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Final report

Fire-safety requirements for textiles, furniture and mattresses in public facilities. What requirements exist and how can these be fulfilled?

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Abstract: Fire-safety requirements for textiles, furniture and mattresses in public facilities. What requirements exist and how can these be fulfilled?

When public contracts are awarded, a significant contribution can be made to the protection of natural resources by taking environmental aspects into account, since the high volume of public contracts means that there is great potential for relieving the burden on the environment. The Federal Environmental Agency offers purchasers product-specific tender recommendations to enable the environmentally friendly procurement of products. However, sometimes there is uncertainty about fire protection requirements for products such as textiles, furniture, or mattresses in the public sector and, if applicable, how the required fire protection can be realised in an as environmentally friendly a way as possible.

This report aims to review the legal fire protection requirements for the product groups PPE, work clothing and shoes, house and home textiles, furniture, mattresses, and floorings in nine public sector areas. It also discusses general structural fire protection. Further, it has the objective of presenting environmentally friendly ways of meeting fire protection requirements and of deriving recommendations here. The public sector areas considered are day care centres, schools, hospitals, office and administrative buildings, the armed forces, correctional facilities, places of assembly, the fire brigade, and the police force/customs authority.

In addition to extensive literature research, various experts were consulted and the preliminary results were presented and debated in technical discussions.

Minimum requirements exist for the fire protection of uniforms for firefighters, but no legal fire protection requirements for mattresses for hospitals and day care centres were identified. We were not able to find any legal fire protection requirements for furniture and house and home textiles in day care centres, schools, office and administrative buildings, and hospitals outside the (required) escape and rescue routes. Escape and rescue routes must be kept free from fire loads in accordance with the German Standard Building Regulations. Floorings, which are classified as building materials, must meet the requirements of the "Normally flammable" building material class and be flame-retardant or non-combustible in certain escape and rescue areas in accordance with the relevant regional building codes, accommodation ordinances, and venue regulations.

Additive flame retardants (FRs), inherent flame retardancy, and the use of alternative materials are options for meeting the fire protection requirements for the various products. Inherent flame retardancy is used particularly for protective work clothing but can also be found in house and home textiles, upholstered furniture, and mattress covers. Alternative flame retardancy in the form of basalt fibres is used in occupational safety textiles; glass filaments, glass fabric, and basalt fibres are used in house and home textiles; and e.g. concrete and gypsum fibreboard are used in furniture. For additive flame retardancy, 31 FRs could be identified as commonly used in the five product groups. An evaluation of the environmental and health properties of these substances on the basis of their hazard codes (HS codes) in accordance with the CLP Regulation identified eight usable FRs; a further six FRs can be used only in certain products or product groups in accordance with this evaluation. Four FRs do not meet the persistence requirements and two of these do not meet the bioaccumulation requirements either. All 10 remaining FRs are not wash-resistant and therefore cannot be used in products that are washed regularly.

Purchasers are recommended to first ask themselves whether fire protection is at all necessary for the products to be acquired. Then, they should check whether fire protection can be realized via inherent flame retardancy or via alternative flame retardancy. Finally, the use of FRs should be checked. Here, a selection should be made - if required - from the 10 FRs identified during the course of this study.

Kurzbeschreibung: Brandschutzanforderungen für Textilien, Möbel und Matratzen in öffentlichen Einrichtungen: Welche Regelungen bestehen und wie können diese erfüllt werden?

Bei der Vergabe öffentlicher Aufträge kann unter Berücksichtigung von Umweltaspekten ein wesentlicher Beitrag zum Schutz der natürlichen Lebensgrundlagen geleistet werden, da mit dem hohen Auftragsvolumen der öffentlichen Hand auch ein großes Potential der Umweltentlastung besteht. Das Umweltbundesamt bietet Beschafferinnen und Beschaffern produktspezifische Ausschreibungsempfehlungen für eine umweltfreundliche Beschaffung. Mitunter besteht jedoch Unsicherheit über die Brandschutzanforderungen an Produkte wie Textilien, Möbel oder Matratzen im öffentlichen Bereich und, sofern notwendig, wie ein geforderter Brandschutz möglichst umweltschonend realisiert werden kann.

Dieser Bericht hat zum Ziel, für die Produktgruppen PSA, Arbeitskleidung und Schuhe, Haus- und Heimtextilien, Möbel, Matratzen und Bodenbeläge in neun öffentlichen Bereichen die gesetzlichen Anforderungen an den Brandschutz aufzuarbeiten. Ergänzend wird auf den allgemeinen baulichen Brandschutz eingegangen. Außerdem besteht das Ziel, umweltschonende Möglichkeiten der Erfüllung der Brandschutzanforderungen darzustellen und Empfehlungen abzuleiten. Zu den betrachteten öffentlichen Bereichen zählen Kindertagesstätten, Schulen, Krankenhäuser, Büro- und Verwaltungsgebäude, Bundeswehr, Justizvollzugsanstalten, Versammlungsstätten, Feuerwehr sowie Polizei/Zoll.

Neben umfangreichen Literaturrecherchen wurden verschiedene Fachexpert*innen konsultiert sowie die Zwischenstände in Form von Fachgesprächen vorgestellt und diskutiert.

An den Brandschutz von Einsatzkleidung der Feuerwehr liegen Mindestanforderungen vor, während keine gesetzlichen Brandschutzanforderungen an Matratzen für Krankenhäuser und Kitas identifiziert wurden. Für Möbel sowie Haus- und Heimtextilien außerhalb der (notwendigen) Flucht- und Rettungswege in Kitas, Schulen, Büro- und Verwaltungsgebäuden sowie Krankenhäusern konnten ebenso keine gesetzlichen Anforderungen an den Brandschutz ausfindig gemacht werden. Flucht- und Rettungswege sind entsprechend der Musterbauordnung von Brandlasten frei zu halten. Bodenbeläge, die als Baustoffe gelten, müssen der Baustoffklasse normalentflammbar entsprechen und nach den jeweiligen Landesbauordnungen, Beherbergungs- und Versammlungsstättenverordnungen in bestimmten Flucht- und Rettungsbereichen schwerentflammbar bzw. nichtbrennbar sein.

Zur Erfüllung der Brandschutzanforderungen an die jeweiligen Produkte kommen grundsätzlich additive Flammschutzmittel (FSM), inhärenter Flammschutz oder die Verwendung alternativer Materialien infrage. Der inhärente Flammschutz kommt insbesondere bei Arbeitsschutzkleidung zur Anwendung, aber auch bei Haus- und Heimtextilien, Polstermöbeln und Matratzenbezugs-stoffen. Der alternative Flammschutz in Form von Basaltfasern findet sich bei Arbeitsschutztextilien; Glasfilamente, Glasgewebe und Basaltfasern bei Haus- und Heimtextilien, oder bspw. Beton und Gipsfaserplatten bei den Möbeln. Bezüglich des additiven Flammschutzes konnten 31 FSM identifiziert werden, die für die fünf Produktgruppen gebräuchlich sind. Mittels einer Bewertung der Umwelt- und Gesundheitseigenschaften über die Gefahrenhinweise (H-Sätze) gemäß CLP-Verordnung wurden acht FSM identifiziert; weitere sechs FSM können nach dieser Bewertung nur in einigen Produkten bzw. Produktgruppen verwendet werden. Vier weitere FSM erfüllen nicht die Anforderungen an die Persistenz, zwei davon auch nicht die Anforderungen an die Bio-akkumulation. Alle 10 FSM sind nicht waschbeständig und können daher nicht in Produkten, die regelmäßig gewaschen werden, verwendet werden.

Für Beschaffer*innen ist zu empfehlen, zunächst zu hinterfragen, ob ein Brandschutz für die zu beschaffenden Produkte überhaupt notwendig ist. Dann ist zu prüfen, ob ein Brandschutz über inhärenten Flammschutz oder über einen alternativen Flammschutz zu realisieren ist. Zuletzt ist

der Einsatz von FSM zu prüfen. Hierbei sollten, wenn erforderlich und notwendig, die im Rahmen dieser Arbeit identifizierten 10 FSM ausgewählt werden.

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Abbreviation	Meaning
AA	Acute Aquatic Toxicity
AGBF	Working Group of the Heads of the Professional Fire Brigades (Arbeitsgemeinschaft der Leiter der Berufsfeuerwehren)
APP	Ammonium polyphosphate
APR	Accident prevention regulations
AT	Acute Mammalian Toxicity
ATH	Aluminium hydroxide
ATO	Antimony trioxide
B	Bioaccumulation; bioaccumulative
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
BDI	Federation of German Industries (Bundesverband der Deutschen Industrie)
BS	British Standard
BUND	Friend of the Earth Germany (Bund für Umwelt und Naturschutz Deutschland)
bw	body weight
C	Carcinogenicity
CA	Chronic Aquatic Toxicity
CAS RN	Chemical Abstracts Service Registry Number
cat.	Category
CF	Correctional facility
C&L	Classification and Labelling
CLP	Regulation on Classification, Labelling and Packaging of Substances and Mixtures
Constr.	Construction
d	day
D	Developmental (Neuro-)Toxicity
DBDPE	1,1'-(ethane-1,2-diyl)bis[pentabromobenzene]
DecaBDE	Decabromodiphenyl ether
DE-UZ	german: Deutschland-Umweltzeichen; Germany - Ecolabel
DFV	German Fire Brigade Association (Deutscher Feuerwehrverband)
DGB	German Trade Union Confederation (Deutscher Gewerkschaftsbund)
DGKH	German Association for Hospital Hygiene (Deutsche Gesellschaft für Krankenhaushygiene)
DGUV	German Statutory Accident Insurance Association
DIBt	German Institute for structural engineering (Deutsches Institut für Bautechnik)
DIN	Deutsches Institut für Normung (German Institute for Standardisation)

Abbreviation	Meaning
DMPPA	Dimethyl [3-[(hydroxymethyl)amino]-3-oxopropyl]phosphonate
DVO-KiTaG	Lower Saxony's Ordinance on Minimum Requirements for Nurseries (Niedersächsische Verordnung über Mindestanforderungen an Kindertagesstätten)
E	Endocrine Activity
EC	European Commission
EC_{50}	Half maximal effective concentration
ECHA	European Chemicals Agency
e.g.	exempli gratia (for example)
EFRA	European Flame Retardants Association
EN	European Norm
EPS	Expanded polystyrene
etc.	et cetera (and the rest)
et seq.	et sequentes (and the following)
EU	European Union
e. V.	Registered association (eingetragener Verein)
F	Flammability
FIGRA	Fire growth rate [W/s]
FPV	Fire prevention visit
FR	Flame retardant
FRs	Flame retardants
FTIR spectroscopy	Fourier-transform infrared spectroscopy
FTP code	Fire test procedures code
GHS	Globally Harmonized System of Classification and Labelling of Chemicals
GMBl	Joint Ministerial Gazette (Gemeinsames Ministerialblatt)
GUV	Statutory Accident Insurance
GUVV	Municipal Accident Insurance Association (Gemeindeunfallversicherungsverband)
GVBl	Law and ordinance gazette (Gesetz- und Verordnungsblatt)
h	hour
H	high
HBB	Hexabromobenzene
HBCD	Hexabromocyclododecane
HDE e. V	German retail federation (Handelsverband Deutschland)
HE-Kita	Recommendations on preventative fire safety for the construction and operation of day care facilities for children (Handlungsempfehlungen zum vorbeugenden Brandschutz für den Bau und Betrieb von Tageseinrichtungen für Kinder)
HI	Heat insulation

Abbreviation	Meaning
HMPA	Hexamethylphosphoramide
HOTREC	Hotels, Restaurants and Cafés; a European umbrella organisation for the catering industry
HPL	High-pressure laminate
HPLC	High-performance liquid chromatography
HS code	Hazard statement code for a chemical substance
HTI	Heat transfer index
HuPF	Manufacturing and testing description for universal firefighters' protective clothing (Herstellungs- und Prüfungsbeschreibung für eine universelle Feuerwehrschutzkleidung)
I	Ignited
i.a.	inter alia (among others)
i.e.	id est (that is)
ICAO	International Civil Aviation Organization
IMO	International Maritime Organization
Inhal.	Inhalation
IrE	Eye Irritation
IrS	Skin Irritation
ISO	International Organization for Standardization
kg	kilogramme
KhBauR	Hospital Construction Guidelines (Krankenhausbaurichtlinie)
KhBauVO	Hospital Construction Ordinance (Krankenhausbauverordnung)
KhsVO	Hospital Ordinance (Krankenhaus-Verordnung)
KiTaG	Lower Saxony's Law on Day Care Facilities for Children (Gesetz über Tageseinrichtungen für Kinder)
K_{ow}	Octanol-water partition coefficient
KVB	Bavarian Doctors' Association (Kassenärztliche Vereinigung Bayern)
l	litre
L	low
LASI	Commission for Occupational Safety and Safety Engineering (Länderausschuss für Arbeitsschutz und Sicherheitstechnik)
LBO	Regional building code
LBO BW	Regional Building Code of Baden-Wuerttemberg
LC_{50}	lethal concentration, 50 %
LD_{50}	lethal dose, 50 %
LFS	lateral flame spread
LOI	limiting oxygen index
M	moderate
MAC	Modacrylic

Abbreviation	Meaning
max.	maximum
MBeVO	Standard Ordinance on Accommodation (Muster-Beherbergungsstättenverordnung)
MBO	German Standard Building Regulations (Musterbauordnung)
MC	Melamine cyanurate
MDH	Magnesium hydroxide
mg	milligramme
MHHR	Standard Highrise Directive (Muster-Hochhaus-Richtlinie)
MLAR	Standard Piping Systems Directive (Muster-Leitungsanlagen-Richtlinie)
M-LüAR	Standard Ventilation Systems Directive (Muster-Lüftungsanlagen-Richtlinie)
MP	Melamine phosphate
MPP	Melamine polyphosphate
MSchulbauR	Standard School Construction Directive (Muster-Schulbau-Richtlinie)
MV	Mecklenburg-Western Pomerania (Mecklenburg-Vorpommern)
MVStättVO	Standard Venue Regulations (Muster-Versammlungsstättenverordnung)
NABU	Nature and Biodiversity Conservation Union (Naturschutzbund Deutschland)
NBauO	Building Code of Lower Saxony
No.	Number
N-repeated	Neurotoxicity with multiple exposure
NRW	North Rhine-Westphalia (Nordrhein-Westfalen)
N-single	Single exposure neurotoxicity
NOAEL	no-observed-adverse-effect level
OctaBDE	Octabromodiphenyl ether
OECD	Organisation for Economic Co-operation and Development
OJ	Official Journal
OSB	Oriented strand board
P	Persistence
p.	page
PAHs	Polycyclic aromatic hydrocarbons
Para.	Paragraph
PBB	Polybrominated biphenyls
PBDDs	Polybrominated dibenzodioxins
PBDE	Polybrominated diphenyl ethers
PBDFs	Polybrominated dibenzofurans
PBI	Polybenzimidazole
PBTs	persistent, bioaccumulative, toxic products
PCDDs	Polychlorinated dibenzodioxins
PCDFs	Polychlorinated dibenzofurans

