarios allow us to make a statement on the effectiveness of the fire protection measures initiated.

To check the statistical reliability of the results, the Wilcoxon signed-rank test is used to compare the central tendency of paired samples. It is not possible to compare the frequencies using other methods because the relevant requirements are not met by the data set. The Wilcoxon test is a nonparametric method for testing the significance and is used because fires are not normally distributed and the sample is small [21].

The results are checked against the null hypothesis (H_0) that assert that the two series of measured values come from populations that show no differences in terms of the central tendency [22]. For evaluating the hypothesis the W-value is used, because the sample size (N) is mostly below 10 in the present work. The test is carried out on both sides with an error probability of $\alpha = 1\%$ (**) and 5% (*). In addition to the W-value, the z-value can also be used if the sample size is larger than 20 ($N > 20$), because then a normal distribution can be assumed (see Table 4). The effect size is determined based on the Wilcoxon test from the z-value and the sample size (cf. [23]) and can be interpreted according to [24].

3. Results and Discussion

Below, the investigation results on the statistical effectiveness of selected fire protection measures are presented and discussed.

The effectiveness of the measures investigated can be assessed based on their objectives and the desired effect on the fire scenario using various collected damage criteria [7]. For the assessment of the fire damage, the following criteria are used:

(a) the estimated material damage in euros,
(b) the spread of fire on the arrival of the fire service units,
(c) the spread of smoke on the arrival of the fire service units,
(d) smoke layering,
(e) the accessibility of escape routes, and
(f) the consumption of extinguishing water required for firefighting.

The following presentation of the results is determined by the fire protection measures investigated and selected for this article. In all cases, the respectively collected case numbers and the related percentages are listed in Table 2.

It is possible for these measures to work together, e.g. fire detection and fire alarm systems often trigger smoke exhaust systems, or fire extinguishing systems are often used in the operational area of private fire services. The following results are considered for each measure and thus simplify this situation. This fact is questioned in follow-up analyses by comparing the differences between the results of individual measures and fires in which several measures are present at the same time.

3.1. Effectiveness of Installed Fire Detection and Fire Alarm Systems

In Table 2, the statistical fire damage criteria for fires in which an installed fire detection and fire alarm system (based on the EN 54 series; without smoke alarm devices) was triggered ($n = 178$) are listed and those fires without fire protection system ($n = 731$) were provided next to them as a reference scenario for assessment.

Figure 1a makes clear that the estimated material damage is considerably lower in fires in which installed fire detection and fire alarm systems were triggered (in 83% of the cases, the estimated material damage is lower than 1,000 EUR) than in fires without fire protection system at 69%. This is the result, although build-

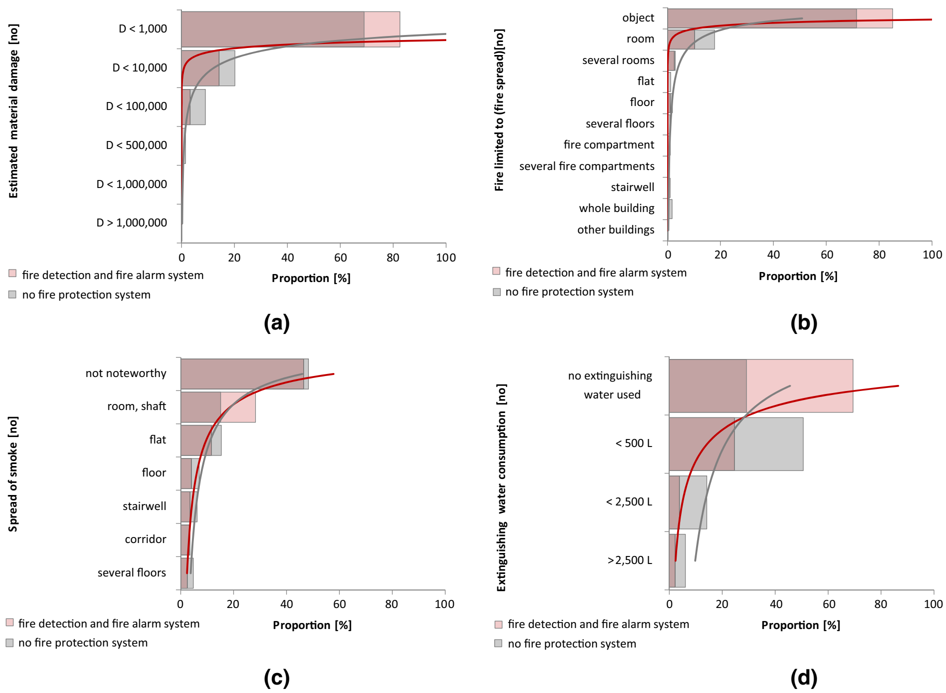

Figure 1. Proof of effectiveness for installed fire detection and fire alarm systems based on the distribution of damages after activating by installed fire detection and fire alarm systems (red bars and curves) compared to all fires without fire protection systems (grey bars and curves): (a) Estimated material damage [%]; (b) Fire limited to (fire spread) [%]; (c) Spread of smoke [%]; (d) Use of fire fighting water [%].

