An overview and experimental analysis of furniture fire safety regulations in Europe

Eric Guillaume1 | Rene de Feijter2 | Laurens van Gelderen2

1Efectis France, Espace Technologique, Saint-Aubin Cedex, France
2Efectis Nederland, Bleiswijk, The Netherlands

Correspondence
Eric Guillaume, Efectis France, Espace Technologique, Route de l’Orme des Merisiers, 91193 Saint-Aubin Cedex, France.
Email: eric.guillaume@efectis.com

Summary
The regulation requirements for upholstered furniture are nationally defined and lead to very different safety levels across Europe. This paper studies the fire performance of upholstered furniture across Europe and demonstrates the differences in the fire safety of sofas in different countries. Real sofas were purchased over Europe and tested first alone then for several of them in a room scenario. The fire performance of such upholstered furniture is related to their constitution and possibly to the improvement of their performance by physical and/or chemical means. Results are presented from a performance point of view and not focusing on the different technical solutions that can be envisaged, such as fire barriers or flame retardants. The results clearly show the effect of stricter regulations, not necessarily on the maximum heat release but mainly on the time available to escape, which is critical in many fire scenarios. Such regulations may have a positive effect, but they have to be performance-based, evaluated properly, and implemented considering market surveillance.

KEYWORDS
fire safety of sofas, heat release, regulation, upholstered furniture

1 FIRE SAFETY REQUIREMENTS FOR SOFAS

In Europe today, the debate around furniture fire safety revolves principally around the need for furniture to meet sufficient fire safety requirements without potentially using solutions such as halogenated flame retardants creating a fire safety layer to reduce ignition. Various publications in favor of fire safety performance requirement and regulations (and not especially opposed to various technical solutions including halogenated flame retardants) have been published1–5 while others that are opposed to any chemical flame retardants or that are skeptical of their actual effect (and hence refuse higher fire safety regulations if their consequences are the use of chemical fire retardants) have also been published6–8. The concept of “flame retardant” is often misleading as it refers to various effects (in gas or solid phase), among a large number of chemical families. This leads to confusion when flame retardant is used as a generic name to deal with toxicity. Some flame retardants, mainly a small number of brominated chemical species, have been banned in the past1 and are known to be persistent pollutants.9 There is also a concern that newer flame retardant chemicals are being applied before their consequences are properly evaluated and that they are no better than those originally banned.7 The United Kingdom, which has the most stringent furniture fire safety regulations in the European Union (EU), is in fact actively trying to change its regulations to “encourage the reduction in usage of flame retardants” (FEU, p. 22).2 Herein, an overview is presented of (recent) literature related to the furniture fire safety and halogenated flame retardants debate and the results of sofa reaction to fire tests conducted at Efectis in 2010.
### 1.1 Statistical evidences

There are several reports available concerning fire statistics related to upholstered furniture in different degrees of detail, from the United States, the United Kingdom, the EU, and Sweden. The statistics and the corresponding analysis for furniture fires in United States and United Kingdom are much extended and show trends and observations in great detail. The primary results are that the number of furniture fires has drastically decreased, likely due to various reasons such as an increase in smoke alarms in households, decrease in the smoking population, child safe lighters, furniture fire safety regulations, etc. Currently in the United States, furniture fires make up 2% of the total amount of residential fires, but make up a significantly higher percentage (19%) of all fire fatalities. These numbers are similar to the British statistics (6% of all fires and 24% of all fire fatalities prior to implementing the furniture fire safety regulations, and 15% of fire fatalities after implementing these regulations). An overview of the distribution of ignition sources among the total number of furniture fires and furniture fire fatalities in the two countries is shown in Tables 1 and 2. Most notably is that in both countries ignition by cigarettes is the primary cause for furniture fire fatalities, whereas it makes up a much smaller proportion of ignition sources among all furniture fires.

While the number of furniture fires in the United States declined over the years, the fires that did occur were more severe, resulting in an increase of fatalities per household (from one fatality per 24 households in 1980-1984 to one fatality per 14 households in 2006). However, the severity of furniture fires increased over the years, with more fires spreading beyond the room of origin.

The EU report presents statistical data of the number of domestic furniture fires per million inhabitants from 19 EU countries. While the data does not directly relate to furniture fires, it nevertheless provides a relevant overview of the (relative) fire safety level between countries with different regulations. The results show a steep decline in fire fatalities in the United Kingdom and Ireland since 1980. However, the number of fire fires dropped by 37% compared to a drop of 10% for other fires in households after implementation of the furniture fire safety regulations. Based on their statistical analysis, Greenstreet Berman Ltd stated that the implemented regulations contributed significantly to the decrease in furniture fires and "account for 54 fewer deaths per year" (p. 30). The amount of furniture fire fatalities decreased from approximately one fatality per 20 households prior to the regulations in 1988 to one fatality per 40 households in 2006. However, the severity of furniture fires increased over the years, with more fires spreading beyond the room of origin.