Abbreviation	Meaning
PCS	Pouvoir calorifique supérieur (higher heating value/HVV)
PentaBDE	Pentabromodiphenyl ether
% w/w	Percentage by weight
PET	Polyethylene terephthalate
pinfa	Phosphorus, Inorganic and Nitrogen Flame Retardants Association
PNC	Polymer nanocomposites
PPE	Personal protective equipment
ppm	parts per million
PPS	Polyphenylene sulphide
PU	Polyurethane
PVC	Polyvinyl chloride
Q_{PCS}	Gross heating value
R	Reproductive Toxicity
RDP	resorcinol bis(diphenyl phosphate
resp.	respectively
RHTI	Radiated heat transfer index
RiSU	Directive on Safety in the Classroom (Richtlinie zur Sicherheit im Unterricht)
RR	Rescue route
Rx	Physical Reactivity
SBI	Single burning item
SCCP	Short chain chlorinated paraffins
SMOGRA	Smoke growth rate [m^2/s^2]
SnR	Respiratory Sensitisation
SnS	Skin Sensitisation
ST-repeated	Systemic Toxicity and Organ Effects (multiple exposed)
ST-single	Systemic Toxicity and Organ Effects (single exposed)
T	Toxicity
TBBPA	Tetrabromobisphenol A
TCEP	Tris(2-chloroethyl)phosphate
TCP	Tris(methylphenyl) phosphate
TCPP	Tris(2-chloro-1-methylethyl)phosphate
TDCPP	Tris(1,3-dichloroisopropyl)phosphate
TEP	Triethyl phosphate
tex	Fineness of textile fibres; tex is a unit and the basic parameter of the tex system (1 tex = 1 gramme per 1000 metres)
THPC	Tetrakis(hydroxymethyl)phosphonium chloride
THR	Total heat release
TMP	Trimethyl phosphate

Abbreviation	Meaning
TRBA	German Technical Rules for Biological Materials (Technische Regeln für Biologische Arbeitsstoffe)
TRGS	German Technical Rules for Hazardous Substances (Technische Regeln für Gefahrstoffe)
TSP	Total smoke production
UNU-FLORES	United Nations University Institute for Integrated Management of Material Fluxes and of Resources
US EPA	United States Environmental Protection Agency
UU	Utilisation unit
VdF	German Association of Fire Brigades (Verband der Feuerwehren)
VdS	German Association of Property Insurers (Verband der Sachversicherer)
vH	very high
vL	very low
vPvB	very persistent, very bioaccumulative
VstättVO M-V	Standard Venue Regulations of Mecklenburg-Western Pomerania (Mecklenburg-Vorpommern)
vzbv	Federal association of the consumer advice centre (Verbraucherzentrale Bundesverband e. V.)
ZNWB	Central Office for Standardisation and Efficiency in Education (Zentralstelle für Normungsfragen und Wirtschaftlichkeit im Bildungswesen); now obsolete

Summary

When equipping inside spaces of public buildings and procuring personal protective equipment (PPE), purchasers often lack current information about the legal requirements for the fire protection of individual products. Whereas there are clear specifications for building materials and building elements in the various regional building codes, the regulations for interior fittings are not so straightforward. In addition, purchasers might not be aware of the means of achieving fire protection, and might not know which more environmentally friendly alternatives are available.

The goals of this research project therefore particularly include a review of the legal fire protection requirements for various products relevant for public procurement and a presentation of the possible ways of meeting these fire protection requirements. We aim to propose environmentally friendly ways for purchasers to achieve flame retardancy so that they can, where possible, request an environmentally friendly alternative as part of the tender process during procurement.

This report therefore looks at the legal bases and recommendations for fire protection requirements in the various public sector areas and presents the standardised test methods for the fire behaviour of the investigated products. The possibilities for meeting fire protection requirements include the use of additive, inherent, or alternative flame retardancy. These options are described in a product-group-specific way using examples. In addition to extensive literature research, various experts were consulted and the preliminary results were presented and debated in technical discussions.

For additive flame retardants (FRs), a rating system was also developed. On the one hand, this is based on the excluded hazard codes in the Blue Angel award criteria. On the other hand, the criteria of persistence, bioaccumulation, wash resistance, combustion products, and costs are used to further assess the remaining FRs.

Fire protection in the public sector in general and for specific public sector areas

According to the standardised vocabulary (DIN EN ISO 13943), the term **fire protection** encompasses methods used to reduce or prevent the spread and effects of fire, heat, or smoke. This includes active fire protection, so the detection and/or suppression of fire, and passive fire protection, which refers to design features and/or appropriate use of materials. **Flame retardants** (FRs) are substances added, or treatments applied, to a material in order to suppress or delay the appearance of a flame and/or reduce the flame spread rate (DIN EN ISO 13943 (2018)).
Building law as per the German Standard Building Regulations (MBO 2019) applies for permanently installed building materials, building elements, and construction products, and the fire protection requirements that are relevant for construction refer to this. Of the products investigated as part of this study, only **floorings** are considered to be construction products. **House and home textiles** and **furniture** are **interior fittings and furnishings**, which do not fall under building law.
In Germany, **fire protection requirements in buildings** are governed by the MBO (2019), supplemented by the various regional building codes. Further provisions include the fire brigade/fire protection laws of the individual federal states. The local fire brigade and building authorities along with specialist planners and other fire and occupational safety experts act as contact partners for matters pertaining to fire protection. In relation to buildings, fire protection means all measures that prevent or impede incipient fire and fire spread. A distinction is made between structural, technical, and organisational fire protection. Defensive fire protection

includes rescuing people and animals as well as effective firefighting. If necessary, further measures are defined in fire protection concepts, fire protection regulations, fire control plans, and fire brigade plans.
The fire protection requirements of a particular building depend on the building class. The five building classes are defined in Art. 2 Para. 3 of MBO 2019.
Particularly with regard to rescuing people and animals, requirements for fire protection increase as the building class increases. The buildings investigated in more detail in this report mainly belong, according to the MBO (2019), to the category of "Special buildings", which are described as facilities and spaces with a special type or usage.
The fire protection requirements research performed as part of this research project focuses on five product groups (see Figure 1) in nine different public sector areas (see Figure 2).

Figure 1: Product groups for fire protection requirements research.

Source: own work, Fraunhofer WKI.

Figure 2: Public sector areas for fire protection requirements research.

Source: own work, Fraunhofer WKI.

For all nine public sector areas, the legal bases and recommendations for fire protection requirements for these five product groups were analysed. For the areas "Fire brigade" and "Police and customs", the fire protection requirements for personal protective equipment (PPE), protective work clothing, and shoes were extremely important, and therefore these were investigated in more detail.
To enable a comparison, the requirements for the structural fire protection of the various areas are also described.

Requirements for structural fire protection of the individual areas

According to the German Standard Building Regulations (MBO) and various regional building codes, **day care centres** are unregulated special buildings for which requirements are defined by means of an individual fire protection concept. According to the MBO, **schools** are special

buildings; building legislation for schools includes the regional building codes, the Standard Guidelines for Building Approval Requirements for Schools (Standard School Guidelines – MSchulbauR), and, in Saarland, the Directive for Fire Protection in Existing Schools.
There are different rules and regulations for structural fire protection in **hospitals** depending on the federal state, and the provisions are not uniform at present. According to the German Standard Building Regulations, hospitals are generally considered to be special buildings due to their usual height and the number and size of the utilisation units (Art. 2 Para. 4 No. 9, 10 of MBO 2019). The federal states of Brandenburg, Mecklenburg-Western Pomerania, Saarland, Schleswig-Holstein, and Berlin have published information relating to the construction and operation of hospitals.
For **office and administrative buildings**, the requirements for structural fire protection depend on the size of the building, as defined in the MBO.
The MBO (2019) classifies **places of assembly** as regulated special buildings. In particular, their structural fire protection requirements are defined by the Standard Venue Regulations (Art. 1 Para. 1 of MVStättVO 2005).
The requirements for the structural fire protection of **correctional facilities** are stipulated by the individual federal states in their regional building codes. Due to the lack of special building regulations, correctional facilities are defined as unregulated special buildings by the MBO. This means that the fire protection of the facility must be considered in a fire protection concept with a view to ensuring adequate protection.

Fire protection requirements for the product groups in the investigated public sector areas

There are different fire protection requirements for the investigated product groups (Figure 1); these depend on the areas in which they are used (Figure 2).
For **PPE**, **protective work clothing**, and **shoes** in child care centres and schools, there are no special fire protection requirements except for lab coats and footwear for science lessons. The Association of Occupational Accident Insurance Funds (GUV) has compiled a set of guidelines for PPE in hospitals, but fire protection is dealt with only through reference to DIN EN 533, which has since been withdrawn. In contrast, fire protection properties play a major role when it comes to clothing for riot police, certain parts of the armed forces (in particular the air force and navy), and the fire brigade. The minimum fire protection requirements for uniforms for firefighters are governed by the accident prevention regulations and are defined in numerous standards.
We were not able to find any legal fire safety requirements for **furniture** and **house and home textiles** in day care centres, schools, office and administrative buildings, and hospitals outside the (required) escape and rescue routes. Escape and rescue routes must be kept free from fire loads in accordance with the MBO. More stringent requirements may be placed upon building equipment in individual fire protection concepts for hospitals and administrative buildings, for example. The legal provisions for correctional facilities are the responsibility of the individual federal states. There is only extremely restricted access to information relating to fire protection requirements. Thus, only the state of affairs in Bavaria was investigated in this study. In Bavarian correctional facilities, flame-retardant materials must be used for furniture and house and home textiles in the cells of inmates.
There are no legal fire protection requirements in Germany for **mattresses** in hospitals or child care centres. Materials that are flame-retardant are to be used for mattresses in Bavarian correctional facilities.
The fire protection requirements upon equipment, props, and decorations in places of assembly are described comprehensively in the Standard Venue Regulations. Equipment and decorations must at least be flame-retardant; in contrast, for props there is merely a requirement that they be normally flammable.

Floorings are classified as building materials and must meet the requirements of the "Normally flammable" building material class as per DIN 4102-1 or DIN EN 13501-1. According to the MBO, floorings in required stairwells etc. must be made from at least building materials that are flame-retardant. Some regional building codes extend the requirement that floorings be flame-retardant to required hallways in the investigated areas. In office and administrative buildings, the fire protection requirements for floorings also depend on the building class. The Standard Venue Regulations place more stringent requirements upon floorings; in this case, floorings in required stairwells etc. must be non-combustible and, in required hallways etc., they must be at least flame-retardant.
Finally, extensive research shows that there are far fewer legal regulations relating to fire protection requirements for the investigated product groups than was assumed at the start of the research.

Test methods for product fire behaviour

"**Fire behaviour**" is defined as the response of a test specimen when it is exposed to fire under specified conditions in a fire test (DIN EN ISO 13943). The relevant test methods below apply to the fire behaviour of the products or product groups listed in Figure 1.

- Upholstered composites (for furniture)
  The fire behaviour of upholstered composites is tested and assessed as per DIN 66084 (paper cushion test). Class P-a imposes the strictest fire protection requirements. As well as DIN 66084, another relevant standard is DIN 50050-2 (large burning cabinet). Class P-b is tested as per DIN EN 1021-1 and assessed as per DIN EN 1021-2; the assessment for Class P-c takes place in accordance with DIN EN 1021-1.

- Mattresses
  The ignitability of mattresses, upholstered bed bases, and mattress pads can be assessed with the test method from DIN EN 597-1. The source of ignition is a smouldering cigarette; in accordance with DIN EN 597-2, the test specimen is brought into contact with a gas flame that is comparable to a match.

- House and home textiles
  The burning behaviour of textile surfaces is tested on the one hand with DIN EN ISO 6941 through the measurement of the flame spread properties of vertically arranged samples. On the other hand, DIN EN ISO 6940 specifies the method for the determination of the ignitability of vertically arranged samples.
  The burning behaviour of **textile curtains** and **drapes** is assessed as per DIN EN ISO 6940, with the method for determining the ignitability of vertically arranged textile samples with a small flame being described in DIN EN 1101.
  The method for determining the flame spread properties of textiles for curtains and drapes as vertically arranged samples is defined in DIN EN 1102; the test takes place as per DIN EN ISO 6941.
  The method for measuring the flame spread properties of vertically arranged textile test samples with a large ignition source is described in DIN EN 13772. During the test, an electric radiator and a small flame as defined in EN ISO 6941 are used.
  DIN EN 13773 defines the classification of textiles for curtains, drapes, and similar, such as blinds and textile wall hangings, for which a classification is required.
  The ignitability of **bedding** by a smouldering cigarette can be tested in accordance with DIN EN ISO 12952-1; the test with a small open flame is described in DIN EN ISO 12952-2.

- In Germany, the **British Standard BS 5852** (2006) is also used to test and classify the inflammability of furniture, house and home textiles, and mattresses.
- The testing of flammable materials such as plastic, wood, and paper through exposure to the flame of a burner is governed by DIN 53438 Parts 1 to 3. A burning cabinet as per DIN 50050 is used for the tests.

- Personal protective equipment (PPE)[1]
  Special requirements are placed upon special clothing to protect against heat and flames. The minimum requirements for brief contact with a small ignition flame are described in DIN EN ISO 14116. Protective clothing as per this standard must achieve limited flame spread index 1, 2, or 3 in accordance with a test as defined in ISO 15025. Protective clothing with index 3 offers the best protection.
  DIN EN ISO 11612 describes the minimum performance requirements for the properties of protective clothing with an extensive range of use for end applications in which clothing with limited flame spread is required and in which the wearer is exposed to radiant heat, convective or contact heat, or splashes of molten metal. For many of the hazards listed in the standard, three performance levels are defined; there is also a fourth performance level for high-performance materials for protection against intense radiated heat.
- Protective clothing for the fire brigade
  The minimum requirements for fire brigade uniforms are described in the following standards:
  - Jackets and trousers for firefighters as per DIN EN 469
  - Firefighter's safety helmet as per DIN EN 443
  - Firefighter's safety hood as per DIN EN 13911
  - Firefighter's safety boots as per DIN EN 15090
  - Protective gloves for firefighters as per DIN EN 659
- Floorings
  For the building material classification of floorings, DIN EN 13501-1 defines seven classes, summarized in Table 1. The criteria for classification into each building material class are also specified in DIN EN 13501-1.

Table 1: Overview of building classes for floorings as per DIN EN 13501-1.

Building material class	Description	Test method	Test standard
$A1_{fl}$	Non-combustible building materials	Non-combustibility test Gross heat of combustion	DIN EN ISO 1182 DIN EN ISO 1716
$A2_{fl}$	Non-combustible building materials	Non-combustibility test Gross heat of combustion	DIN EN ISO 1182 DIN EN ISO 1716 DIN EN ISO 9239-1

[1] Personal protective equipment: Equipment that is worn to protect against health and safety risks at the workplace (e.g. protective clothing, breathing protection, safety gloves, protection against piercing and cutting injuries, goggles and visors, helmets, hearing protectors) (as per DGUV 2006).

Building material class	Description	Test method	Test standard
		Exposure to radiant heat source	
B_{fl}	Flame-retardant building materials	Exposure to radiant heat source Single-flame source test	DIN EN ISO 9239-1 DIN EN ISO 11925-2
C_{fl}	Flame-retardant building materials	Exposure to radiant heat source Single-flame source test	DIN EN ISO 9239-1 DIN EN ISO 11925-2
D_{fl}	Normally flammable building materials	Exposure to radiant heat source Single-flame source test	DIN EN ISO 9239-1 DIN EN ISO 11925-2
E_{fl}	Normally flammable building materials	Single-flame source test	DIN EN ISO 11925-2
F_{fl}	Highly flammable building materials	None	

Possibilities for meeting fire protection requirements

In order to meet fire protection requirements, it might be necessary to strengthen the properties of the used materials using FRs. Three methods can be used to reduce the inflammability of products: Additive flame retardancy, inherent flame retardancy, and alternative flame retardancy (so the use of materials that are not readily ignitable or not combustible in themselves).