ings which are equipped with a fire detection and fire alarm system have a more complex design and thus a higher damage potential. In fires in which a fire detection and fire alarm system was triggered, the fire was limited to an object or device on arrival of the fire service (see Fig. 1b) in 85% of the cases. By comparison, this applied to only 71% of the fires without a fire protection system. Moreover, it became apparent that, in fires without a fire protection system (see Fig. 1c), the smoke had continued to spread itself out (in the flat, stairwell, corridor or across several floors) on arrival of the fire service. In particular, the escape routes can still be used more frequently on arrival of the fire service (with a fire detection and fire alarm system in 79% with 156 out of 198 cases) than in fires without a fire protection system (58%). Installed fire detection and fire alarm systems also have an impact on the consumption of extinguishing water (see Fig. 1d): In fires without a fire protection system, more than 500 L of extinguishing water were used in 20% of the cases, whereas this was only necessary in 6% of the cases when a fire detection and fire alarm system was triggered.

In summary, it can be seen that, based on all sheet criteria, installed fire detection and fire alarm systems resulted in lower fire damage.

3.2. Effectiveness for Fire Extinguishing Systems

Similarly to the effectiveness of the installed fire detection and fire alarm systems, the effectiveness of fire extinguishing systems can be assessed. However, the case numbers are lower with respect to fires in buildings with fire extinguishing systems (due to the small number of cases in the evaluation, sprinklers, water spray systems, foam systems and gas extinguishing systems are considered together): From 5,016 recorded building fire interventions, information on fire extinguishing systems is available in 128 cases, whereby more detailed information on the damage criteria is only available for a maximum of 12 real fires—with multiple answers regarding the fire size. Although this proof of effectiveness does not therefore provide reliable statistical information, a first trend can be observed.

Table 2 shows the result of the evaluation of the fire damage criteria in fires in which fire extinguishing systems were triggered (n = 12) compared to the reference scenario with fires in which no fire protection system (n = 731) was available.

From Fig. 2a, it becomes apparent that the material damage was not higher than 100,000 EUR in any of the registered cases of building fire interventions in which fire extinguishing systems were available. Due to the high value concentration in objects with fire extinguishing systems, it is to be assumed that the prevented material damage in fires with fire extinguishing systems was higher than for objects without fire extinguishing systems. In none of the cases in which fire extinguishing systems were available in the building, the fire spread to the entire fire compartment (see Fig. 2b). Compared to this, the fire spread to at least the entire fire compartment or several floors in 32 out of 747 cases without fire protection systems. With respect to the spread of fire (see Fig. 2c), it becomes apparent that 10 out of 12 fires with fire extinguishing systems were limited to one flat. When fire extinguishing systems are available, the smoke is spread over one flat to the floor and the stairwell in 16% of the cases, whereas several floors (5%), the corridor (3%), the stairwell (5%) or one floor (5%) were affected in fires without a fire protection system in a total of 21% of the cases. On arrival of the fire service, the escape routes could be used equally with 58% (7 out of 12 cases with fire extinguishing systems and 446 out of 774 cases without a fire protection system). The lower use of additional extinguishing water (see Fig. 2d) in 9 out of 11 cases with less than 500 L together with the lower spread of fire strongly suggests that fire extinguishing systems have a positive effect on limiting the spread of fire and on supporting the effective fire-fighting operations in the investigated cases.

3.3. Effectiveness for Smoke and Heat Exhaust Systems

Table 2 shows the distributions of the fire damage criteria between the fires in which natural and mechanical smoke and heat exhaust systems (n = 38) were triggered compared to cases in which no fire protection system (n = 731) was available according to the fire services. In 38 cases out of 5,016 registered building