### TABLE 1 Furniture fire statistics in the United States (2006-2010)

| Ignition source          | Furniture fires | Furniture fire fatalities |
|--------------------------|-----------------|---------------------------|
| Lighted tobacco product  | 21%             | 45%                       |
| Open flame of other fire | 25%             | 21%                       |
| Operating equipment      | 17%             | 12%                       |
| Small open flame         | 16%             | 10%                       |
| Embers and ash           | 15%             | 10%                       |
| Unclassified             | 7%              | 3%                        |

*The percentages were derived from bar plots.*

### TABLE 2 Furniture fire statistics in the United Kingdom

| Ignition source            | 1981-1985 | 2001-2006 | 1981-1985 | 2001-2006 |
|----------------------------|-----------|-----------|-----------|-----------|
| Matches                    | 16%       | 18%       | 10%       | 3%        |
| Lighters                   | 2%        | 11%       | 2%        | 6%        |
| Smoking materials          | 52%       | 38%       | 64%       | 71%       |
| Candles                    | 1%        | 4%        | 1%        | 3%        |
| Paper                      | 1%        | 3%        | 2%        | 1%        |
| Other naked flame          | 1%        | 7%        | 2%        | 2%        |
| Other sources of ignition  | 28%       | 18%       | 20%       | 14%       |
fatalities per million inhabitants is still higher in these countries than in for example Germany or the Netherlands. Overall, no correlations could be established between the presented results and fire safety regulations for furniture and textiles in each of the included EU countries. The results primarily suggest that also national culture and other legislation, such as the taxation on alcohol, influence domestic fire safety.

### 1.2 | Testing

All of the implemented testing standards (ie, TB 117, BS 5852, EN 1021) focus on the ignitability of upholstered furniture in smoldering or open-flame scenarios. No requirements are in place for other parameters such as the peak heat release rate, the time to peak heat release rate, or the total heat release. These parameters have been studied in the early nineties during the CBUF study but were never implemented. There were also two projects of European standards in the nineties for stronger ignition sources than a cigarette and a match, but these projects have been cancelled (projects prEN1021-3 and -4).

Cigarette and match tests are the principal test methods (see Table 3). Chivas et al reported that these test methods are not of growing severity, but more covering two ways of ignition problematics. In details, they found several solutions that failed the cigarette test while passing the match test, and vice-versa.

The European Fire Services Recommendations on Test Methods proposed to implement regulations in the EU to improve fire safety of furniture, but that does not require full scale testing as this is not considered feasible or economically justified. The United States Consumer Product Safety Commission (CPSC) and UL studies showed that the results from mock-up tests do not accurately predict the fire performance for furniture protected by fire barriers. The British sofa that was burned as part of the study conducted by Efectis Nederland in 2010 also burned down fully when ignited by a crib 5 ignition source, despite the British regulations. Experimental results strongly suggest that, following the current standards, full-scale testing is required to properly assess the fire performance of upholstered furniture.

### 1.3 | Regulations across Europe

Sainrat presented in 2006 the status on fire regulations related to upholstered furniture. Table 4 is a summary of his work with the updates from Chivas et al and further ones, such as. Since these studies, the introduction of low ignition propensity cigarettes in Europe makes the “cigarette” test scenario less relevant but the change is too recent to observe any noticeable effect on fire statistics. Recently in France (2014), ANSES (the French national safety and sanitary agency) performed a review at the request of ministries to balance the consequences of a possible reinforcement of regulation on upholstered furniture flammability that could lead to an increase in use of flame retardants, and the related impact. As conclusion of the study, ANSES recommended the status-quo on the French regulation.

The European Commission started to investigate the possibility to develop a regulation on smoke toxicity of construction products. The conclusion of the report was that a prescriptive approach could not be adapted, and that further analyses are needed. Consecutively, Fire Safe Europe launched recently an initiative to develop a methodology to assess and classify the smoke toxicity of fire-exposed construction products. These studies are not impacting upholstered furniture but discuss about measuring toxicity and relations between contributions of the contents (ie, furniture) vs the construction products to fire growth and smoke generation and effects.