- **Additive flame retardancy**: FRs are added to combustible materials (mixed with the materials) as additives or are applied to the materials from the outside as a flame-retardant coating. The FRs investigated here include halogenated, inorganic phosphorous, organophosphorous, nitrogenous, other inorganic FRs, and other FRs. These are used differently in the five product groups investigated here (Figure 1). Flame retardancy solutions prohibited as per the REACH Regulation (No 1907/2006) or EU POP Regulation ((EU) 2019/1021) were not taken into consideration. In total, 31 FRs used in the investigated product groups were identified.

  In the case of **occupational safety textiles**, the commonly used additive FRs come from the group of organophosphorous FRs. A large number of FRs from all six categories are used for **house and home textiles** and **carpets**. The situation is similar for **furniture upholstered with textiles** and **mattress and upholstery foam** (FRs from five categories are commonly used here). In the case of **leather upholstered furniture**, **mattress materials**, and **carpet fibres**, four categories are used: All except halogenated FRs and "others". For **wood and wooden materials**, FRs from the categories of inorganic phosphorous-based FRs, nitrogenous FRs, and other inorganic FRs are typical.

  Table 2 below shows the six groups of FRs, the individual FRs, and which FRs are relevant for which product group.

Table 2: Commonly used additive FRs for the five investigated product groups.

FR group	FR	Used in product group				
		PPE	House and home textiles	Furniture	Mattresses	Floorings
Organic halogenated	Decabromodiphenyl ethane (DBDPE)		x	x		x
	Tetrabromobisphenol A (TBBPA			x		
	Tris(2-chloro-1-methylethyl) phosphate (TCPP)			x	x	
	Tris(1,3-dichloroisopropyl)phosphate (TDCPP)			x	x	
Inorganic phosphorous-based	Ammonium polyphosphate (APP)		x	x	x	x
	Ammonium phosphate			x		
	Di-Ammonium hydrogen phosphate		x	x		x
	Red phosphorous		x	x	x	x
Organophosphorous	Methylphosphonic acid		x	x	x	x
	Mixture of cyclical phosphonates		x	x	x	x
	Resorcinol bis(diphenyl phosphate) (RDP)		x	x	x	x
	N-hydroxymethyl(3-dimethyl phosphono)propionamide (DMPPA)	x	x	x	x	x
	Tetrakis(hydroxymethyl)phosphonium chloride (THPC)	x	x	x	x	
	Tricresyl phosphate (TCP)		x	x		x
	Triethyl phosphate (TEP)				x	x
Nitrogenous	Melamine		x	x		x
	Melamine cyanurate (MC)		x	x	x	x
	Melamine phosphate (MP)		x	x	x	x
	Melamine polyphosphate (MPP)			x	x	x
	Thiourea		x			x
Other organic	Ammonium bromide		x	x		
	Aluminium hydroxide (ATH)		x	x	x	x
	Ammonium sulphate		x	x	x	
	Ammonium sulphamate		x	x	x	x
	Antimony trioxide (ATO)		x	x		x

FR group	FR	Used in product group				
		PPE	House and home textiles	Furniture	Mattresses	Floorings
	Dipotassium hexafluorotitanate		x			x
	Sodium tetraborate decahydrate (Borax)			x		
	Expandable graphite		x	x	x	x
	Dipotassium hexafluorozirconate			x		
	Magnesium hydroxide (MDH)			x	x	x
Other	Zirconium acetate					x

- **Inherent flame retardancy**: Substances (in this case, fibres) acquire a permanently flame-retardant property, making the material produced from them flame-resistant, through a chemical reaction with an FR or through an inherently flame-retardant polymer structure. The following materials are investigated in more detail and their possible usage in the various product groups is stated: Wool, cellulose and viscose, polyester, polyamides/aramids, polymelamine fibres, polyetherimides, and other fibre/material variants. Particularly in the area of **protective work clothing**, it can be seen that almost all of these investigated inherent fibres are used. Practically one in two of the inherent fibres is also used in **house and home textiles**, **fabric upholstered furniture**, and in **mattress materials**. In contrast, inherently flame-retardant materials are used only rarely for **mattress foam** and **foam for upholstered furniture** and for **carpets**. Table 3 below shows inherently flame-retardant materials for the specific product groups.

Table 3: Possible uses of inherently flame-retardant materials by product group.

Material	Products/product names	Product group					
		Protective work clothing	House and home textiles	Upholstered furniture (fabric)	Mattress materials	Foams (mattresses and upholstery)	Carpets
Wool	-		x	x	x		x
Cellulose and viscose	Visil®				x[2]		
	Lenzing™FR	x		x	x	x	
Polyester	Trevira CS		x	x	x		
	Zeroxy™	x	x	x			
Polyamides/aramids	Nomex®	x					
	Twaron®	x					
	Kevlar®	x					
	Kermel®	x					
Polymelamine fibres	Basofil®	x		x	x		
Polyetherimides	Ultem™ 9011	x	x	x	x		
Other	Modacrylic (MAC) fibres	x	x				x
	PyroTex®	x		x[3]			
	Diofort®		x	x			
	Proban®	x	x	x	x		
	Melamine resin foam					x	

- **Alternative flame retardancy:** This includes materials and products whose flame retardancy is ensured even without the use of FRs because they are non-combustible, e.g. plaster and concrete materials, use of glass or basalt fibres in products. The possible usage of alternative flame retardancy was investigated for the product groups occupational safety textiles, house and home textiles, furniture, mattresses, and floorings. Basalt fibres can be used to create fire-resistant fabric and for **occupational safety textiles**, for example. Non-combustible glass filaments, glass fabric and basalt fibres are used to produce **house and**

[2] E.g. as covers for mattresses (see e.g. https://patents.google.com/patent/US7484256B2/en).

[3] Used for seats in e.g. trains, aeroplanes, cinemas, theatres.

home textiles. Diverse possibilities relating to alternative flame retardancy can also be found in the **furniture** area: For instance, concrete furniture, gypsum fibreboard (as a carrier material), or even substrates and substructures made from non-combustible metals. In the case of **upholstered furniture**, the glass fibres already mentioned for house and home textiles can be added. In the case of **laminate**, a non-combustible material such as a glass fibre mat could be used.

The choice of the most suitable solution is always dependent on the usage area of the materials and the method-dependent costs. In the case of additive flame retardancy, there is generally a risk that the FRs will be washed out of the products during cleaning. This danger exists for protective work clothing and some house and home textiles. As a rule, inherent FRs or alternative fire retardancy solutions are therefore used in such cases. To sum up, we should stress that there is no solution that can be used for all materials; instead, each flame retardancy solution has been developed for a special application area.

Evaluation of additive flame retardants

A rating system was developed for the 31 additive FRs identified. Initially, the evaluation of the FRs takes place on the basis of the excluded hazard codes (HS codes) in accordance with the CLP Regulation in all product groups here relevant for the Blue Angel award criteria (see Table 4). The relevant product groups are Low-Emission Panel-Shaped Materials (Construction and Furnishing Panels for Interior Construction) (DE-UZ 76 (2016)), Low-Emission Upholstered Furniture (DE-UZ 117 (2018)), Mattresses (DE-UZ 119 (2018)), Elastic Floor Coverings (DE-UZ 120 (2011)), Low-Emission Textile Floor Coverings (DE-UZ 128 (2016)), Leather (DE-UZ 148 (2015)), Textiles (DE-UZ 154 (2017)), and Shoes (DE-UZ 155 (2018))[4]. In addition, more individual HS codes may lead to substance exclusion in the before mentioned product groups.

The classification of a substance or mixture is regulated by the CLP Regulation (2021), which ensures a high level of protection for human health and for the environment and for the free circulation of substances, mixtures, and articles. This EU regulation harmonises the criteria for the classification of substances and mixtures along with the provisions for the labelling and packaging of hazardous substances and mixtures. It also governs the HS codes that must be used to identify a substance or mixture. To simplify the evaluation, all substances with HS codes that are excluded as per the Blue Angel award criteria are excluded from the evaluation here.

Table 4: HS codes that lead to an exclusion from the Blue Angel award[5] in accordance with the current award criteria.

HS code	Meaning
H300	Fatal if swallowed
H301	Toxic if swallowed
H310	Fatal in contact with skin
H311	Toxic in contact with skin
H330	Fatal if inhaled

[4] See also https://www.blauer-engel.de/en/certification/basic-award-criteria.

[5] DE-UZ 76 (2016): Low-Emission Panel-Shaped Materials (Construction and Furnishing Panels for Interior Construction); DE-UZ 117 (2018): Low-Emission Upholstered Furniture; DE-UZ 119 (2018): Mattresses; DE-UZ 120 (2011): Elastic Floor Coverings; DE-UZ 128 (2016): Low-Emission Textile Floor Coverings; DE-UZ 148 (2015): Leather; DE-UZ 154 (2017): Textiles; DE-UZ 155 (2018): Shoes (see also https://www.blauer-engel.de/en/certification/basic-award-criteria).

HS code	Meaning
H331	Toxic if inhaled
H340	May cause genetic defects
H350	May cause cancer
H350i	May cause cancer by inhalation
H360D	May damage the unborn child
H360Df	May damage the unborn child; suspected of damaging fertility
H360F	May damage fertility
H360FD	May damage fertility; may damage the unborn child
H360Fd	May damage fertility; suspected of damaging the unborn child
H370	Causes damage to organs
H372	Causes damage to organs through prolonged or repeated exposure

As a result, 14 FRs are identified that may be used in the products or product groups investigated. There are the following:

- Phosphoric acid, ammonium phosphate (CAS RN 10124-31-9)
- Polyphosphoric acids, ammonium polyphosphate (CAS RN 68333-79-9)
- 1,3,5-triazine-2,4,6-triamine phosphate, melamine phosphate (CAS RN 41583-09-9)
- 1,3,5-triazine-2,4,6-triamine monophosphate, melamine polyphosphate (CAS RN 218768-84-4)
- Ammonium sulphamate (CAS RN 13765-36-1)
- Sulphuric acid, compound with graphite, expandable graphite (CAS RN 12777-87-6)
- Graphite, acid-treated, expandable graphite (CAS RN 90387-90-9)
- Zirconium acetate (CAS RN 7585-20-8)
- 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol, tetrabromobisphenol A (TBBPA, CAS RN 79-94-7) in upholstered furniture
- 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene], decabromodiphenyl ethane (DBDPE, CAS RN 84852-53-9) in upholstered furniture and in carpet back coatings
- Tetraphenyl m-phenylene bis(phosphate), resorcinol bis(diphenyl phosphate) (RDP, CAS RN 57583-54-7) in upholstered furniture, mattresses, and textile floors
- 1,3,5-triazine-2,4,6(1H,3H,5H)-trione, compound with 1,3,5-triazine-2,4,6-triamine (1:1), melamine cyanurate (MC, CAS RN 37640-57-6) in floorings and textiles

- Aluminium hydroxide (ATH; CAS RN 21645-51-2) in textile floorings
- Ammonium bromide (CAS RN 12124-97-9) in textiles

The following assessment criteria were used for a further evaluation of these 14 FRs deserving further investigation:

- Persistence, so the amount of time that a chemical substance can exist in the environment before it is destroyed (transformed) by natural processes (US EPA 2011)
- Bioaccumulation, so the potential of a substance or certain substances of a mixture to accumulate in the environment and thus enter the food chain (Employer's Liability Insurance Association for the Construction Industry (BG BAU) 2021)
- Wash resistance of additive FRs: Classification as non-durable (i.e. FR is not wash-resistant), semi-durable (FR can withstand a limited number of washing cycles), and durable (FR withstands at least 50 washing cycles with boiling water)
- Combustion products: The thermal combustion of burning materials can result in toxic or irritant gases or vapours, e.g. carbon monoxide, hydrogen halides (hydrogen chloride, hydrogen fluoride, or hydrogen bromide), acrolein, sulphur dioxide, nitrogen oxides, and hydrogen cyanide (condensed: prussic acid).
- Costs of the necessary procurement of products with flame retardancy (e.g. per unit of weight, per unit of area)

These criteria were selected because they represent important aspects for the usage area of the products. For example, washing resistance, which should be considered only for materials that are intended to be washed, provides lifecycle and environmental impact information. The combustion products provide information on hazards in the event of a fire. Costs are important in order to enable the planning of budgets in procurement. The bioaccumulation and persistence criteria look at degradability and the accumulation of the substances in the environment. Both are to be avoided.

During the course of this study, we were able to demonstrate that the FRs TBBPA and DBDPE do not meet the requirements for bioaccumulation and persistence, and thus both must be excluded. The FRs melamine phosphate and melamine cyanurate do not meet the persistence requirements and are unsuitable for this reason. The remaining 10 FRs are not wash-resistant, and can therefore not be used in products that need to be cleaned, e.g. textiles and many products from the house and home textiles group and mattress covers. This does not apply to upholstery with a fixed cover: This does not need to be wash-resistant and therefore these flame retardants could be used as long as legal prerequisites are met. On this basis, if other solutions are not feasible, these 10 flame retardants are to be recommended to purchasers for products that do not need to be washed. Possible usage areas include shoes, furniture, floorings, and house and home textiles that do not need to be washed.

The assessment criteria "Combustion products" and "Costs" could not be used in a meaningful manner. For the assessment criteria "Combustion products", this is because it is impossible to make a general statement for any one FR; instead, the products are always dependent on the textile that requires fire protection. For the criteria "Costs", we attempted to investigate various costs but it became clear that without extremely specific references to a concrete (potential) contract item, a cost comparison is ineffective, since the variation in costs is so high that it is not possible to derive any recommendation.

In the future, further FRs might be added if they meet the criteria developed in this study.

Purchasers are recommended to first ask themselves whether fire protection is at all necessary for the products to be acquired. Then, they should check whether fire protection can be realized via inherent flame retardancy or via alternative flame retardancy. Finally, the use of FRs should be checked. Here, the 10 FRs listed here should be selected if required (see Table 5).

Table 5: Commonly used additive FRs for the five investigated product groups.

FR group	FR	Used in product group				
		PPE	House and home textiles	Furniture	Mattresses	Floorings
Inorganic phosphorous-based	Ammonium polyphosphate (APP)		x	x	x	x
	Ammonium phosphate			x		
Organophosphorous	Resorcinol bis(diphenyl phosphate) (RDP)		x	x	x	x
Nitrogenous	Melamine polyphosphate (MPP)		x	x	x	x
Other organic	Ammonium bromide		x	x		
	Aluminium hydroxide (ATH)		x	x	x	x
	Ammonium sulphamate		x	x	x	x
	Expandable graphite[6]		x	x	x	x
Other	Zirconium acetate					x

[6] Expandable graphite with CAS RNs 12777-87-6 and 90387-90-9.

Zusammenfassung

Bei der Ausstattung von Innenräumen in öffentlichen Gebäuden und der Anschaffung von persönlicher Schutzausrüstung (PSA) fehlen dem Beschaffer oder der Beschafferin häufig aktuelle Informationen über die gesetzlichen Anforderungen an den Brandschutz der einzelnen Produkte. Während es für Baustoffe und Bauteile klare Vorgaben in den jeweiligen Landesbauordnungen gibt, sind die Regelungen hinsichtlich der Innenausstattung weniger eindeutig. Darüber hinaus sind eventuell den Beschaffer*innen die Möglichkeiten zur Erreichung des Brandschutzes nicht bewusst und zudem nicht, welche umweltfreundlicheren Alternativen möglich sind.

Die Ziele dieses Forschungsvorhabens umfassen daher insbesondere die Aufarbeitung der gesetzlichen Anforderungen an den Brandschutz für verschiedene für die öffentliche Beschaffung relevante Produkte und die Darstellung der Möglichkeiten, diese Brandschutzanforderungen zu erfüllen. Ein weiteres Ziel besteht darin, Beschaffer*innen umweltfreundliche Wege zur Erreichung eines Flammschutzes vorzuschlagen, damit diese in Ihrer Beschaffungspraxis, wenn möglich, eine umweltfreundliche Alternative im Rahmen des Ausschreibungsprozesses einfordern.