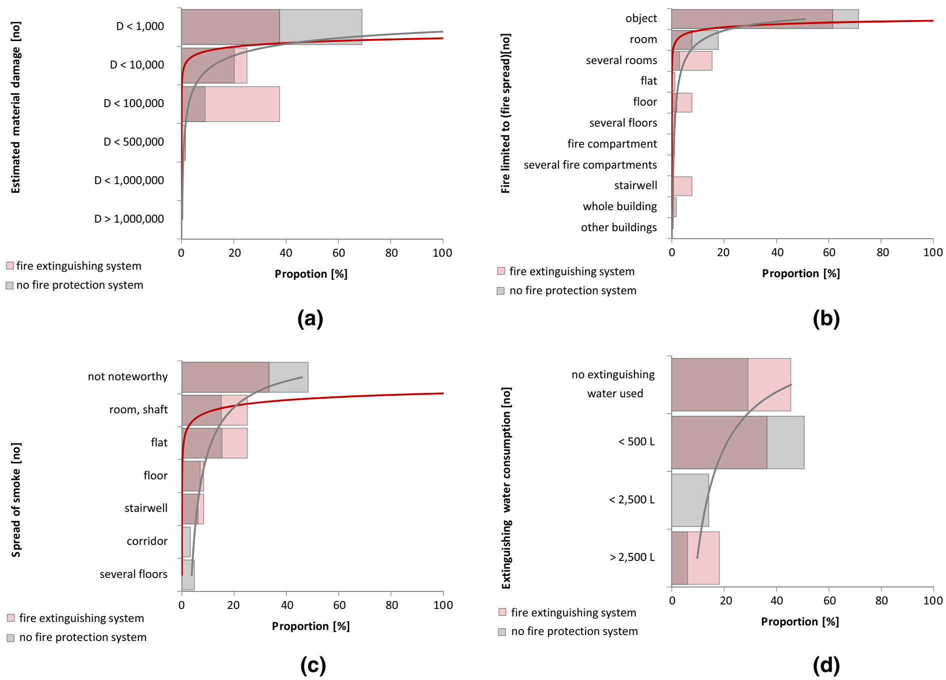

Figure 2. Proof of effectiveness for fire extinguishing systems based on the distribution of damages after activating by fire extinguishing systems (red bars and curves) compared to all fires without fire protection systems (grey bars and curves). (a) Estimated material damage [%]; (b) Fire limited to (fire spread) [%]; (c) Spread of smoke [%]; (d) Use of fire fighting water [%].

fire interventions, information on smoke and heat exhaust systems with differentiated information on the damage criteria is available. Amongst other factors, this low case number is due to the fact that smoke and heat exhaust systems are mainly installed in more complex buildings. These cases can thus also contain a higher damage potential than that of the average existing building stock. The proof of effectiveness for smoke and heat exhaust systems therefore does not provide fully reliable statistical information yet, but already allows more than merely general conclusions of trends.

The parameters of the effectiveness of smoke and heat exhaust systems can be seen in Table 2. Figure 3a shows that, when a smoke and heat exhaust system was available, no fires in which the material damage was estimated to a value of more than 100,000 EUR were registered and that only 8 fires (22%) in which the estimated material damage was higher than 10,000 EUR were registered—and this although a high damage potential is to be expected for buildings with a smoke and heat exhaust system. In comparison, the fire size (see Fig. 3b) is similarly often limited to an object (67% in fires in which a smoke and heat exhaust system was triggered). With respect to the spread of smoke (see Fig. 3c), the percentage

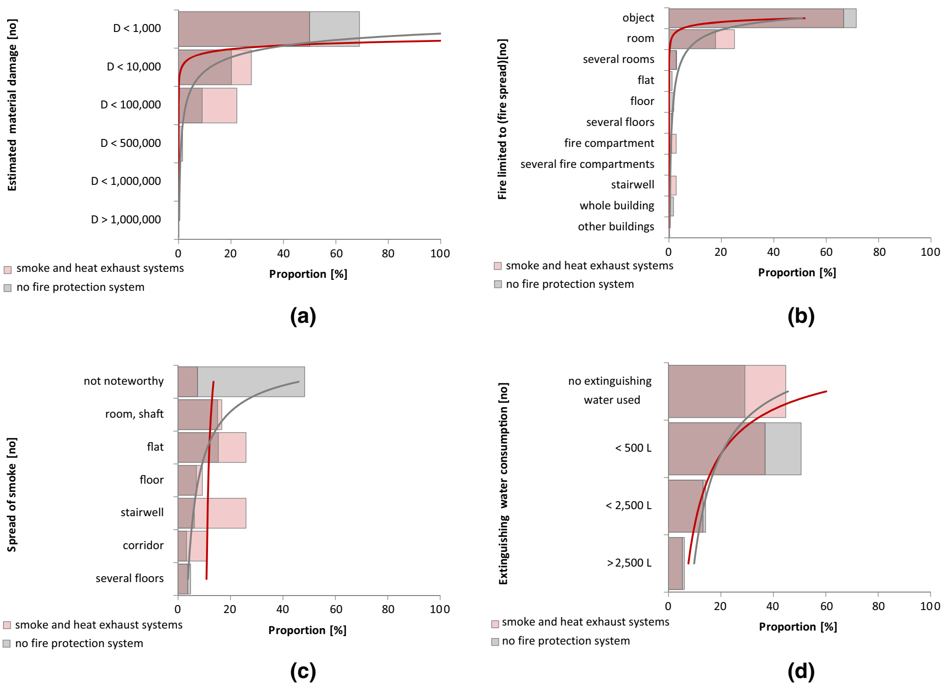

Figure 3. Proof of effectiveness for *smoke and heat exhaust systems* based on the distribution of damages after activating by smoke and heat exhaust systems (red bars and curves) compared to all fires without fire protection systems (grey bars and curves): (a) Estimated material damage [%]; (b) Fire limited to (fire spread) [%]; (c) Spread of smoke [%]; (d) Use of fire fighting water [%].