### 2 | LITERATURE REVIEW

#### 2.1 | Furniture fire safety

A former study focusing on upholstered furniture smoke toxicity, sponsored by the French Ministry of Economy, has been presented by
| Country      | Type of Building | Reference regulations          | Type of furniture | Requirement                                           | Test methods                                      | Classification |
|-------------|-----------------|--------------------------------|-------------------|-------------------------------------------------------|---------------------------------------------------|---------------|
| France      | Domestic        | N’2000-164                     | Bedding           | No ignition by cigarette                              | EN ISO 12952-1 and 2                              | Pass/Fail     |
|             | Public          | U 23 (Health)                  | Bedding           | No ignition by cigarette                              | EN ISO 12952-1 and 2                              | Pass/Fail     |
|             |                 | AM 18 (Spectacle)              | Mattress          | No ignition by cigarette                              | EN 597-1                                          |               |
|             |                 | GPEM D1-90 (Prisons)           | Seat              | No ignition by cigarette                              | NF D 60–013                                       | Pass/Fail     |
|             |                 |                                | Mattress          | No ignition by cigarette                              | NF P92-501 and NF P92-507                         | M3            |
|             |                 |                                |                   | No ignition by cigarette                              | EN 597-1                                          | E             |
|             |                 |                                |                   | No ignition by match                                  | EN 597-2                                          | D             |
|             |                 |                                |                   | No ignition by higher ignition sources                 | GPEM D1-90                                        | C,B,A (A the best) |
| United Kingdom | Domestic  | Furniture and furnishing Regulations n’1324 | Seat/Mattress     | No ignition by cigarette                              | EN 1021-1 and EN 1021-2                           | Pass/Fail     |
|             | Public         | BS 7176                        | Filling           | No ignition by crib five                              | BS 5852                                           |               |
|             |                 |                                | Seat              | No ignition by cigarette                              | EN 1021-1 and EN 1021-2                           | Pass/Fail     |
|             |                 | BS 7177                        | Mattress          | No ignition by cigarette                              | EN 1021-1 and EN 1021-2                           | Pass/Fail     |
|             |                 |                                |                   | No ignition by match                                  | BS 5852                                           |               |
| Ireland     | Domestic        | S.I. No. 316/1995              | Seat/Mattress     | No ignition by cigarette                              | I.S. 419:1988                                     | Pass/Fail     |
|             | Public          | No regulation but a "Code of Practice for Fire Safety of Furnishings and Fittings in Places of Assembly" | Seat              | No ignition by cigarette                              | IS 254                                            | Pass/Fail     |
| Italy       | Public          | DM26/06/1984                   | Seat/Mattress     | No ignition by a 40 mm high flame during (s) 20, 80, 140 | CSE RF 4/83                                       | 3IM           |
|             |                 |                                | Filling           |                                                       |                                                   | 2IM           |
|             |                 |                                |                   |                                                       |                                                   | 1IM           |
| Czech Republic | Domestic | Statutory Instrument N° 23 – Notice on technical requirement fire safeguard building | Seat/Mattress     | No ignition by match                                  | EN1021-2                                          | Pass / Fail   |
| Finland     | Domestic        | N°743/1990                    | Seat              | No ignition by cigarette                              | EN 1021-1                                         | SL2           |
|             |                 | N°479/96                      |                   |                                                       |                                                   |               |

(Continues)
Sainrat and Le Tallec\textsuperscript{41} in 2001, summarizing many years of work. As far as we know, this is the last extensive study at realistic scale comparing gas data with animal testing performed in continental Europe. The objective of this study was to check if there is a relation between the mass loss of upholstered furniture and the toxic effect due to the smoke production during the combustion of this furniture. Several chairs and mattresses have been used with different ignition sources. Relations between the mass loss and the toxic effects (incapacitation and lethality) due to the combustion of upholstered furniture in a 30 m\textsuperscript{3} room have been established, and criteria for a simple evaluation of a toxic effect in a small room by a mass loss measurement have been proposed. The established relation is detailed in Figure 1. The toxic effects have been measured directly on mice and by gas analysis. No incapacitation was observed at emission levels below 17 g/m\textsuperscript{3} in a closed, poorly ventilated room. This level did not greatly depend on the composition of the upholstered furniture or ignition sources tested. Furthermore, the relation between time to incapacitation and mass loss was independent of the composition of the upholstered furniture and ignition source, which suggests that incapacitation is directly related to mass loss. This study thus shows that the incapacitation time can be simply assessed during combustion of upholstered furniture in a small, closed, poorly ventilated 30 m\textsuperscript{3} room, just on the basis of mass loss. Measurements of Carbon monoxide (CO) and Hydrogen cyanide (HCN) were insufficient to correlate models with the observations on lethality.

Some French authors also mentioned a relation between a critical mass loss in a characteristic volume and the toxic effects. Guerbet et al have underlined a relation between the smoke optical density, the mass loss and the lethality (expressed through LC50).\textsuperscript{42} In the same way, based on room corner tests, revision of provisions for theater seats and other upholstered furniture in public buildings has been modified for France in 2006.\textsuperscript{43} This study was adapted to large volumes such as the ones available in theaters and other spectacle rooms, and the toxic risk was considered as covered during the ignition test (gas burner equivalent to 20 g paper cushion) if there was no lateral spread of flame from one seat to another and if the mass loss of an individual seat was less than 300 g. In these conditions, it was considered that burning 300 g in such a volume would not lead to untenable conditions for occupants, whatever the burning seat was.

### 2.2 | Fire dynamics

There are several papers that discuss the fire dynamics of upholstered furniture fires.\textsuperscript{44-47} These studies have focused purely on the fire behavior of furniture with respect to, for example, flame spread, heat release rates, modeling, and the correlation to standard test scenarios. The presented knowledge can provide relevant information to help policy makers make decisions with respect to implement new or update current furniture fire safety regulations. By themselves, however, these studies provide little new information that is directly related to the societal debate about furniture fire safety and halogenated flame retardants.
Greenstreet Berman Ltd, they focused only on whether the ignition source of upholstered furniture fires. This issue is raised by the regulations available, it is unclear why the relative severity of furniture fires is as such not a consequence of an increase in strong ignition sources. The statistics in Table 2, however, clearly show that the relative amount of ignitions by other sources that are not targeted by the regulations in fact decreased over time. The increase in more severe fires is as such not a consequence of an increase in strong ignition sources that would bypass the ignition scenarios targeted by the furniture fire safety regulations. Instead, the more severe fires probably originate mostly from ignition sources that are in fact covered by the furniture fire safety regulations. From the current statistical data form the United States, United Kingdom, and EU, several points of discussion were revealed that make the effect and impact of furniture fire safety regulations questionable.