Im vorliegenden Bericht werden daher die gesetzlichen Grundlagen sowie Empfehlungen zu den Brandschutzanforderungen in verschiedenen öffentlichen Bereichen recherchiert und die normierten Prüfverfahren für das Brandverhalten der untersuchten Produkte dargestellt. Zu den Möglichkeiten zur Erfüllung der Brandschutzanforderungen zählen der Einsatz von additivem, inhärentem oder alternativem Flammschutz, der anhand von Beispielen produktgruppenspezifisch beschrieben wird. Neben umfangreichen Literaturrecherchen wurden verschiedene Fachexpert*innen konsultiert sowie die Zwischenstände in Form von Fachgesprächen vorgestellt und diskutiert.

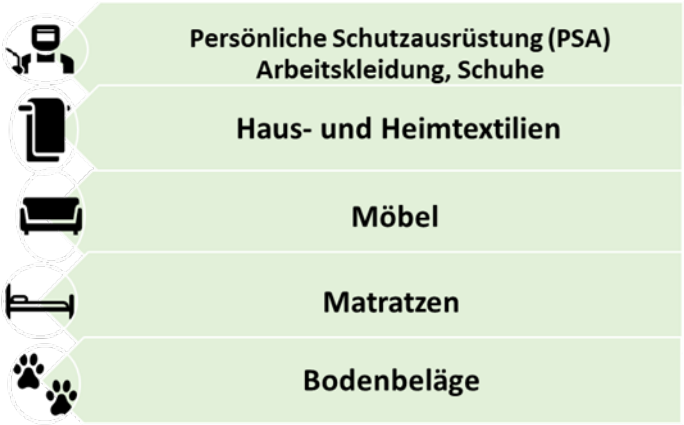
Für additive Flammschutzmittel (FSM) wurde außerdem ein Bewertungssystem entwickelt. Dieses basiert zum einen auf den ausgeschlossenen Gefahrenhinweisen (H-Sätzen) bei den Vergabekriterien des Blauen Engel. Zum anderen werden die Kriterien Persistenz, Bioakkumulation, Waschbeständigkeit, Brandfolgeprodukte und Kosten herangezogen, um die verbleibenden FSM weiter zu bewerten.

Brandschutz im öffentlichen Raum im Allgemeinen und für spezifische öffentliche Bereiche

Der Begriff **Brandschutz** umfasst nach dem normativen Brandschutzvokabular (DIN EN ISO 13943) Methoden, die der Eindämmung oder Verhinderung der Ausbreitung von Feuer, Wärme oder Rauch dienen. Hierzu gehören der aktive Brandschutz, d. h. die Erkennung und/oder Bekämpfung des Feuers, sowie der passive Brandschutz, der konstruktive Eigenschaften und/oder die Verwendung angemessener Materialien umfasst. Als **FSM** werden Substanzen bezeichnet, die Materialien zugegeben oder mit denen Materialien behandelt werden, um deren Entflammung zu verzögern oder bestenfalls zu verhindern und/oder die Ausbreitungsgeschwindigkeit der Flammen zu reduzieren (DIN EN ISO 13943 (2018)).
Das Baurecht nach der Musterbauordnung (MBO 2019) gilt für fest verbaute Baustoffe, Bauteile und Bauprodukte und hierauf beziehen sich die für das Bauwesen relevanten Brandschutzanforderungen. Bei den im Rahmen dieser Studie untersuchten Produkten zählen nur die **Bodenbeläge zu den Bauprodukten**. Bei den **Haus- und Heimtextilien** sowie **Möbeln** handelt es sich dagegen um **Ausstattungs- und Einrichtungsgegenstände**, die vornehmlich nicht unter das Baurecht fallen.
Die Anforderungen an den **Brandschutz in Gebäuden** sind in Deutschland durch die MBO (2019) geregelt und in den jeweiligen Landesbauordnungen umgesetzt. Zu den weiteren

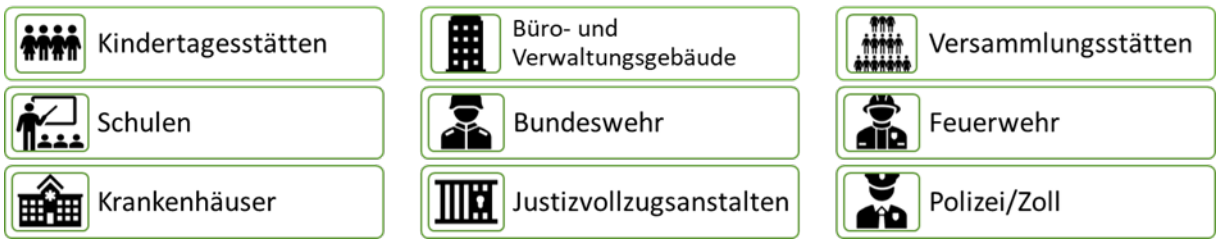
Rechtsvorschriften gehören z. B. die Feuerwehr-/Brandschutzgesetze der einzelnen Bundesländer. Die örtliche Feuerwehr und Baubehörde sowie Fachplaner*innen und weitere Brand- und Arbeitsschutzfachleute sind Ansprechpartner, wenn es um den Brandschutz geht. Bezogen auf Gebäude umfasst der Begriff Brandschutz alle Maßnahmen, die der Entstehung und Ausbreitung eines Brandes vorbeugen oder diesen verhüten. Hierbei wird zwischen baulichem, technischem und organisatorischem Brandschutz unterschieden. Zum abwehrenden Brandschutz gehört die Rettung von Menschen und Tieren sowie wirksame Löscharbeiten. Weitere Maßnahmen werden, sofern erforderlich, in Brandschutzkonzepten, Brandschutzordnungen, Brandschutzplänen sowie Feuerwehrplänen definiert.
Die Brandschutzanforderungen der einzelnen Gebäude sind von der Gebäudeklasse abhängig, die nach § 2 Absatz 3 MBO 2019 in fünf Klassen eingestuft werden.
Besonders vor dem Hintergrund der Menschen- und Tierrettung erhöhen sich die Anforderungen an den Brandschutz mit steigender Gebäudeklasse. Die Gebäude, auf die in diesem Bericht näher eingegangen wird, gehören nach MBO (2019) hauptsächlich zur Kategorie der Sonderbauten, die als Anlagen und Räume besonderer Art oder Nutzung beschrieben sind.
Die im Rahmen dieses Forschungsvorhabens durchgeführte Recherche zu den Brandschutzanforderungen konzentriert sich auf fünf Produktgruppen (siehe Abbildung 1) in neun verschiedenen öffentlichen Bereichen (siehe Abbildung 2).

Abbildung 1: Produktgruppen für die Recherche der Brandschutzanforderungen.



Quelle: eigene Darstellung, Fraunhofer WKI.

Abbildung 2: Öffentliche Bereiche für die Recherche der Brandschutzanforderungen.



Quelle: eigene Darstellung, Fraunhofer WKI.

Für alle neun öffentlichen Bereiche wurden die gesetzlichen Grundlagen und Empfehlungen zu den Brandschutzanforderungen dieser fünf Produktgruppen analysiert. Für die Bereiche Feuerwehr sowie Polizei und Zoll waren die Brandschutzanforderungen an die Persönliche

Schutzausrüstung (PSA), die Arbeitskleidung und Schuhe von großem Interesse und wurden daher noch zusätzlich recherchiert. Zum Vergleich wurden außerdem die Anforderungen an den baulichen Brandschutz der verschiedenen Bereiche beschrieben.

Anforderungen an den baulichen Brandschutz der einzelnen Bereiche

Kindertagesstätten zählen nach MBO und den jeweiligen Landesbauordnungen zu den ungeregelten Sonderbauten, bei denen die Anforderungen durch ein individuelles Brandschutzkonzept festgelegt werden. **Schulen** gehören nach MBO zu den Sonderbauten; zu den baurechtlichen Vorschriften für Schulen zählen außerdem die Landesbauordnungen, die Muster-Richtlinie über bauaufsichtliche Anforderungen an Schulen (Muster-Schulbaurichtlinie – MSchulbauR) sowie im Saarland die Richtlinie über Brandschutz in bestehenden Schulen.
Je nach Bundesland bilden verschiedene Vorschriften und Richtlinien den Rahmen für den baulichen Brandschutz in **Krankenhäusern**, wobei die Vorgaben zurzeit keinen einheitlichen Stand haben. Nach der MBO gelten Krankenhäuser aufgrund ihrer üblichen Gebäudehöhe sowie Anzahl und Größe der Nutzungseinheiten in der Regel als Sonderbauten (MBO 2019 § 2 Abs. 4 Nr. 9, 10). Die Bundesländer Brandenburg, Mecklenburg-Vorpommern, Saarland, Schleswig-Holstein und Berlin haben Schriften in Bezug auf den Bau und Betrieb von Krankenhäusern herausgegeben.
Für **Büro- und Verwaltungsgebäude** sind die Anforderungen an den baulichen Brandschutz von der Gebäudegröße abhängig und entsprechend in der MBO verzeichnet.
Versammlungsstätten sind nach MBO (2019) als geregelte Sonderbauten eingestuft. Die Anforderungen an deren baulichen Brandschutz sind im Speziellen durch die Muster-Versammlungsstättenverordnung definiert (MVStättVO 2005 §1 Abs. 1).
Die Anforderungen an den baulichen Brandschutz einer **JVA** werden durch die einzelnen Bundesländer im Rahmen der Landesbauordnungen dargelegt. Auf Grund der fehlenden Sonderbauvorschriften ist die JVA nach MBO als nicht geregelter Sonderbau definiert. Dadurch erfolgt eine schutzzielorientierte Betrachtung des Brandschutzes der Anlage in einem Brandschutzkonzept.

Brandschutzanforderungen an die Produktgruppen in den betrachteten öffentlichen Bereichen

Für die untersuchten Produktgruppen (Abbildung 1) bestehen unterschiedliche Anforderungen an den Brandschutz; diese sind abhängig von den jeweiligen Bereichen, in denen sie verwendet werden (Abbildung 2).
Für **PSA**, **Arbeitskleidung** und **Schuhe** in Kindertagesstätten und Schulen gibt es, abgesehen von Laborkitteln und Handschuhen für den naturwissenschaftlichen Unterricht, keine besonderen Anforderungen an den Brandschutz. Zu PSA im Krankenhaus hat die Gesetzliche Unfallversicherung (GUV) ein Regelwerk zusammengestellt, wobei nur mit der inzwischen zurückgezogenen DIN EN 533 auf den Brandschutz verwiesen wird. Eine große Rolle spielen dagegen die Brandschutzeigenschaften der Kleidung für die Bereitschaftspolizei, einige Bereiche der Bundeswehr, insbesondere der Luftwaffe und der Marine, sowie für die Feuerwehr. Die Mindestanforderungen an den Brandschutz von Einsatzkleidung der Feuerwehr sind über die Unfallverhütungsvorschriften geregelt und in zahlreichen Normen festgelegt.
Für **Möbel** sowie **Haus- und Heimtextilien** außerhalb der (notwendigen) Flucht- und Rettungswege in Kitas, Schulen, Büro- und Verwaltungsgebäuden sowie Krankenhäusern konnten keine gesetzlichen Anforderungen an den Brandschutz ausfindig gemacht werden. Flucht- und Rettungswege sind entsprechend der MBO von Brandlasten frei zu halten. In individuellen Brandschutzkonzepten, zum Beispiel für Krankenhäuser oder Verwaltungsgebäude, können höhere Anforderungen an die Ausstattung der Gebäude gestellt werden. Die gesetzlichen Regelungen für JVA sind Ländersache. Es besteht nur sehr begrenzter Zugang zu Informationen,

welche die Anforderungen an den Brandschutz betreffen. In dieser Studie wurde daher nur die Sachlage in Bayern betrachtet. Danach müssen in bayerischen JVAs schwerentflammbare Materialien für Möbel, Haus- und Heimtextilien in den Zellen für die Inhaftierten eingesetzt werden.
In Deutschland bestehen keine gesetzlichen Brandschutzanforderungen an **Matratzen** für Krankenhäuser und Kitas. In bayerischen JVAs sind für Matratzen schwerentflammbare Materialien einzusetzen.
Die Brandschutzanforderungen an die Ausstattung, Requisiten und Ausschmückungen von Versammlungsstätten sind in der Muster-Versammlungsstättenverordnung umfassend dargestellt. Ausstattung und Ausschmückungen müssen mindestens schwerentflammbar sein, dagegen besteht an Requisiten nur die Anforderung, dass sie normalentflammbar sein müssen.

Bodenbeläge gelten als Bauprodukte und müssen der Baustoffklasse normalentflammbar nach DIN 4102-1 bzw. DIN EN 13501-1 entsprechen. Nach der MBO müssen Bodenbeläge in notwendigen Treppenräumen etc. aus mindestens schwerentflammbaren Baustoffen bestehen. Einige Landesverordnungen erweitern die Schwerentflammbarkeit der Bodenbeläge in den untersuchten Bereichen auch auf notwendige Flure. In Büro- und Verwaltungsgebäuden richten sich die Brandschutzanforderungen an die Bodenbeläge auch nach der Gebäudeklasse. Hohe Anforderungen an Bodenbeläge stellt die Muster-Versammlungsstättenverordnung; hier wird für notwendige Treppenräume etc. gefordert, dass die Bodenbeläge nichtbrennbar sind und in notwendigen Fluren etc. müssen sie mindestens schwerentflammbar sein.
Letztendlich zeigt die umfassende Recherche, dass bezüglich der Brandschutzanforderungen an die untersuchten Produktgruppen weitaus weniger gesetzliche Regelungen vorliegen, als zu Beginn der Recherche vermutet wurde.

Prüfverfahren für das Brandverhalten von Produkten

Das **Brandverhalten** bezeichnet die Reaktion eines Probekörpers, wenn dieser bei einer Brandprüfung unter festgelegten Bedingungen Feuer ausgesetzt ist (DIN EN ISO 13943). Zum Brandverhalten der in Abbildung 1 aufgeführten Produkte bzw. Produktgruppen gelten die nachstehenden relevanten Prüfverfahren.

- Polsterverbunde (bei Möbeln)
  Das Brandverhalten von Polsterverbunden wird nach DIN 66084 (Papierkissentest) geprüft und bewertet. Die Klasse P-a stellt die höchsten Anforderungen an den Brandschutz. Zu den relevanten Normen zählen neben der DIN 66084 die DIN 50050-2 (Großer Brennkasten). Die Klasse P-b wird über die DIN EN 1021-1 geprüft und nach DIN EN 1021-2 bewertet, die Bewertung der Klasse P-c erfolgt nach DIN EN 1021-1.

- Matratzen
  Die Entzündbarkeit von Matratzen, gepolsterten Bettböden oder Matratzenauflagen kann mit dem Prüfverfahren nach DIN EN 597-1 beurteilt werden. Als Zündquelle dient eine glimmende Zigarette; nach DIN EN 597-2 wird der Prüfkörper mit einer einem Streichholz vergleichbaren Gasflamme in Kontakt gebracht.