of fires in which the fire spread to the stairwell was higher in fire interventions in which a smoke and heat exhaust system was triggered (26% compared to 6% in interventions without a fire protection system). This can be derived from the building legislation requirement of a smoke exhaust opening in the stairwell as well as from the natural flow paths in the building. By means of different smoke and heat exhaust systems, different mechanisms of action (smoke removal, keeping areas free of smoke as well as generating a low-smoke layer) are combined to achieve different protection goals. With regard to the registered number of reported smoke and heat exhaust systems, it is not yet possible to differentiate the effectiveness according to different systems. It is generally apparent that there is a trend of less extinguishing water being used when smoke and heat exhaust systems were triggered compared to fires in which no fire protection system is available (see Fig. 3d): No extinguishing water was used in 45% of the cases (29% in fires without a fire protection system).

Based on the damage criteria, it is possible to prove a positive influence of smoke and heat exhaust systems on the fire development.

3.4. Effectiveness Depending on the Type of Fire Service

It is evident from the evaluation of the data pool that there are differences with respect to the effectiveness of professional fire services ($FS_{prof.}$), volunteer fire services ($FS_{vol.}$) and private fire services ($FS_{priv.}$) due to a number of different intervention conditions (as addressed below in the description of the results).

Table 3 is the data basis based on which the effectiveness of the fire service is quantified by comparing them with each other according to their type.

The results in Fig. 4a show that the estimated material damage is lower than 1,000 EUR in 91% of the cases in which private fire services were deployed, whereas the same applied to 60% of the cases in which volunteer fire services were deployed and to 56% of the cases in which professional fire services were deployed. For professional fire services, however, the material damage is higher than 10,000 and lower than 100,000 Euro in 10% of the cases, whereas this value is 8% for volunteer fire services and 2% for private fire services. In almost all registered fires (96%) in which a private fire service was alerted, the fire was limited to one object (see Fig. 4b). This percentage was lower in fires extinguished by the volunteer fire service (71%) and in those extinguished by the professional fire service (67%). Professional and volunteer fire services thus show the same tendencies regarding the spread of fire. With respect to the spread of smoke, it becomes clear (see Fig. 4c) that there is no noteworthy spread in 91% of the fires in which a private fire service was alerted. For volunteer fire services, this applies to 36% of the cases and, for professional fire services, to 29% of the cases. For professional and volunteer fire services, the spread of smoke over one or several floors shows similar values with 7 and 5% respectively, whereas the spread of smoke is very limited for private fire services with only one case (one floor) and 1% (several floors) respectively. It is therefore clear that, comparable to the spread of fire, the spread of smoke is similarly and proportionately larger in interventions of the professional fire service and the volunteer fire service than in fires which were registered by private fire services. With respect to the use of extinguishing water, extinguishing water is not used by professional and volunteer fire services in most of the fire interventions—45% by professional fire services and 40% by volunteer fire services (see Fig. 4d). For private fire services, however, extinguishing water is not used only in 28% of the fires, but less than 500 L of extinguishing water were used in 68% of the cases. It can be derived from the low case numbers of the private fire services in which more than 500 L of extinguishing water (3% and 2% respectively) were used that, compared to the respectively higher case numbers of the professional fire services and volunteer fire services, private fire services take more rapid and more effective extinguishing measures and that there are rare cases of large fires in which a large amount of extinguishing water is used.

Overall, this statistical proof of effectiveness shows, depending on the type of fire service, that the distribution of damage in the case of the private fire services differs from that of the professional and volunteer fire services, whereas the distribution between the professional and volunteer fire services is very similar (last point is intended). In this context, differences result from the different structural range of interventions of the professional and volunteer fire services (e.g. volume