Despite the stringent regulations that upholstered furniture needs to comply with in the United Kingdom, cigarettes remain the primary ignition source of upholstered furniture fires. This issue is raised by Greenstreet Berman Ltd, but they focused only on whether the ignition sources in the BS 5852 are still matching the ignition strength of current cigarettes and matches. Considering that furniture also needs to comply with the no-ignition requirement from the crib 5 ignition source, it seems unlikely that ignition strength could explain the difference between test results and practice. Furthermore, the introduction of fire safe cigarettes with a reduced ignition strength should in theory lower the ignition strength of cigarettes, not increase it. Thus, there is a clear disparity between the testing method and how upholstered furniture ignites from exposure to smoldering cigarettes.

The difference between test results and real-life ignition scenarios is possibly due to the limited testing times of the various used standards. Typical smoldering ignition tests are stopped after 60 minutes, whereas experiments conducted by the CPSC showed that flaming combustion can occur several hours after placing a cigarette. This result is in line with other findings from Hall, who showed that the human factor contributing most to furniture ignition is a lack of attention, either due to, for example, sleep, drugs or alcohol. In such situations, a much longer time than 60 minutes is indeed available for smoldering cigarettes to develop into flaming combustion.

The statistics showed that the relative amount of furniture fires that spread beyond the room of origin in the UK nearly doubled since 1981 and has only increased over time, despite the implemented regulations in 1988. It could be argued that this is in fact partially a consequence of the implemented regulations, as these are aimed at preventing the ignition of furniture by weak to intermediate strength ignition sources. The statistics in Table 2, however, clearly show that the relative amount of ignitions by other sources that are not targeted by the regulations in fact decreased over time. The increase in more severe fires is as such not a consequence of an increase in strong ignition sources that would bypass the ignition scenarios targeted by the furniture fire safety regulations. Instead, the more severe fires probably originate mostly from ignition sources that are in fact covered by the furniture fire safety regulations. From the current statistical information available, it is unclear why the relative severity of furniture fires increases from ignition sources that are covered by fire safety regulations. This may be due to the fact that current furniture fire safety regulations only focus on ignition and do not account for the fire development after ignition, which has been commented on in other studies as well. Alternatively, it is possible that this trend is unrelated to the furniture fire safety regulations, but instead is correlated to other social trends such as the modernization of household interiors. Either way, the results indicate that the current test standard scenarios do not fully represent actual ignition scenarios of (modern) residential furniture fires.

Very recently, Blais et al made experiments on upholstered furniture from France, United States, and United Kingdom. The authors concluded that the UK standard does provide a significantly better performance for an identical size and shaped couch based on time to
peak heat release rate (HRR), maximum HRR, time to peak smoke, and total smoke production. The authors also highlighted that this level of performance was not achieved at the expense of the smoke toxicity.

2.4 Analyses from literature review

The literature study showed that there have been no new significant advances in the upholstered furniture fire safety and flame retardants debate in the past decades. The British regulations, which are the most stringent regulations in place in the EU and the United States, are considered to have had a positive contribution to residential fire safety. Whether implementation of the current British furniture fire safety regulations in other EU countries will result in an observable improvement of the residential fire safety is, however, questionable. One of the main issues with the current furniture fire safety regulations in place is that they do not seem to accurately cover modern residential furniture ignition scenarios. This disparity between legislation and practice should first be addressed prior to implementing new or revising current regulations. The underlying causes of the disparity are, however, not well understood and would require further research to be systematically identified.

3 EXPERIMENTAL ANALYSIS OF EUROPEAN FURNITURES

The goal of this study was to determine the fire performance of upholstered sofas from each country of the EU that were available on the consumer market at the time. Two experimental series were conducted as a part of this study, the first series tested a single sofa from each country of the EU and the second series tested a selection of sofas in a furnished room setup.

In the first series, the sofas were ignited using a wood crib #5 (BS 5852), and the HRR and smoke production rate were measured during the experiments. Test configuration was free burning of sofas under a 3 m × 3 m calorimetric hood, mechanically ventilated. When possible, the sofas were allowed to burn until natural extinction. For ten sofas, the temperature in the ventilation ducts became critical, typically for fires that reached an HRR over 1200 kW, and the fire was extinguished prematurely.

In the second series, six sofas were ignited using the wood crib #5 in identically furnished rooms. The test configuration was similar to ISO 9705-1/EN 14390 standards, with the described test room. The heat release rate, smoke production rate, temperature in the room and time to flashover were measured using the standardized calorimetric hood placed at the door.

The heat release rate, expressed in kW, is calculated using the oxygen consumption method, as proposed by Thornton and modified by Huggett. In practice, resolution on the heat release rate is driven by dilution and the size of the equipment. So, to allow accurate measurement, the used hood size and flow rate in the duct have to be adapted to the expected heat release rate to obtain a depletion factor not exceeding 17% of oxygen in the effluents, but being significantly different from the initial oxygen concentration. The measurement uncertainty of the heat release rate is evaluated as ±10%. The smoke production rate is calculated according to the light transmission method, using a white light opacimeter. The beam attenuation is expressed as the extinction coefficient in m⁻¹. The smoke production rate, expressed in m²/s, is given by multiplying the extinction coefficient with the flow rate and its measurement uncertainty is evaluated as ±20%. Temperatures during the second series of tests have been measured using K-type 1.5 mm Inconel shielded thermocouples, which have an evaluated measurement uncertainty of ±2.5 K.