- Haus- und Heimtextilien
  Das Brennverhalten von textilen Flächengebilden wird zum einen mit DIN EN ISO 6941 durch die Messung der Flammenausbreitungseigenschaften vertikal angeordneter Proben geprüft. Zum anderen gibt DIN EN ISO 6940 das Verfahren für die Bestimmung der Entzündbarkeit vertikal angeordneter Proben an.
  Die Prüfung des Brennverhaltens **textiler Vorhänge** und **Gardinen** erfolgt nach DIN EN ISO

6940, wobei das Verfahren zur Bestimmung der Entzündbarkeit vertikal angeordneter Textilproben mit kleiner Flamme in DIN EN 1101 beschrieben ist.
Das Verfahren zur Bestimmung der Flammenausbreitungseigenschaften von Textilien für Vorhänge und Gardinen als vertikal angeordnete Proben ist in DIN EN 1102 festgelegt, die Prüfung erfolgt nach DIN EN ISO 6941.
Das Vorgehen zur Messung der Flammenausbreitungseigenschaften vertikal angeordneter textiler Messproben mit großer Zündquelle ist in DIN EN 13772 beschrieben. Bei der Prüfung werden ein elektrischer Strahler sowie eine in DIN EN ISO 6941 definierte kleine Flamme verwendet.
In DIN EN 13773 ist die Klasseneinteilung von Textilien für Vorhänge, Gardinen und Ähnliches, wie Jalousien und textile Wandbehänge, bei denen eine Klassifizierung erforderlich ist, dargestellt.
Die Entzündbarkeit von **Bettzeug** durch eine glimmende Zigarette kann nach DIN EN ISO 12952-1 geprüft werden; die Prüfung mit kleiner offener Flamme ist in DIN EN ISO 12952-2 beschrieben.

- In Deutschland wird auch der **Britische Standard BS 5852** (2006) zur Prüfung und Klassifizierung der Entflammbarkeit von Möbeln, Haus- und Heimtextilien sowie Matratzen herangezogen.
- Die Prüfung von brennbaren Werkstoffen (z. B. Kunststoffe, Holz, Papier) durch das Beflammen mit einem Brenner ist in DIN 53438 in den Teilen 1 bis 3 geregelt. Für die Prüfungen wird ein Brennkasten nach DIN 50050 verwendet.

► Persönliche Schutzausrüstung (PSA)[7]
An spezielle Kleidung zum Schutz gegen Hitze und Flammen werden besondere Anforderungen gestellt. Die Mindestanforderungen bei kurzem Kontakt mit einer kleinen Zündflamme sind in DIN EN ISO 14116 beschrieben. Schutzkleidung, die dieser Norm entspricht, muss bei einer Prüfung nach ISO 15025 einen Index der begrenzten Flammenausbreitung von 1, 2 oder 3 erzielen. Schutzkleidung mit Index 3 bietet hiernach den größten Schutz.
DIN EN ISO 11612 beschreibt die Mindestleistungsanforderungen an die Eigenschaften von Schutzkleidung mit einem umfangreichen Einsatzbereich für Endanwendungen, bei denen Kleidung mit begrenzter Flammenausbreitung erforderlich ist und der Träger Strahlungswärme, konvektiver oder Kontaktwärme oder Spritzern geschmolzenen Metalls ausgesetzt ist. Es sind für zahlreiche der in der Norm aufgeführten Gefährdungen jeweils drei Leistungsstufen festgelegt, eine vierte Leistungsstufe betrifft Hochleistungsmaterialien für den Schutz gegen intensive Strahlungswärme.

► Feuerwehrschutzkleidung
Die Mindestanforderungen an die Einsatzkleidung der Feuerwehr werden in den folgenden Normen beschrieben:

- Feuerwehrjacke und Feuerwehrhose nach DIN EN 469
- Feuerwehrschutzhelm nach DIN EN 443
- Feuerschutzhaube nach DIN EN 13911

[7] Persönliche Schutzausrüstung: Ausrüstungen, die getragen werden, um sich gegen Gefährdungen der Sicherheit und Gesundheit am Arbeitsplatz zu schützen (z. B. Schutzkleidung, Atemschutz, Handschutz, Schnitt- und Stechschutz, Augen- und Gesichtsschutz, Kopfschutz, Gehörschutz) (nach DGUV 2006).

- Feuerwehrschuhwerk nach DIN EN 15090
- Feuerwehr-Schutzhandschuhe nach DIN EN 659

► Bodenbeläge
Für die Baustoffklassifizierung von Bodenbelägen definiert DIN EN 13501-1 sieben Klassen, die in Tabelle 1 zusammengefasst sind. Die Kriterien zum Erreichen der jeweiligen Baustoffklasse sind ebenfalls in DIN EN 13501-1 angegeben.

Tabelle 1: Übersicht der Baustoffklassen nach DIN EN 13501-1 für Bodenbeläge.

Baustoffklasse	Benennung	Nachweisverfahren	Prüfnorm
$A1_{fl}$	nichtbrennbare Baustoffe	Nichtbrennbarkeitsprüfung Verbrennungswärme	DIN EN ISO 1182 DIN EN ISO 1716
$A2_{fl}$	nichtbrennbare Baustoffe	Nichtbrennbarkeitsprüfung Verbrennungswärme Beanspruchung Wärmestrahler	DIN EN ISO 1182 DIN EN ISO 1716 DIN EN ISO 9239-1
B_{fl}	schwerentflammbare Baustoffe	Beanspruchung Wärmestrahler Einzelflammentest	DIN EN ISO 9239-1 DIN EN ISO 11925-2
C_{fl}	schwerentflammbare Baustoffe	Beanspruchung Wärmestrahler Einzelflammentest	DIN EN ISO 9239-1 DIN EN ISO 11925-2
D_{fl}	normalentflammbare Baustoffe	Beanspruchung Wärmestrahler Einzelflammentest	DIN EN ISO 9239-1 DIN EN ISO 11925-2
E_{fl}	normalentflammbare Baustoffe	Einzelflammentest	DIN EN ISO 11925-2
F_{fl}	leichtentflammbare Baustoffe	Keines	

Möglichkeiten zur Erfüllung der Brandschutzanforderungen

Um die Anforderungen an den Brandschutz zu erfüllen, kann es notwendig sein, die eingesetzten Materialien mit FSM zu ertüchtigen. Um die Entflammbarkeit von Produkten zu verringern, können drei Vorgehensweisen zum Einsatz kommen: additiver Flammschutz, inhärenter Flammschutz und alternativer Flammschutz (d. h. Einsatz von Materialien, die bereits schwer entflammbar oder nicht brennbar sind).

► **Additiver Flammschutz:** FSM werden als Zusatzstoffe in brennbare Materialien eingearbeitet (mit dem Material gemischt) oder als FSM-Beschichtung (Coating) von außen auf das Material aufgebracht. Zu den hier betrachteten FSM gehören die halogenierten, anorganisch phosphorbasierten, organisch phosphorbasierten, stickstoffhaltigen, sonstigen anorganischen und sonstigen FSM. Diese werden in den hier betrachteten fünf Produkten (Abbildung 1) unterschiedlich eingesetzt. Flammschutzlösungen, die nach REACH-VO (Nr. 1907/2006) oder EU-POP-VO ((EU) 2019/1021) verboten sind, wurden nicht betrachtet. Insgesamt wurden 31 FSM identifiziert, die bei den untersuchten Produktgruppen zum Einsatz kommen.

Bei den **Arbeitsschutztextilien** sind gebräuchliche additive FSM die der Gruppe der organischen phosphorbasierten FSM. Bei den **Haus- und Heimtextilien** sowie den **Teppichen** kommen eine Vielzahl an FSM aus allen sechs Kategorien zum Einsatz. Ähnlich verhält es sich bei den **textilen Polstermöbeln**, den **Matratzen- und Polsterschäumen** (hier sind FSM aus fünf Kategorien gebräuchlich). Bei den **Polstermöbeln aus Leder**, den **Matratzenstoffen** und den **Teppichfasern** kommen abgesehen von den halogenierten FSM und den „Sonstigen" alle weiteren vier Kategorien zur Anwendung. Bei **Holz- und Holzwerkstoffen** sind FSM aus den Kategorien anorganische phosphorbasierte FSM, stickstoffhaltige FSM und sonstige anorganische FSM typisch.

Nachstehende Tabelle 2 zeigt die sechs Gruppen an FSM, die einzelnen FSM sowie welches FSM für welche Produktgruppe von Relevanz ist.

Tabelle 2: Gebräuchliche additive FSM für die fünf adressierten Produktgruppen.

FSM Gruppe	FSM	Verwendet in Produktgruppe				
		PSA	Haus- und Heimtextilien	Möbel	Matratzen	Bodenbeläge
Halogeniert organisch	Decabromdiphenylethan (DBDPE)		x	x		x
	Tetrabrombisphenol A (TBBPA)			x		
	Tris(2-chloro-1-methylethyl)-phosphat (TCPP)			x	x	
	Tris(1,3-dichlorisopropyl)-phosphat (TDCPP)			x	x	
anorganische phosphorbasiert	Ammoniumpolyphosphat (APP)		x	x	x	x
	Ammoniumphosphat			x		
	Diammoniumhydrogenphosphat		x	x		x
	Roter Phosphor		x	x	x	x
organische phosphorbasiert	Methylphosphonsäure		x	x	x	x
	Mischung cyclischer Phosphonate		x	x	x	x
	Resorcinolbisdiphenylphosphat (RDP)		x	x	x	x
	N-Hydroxymethyl-3-dimethylphos-phonpropionamid (DMPPA)	x	x	x	x	x
	Tetrakis(hydroxymethyl)-phosphoniumchlorid (THPC)	x	x	x	x	
	Trikresylphosphat (TCP)		x	x		x
	Triethylphosphat (TEP)				x	x

FSM Gruppe	FSM	Verwendet in Produktgruppe				
		PSA	Haus- und Heimtextilien	Möbel	Matratzen	Bodenbeläge
stickstoffhaltig	Melamin		x	x		x
	Melamincyanurat (MC)		x	x	x	x
	Melaminphosphat (MP)		x	x	x	x
	Melaminpolyphosphat (MPP)			x	x	x
	Thioharnstoff		x			x
sonstige anorganische	Ammoniumbromid		x	x		
	Aluminiumhydroxid (ATH)		x	x	x	x
	Ammoniumsulfat		x	x	x	
	Ammoniumsulfamat		x	x	x	x
	Antimontrioxid (ATO)		x	x		x
	Dikaliumhexafluorotitanat		x			x
	Dinatriumtetraborat Decahydrat (Borax)			x		
	Expandierbarer Graphit (Blähgraphit)		x	x	x	x
	Kaliumhexafluorzirkonat			x		
	Magnesiumhydroxid (MDH)			x	x	x
sonstige	Zirkoniumacetat					x

- **Inhärenter Flammschutz**: Stoffe, in diesem Fall Fasern, erhalten durch chemische Reaktion mit einem FSM oder durch eine inhärent flammhemmende Polymerstruktur eine permanent flammhemmende Eigenschaft, wodurch das daraus hergestellte Material flammwidrig wird. Folgende Materialien werden näher betrachtet und die mögliche Verwendung in den verschiedenen Produktgruppen aufgezeigt: Wolle, Zellulose und Viskose, Polyester, Polyamide/Aramide, Polymelaminfasern, Polyetherimide, sonstige Faser- und Materialvarianten. Es zeigt sich, dass insbesondere im Bereich der **Arbeitsschutzkleidung** fast alle dieser recherchierten inhärenten Fasern zum Einsatz kommen. Nahezu jede zweite inhärente Faser kommt auch bei den **Haus- und Heimtextilien**, den **Polstermöbeln aus Stoff** und den **Matratzenstoffen** in Anwendung. Bei den **Schäumen für die Matratzen** und für die **Polstermöbel** sowie bei den **Teppichen** kommen hingegen nur selten inhärent flammgeschützte Materialien zum Einsatz. Nachstehende Tabelle 3 zeigt die produktgruppenspezifischen inhärent flammgeschützten Materialien.

Tabelle 3: Mögliche Verwendung inhärent flammgeschützter Materialien nach Produktgruppen.

Material	Produkte oder Produktnamen	Produktgruppe					
		Arbeitsschutzkleidung	Haus- und Heimtextilien	Polstermöbel (Stoff)	Matratzenstoffe	Schäume (Matratzen und Polster)	Teppiche
Wolle	-		x	x	x		x
Zellulose und Viskose	Visil®				x[8]		
	Lenzing™FR	x		x	x	x	
Polyester	Trevira CS		x	x	x		
	Zeroxy™	x	x	x			
Polyamide/Aramide	Nomex®	x					
	Twaron®	x					
	Kevlar®	x					
	Kermel®	x					
Polymelaminfasern	Basofil®	x		x	x		
Polyetherimide	Ultem™ 9011	x	x	x	x		
sonstige	Modacryl-Fasern (MAC)	x	x				x
	PyroTex®	x		x[9]			
	Diofort®		x	x			
	Proban®	x	x	x	x		
	Melaminharzschaum					x	

- **Alternativer Flammschutz:** Hierzu gehören Materialien und Produkte, deren Flammschutz auch ohne den Einsatz von FSM gewährleistet ist, indem diese beispielsweise nichtbrennbar sind, z. B. Gips- und Betonwerkstoffe sowie durch Verwendung von Glas- oder Basaltfasern. Die mögliche Anwendung des alternativen Flammschutzes wurde für die Produktgruppen Arbeitsschutztextilien, Haus- und Heimtextilien, Möbel, Matratzen und Bodenbeläge betrachtet. So können für die Erzeugung feuerfester Gewebe und im Bereich der **Arbeitsschutztextilien** Basaltfasern zum Einsatz kommen. Nichtbrennbare Glasfilamente,

[8] z. B. als Ummantelung von Matratzen (siehe z. B. https://patents.google.com/patent/US7484256B2/en).

[9] Verwendung für Sitze z. B. in Bahn, Flugzeug, Kino, Theater.

Glasgewebe und Basaltfasern werden für die Herstellung von **Haus- und Heimtextilien** eingesetzt. Vielfältige Möglichkeiten bzgl. des alternativen Flammschutzes ist auch im Bereich der **Möbel** zu finden: so gibt es beispielsweise Betonmöbel, Gipsfaserplatten (als Trägermaterial) oder auch Untergestelle bzw. Unterkonstruktionen aus nicht brennbaren Metallen. Bei den **Polstermöbeln** lassen sich die schon bei den Haus- und Heimtextilien erwähnten Glasfasern ergänzen. Bei **Laminat** könnte ein nichtbrennbares Material, z. B. eine Glasfasermatte, eingesetzt werden.

Die Auswahl des geeigneten Verfahrens ist immer abhängig vom Einsatzbereich der Materialien und den verfahrensabhängigen Kosten. Beim additiven Flammschutz besteht in der Regel die Gefahr, dass die FSM während der Reinigungsvorgänge ausgewaschen werden. Diese Gefahr besteht bei der Arbeitsschutzkleidung und bei einigen Haus- und Heimtextilien. Daher werden hier in der Regel inhärente FSM oder alternative Flammschutzlösungen eingesetzt. Zusammenfassend ist zu erwähnen, dass es keine Lösung gibt, die bei allen Materialien angewendet werden kann, sondern jede Flammschutzlösung für einen speziellen Anwendungsbereich entwickelt wurde.

Bewertung von additiven Flammschutzmitteln

Für die Bewertung der identifizierten 31 additiven FSM wird ein Bewertungssystem entwickelt. Die Bewertung der FSM erfolgt zunächst anhand der ausgeschlossenen Gefahrenhinweise (H-Sätzen) nach CLP-Verordnung in allen hier relevanten Produktgruppen des Blauen Engel (siehe Tabelle 4). Die relevanten Produktgruppen sind Emissionsarme plattenförmige Werkstoffe (Bau- und Möbelplatten) für den Innenausbau (DE-UZ 76 (2016)), Emissionsarme Polstermöbel (DE-UZ 117 (2018)), Matratzen (DE-UZ 119 (2018)), Elastische Bodenbeläge (DE-UZ 120 (2011)), Emissionsarme textile Bodenbeläge (DE-UZ 128 (2016)), Leder (DE-UZ 148 (2015)), Textilien (DE-UZ 154 (2017)) und Schuhe (DE-UZ 155 (2018))[10]. Darüber hinaus können in den vorgenannten Produktgruppen einzelne weitere H-Sätze zum Stoffausschluss führen.