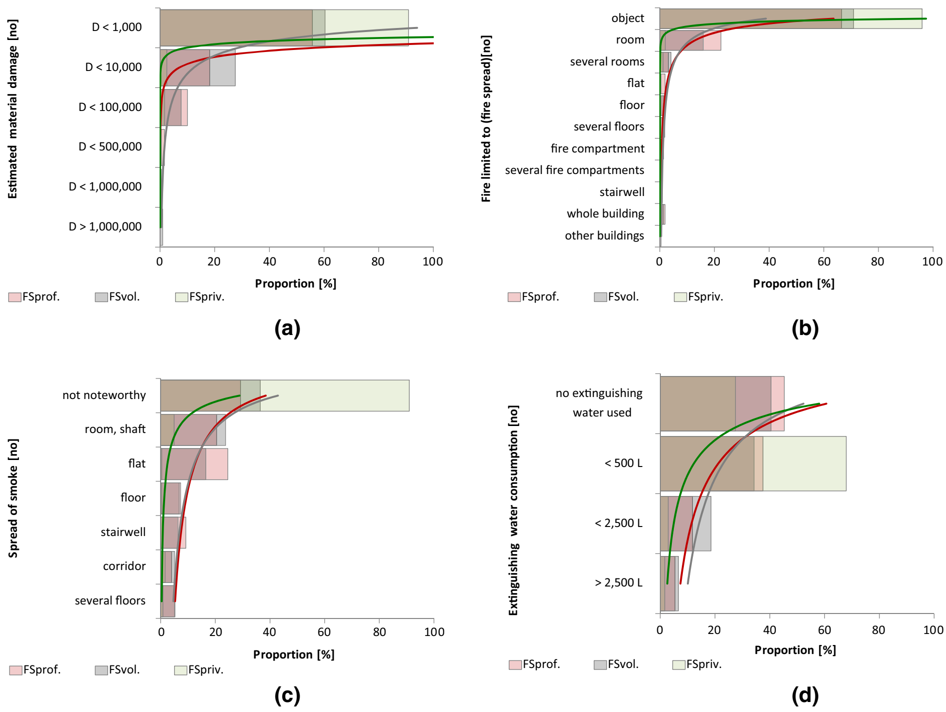

Figure 4. Proof of effectiveness for fire services depending on *fire service status* based on the distribution of damages (professional fire services with red bars and curves; volunteer fire services with grey bars and curves; private fire services with green bars and curves): (a) Estimated material damage [%]; (b) Fire limited to (fire spread) [%]; (c) Spread of smoke [%]; (d) Use of fire fighting water [%].

of high-rise buildings and apartment buildings). Since the municipalities have to provide an effective public fire service meeting the requirements of the local conditions in accordance with the country-specific provisions as well as with the fire protection requirements planning, there are no important differences between professional and volunteer fire services. Moreover, private fire services are provided where the majority of buildings are buildings of particular type or use according to building legislation. In this respect, the volume of fire protection systems is high, which means that early alerting by means of early fire detection as well as an early initiation of the firefighting measures by means of fire extinguishing systems are to be assumed. Together with the more rapid intervention of a private fire service that is particularly familiar with the object and stationed directly at the object compared to public fire services, the differences in the dependence on the type of fire service and the high effectiveness of the private fire services can be explained.

3.5. Evaluation of the Significance and Application of the Results

The evaluation of the significance of the criteria ‘‘smoke layering’’, ‘‘escape route usable’’ and ‘‘extinguishing water consumption’’ is not examined in more detail. For all other criteria, the significance tests show that the central tendencies between fires under the influence of fire detection and fire alarms systems, fire extinguishing systems and smoke and heat exhaust systems show significantly lower fire damage compared to fires without a fire protection system. In the case of fire extinguishing systems and smoke and heat exhaust systems, the results should be viewed as trends despite the significant difference and large effect size, since the number of cases is low.

When analysing the damage by type of fire service, the results are not so clear. Between professional fire services ($FS_{prof.}$) and voluntary fire services ($FS_{vol.}$), the study provides similar results, which was also explained logically (cf. Chapter 3.4). The significant tests show different results depending on the criterion. Regarding ‘‘est. material damage’’, the frequencies of the damage categories are similar, while they differ significantly for the criteria‘‘ fire limited to (fire spread) ’’and‘‘ spread of smoke’’. The comparison of fire damage between $FS_{prof.}$ and private fire services ($FS_{priv.}$) shows significant differences. However, the differences in the central tendencies between $FS_{vol.}$ and FS_{priv}. are not significant, although the fire damage clearly differs. The evaluation of the results with regard to their significance is given in Tables 4 and 5.

The results derived here can be used in qualitative and quantitative models to describe fire scenarios. Such an application is indicated in Fig. 5 in a first step and can be developed in further steps using specific fire models (see [25]).

Different (sub-) scenarios can be supported with concrete assumptions and compared with another. This allows to determine the influence of measures in concrete applications and to explain the need for measures to authorities and building owners.

4. Conclusion

As the results presented above reveal, the damage caused by fires is reduced due to installed fire detection and fire alarm systems, fire extinguishing systems, smoke and heat exhaust systems, as well as according to the type of fire service (where the distribution of damage in the case of the private fire services differs from that of the public fire services—not always significantly, however). In this respect, the results are to be assessed even conservatively, as a higher damage potential is to be expected for the buildings with these measures than in the respective reference scenarios without fire protection measures. The effect of the investigated fire protection measures provides a quantified basis of their influence on the fire developments based on real fires.