The crib #5 ignition source used in this study best describes the ignition scenario of sofas being ignited by open flames from another item on fire. Statistics from the United States indicate that this scenario is the most frequent ignition scenario (25%) for upholstered furniture fires. These statistics show that the tested scenario is relevant in terms of upholstered furniture fires.

The data set was analyzed and presented relative to the best performing sofa and the results of the room experiments were evaluated with respect to evacuation. Pictures of the different sofas and rooms tested are available as supplementary material.

3.1 Phase 1: Sofa experiments

There was no selection criteria for the tested sofas, apart from their commercial availability. The tested sofas therefore showed a wide variety of physical properties and used materials. In a certain degree, they represent customer preferences in each country. As such, the fire performance of the sofas could not be related to any specific sofa property or physical parameter, including construction materials. Each sofa should, however, adhere to the fire safety regulations of its respective country where it was sold. The data set thus provides the opportunity to analyze whether the fire performance of sofas improves with increasingly stringent fire safety regulations. Only for Ireland, the country with the second most stringent fire safety regulations, two sofas were tested because the first sofa performed very poorly. Based on this poor fire performance, the first sofa was initially estimated to not comply with the Irish fire safety regulations. A second sofa that should have complied with the Irish fire safety regulations was therefore purchased and tested as well. It should be noted that while the UK sofa had the best fire performance, it did in fact not pass the crib 5 test as described by BS 5852 (no flaming at 10 minutes after ignition of the crib). This may be a typical example of a mock-up that had passed the test while the results are not representative of the actual sofa, which has been observed during other experimental series as well.

The main results are available in Tables 5–7. Heat release rate curves and smoke production rate curves are available online in supplementary material for each test. Graphs for the total heat release (THR) after five minutes and for the total smoke production after
| Country         | Regulatory level | Results (total) | Results (after 5 min) | Manual extinction (min) |
|----------------|------------------|----------------|-----------------------|------------------------|
|                | Weight (kg)      | Peak HRR (kW)  | Time to peak (s)      | THR (MJ)               | Peak SPR (m²/s) | TSP (m²) | Max HRR₃₀₀ (kW) | THR₃₀₀ (MJ) | Max SPR₃₀₀ (m²/s) | TSP₃₀₀ (m²) |
| Austria        | 1                | 45.9           | 779                   | 231                    | 339                  | 13       | 11 777         | 779          | 126                | 12                       |
| Belgium        | 1                | 42.8           | 1207                  | 357                    | N/A                  | 12       | 761            | 61           | 6                       | 9                       |
| Bulgaria       | 1                | 55.7           | 953                   | 255                    | N/A                  | 22       | 718            | 84           | 7                       | 809                     |
| Cyprus         | 1                | 39.4           | 953                   | 255                    | N/A                  | 22       | N/A            | N/A          | N/A                | N/A                     |
| Czech Rep.     | 3                | 44.1           | 1154                  | 273                    | 373                  | 10       | 8215           | 1154         | 103                | 8                       |
| Denmark        | 1                | 40.3           | 1270                  | 375                    | N/A                  | 17       | 6907           | 695          | 32                 | 11                       |
| Estonia        | 1                | 80             | 861                   | 435                    | 549                  | 11       | 425            | 17           | 3                       | 60                      |
| Finland        | 2                | 61             | 1505                  | 291                    | N/A                  | 24       | 1505           | 84           | 22                 | 632                     |
| France         | 1                | 48.3           | 996                   | 570                    | 422                  | 9        | 5855           | 295          | 21                 | 151                     |
| Germany        | 1                | 66.7           | 845                   | 252                    | 353                  | 8        | 845            | 114          | 8                   | 984                     |
| Greece         | 1                | 31             | 1084                  | 381                    | N/A                  | 25       | 317            | 23           | 4                   | 272                     |
| Hungary        | 1                | 65             | 1052                  | 270                    | 527                  | 18       | 15 760         | 1052         | 140                | 13                       |
| Ireland        | 4                | 47             | 1271                  | 300                    | N/A                  | 49       | 1271           | 78           | 49                 | 2183                    |
| Ireland2       | 4                | 48.8           | 684                   | 1047                   | 376                  | 13       | 9              | 1            | 0                   | 2                       |
| Italy          | 1                | 25.7           | 1082                  | 207                    | 156                  | 10       | 2401           | 1082         | 130                | 10                       |
| Latvia         | 1                | 52.8           | 1087                  | 321                    | 490                  | 10       | 8577           | 1024         | 66                 | 10                       |
| Lithuania      | 1                | 72.5           | 826                   | 465                    | 492                  | 16       | 13 720         | 646          | 66                 | 14                       |
| Luxembourg     | 1                | 45.5           | 1190                  | 261                    | N/A                  | 10       | N/A            | N/A          | N/A                | N/A                     |
| Spain          | 1                | 60.9           | 1163                  | 228                    | N/A                  | 38       | N/A            | N/A          | 38                 | 2851                    |
| Sweden         | 2                | 53.6           | 1236                  | 495                    | N/A                  | 12       | N/A            | N/A          | 7                  | 1                       |
| United Kingdom | 5                | 47.6           | 576                   | 1527                   | 542                  | 2        | 542            | 2            | 9                   | 2                       |

Abbreviations: HRR, heat release rate; THR, total heat release; TSP, total smoke production; SPR, smoke production rate.