Die Einstufung eines Stoffes oder eines Gemisches ist in der CLP-Verordnung (2021) geregelt, mit der ein hohes Schutzniveau für die menschliche Gesundheit und für die Umwelt sowie den freien Verkehr von Stoffen, Gemischen und Erzeugnissen gewährleistet wird. Mit dieser europäischen Verordnung erfolgt eine Harmonisierung der Kriterien zur Einstufung von Stoffen und Gemischen sowie der Vorschriften für die Kennzeichnung und Verpackung gefährlicher Stoffe und Gemische. Dort ist auch geregelt, mit welchen H-Sätzen ein Stoff oder Gemisch gekennzeichnet werden muss. Zur Vereinfachung der Bewertung werden alle Substanzen, die H-Sätze aufweisen, die in den hier relevanten Vergabekriterien des Blauen Engel unzulässig sind, von der Bewertung ausgeschlossen.

Tabelle 4: H-Sätze, die nach den relevanten Vergabekriterien[11] zum Ausschluss aus dem Blauen Engel führen.

H-Satz	Bedeutung
H300	Lebensgefahr bei Verschlucken
H301	Giftig bei Verschlucken
H310	Lebensgefahr bei Hautkontakt

[10] Siehe auch https://www.blauer-engel.de/de/fuer-unternehmen/vergabekriterien.

[11] DE-UZ 76 (2016): Emissionsarme plattenförmige Werkstoffe (Bau- und Möbelplatten) für den Innenausbau, DE-UZ 117 (2018): Emissionsarme Polstermöbel, DE-UZ 119 (2018): Matratzen, DE-UZ 120 (2011): Elastische Bodenbeläge, DE-UZ 128 (2016): Emissionsarme textile Bodenbeläge, DE-UZ 148 (2015): Leder, DE-UZ 154 (2017): Textilien, DE-UZ 155 (2018): Schuhe (siehe auch https://www.blauer-engel.de/de/fuer-unternehmen/vergabekriterien).

H-Satz	Bedeutung
H311	Giftig bei Hautkontakt
H330	Lebensgefahr bei Einatmen
H331	Giftig bei Einatmen
H340	Kann genetische Defekte verursachen
H350	Kann Krebs erzeugen
H350i	Kann bei Einatmen Krebs erzeugen
H360D	Kann das Kind im Mutterleib schädigen
H360Df	Kann das Kind im Mutterleib schädigen; Kann vermutlich die Fruchtbarkeit beeinträchtigen
H360F	Kann die Fruchtbarkeit beeinträchtigen
H360FD	Kann die Fruchtbarkeit beeinträchtigen. Kann das Kind im Mutterleib schädigen
H360Fd	Kann die Fruchtbarkeit beeinträchtigen. Kann vermutlich das Kind im Mutterleib schädigen
H370	Schädigt die Organe
H372	Schädigt die Organe bei längerer oder wiederholter Exposition

Dabei werden 14 FSM identifiziert, die in den untersuchten Produkten bzw. Produktgruppen eingesetzt werden dürfen. Hierbei handelt es sich um:

- Ammoniumphosphat (CAS-Nr.: 10124-31-9)
- Ammoniumpolyphosphat (CAS-Nr.: 68333-79-9)
- Melaminphosphat (Cas-Nr.: 41583-09-9)
- Melaminpolyphosphat (CAS-Nr.: 218768-84-4)
- Ammoniumsulfamat (CAS-Nr.: 13765-36-1)
- Expandierbarer Graphit (CAS-Nr.: 12777-87-6)
- Expandierbarer Graphit (CAS-Nr.: 90387-90-9)
- Zirkoniumacetat (CAS-Nr.: 7585-20-8)
- Tetrabrombisphenol A (TBBPA; CAS-Nr.: 79-94-7) in Polstermöbeln
- Decabromdiphenylethan (DBDPE; CAS-Nr.: 79-94-7) in Polstermöbeln und in der Teppichrückenbeschichtung
- Resorcinolbisdiphenylphosphat (RDP; CAS-Nr.: 57583-54-7) in Polstermöbeln, Matratzen und textilen Fußböden
- Melamincyanurat (MC; CAS-Nr.: 37640-57-6) in Fußböden und Textilien

- Aluminiumhydroxid (ATH; CAS-Nr.: 21645-51-2) in textilen Fußböden
- Ammoniumbromid (CAS-Nr.: 12124-97-9) in Textilien

Für eine weitere Bewertung dieser weiter zu untersuchenden 14 FSM wurden folgende Bewertungskriterien herangezogen:

- Persistenz, d. h. die Zeitspanne, die eine Chemikalie in der Umwelt existieren kann, bevor diese Substanz durch natürliche Prozesse zerstört (d. h. umgewandelt) wird (US EPA 2011).
- Bioakkumulation, d. h. das Potential eines Stoffs oder bestimmter Stoffe eines Gemischs, sich in der belebten Umwelt anzureichern und somit in der Nahrungskette aufzusteigen (BG BAU 2021).
- Waschbeständigkeit von additiven FSM: Einteilung in nicht-dauerhaft (d. h. FSM weist keine Waschbeständigkeit auf), semi-dauerhaft (d. h. FSM kann eine begrenzte Anzahl an Waschzyklen überstehen) und dauerhaft (FSM übersteht mindestens 50 Waschzyklen mit kochendem Wasser).
- Brandfolgeprodukte: infolge der thermischen Zersetzung der brennenden Materialien können giftige bzw. reizende Gase oder Dämpfe, wie z. B. Kohlenmonoxid, Halogenwasserstoffe (Chlor-, Flur- oder Bromwasserstoff), Acrolein, Schwefeldioxid, Stickoxide und Cyanwasserstoff (kondensiert: Blausäure) entstehen.
- Kosten zur notwendigen Beschaffung von Produkten mit Flammschutz (z. B. pro Gewichtseinheit, pro Flächeneinheit).

Diese Kriterien wurden ausgewählt, da sie wichtige Aspekte für den Einsatzbereich der Produkte darstellen. Mittels der Waschbeständigkeit, die nur für Materialien betrachtet werden soll, die auch gewaschen werden, werden beispielsweise Erkenntnisse über die Lebensdauer und die Umweltbelastung erhalten. Die Brandfolgeprodukte geben eine Auskunft zu den Gefahren im Brandfall. Die Kosten sind von Relevanz, um bestimmte Budgets bei der Beschaffung einzuplanen. Im Falle von Bioakkumulation und Persistenz werden die Aspekte der Abbaubarkeit sowie der Anreicherung der Substanzen in der Umwelt betrachtet. Beides ist zu vermeiden.

Im Rahmen dieser Arbeit konnte gezeigt werden, dass die FSM TBBPA und DBDPE die Anforderungen an die Bioakkumulation und die Persistenz nicht erfüllen und ebenfalls auszuschließen sind; die FSM Melaminphosphat und Melamincyanurat erfüllen nicht die Anforderungen an die Persistenz und sind aus diesem Grund nicht geeignet. Die verbleibenden 10 FSM sind nicht waschbeständig und können daher nicht in Produkten eingesetzt werden, die gereinigt werden müssen, so z. B. die Textilien, aber auch viele Produkte aus dem Bereich der Haus- und Heimtextilien und der Matratzenbezüge. Anders ist dies beispielsweise für die mit einem festen Bezug versehenen Polster: diese müssen nicht waschbeständig sein und könnten, sofern die rechtlichen Anforderungen an das Brandverhalten vorhanden sind, damit ausgerüstet werden. Basierend darauf sind, wenn nicht anders realisierbar, diese 10 FSM für Produkte, die nicht gewaschen werden müssen, Beschaffer*innen zu empfehlen. Mögliche Einsatzgebiete sind Schuhe, Möbel und Bodenbeläge sowie Haus- und Heimtextilien, die nicht gewaschen werden.

Die Bewertungskriterien Brandfolgeprodukte sowie die Kosten konnten nicht als aussagekräftige Bewertungskriterien herangezogen werden. Die Ursache beim Bewertungskriterium Brandfolgeprodukte liegt darin, dass diese nicht für ein FSM verallgemeinert werden können, sondern immer vom eigentlichen Textil, welches

brandschutztechnisch ertüchtigt werden muss, abhängig sind. Für das Kriterium Kosten wurde versucht, verschiedene Kosten zu recherchieren. Es wurde jedoch deutlich, dass ohne sehr spezifischen Bezug zum konkreten (potentiellen) Auftragsgegenstand ein Kostenvergleich nicht zielführend ist, da die Varianz der Kosten so hoch ist, dass keine Empfehlung daraus abgeleitet werden kann.

Weitere FSM können in der Zukunft dazukommen, sofern diese die im Rahmen dieser Arbeit entwickelten Kriterien erfüllen.

Für Beschaffer*innen ist zu empfehlen, zunächst zu hinterfragen, ob ein Brandschutz für die zu beschaffenden Produkte überhaupt notwendig ist. Dann ist zu prüfen, ob ein Brandschutz über inhärenten Flammschutz oder über einen alternativen Flammschutz zu realisieren ist. Zuletzt ist der Einsatz von FSM zu prüfen. Hierbei sollten, wenn erforderlich und notwendig, die 10 hier aufgeführten FSM ausgewählt werden (siehe Tabelle 5).

Tabelle 5: Gebräuchliche additive FSM für die fünf adressierten Produktgruppen

FSM Gruppe	FSM	Verwendet in Produktgruppe				
		PSA	Haus- und Heimtextilien	Möbel	Matratzen	Bodenbeläge
anorganische phosphorbasiert	Ammoniumpolyphosphat (APP)		x	x	x	x
	Ammoniumphosphat			x		
organische phosphorbasiert	Resorcinolbisdiphenylphosphat (RDP)		x	x	x	x
stickstoffhaltig	Melaminpolyphosphat (MPP)		x	x	x	x
sonstige anorganische	Ammoniumbromid		x	x		
	Aluminiumhydroxid (ATH)		x	x	x	x
	Ammoniumsulfamat		x	x	x	x
	Expandierbarer Graphit (Blähgraphit)[12]		x	x	x	x
sonstige	Zirkoniumacetat					x

[12] Expandierbarer Graphit mit den CAS-Nr.: 12777-87-6 und 90387-90-9

1 Introduction

When fitting out inside spaces in public buildings and procuring personal protective equipment (PPE)[13], various aspects must be considered. Purchasers are faced with the challenge of reconciling requirements relating to environmental protection, health, fire protection, and cost effectiveness. Some flame retardants (FRs) can have an adverse effect on health and the environment. Further, products with FRs are often more expensive. Alternative solutions are not necessarily known to all purchasers.
Moreover, time-consuming research is often required in order to determine the fire protection requirements that apply in a specific equipment scenario. Whereas there are clear specifications for building materials and building elements in the various regional building codes, the regulations for interior fittings are not so straightforward. Among other factors, the type of product and usage area determine whether - and the extent to which - the inflammability of products plays a role. For example, rescue routes such as hallways are subject to different fire protection requirements than office spaces where, in comparison with hallways, relatively few people will be present in the event of a fire. In addition, fire protection requirements differ between the federal states, since they are defined in the various regional building codes.

Thus, this research project first aims to present the legal fire safety requirements for various products relevant for public procurement. Second, it should suggest possibilities for meeting these fire protection requirements. A third goal is to propose environmentally friendly ways for purchasers to achieve fire protection so that they can, where possible and necessary, request an environmentally friendly alternative as part of the tender process during procurement. This gives purchasers more certainty and scope for action in their practical work.

In order to achieve these goals, we conducted extensive literature research, particularly with regard to a large number of regulations, directives, and DIN standards. Further, we consulted with various experts from the field of industry and science. The preliminary results were presented to and debated with experts in technical discussions.

For additive flame retardants (FRs), a rating system was also developed. On the one hand, this is based on the excluded HS codes in the Blue Angel award criteria. On the other hand, the criteria of persistence, bioaccumulation, wash resistance, combustion products, and costs were used to further assess the remaining FRs.

[13] Definition as per DGUV (2006):

Personal protective equipment: Equipment that is worn to protect against health and safety risks at the workplace (e.g. protective clothing, breathing protection, safety gloves, protection against piercing and cutting injuries, goggles and visors, helmets, hearing protectors).

Work clothing: Clothing that is worn at work but that does not have any special protection function (e.g. a lab coat to prevent soiling of the wearer's usual clothes).

2 General information on fire safety

According to DIN EN ISO 13943 (2018), the term **fire safety** refers to methods for the containment or prevention of the spread of fire, heat or smoke. These methods include both the detection and/or the control of the fire (active fire safety) as well as design features and/or the use of appropriate materials (passive fire safety).

DIN EN ISO 13943 (2018) defines a **fire** as an uncontrolled self-supporting combustion that has not been deliberately arranged. **Course of the fire** is described in the following four phases:

- Incipient fire
- Growth (-> flashover)
- Fully developed fire
- Decaying fire

In order for a fire to occur, combustible material must be present along with a sufficient quantity of oxygen and an external heat supply to initiate combustion (**ignition energy**). The ignition source ignites a combustible material, thus bringing about combustion (incipient fire). This creates heat that ignites more material, causing increased release of heat into the environment. The flammable gases that are produced mix with the ambient air to form a flammable air-gas mixture that can ignite abruptly (**flashover**) due to the sudden supply of oxygen, for example, resulting in the explosive propagation of flames along with rapidly rising temperatures. This fire, having fully developed as described, now begins to decay once an attempt is made to extinguish it or once a large part of the combustible material has been thermally decomposed (Novak 2001, Jeske 2012). The quantity of heat that could be released by the complete combustion of all of the combustible materials is called the **fire load** (DIN EN ISO 13943 (2018)). It increases with the entry of combustible materials or products into a room or building. Non-combustible materials and products do not increase the fire load of a room or building.

The ability of a material to burn with a flame under specified conditions is called **combustibility** (flammability). **Ignitability** is a measure of the ease with which a test specimen can be ignited under specified conditions. **Flame retardants** are substances added, or treatments applied, to a material in order to suppress or delay the appearance of a flame and/or reduce the flame spread rate (DIN EN ISO 13943 (2018)).
The fire safety requirements described in the report below relate mainly to work clothing, PPE, textiles, furniture, and mattresses whose components (e.g. synthetic fibres, foam) are referred to collectively as **material**.

Fire safety requirements that are relevant for construction relate to building materials, building elements, and construction products. DIN EN 13501-1 (2019) defines **building materials** as a single basic substance or uniformly dispersed mixture of substances (e.g. timber, concrete). The assessment of the fire behaviour of building materials takes place at a national level in accordance with DIN 4102-1 (1998) and at a European Union level in accordance with DIN EN 13501-1 (2019). A **building element** is a functional component of a building that, as per DIN EN ISO 10209 (2012) "*cannot be further dismantled without losing its basic properties*". Building elements and materials are to be considered **construction products** if they are intended for permanent installation in structural installations (MBO 2019).