The proof of effectiveness resulting from the investigation can be used by applying engineering methods for quantitative risk analyses within the scope of the risk-based performance level oriented planning of object-specific protection strategies. Using these methods, the performance levels can be achieved effectively, flexibly

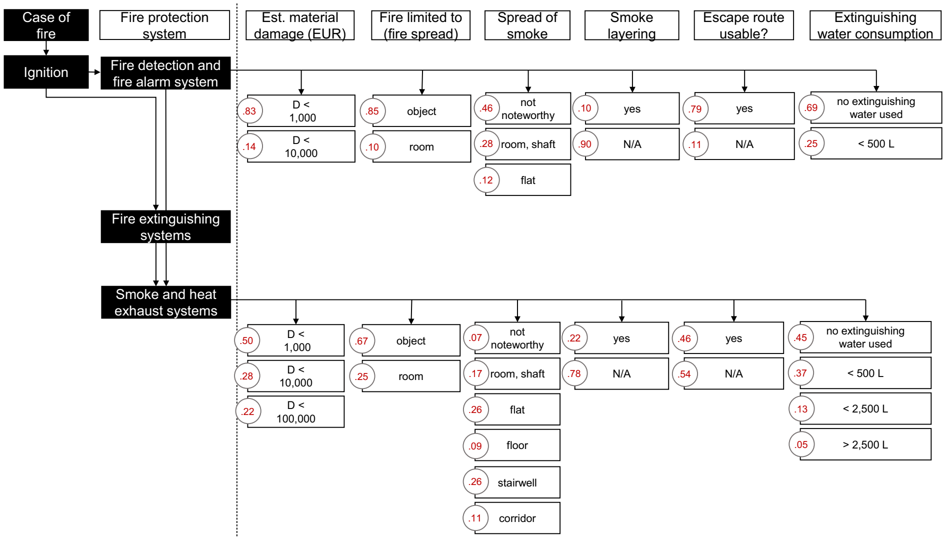

Figure 5. Approach to illustrate the integration of effectiveness criteria in the development of fire models (based on [25])—values that lead to less than 5 percent were neglected here.

and economically. Due to the greater efforts in the planning phase of the fire protection, it is to be assumed that this approach will be particularly applied for buildings of particular type and use and that, with the results obtained, the appropriate measures can be increasingly integrated into the risk-based performance level oriented fire protection planning.

Coile, Hopkin and Lange (2019) describe with regard to Watts & Hall [26] that "every decision related to fire safety is a fire risk decision" (cf. [27]), and thus a question of the probability and severity of damage caused by a fire. They further state that probabilistic and risk-based methods are accepted for the calibration of prescriptive requirements and for performance-based design, but their applications are limited. The limit of the "lack of data to support choices of input (stochastic) variables and probabilistic models" (see [28]) is partial and in relation to a specific context closed with the present work.

The results obtained agree in their tendency with other studies when it comes to the use of safety systems (cf. [29]).

The developed risk-based values/variables can enable the risk-based use of probabilistic methods, taking into account the discussion on the "acceptable level of fire safety and the relationship between the different risk acceptance concepts applied in probabilistic fire safety engineering" [27].

Such information as given in the present article, is included in pre-normative works [7] (see [5])—similar to [30].

On the basis of valid data, with probabilistic methods the fire protection engineers are provided with an additional toolbox for the implementation of quality projects and enable the regulator to specify requirements which bring the most benefit [26]. In addition, risk-based methods offer the opportunity of perfect communication to stakeholders in the context of the entire scope of services of a building and performance which can be expected from a fire safety design [27].

In addition, data (within the codes) are often very old, and as such they add an extra level of uncertainty about their validity to be used [28]. In other words, current data—as compiled here—are important for probabilistic approaches. But the user must check on a case-by-case basis whether the effectiveness parameters can be used appropriately for the specific object.

For the fire extinguishing systems as well as for the smoke and heat exhaust systems, still relatively low case numbers are considered in the analysis and are to be used with caution accordingly. For the installed fire detection and fire alarm systems and the results according to the type of fire service, sufficient case numbers are available. This is shown by the fact that the results did not change greatly with increasing case numbers when the database almost doubled from phase I to II of the project. Thus, this proof of effectiveness can be used directly.

An approach how the data can be integrated into a risk decision was shown. In [30] a more in-depth analysis is given to show how such data can be taken up with integrated probabilistic risk assessment methodology in the context of fire safety design with the purpose of quantifying the life safety level of people present in buildings.

This article presents the results from the core of the ‘‘Fire Loss Statistic’’ project to an international audience for the first time. The statistical conclusions obtained with respect to the fire phenomenon within the scope of the project exceed the facts of the proof of effectiveness presented in this article. Key risk factors, trends and cause–effect relationships as well as fire-service-specific dependencies with respect to the registered building fire interventions and the related fires can be derived from the data. The data provide an opportunity of performing in-depth analyses of related criteria (e.g. fire/false alarm in combination with the floor where the fire broke out or the building use in connection with the suspected object where the fire broke out) or by forming clusters according to municipality size classes (comparison between urban and rural environments). Furthermore, the chronological classification of building fire interventions, fires and false alarms can be derived. All these statistical conclusions are in process and have to be published in the future.

In parallel, the technical infrastructure related to the database of the project is currently being optimised and a third phase is being initiated to collect additional fire service intervention data using our sheet. The objective of the project’s third phase is to increasingly include voluntary fire services and private fire services in particular in the database in order to obtain an even more solid database with increased case numbers. This allows differentiated statements to be made where in-depth analyses cannot be carried out so far due to too low numbers of cases. With the development of the case numbers, it can also be examined how certain specific results are still changing. The work will be continued.