*a* Regulatory levels for the private sector only: 1) no regulations, 2) no ignition by cigarette, 3) no ignition by small flame, 4) no ignition by cigarette and small flame and 5) no ignition by cigarette, small flame and wood crib 5.

*b* Burns were extinguished prematurely "to prevent damage to the measuring equipment in the system and to the ventilator fins" for which a maximum equipment temperature of 350°C was set. N/A means not applicable.
**TABLE 6** Minimum and maximum results obtained for the main parameters measured

| Parameter                  | Min. | Max.     | Country min. | Country max. |
|----------------------------|------|----------|--------------|--------------|
| Weight (kg)                | 17.5 | 80       | Slovenia     | Estonia      |
| Burning time (s)           | 198  | 2538     | Portugal     | United Kingdom |
| Peak HRR (kW)              | 576  | 1505     | United Kingdom | Finland      |
| Time to peak HRR (s)       | 183  | 1527     | Slovakia     | United Kingdom |
| Total heat (MJ)            | 123  | 549      | Slovakia     | Estonia      |
| Peak SPR (m²/s)            | 6.56 | 48.9     | Netherlands  | Ireland      |
| Time to peak SPR (s)       | 168  | 1245     | Slovakia     | Estonia      |
| Avg. SPR (m²/s)            | 1.41 | 18.36    | Sweden       | Slovenia      |
| Total smoke (m²)           | 1538 | 15905    | Slovakia     | Poland       |

Abbreviation: HRR, heat release rate.

**TABLE 7** Minimum and maximum results obtained at 300 s

| Parameter (300 s)          | Min. | Max.     | Country min. | Country max. |
|----------------------------|------|----------|--------------|--------------|
| Peak HRR (kW)              | 8.6  | 1505     | Ireland2     | Finland      |
| Avg HRR (kW)               | 4.9  | 469      | Ireland2     | Hungary      |
| Total heat (MJ)            | 1.47 | 140      | Ireland2     | Hungary      |
| Peak SPR (m²/s)            | 0.035| 48.9     | Ireland2     | Ireland      |
| Avg SPR (m²/s)             | 0.0073| 9.70   | Ireland2     | Spain        |
| Total smoke (m²)           | 2.19 | 2851     | Ireland2     | Spain        |

Abbreviations: HRR, heat release rate; SPR, smoke production rate.

**FIGURE 2** Total heat released after 5 minutes. The Cyprus test had measurement problem. The Portugal and Luxembourg tests were stopped before the 5-minute mark. [Colour figure can be viewed at wileyonlinelibrary.com]

**FIGURE 3** Total smoke production (TSP) after 5 minutes. The Cyprus test had measurement problem. The Portugal and Luxembourg tests were stopped before the 5 minutes mark. [Colour figure can be viewed at wileyonlinelibrary.com]
5 minutes are presented in Figures 2 and 3. Open symbols represent the experiments that were extinguished manually to prevent the measurement systems from overheating (see also Table 5). Since the data set is very limited, any observed trends from the results should be considered as preliminary results until more data becomes available.

The different types of fire safety regulation levels related to upholstered furniture that were active in the EU in 2010 can be summarized as follows:\textsuperscript{1,13}:

1. no regulation;
2. no ignition by cigarettes;
3. no ignition by a small flame;
4. no ignition by cigarettes and a small flame;
5. no ignition by cigarettes, a small flame and a wood crib (Crib #5 or Crib #7).

Of the 27 countries in the EU in 2010, 17 countries had no regulation regarding the fire safety of upholstered furniture. Of the other 10 countries, only four had regulations regarding the fire safety of furniture intended for domestic use and one had a recommended standard for furniture fire safety. Finland has the “no ignition by cigarette” requirement for seats since 1991, following the EN 1021-1 standard. Sweden follows the same standard, but only through a recommendation of the Swedish Consumer Agency. The regulations in the Czech Republic require "no ignition by a small flame" since 2008, among others following the EN 1021-2 standard. Ireland has the “no ignition by cigarettes and a small flame” for furniture since 1996, following the EN 1021-1 and EN 1021-2 standards. The United Kingdom has the most stringent regulations, following BS 5852 since the late 1980s, which requires no ignition by cigarettes, a small flame and a wood crib (crib #5). Since all sofas were purchased from the consumer market, furniture fire safety regulations related to the public domain are therefore not considered in this analysis.

### 3.2 Heat release rate analysis

By plotting the time to the peak HRR as a function of the regulation level (Figure 4), the data clearly show that only the second sofa from Ireland (level 4) and the sofa from the United Kingdom (level 5) have a markedly better fire performance than the other sofas. Although the poor fire performance of the first sofa from Ireland was deemed to be non-representative of Irish sofas, it cannot be excluded that the sofa in fact complied with the Irish regulations. Because the used ignition source (wood crib 5) was much stronger than what a level 4 sofa would be designed for, the obtained results simply do not reflect any form of compliance to lower fire safety levels than crib #5. It seems therefore more reasonable to assume that both Irish sofas complied with the Irish regulations. In principle, the results thus suggest that subjected to a relatively large ignition source, level 4 regulations lead to a better fire performance in 50% of the compliant sofas and level 5 regulations lead a better performance for all compliant sofas. Alternatively, it is plausible that the second Irish sofa was compliant with level 5 regulations, considering the Irish market may also present sofas intended for sale in the UK market. Either way, the issue of market surveillance or strong divergences of performances in the Irish market has to be noted.