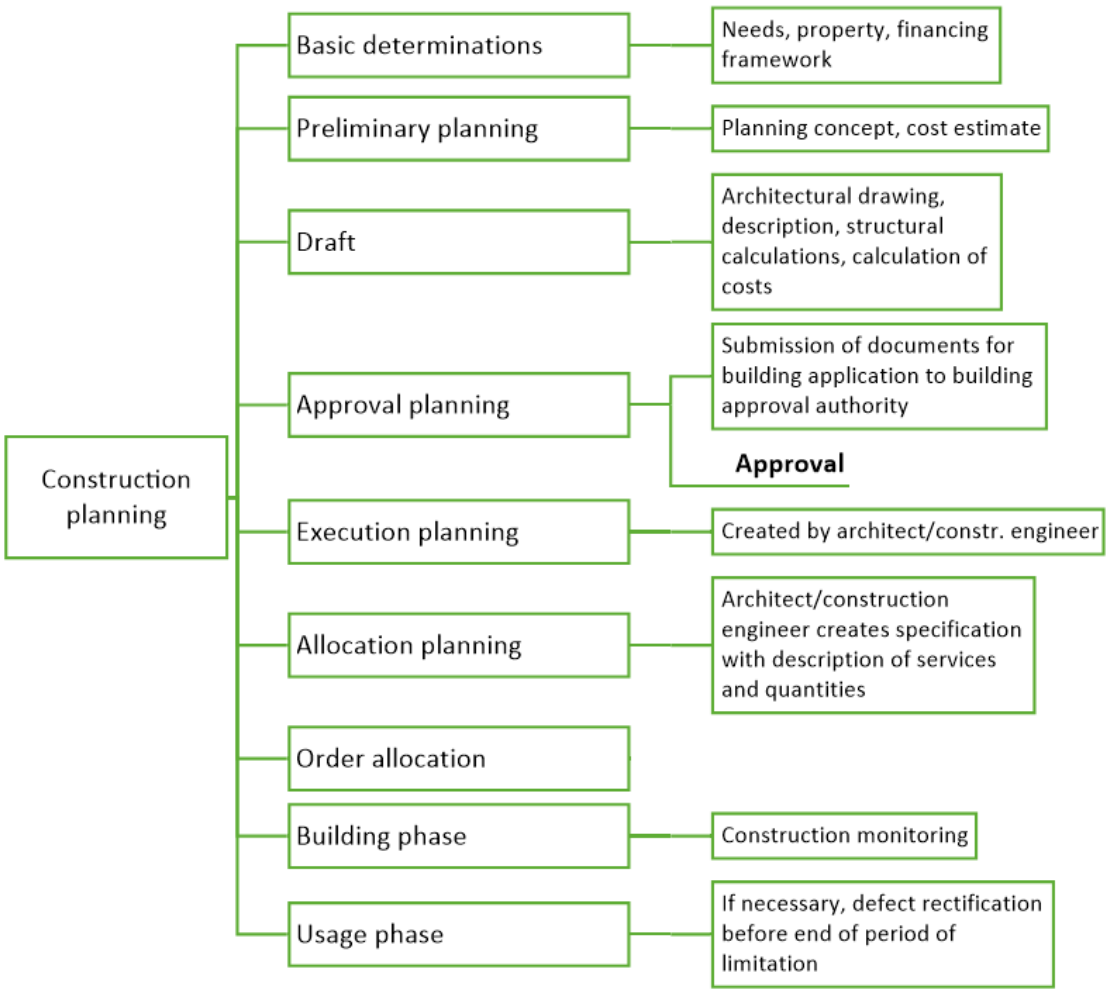
3 Fire safety in public spaces: Concepts and actors

Generally, when we hear about fire safety in public spaces, we think about the fire safety of buildings. In order to distinguish between the various areas and concepts, structural fire safety is depicted below. Building law in accordance with the German Standard Building Regulations (MBO 2019) applies only to permanently installed building materials, building elements, and construction products. Of the textile products under consideration, only textile floorings are included in the building materials as per the MBO. House and home textiles and furniture are interior fittings and furnishings, which are not covered by building law.

3.1 General information on building design

When constructing a building, the builder - whether a private individual or a public body - goes through a number of construction phases with legal bases anchored in the regional building codes, among other places. The builder, planner, and contractor are included in the individual planning stages. Figure 3 provides an overview of the various stages of building design.

Figure 3: Building design process diagram.



Source: own work, Fraunhofer WKI.

In accordance with public law, construction supervision is performed by the building control authorities. These authorities are responsible for enforcing building regulations and building design law. In Germany, building regulations law is governed by each federal state through regional building codes. There are a total of 16 regional building codes determining which authorities are responsible for construction supervision. In their turn, the building control authorities are subdivided into the subordinate building control authority whose tasks are generally discharged by the counties, independent cities, and large independent towns, and the superordinate building control authority, the sectorial ministry (as is the case in the Lower Saxony Regional Building Code 2018). The regional building codes govern the design, dimensioning, and execution of structures and the use of construction products. They document general and material requirements and procedural rules and provide links to the technical building regulations (DIBt 2020).

3.2 General information on the fire safety of buildings

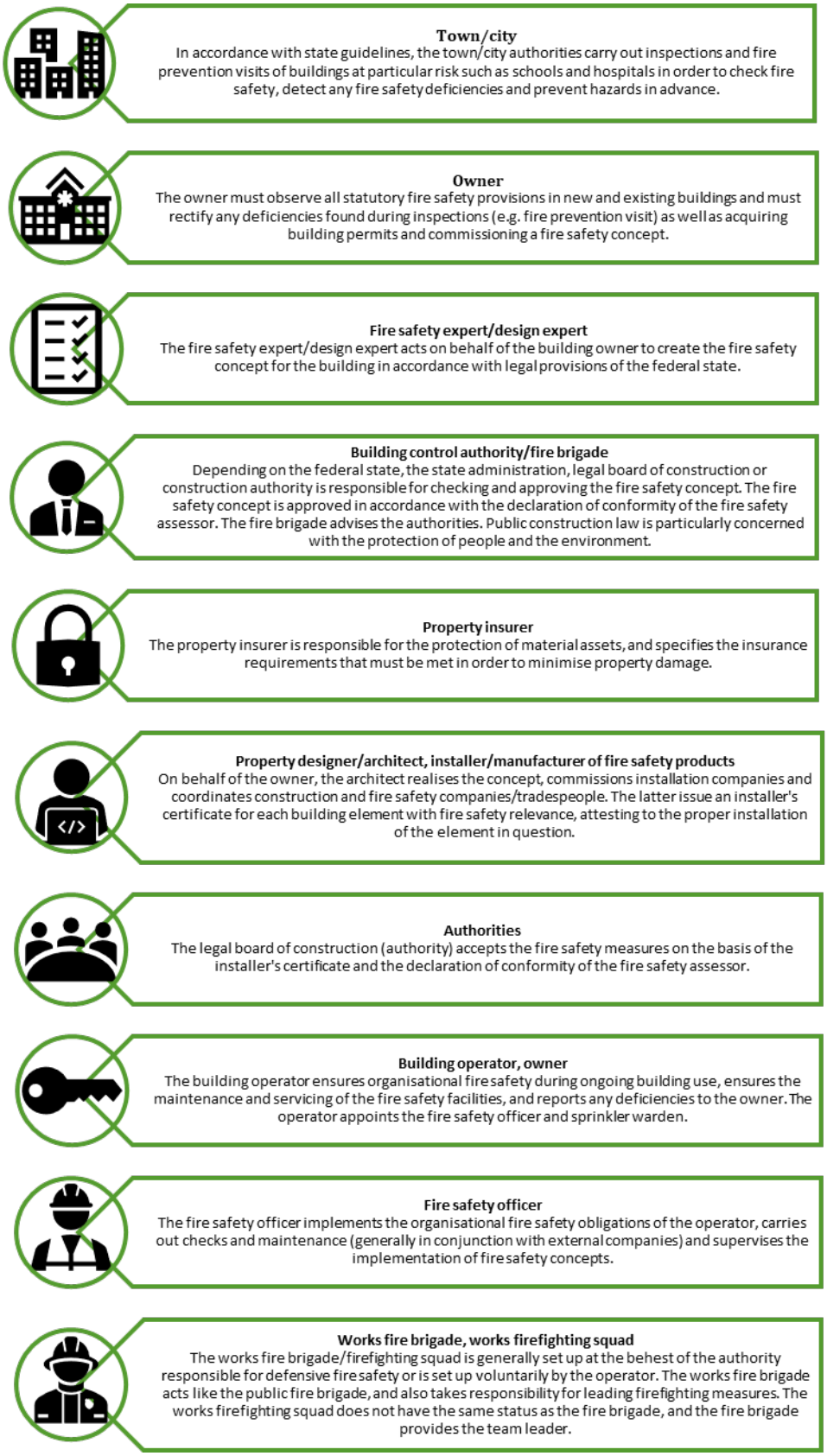
In Germany, fire safety requirements for buildings are governed by the German Standard Building Regulations (MBO 2019) and supplemented by the various regional building codes. Further provisions include the fire brigade/fire safety laws of the individual federal states. The local fire brigade and building authorities along with specialist planners and other fire and occupational safety experts act as contact partners for matters pertaining to fire safety. The various steps and institutions involved in ensuring fire safety are summarised in Figure 4 using a hospital as an example.

The term **fire safety** encompasses all measures that prevent or impede incipient fire and fire spread. A distinction is made between structural, technical, and organisational fire safety. Defensive fire safety includes rescuing people and animals as well as effective firefighting.

A **fire safety concept** includes all necessary structural, technical, and organisational measures to prevent fire from breaking out and spreading and to enable prompt rescue (e.g. BGW/BuS-I-12/13, 2015). A fire safety concept must be created for a building if the building in question is a special building (MBO 2019) such as a hospital or a school and if no special building regulations have been introduced by the building control authorities or if deviations from standard building regulations apply. The fire safety concept is created by a design expert. The managing director, operator, or person responsible for a facility must check whether there is a fire safety concept for the building. If this is the case, the concept should be updated or adjusted in accordance with the usage of the facility if required. A fire safety concept for a building may result in more stringent fire safety requirements being placed upon the various product groups than are prescribed in law. For more information about fire safety concepts and certificates, see German Loss Prevention Council (VdS) Brochure 3547 (2014), for example.

Fire safety regulations contain provisions governing the conduct of persons in buildings or businesses in the case of a fire as well as measures for preventing fires. These regulations must be adjusted in line with the actual conditions in the building or business in question and must always be kept up-to-date. Fire safety regulations must be checked by an expert every two years. Fire safety regulations comprise parts A, B, and C, these parts being targeted at different groups of people in the building (e.g. employees, visitors, employees with a fire safety task) (FeuerTrutz 2017). The **fire safety plan** is a drawing that illustrates the fire safety requirements. It includes the building layout plan and indicates fire safety equipment and escape routes. The **fire brigade plan** for building structures illustrates firefighting and rescue measures in particular places or for particular buildings. The requirements for its components, plan content, and design are defined in DIN 14095. The obligation to create fire safety regulations and/or a fire brigade plan depends on the size and type of the building. It is governed by the various building codes.

Figure 4: Distribution of fire safety tasks.



Source: own work, Fraunhofer WKI, according to BVFA (2019a).

3.2.1 Building classification

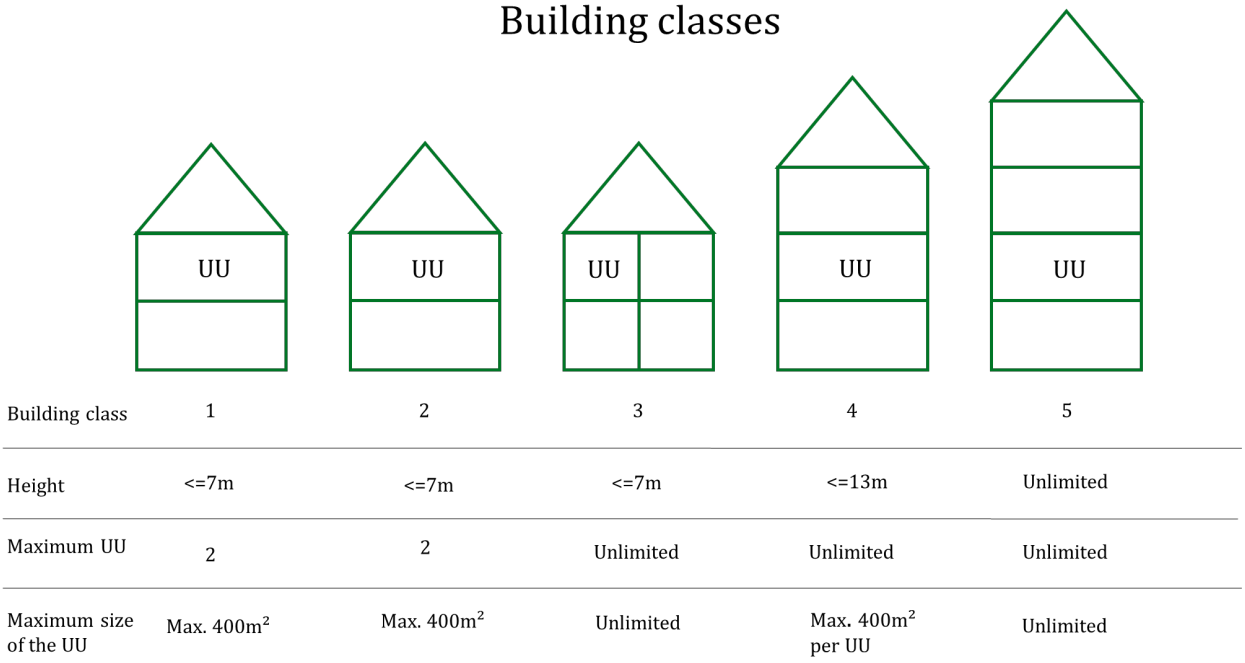
As mentioned above, the requirements placed upon fire safety in buildings are governed by the German Standard Building Regulations (MBO 2019). Art. 2 Para. 2 of the MBO defines buildings as:
"*independently usable, covered structures that can be entered by people and that are suitable for or intended for the protection of people, animals or property*".
The fire safety requirements of a particular building depend on the building class. The five building classes are defined in Art. 2 Para. 3:

Table 6: Building classes as per German Standard Building Regulations (MBO 2019).

Building class	
1	a) Free-standing buildings with a height of up to 7 m and no more than two utilisation units of no more than 400 m² in total and b) Free-standing buildings used for agriculture or forestry
2	Buildings with a height of up to 7 m and no more than two utilisation units of no more than 400 m²
3	Other buildings with a height of up to 7 m
4	Buildings with a height of up to 13 m and utilisation units of no more than 400 m² each
5	Other buildings, including underground facilities

The height specifications in Table 6 relate to the height of the top edge of the floor of the topmost habitable storey, measured relative to the ground surface median. The usable area relates to gross floor space without cellar space. Figure 5 shows an overview of the building classes.

Figure 5: Overview of building classes as per MBO 2019 (UU = utilisation unit).



Source: own work, Fraunhofer WKI.