Appendix

See Tables 2, 3, 4, and 5.

Table 2
Fire Damage Criteria Without Activating Fire Protection Systems and When Activating Installed Fire Detection and Fire Alarm Systems, Fire Extinguishing Systems, Smoke and Heat Exhaust Systems [N = 5,016; n_{Fire} = 1,216]

		No fire protection system		Fire detection and fire alarms systems		Fire extinguishing systems		Smoke and heat exhaust systems	
Criterion		[no]	[%]	[no]	[%]	[no]	[%]	[no]	[%]
Estimated material damage [EUR]	D < 1,000	452	69	128	83	3		18	50
	D < 10,000	132	20	22	14	2		10	28
	D < 100,000	59	9	5	3	3		8	22
	D < 500,000	10	2	0	0	0		0	0
	D < 1,000,000	1	0	0	0	0		0	0
	D > 1,000,000	1	0	0	0	0		0	0
	No data possible	76	–	23	–	3		2	–
	Sum	731	100	178	100	11		38	100
Fire limited to (fire spread)	Object	534	71	166	85	8		24	67
	Room	133	18	20	10	1		9	25
	Several rooms	22	3	5	3	2		1	3
	Flat	9	1	0	0	0		0	0
	Floor	14	2	2	1	1		0	0
	Several floors	7	1	0	0	0		0	0
	Fire compartment	8	1	0	0	0		1	3
	Sev. fire compartments	2	0	0	0	0		0	0
	Stairwell	3	0	2	1	1		1	3
	Whole building	13	2	0	0	0		0	0
	Other buildings	2	0	0	0	0		0	0
	Sum	747	100	195	100	13		36	100
Spread of smoke	Not noteworthy	374	48	92	46	4		4	7
	Room, shaft	117	15	56	28	3		9	17
	Flat	119	15	23	12	3		14	26
	Floor	54	7	8	4	1		5	9
	Stairwell	48	6	7	4	1		14	26
	Corridor	25	3	7	4	0		6	11
	Several floors	37	5	5	3	0		2	4
	Sum	774	100	198	100	12		54	100
	Smoke layering	158	20	20	10	3		12	22
	Escape route usable? yes	446	58	156	79	7		25	46
Extinguishing water consumption	No extinguishing water used	216	29	127	69	5		17	45
	<500 L	375	51	45	25	4		14	37
	<2,500 L	105	14	7	4	0		5	13
	>2,500 L	45	6	4	2	2		2	5
	Sum	741	100	183	100	11		38	100

Table 3
Fire Damage Criteria Depending on Fire Service Status: Professional Fire Services ($FS_{prof.}$), Volunteer ($FS_{vol.}$) and Private Fire Services ($FS_{priv.}$) [N = 5,016; n_{Fire} = 1,216]

Criterion		$FS_{prof.}$ [no]	$FS_{vol.}$ [no]	$FS_{priv.}$ [no]	$FS_{prof.}$ [%]	$FS_{vol.}$ [%]	$FS_{priv.}$ [%]
Estimated material damage [EUR]	D < 1,000	383	125	220	56	60	91
	D < 10,000	125	57	6	18	28	2
	D < 100,000	69	16	4	10	8	2
	D < 500,000	11	1	0	2	0	0
	D < 1,000,000	1	1	0	0	0	0
	D > 1,000,000	0	2	0	0	1	0
	No data possible	98	5	12	14	2	5
	Sum	687	207	242	100	100	100
Fire limited to (fire spread)	Object	485	156	238	67	71	96
	Room	163	35	5	22	16	2
	Several rooms	23	9	3	3	4	1
	Flat	14	1	0	2	0	0
	Floor	11	4	1	2	2	0
	Several floors	7	4	0	1	2	0
	Fire compartment	7	3	0	1	1	0
	Sev. Fire compartments	1	2	0	0	1	0
	Stairwell	3	2	1	0	1	0
	Whole building	14	3	0	2	1	0
	Other buildings	1	1	0	0	0	0
	Sum	729	220	248	100	100	100
Spread of smoke	Not noteworthy	228	86	222	29	36	91
	Room, shaft	160	56	12	20	24	5
	Flat	192	39	1	25	17	0
	Floor	57	16	1	7	7	0
	Stairwell	72	15	2	9	6	1
	Corridor	31	12	4	4	5	2
	Several floors	41	12	2	5	5	1
	Sum	781	236	244	100	100	100
	Smoke layering	107	114	5	14	48	2
	Escape route usable? yes	460	165	164	59	70	67
Extinguishing water consumption	No extinguishing water used	326	85	66	45	40	28
	<50 L	270	72	163	38	34	68
	<2,500 L	85	39	7	12	19	3
	>2,500 L	39	14	4	5	7	2
	Sum	720	210	240	100	100	100