Fire safety requirements for either cigarettes or small flames seem to have no influence on the fire performance when subjected to a more severe ignition source. Only for the highest regulatory requirements, a significant delay in the fire growth to reach the peak HRR becomes apparent. When plotting the THR as a function of the burning time (Figure 5), the plot shows a linear trend with in which sofas with higher regulation levels require longer burning times compared to other sofas to release the same level of energy. This result indicates that compliance to a high regulation level mostly slows the fire growth and the burning rate, but does not in fact reduce how much of the sofa is burned. As such, these experiments show that furniture fire safety regulations only address the ignitability of furniture and do not ultimately affect the fire load of furniture. This result is in line with conclusions from literature.\textsuperscript{10}

No correlation was found between the peak heat release rate and the total heat release, as shown in Figure 6. All tests showed peak heat release rates over 500 kW, independent of the total heat released. Figure 7 also does not show any correlation between the initial mass of the sofa and the total heat released, but does indicate that for this type of dataset, with furniture items lighter than 100 kg, the heat released is limited to 600 MJ. Overall, all sofas ignited and were either extinguished manually due to too rapid fire growth or burned out fully, extinguishing because of a lack of fuel.
**Figure 5** Total heat release as a function of the burning time [Colour figure can be viewed at wileyonlinelibrary.com]

**Figure 6** Total heat release as a function of peak heat release rate [Colour figure can be viewed at wileyonlinelibrary.com]

**Figure 7** Total heat released as a function of the initial mass of the furniture [Colour figure can be viewed at wileyonlinelibrary.com]

**Figure 8** Peak smoke production rate as a function of the regulatory level [Colour figure can be viewed at wileyonlinelibrary.com]

**Figure 9** Total smoke production as a function of the time to peak smoke production rate [Colour figure can be viewed at wileyonlinelibrary.com]
3.3 Smoke release analysis

The relevant plots related to the smoke production are shown in Figures 8–10. Due to a measurement error there is no smoke data available for the sofa from the United Kingdom. There does not seem to be any sort of correlation between the different regulatory levels and the smoke production (rate). There was also no strong correlation found between the HRR and smoke production (rate), indicating that different types of materials were used in the fillings of the sofas. Because the material composition of the tested sofas was unknown, it is not possible to provide a more detailed analysis of the data. As for the total heat released, Figure 10 shows no correlation between the initial mass of the sofa and the smoke released.

3.4 Phase 2: Room experiments

In this phase, six sofas are tested in a small furnished room to demonstrate the consequences of their performance in a semi-realistic consumer application. The room chosen is based on the room corner test (ISO 9705-1/EN 14390) with dimensions of 3.6 m × 2.4 m × 2.4 m (w × l × h). The room has only one opening, a doorway of 0.8 m × 2.0 m. The room is furnished with standard items (same products in each test). These standard items include a small wooden table, a wooden chair, a wooden book shelf, a cushion, four reed baskets, a floor cover, a wall cover/curtain and some kilograms (not determined) of books.

Based on the results of the burns in phase 1 and also on their availability, sofas from Greece, Ireland, Lithuania (in a different color), Portugal, Sweden, and United Kingdom were selected for this phase. They represent the whole range of performances observed during phase 1 for all parameters. The ignition source and the place of ignition are identical to the ones used in phase 1. In this phase, the heat release rate and the smoke production rate of the burning sofas are measured as well as the temperature of the smoke leaving the room through the door opening. Due to technical problems, no smoke measurements of the burning of the Greece sofa and no heat release measurements of the full burn of the Lithuanian sofa are available. To avoid damage to the measuring equipment and the fans, because of high temperatures in the measuring section and at the fan, the burn of the Portugal sofa was terminated prematurely (2.5 MW).

The results are summarized in Table 8 and plotted in Figures 11–13. The UK sofa performed better than the other tested sofas during a fire inside a small furnished room, for all parameters. Similar to the single sofa tests, the primary effect of the stricter regulations in the United Kingdom is the delay of the fire growth. High heat release levels are postponed for 15 to 20 minutes in comparison to the other sofas tested, which create a heat release rate over 200 kW in the room in 2.5 to 7 minutes. While 7 minutes are more than sufficient in this scenario (this fire in this room) to escape the room concerned, the substantial safety margin provided by the UK sofa might be very important in many other fire scenarios. In a typical fire scenario in a room corner setup, a heat release rate around 1000 kW is needed to initiate flashover. This value is reached in all tests, but the UK sofa strongly deviates from the others by delaying the time to flashover.

The environment (ventilation, radiative boundaries) and other items are known to be dominant in the fire performance of upholstered furniture, the differences in these components in the sofas are probably the reason of the very different fire behavior. However, no further investigations were done to underpin this assumption for this study.

The fire performance of the sofas and of the room fires in which the sofas are involved were best presented by the HRR as a function of time and the maximum HRR. The sofa complying with level 5 regulations showed significant delays of ignition and development of the fire. These are important parameters to predict the hazard in normal

### Table 8 Results from room experiments

| Room furnished with sofa from | HRR<sub>max</sub> (kW) | T<sub>max at door (°C) | SPR<sub>max</sub> (m²/s) |
|-----------------------------|------------------------|-----------------------|-----------------------|
| Greece                      | 1583                   | 639                   | N/A                   |
| Ireland                     | 1850                   | 979                   | 36.8                  |
| Lithuania                   | 640<sup>a</sup>        | 928                   | 53.2                  |
| Portugal<sup>b</sup>        | 2473<sup>b</sup>       | 998<sup>b</sup>       | 51.7<sup>b</sup>      |
| Sweden                      | 2173                   | 1025                  | 42.7                  |
| United Kingdom              | 1878                   | 880                   | 25.9                  |

Abbreviation: HRR, heat release rate.

<sup>a</sup>Heat release measurement stopped during test.

<sup>b</sup>Test terminated prematurely.
consumer applications of furniture. With high heat release levels being delayed for 15 to 20 minutes in comparison to sofas complying to lower regulatory levels, the British sofa can provide a substantially longer safety margin. Such margins can be very important in a variety of fire scenarios. On the other hand, though, the sofa did ignite from a crib #5 ignition source, which, according to the British regulations, should not lead to ignition of a corresponding sofa mock-up. Thus, while there was a noticeable improvement of the fire performance,

**FIGURE 11** Heat release rate from room experiments

**FIGURE 12** Average temperature at door opening from room experiments
ignition was not prevented and the test methods do not accurately reflect real ignition scenarios. This shortcoming is a known weakness of standardized testing in general. Full scale testing, however, is often not an economically or practically feasible alternative and will not necessarily give more reliable test and classification results. Standardized testing as alternative produces comparable and reproducible results, which do translate to an improved fire performance in real-scale scenarios as shown by the results in this study. These results highlight also that fire safety cannot be only reduced to a material selection problematic in end-use scenarios. Fire safety shall be assessed with a holistic approach, including early fire detection, evacuation, compartmentation, and eventually fire suppression.

As shown in the analysis of furniture fire statistics, the tested crib #5 scenario is relevant in terms of upholstered furniture fires. For this scenario, only level 5 regulations provided a reliable improvement of the fire performance. The results thus indicate that improvements of the regulatory framework for furniture fire safety amongst European countries to reduce the fire hazard of upholstered furniture in dwellings would be relevant. These results are in line with those presented recently by Blais et al51 on a smaller number of sofas. In addition, the results of this study contribute to data sets that are needed for fire safety engineering scenarios in dwelling fires.

4 | CONCLUSIONS

The literature study and the experiments on the European sofas have shown that the current furniture fire safety regulatory frameworks have reduced domestic furniture fires only to a limited degree. The ignition scenarios that are commonly covered by the regulations remain the primary ignition causes of furniture fires. This is also observed during the tests, where instead of preventing ignition, compliance with the most stringent regulations only delayed ignition for high ignition sources such crib #5. The prescribed tests and regulations should therefore be updated to better reflect the actual modes of accidental ignition for upholstered furniture. Furniture fire safety regulations should ideally be based on the fire performance of the full piece of furniture, and not just mockups, to reach the expected level of fire safety. Since tests on mock-ups seem to provide only limited data that is relevant for end-use scenarios, there is a need for further research on scaling between mock-ups and real-scale tests. Furthermore, assessments are needed for variations inside a family of upholstered furniture using the mock-up scale test samples.

Furthermore, fire safety regulations also remain affected indirectly by other political concerns. The most prominent example is that the British regulations are being revised with the possibility to reduce the use of halogenated flame retardants in upholstered furniture, despite the reduction in fire deaths observed after implementing the regulations. Overall, it seems very likely that the regulatory status quo in European countries regarding furniture fire safety will be maintained, until an environmentally friendly and effective flame retardant will be developed to replace halogenated flame retardants. When such a flame retardant can then be used to pass representative fire performance tests, in terms of, for example, time to ignition and maximum HRR, fire safety regulations, and thereby the fire safety level, can be significantly improved. Alternatively, technical solutions, such as the choice of materials and protective layers, could be developed further to provide

![FIGURE 13 Smoke production rate from room experiments](image-url)
suitable alternatives to chemical flame retardants to comply with fire safety regulations. Ultimately, fire safety regulations should focus solely on the fire performance, irrespective of the solutions chosen by the industry to achieve the desired fire performance. Whether or not chemical flame retardants are accepted, and if so in which form, should be covered by regulations related to toxicity issues.

Regarding tests performed randomly on sofas available on European market, technical solutions exist to provide a significant improvement in terms of fire safety performance. Nevertheless, these solutions are only applied if requested by the regulation. They provide a partial improvement that shall be completed with other fire safety measures.

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ORCID
Eric Guillaume https://orcid.org/0000-0002-3055-2741
Laurens van Gelderen https://orcid.org/0000-0002-1690-8334

ENDNOTES
1 “Penta-BDE and Octa-BDE were voluntarily phased out of production in 2004. Also in 2004, the sale of penta and octa in concentrations higher than 0.1% by mass were banned in the European Union. In 2006, EPA required that any new manufacture or use of penta or octa would constitute a new use and require prior evaluation before approval.” Cited from NFPA.10
2 Fire Safe Europe (FSEU) is a European alliance which aims to raise the profile of fire safety in buildings, particularly amongst EU policy makers and regulators, founded mainly by industries of fire protection products

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