Table 4
Evaluation of the Significance of the Results Using the W-value (Wilcoxon Test)

Fire protection system/ Criterion	W-value	Mean difference	Sum of pos. ranks	Sum of neg. ranks	Sample size (N)	Significant
Fire detection and fire alarms systems compared to fires without a fire protection systems						
Est. material damage	0	82.43	28	0	7	Yes*
Fire limited to (fire spread)	0	47.91	66	0	11	Yes**
Spread of smoke	0	54.57	28	0	7	Yes*
Extinguishing water consumption	N/A sample size (N) to small					
Fire extinguishing systems compared to fires without a fire protection systems						
Est. material damage	0	102.43	28	0	7	Yes*
Fire limited to (fire spread)	0	66.91	66	0	11	Yes**
Spread of smoke	0	107.57	28	0	7	Yes*
Extinguishing water consumption	N/A sample size (N) to small					
Smoke and heat exhaust systems compared to fires without a fire protection systems						
Est. material damage	0	94.43	28	0	7	Yes*
Fire limited to (fire spread)	0	58.91	66	0	11	Yes**
Spread of smoke	0	101.57	28	0	7	Yes*
Extinguishing water consumption	N/A sample size (N) to small					
Professional Fire Services ($FS_{prof.}$) compared to Voluntary Fire Services ($FS_{vol.}$)						
Est. material damage	1	48	20	1	6	No
Fire limited to (fire spread)	1.5	34.4	53.5	1.5	10	Yes**
Spread of smoke	0	55.57	28	0	7	Yes*
Extinguishing water consumption	N/A sample size (N) to small					
Professional Fire Services ($FS_{prof.}$) compared to Private Fire Services ($FS_{priv.}$)						
Est. material damage	0	107.5	21	0	6	Yes*
Fire limited to (fire spread)	0	61.27	66	0	11	Yes**
Spread of smoke	0	99.57	28	0	7	Yes*
Extinguishing water consumption	N/A sample size (N) to small					
Voluntary Fire Services (FSvol.) compared to Private Fire Services ($FS_{priv.}$)						
Est. material damage	11	23.57	17	11	7	No
Fire limited to (fire spread)	11	15	55	11	11	No
Spread of smoke	7	21.71	21	7	7	No
Extinguishing water consumption	N/A sample size (N) to small					

*Significance level ($p = 0.5$)
**Significance level ($p = 0.1$)

Table 5
Evaluation of the Significance and Effect Size of the Results Using the z-value (Wilcoxon Test)

Fire protection system/ Criterion	z-value	Mean (W)	Standard deviation (W)	p-value	Significant	Effect size	
Fire detection and fire alarms systems compared to fires without a fire protection systems							
Est. material damage	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Fire limited to (fire spread)	– 2.934	33	11.25	0.00338	Yes**	0.88	Large
Spread of smoke	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Extinguishing water consumption	N/A sample size (N) to small						
Fire extinguishing systems compared to fires without a fire protection systems							
Est. material damage	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Fire limited to (fire spread)	– 2.934	33	11.25	0.00338	Yes**	0.88	Large
Spread of smoke	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Extinguishing water consumption	N/A sample size (N) to small						
Smoke and heat exhaust systems compared to fires without a fire protection systems							
Est. material damage	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Fire limited to (fire spread)	– 2.934	33	11.25	0.00338	Yes**	0.88	Large
Spread of smoke	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Extinguishing water consumption	N/A sample size (N) to small						
Professional Fire Services ($FS_{prof.}$) compared to Voluntary Fire Services ($FS_{vol.}$)							
Est. material damage	– 1.992	N/A	N/A	N/A	N/A	0.81	Large
Fire limited to (fire spread)	– 2.650	27.5	9.81	0.00804	Yes**	0.84	Large
Spread of smoke	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Extinguishing water consumption	N/A sample size (N) to small						
Professional Fire Services ($FS_{prof.}$) compared to Private Fire Services ($FS_{priv.}$)							
Est. material damage	– 2.201	N/A	N/A	N/A	N/A	0.90	Large
Fire limited to (fire spread)	– 2.934	33	11.25	0.00338	Yes**	0.88	Large
Spread of smoke	– 2.366	N/A	N/A	N/A	N/A	0.89	Large
Extinguishing water consumption	N/A sample size (N) to small						

Table 5
continued

Fire protection system/ Criterion	z-value	Mean (W)	Standard deviation (W)	*p*-value	Significant	Effect size	
Voluntary Fire Services (FSvol.) compared to Private Fire Services ($FS_{priv.}$)							
Est. material damage	– 2.201	N/A	N/A	N/A	N/A	0.79	Small
Fire limited to (fire spread)	– 2.934	33	11.25	0.05	No	0.59	Medium
Spread of smoke	– 2.366	N/A	N/A	N/A	N/A	0.45	Small
Extinguishing water consumption	N/A sample size (N) to small						

*Significance level ($p = 0.5$)
**Significance level ($p = 0.1$)

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