With regard to fire safety, Art. 14 of MBO 2019 requires that "*building structures [...] must be arranged, erected, changed, and maintained in a way that prevents fire from breaking out and prevents fire and smoke from spreading (fire propagation) and so that, if a fire occurs, it is possible to rescue people and animals and to perform effective firefighting*."
In particular with regard to rescuing people and animals, fire safety requirements become more stringent as the building class increases, as can be explained using the case of requirements for load-bearing walls or pillars (Art. 27 MBO 2019) as an example:

- Building class 5: Fire-resistant building elements (fire resistance of 90 minutes)
- Building class 4: Fire-retardant building elements (fire resistance of 60 minutes)
- Building classes 2 and 3: Fire-retardant building elements (fire resistance of 30 minutes)
- Building class 1: No fire resistance requirements; all used building materials must be classified as normally flammable (Art. 26, Para. 1 Clause 2 MBO 2019)

In addition to building classes 1 to 5, the MBO (2019) also defines special buildings which, as per Art. 2 Para. 4, are described as facilities and spaces with a special type or usage, and which are subdivided into the following categories:

1. *"High-rise buildings (buildings with a height of more than 22 m),*
2. *building structures with a height of more than 30 m,*
3. *buildings with more than 1600 m^2 floor space of the storey with the largest extension, except for residential buildings and garages,*
4. *sales premises whose sales rooms and shopping streets have a total floor space of more than 800 m^2,*
5. *buildings with rooms which are used as office space or administration space and which, individually, have a floor space of more than 400 m^2,*
6. *buildings with rooms which, individually, are intended for use by more than 100 people,*
7. *places of assembly:*
   a) *with assembly rooms that can hold more than 200 visitors in total if these rooms have shared rescue routes;*
   b) *outside with performance areas as well as outdoor sports facilities, both with stands, which are not flying structures and which, in total, can hold more than 1000 visitors,*
8. *bars and restaurants with more than 40 seats in buildings or more than 1000 seats outside, accommodation with more than 12 beds, and amusement arcades with a floor space of more than 150 m^2,*
9. *buildings with utilisation units for caring for or supporting persons in need of care or persons with a disability whose self-rescue ability is restricted if the utilisation units:*
   a) *are intended individually for more than 6 persons or;*
   b) *are intended for persons with an intensive need for care or;*
   c) *have a shared rescue route and are intended for more than 12 persons in total,*
10. *hospitals,*
11. *other facilities for accommodating persons as well as residential homes,*
12. *day care facilities for children, persons with a disability, and the elderly, except for day care facilities including day care for no more than ten children,*
13. *schools, colleges, and similar facilities,*
14. *correctional facilities and building structures for the involuntary treatment of patients,*

15. *camping sites and weekend camps,*
16. *leisure and amusement parks,*
17. *flying structures, where a design approval is required,*
18. *high-bay stores with an item top edge height of more than 7.5 m,*
19. *building structures whose use is associated with a higher than normal risk of explosion or fire due to the handling or storage of certain substances,*
20. *facilities and spaces not included in points 1 to 19 whose type or usage is associated with comparable risks."*

The buildings whose fire safety requirements are handled in more detail in the sections below mainly belong to the special buildings category as per MBO 2019. Office and administrative buildings might be an exception here. Depending on their size, they may be included in building classes 1 to 5 or they may constitute special buildings.

4 Fire safety requirements in specific areas

The research performed on fire safety requirements for specific product groups as part of this research project relate to the following public facilities:

- Nurseries
- Schools
- Hospitals
- Office and administrative buildings
- Armed forces facilities
- Correctional facilities
- Places of assembly
- Fire brigade facilities
- Police/customs facilities

For each of these areas, the fire safety requirements for the following product groups are analysed as part of this work:

- PPE and work clothing
- Footwear
- House and home textiles[14]
- Furniture
- Mattresses
- Floorings[15]

For fire brigade, police, and customs facilities, only the fire safety requirements for PPE and work clothing are discussed. The investigated areas and the product groups relevant there are listed in Table 7, Table 8 and Table 9.

[14] Household and home textiles are goods that are used for interior design and decor. This includes blankets, throws, bedlinen, table linen, kitchen linen, bathroom textiles, toilet linen, curtains, drapes, valances, passements, and furniture coverings.

[15] Flooring as per EN 13501-1: The "upper layer(s) of a floor, comprising any surface finish with or without an attached backing and with any accompanying underlay, interlayer, and adhesives".

Table 7: Matrix representation of analysed fire safety requirements for various product groups for the areas "Nurseries", "Schools" and "Hospitals".

Product group	Nurseries	Schools	Hospitals
PPE and work clothing	Clothing for: →Caretakers →Cleaning personnel	Clothing for: →Caretakers →Cleaning personnel Lab coats for teachers and students	Clothing for: →Caretakers →Cleaning personnel →Medical personnel
Footwear	Footwear for: →Caretakers →Cleaning personnel	Footwear for: →Caretakers →Cleaning personnel	Footwear for: →Caretakers →Cleaning personnel →Medical personnel
House and home textiles	Curtains Bedding (blankets, pillows) Bedlinen Upholstery fabrics Decorative fabrics Drapes Blankets Play mats	Curtains Drapes Upholstery fabrics Decorative fabrics	Bedlinen Bedding (blankets, pillows) Towels Curtains Drapes Table cloths Upholstery fabrics Decorative fabrics
Furniture	Upholstered furniture Beds Cupboards Tables Chairs Shelves Coat racks Play equipment (e.g. play kitchens, climbing frames etc.) →In group spaces →In escape routes	Tables Chairs Cupboards Blackboards and whiteboards Display cabinets/shelves Upholstered furniture Coat racks Lockers →In classrooms →In staff rooms →In escape routes →In assembly halls	Hospital beds Desks Desk chairs Chairs/tables Upholstered furniture Cupboards Coat racks →In patients' rooms →In nurses'/doctors' rooms →In escape routes →In break areas →In meeting rooms
Mattresses	Relevant for the area	Not relevant	Relevant for the area
Floorings	Relevant for the area	Relevant for the area	Relevant for the area

Table 8: Matrix representation of analysed fire safety requirements for various product groups in the areas "Office and administrative buildings", "Armed forces facilities" and "Correctional facilities".

Product group	Office and administrative buildings	Armed forces facilities	Correctional facilities
PPE and work clothing	Clothing for: →Caretakers →Cleaning personnel	Clothing for: →Caretakers →Cleaning personnel →Soldiers	Clothing for: →Caretakers →Cleaning personnel →Guards →Detainees
Footwear	Footwear for: →Caretakers →Cleaning personnel	Footwear for: →Caretakers →Cleaning personnel →Soldiers	Footwear for: →Caretakers →Cleaning personnel →Guards →Detainees
House and home textiles	Curtains Drapes Upholstery fabrics Decorative fabrics	Bedding (blankets, pillows) Bedlinen Towels Covers Curtains Upholstery fabrics Decorative fabrics Drapes	Bedding (blankets, pillows) Bedlinen Towels Covers Curtains Upholstery fabrics Decorative fabrics Drapes
Furniture	Desks Desk chairs Sofas Chairs Cupboards Coat racks →In offices →In escape routes →In meeting rooms →In break areas	Beds Upholstered furniture Chairs Tables Cupboards Coat racks →In barracks →In escape routes →In meeting rooms →In break areas	Beds Upholstered furniture Chairs Tables Cupboards Coat racks →In cells →In escape routes →In meeting rooms →In break areas
Mattresses	Not relevant	Not considered	Relevant for the area
Floorings	Relevant for the area	Relevant for the area	Relevant for the area

Table 9: Matrix representation of analysed fire safety requirements for various product groups for the areas "Places of assembly", "Fire brigade facilities" and "Police and customs facilities".

Product group	Places of assembly	Fire brigade facilities	Police/customs facilities
PPE and work clothing	Clothing for: →Caretakers →Cleaning personnel	Clothing for: →Caretakers →Cleaning personnel → Firefighter jackets → Firefighter trousers → Firefighter helmets → Firefighter gloves → Firefighter hoods	Clothing for: →Caretakers →Cleaning personnel →Police/customs officials →Staff in closed units
Footwear	Footwear for: →Caretakers →Cleaning personnel	Footwear for: →Caretakers →Cleaning personnel →Firefighters	Footwear for: →Caretakers →Cleaning personnel →Police/customs officials →Staff in closed units
House and home textiles	Curtains Upholstery fabrics Decorative fabrics Drapes	Not considered	Not considered
Furniture	Desks Desk chairs Stage sets Sofas Chairs Cupboards Coat racks	Not considered	Not considered
Mattresses	Not relevant	Not considered	Not considered
Floorings	Relevant for the area	Not considered	Not considered

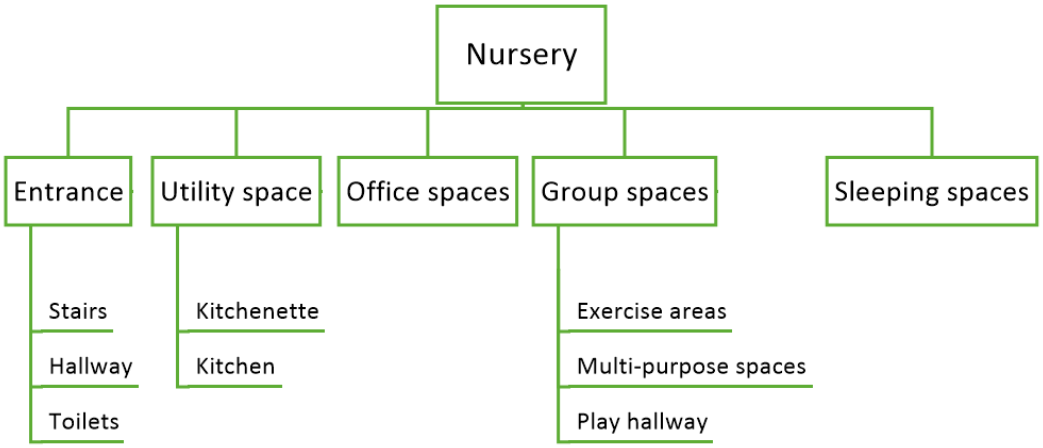
The following subsections describe the fire safety requirements for the individual product groups in an area-specific manner on the basis of legal provisions and recommendations.

4.1 Nurseries

Crèches (up to 3 years) and playschools (from 3 years to the start of compulsory schooling) for the care and/or stimulation of pre-school children are collectively referred to as "nurseries". Infants and small children may spend between a few hours and the entire working day in a facility of this kind. Nurseries can be run by churches, welfare organisations, town councils, or private/commercial providers. A nursery can be subdivided into the following areas[16] (Figure 6):

[16] According to the North Rhine-Westphalia Building Code, a play hallway is "a required hallway that can be used for rescue routes. This is a room (hallway) with fire loads that, in addition to its function as a circulation area, is also used as a play area. An escape route width of at least 1.20 m should be ensured. Fire loads in this context include any furniture relating to the use of the area including toys and decorations" (quoted from VdF NRW, 2016).

Figure 6: Commonly found areas in a nursery.



Source: own work, Fraunhofer WKI.

4.1.1 Requirements relating to structural fire safety

In Germany, the requirements relating to the building and fitting out of day care centres arise from national legal provisions and from the regulations of statutory accident insurance providers (e.g. accident prevention regulations). In accordance with Art. 2 Para. 4 No. 12 MBO and the various regional building codes, nurseries fall among the unregulated special buildings for which requirements must be governed by a case-specific fire safety concept. In accordance with Art. 14 MBO, building structures must be arranged, erected, changed, and maintained in a way that prevents fire from breaking out and prevents fire and smoke from spreading (fire propagation). With regard to the general requirements upon the fire behaviour of building materials and building elements, the German Standard Building Regulations state that building materials that are not at least normally flammable (so that are highly flammable materials) may not be used (Art. 26 MBO); however, this does not apply if they are not highly flammable when used in conjunction with other building materials. Nevertheless, only the floorings, as covered in Section 4.1.2.6, fall within the scope of the construction products considered by the MBO.
There are no special building regulations for day care centres in Germany (Anwander 2011). Due to the similarity of the user group, it can be assumed that the minimum requirements of the Standard School Construction Directive (see also Section 4.2) must be observed.
Fire safety topics are not mentioned in the statutory regulations of the individual federal states on childcare. Lower Saxony's Law on Day Care Facilities for Children (KiTaG 2002), for example, states the following in Art. 6 Para. 1: "*The rooms and fittings of nurseries must be suitable for children, safe for the age of the children cared for, and generally designed in such a way to ensure appropriate educational, training and care work to be carried out*". General requirements can also be found at federal state level, e.g. in Lower Saxony's Ordinance on Minimum Requirements for Nurseries (DVO-KiTaG 2002). Here, too, no stipulations about fire safety are made. The nursery laws of the individual federal states are summarised on the Website of BAGE e. V. (2020), for example.
Technical fire safety guidelines have been compiled by professional associations and/or the supreme building authority in the individual federal states, but these have not been introduced by the building control authorities (Anwander 2011). For example, the fire safety guide for day care facilities for children of Landesfeuerwehrverband Brandenburg e. V. (2018) states that nurseries are unregulated special buildings for which there are no mandatory special construction regulations. From a technical fire safety perspective, the necessary fire safety measures must be defined in an individual fire safety concept in accordance with Brandenburg's

Law on Building Documents (Art. 11 Para. 2 BbgBauVorlV 2016). This means that relaxations may be granted or more stringent requirements may be placed upon building structures.
Due to the difference in the age and mobility of the children cared for, a relatively long evacuation time can be assumed in the case of a hazardous situation (Anwander 2009). This means that if an evacuation is required, the children are dependent on the help of the day care staff. The requirements for rescue routes are defined in Art. 33 Para. 1 to 3 MBO. The following applies for special buildings: "*The second rescue route via rescue equipment of the fire brigade is permitted only if there are no concerns about the rescue of persons*". The number of people, child care ratio, length of the rescue routes and position of the crèche in the building must be considered as marginal conditions in the "Nurseries" area. In accordance with the fire safety guide for day care facilities for children of the Landesfeuerwehrverband Brandenburg e. V. (2018), nurseries should have two independent structural rescue routes (with two stairwells in the case of multiple storeys). If required, a hallway must be provided to enable persons to reach the exits/stairwells, and this hallway must be kept free from fire loads.
Play hallways are areas that are not simply used as circulation areas[17] but are also used as group spaces or play areas. Unlike required hallways, a play hallway contains fire loads and fire hazards. In accordance with the guide mentioned above, any space intended for occupation by children must have a direct exit to the outside or a second independent rescue route. The first rescue route is not allowed to lead across a play hallway, but the second rescue route may do so.
In addition, the regulations of the DGUV (DGUV Regulation 82 2007) govern the "*structural design and equipment in day care facilities for children where this is necessary in order to prevent any risk to the life and health of the children and where these facilities are accessible to the children as intended*". The appendix to DGUV Rule 102-002 (2009) also lists regulations, rules, and information. The "Safe Nurseries" ("Sichere Kita") brochure of the North Rhine-Westphalia Accident Compensation Fund (UK NRW 2017a) presents the essential requirements for the building and fitting out of day care centres for children along with the corresponding legal bases.
With regard to the topic of "required hallways", the fire safety brochure of the Rhineland Municipal Accident Insurance association (GUVV 2006) specifies the following: "*If the group spaces do not have their own emergency exits, the accessible hallway remains a required escape and rescue route. This means that the hallway in question may only be used as a play area with extreme restrictions, and must be kept as free as possible from fire loads. It may not be constricted by fixtures such as play equipment. This hallway is essential to safeguarding the primary structural escape and rescue route. Here, too, the functionality of any fire/smoke protection doors must be ensured.*"
Since early fire detection is possible only through the use of automatic fire alarm systems at night and outside working hours, Section 4.1 of the HE-Kita (2012) specifies that all rooms of day care facilities for children must be fitted with smoke detectors.

4.1.2 Fire safety requirements for various product groups

Below, the fire safety requirements for the products specified in Table 7 are presented, taking into account the various areas of a day care centre for children. Essentially, the specifications of the Occupational Health and Safety Act (ArbSchG) and the Workplaces Ordinance (ArbStättV) apply to employees working in nurseries. Art. 3a ArbStättV (2004) states that "*the employer must ensure that workplaces are set up and operated in a way that avoids health and safety risks to the employees to the greatest extent possible and that keeps any residual risks to a minimum*".

[17] Circulation areas are areas that allow access to the structure, e.g. corridors and stairs (see DIN 277-1, 2016).

4.1.2.1 PPE and work clothing

There are no fire safety requirements relating to the work clothing of employees working in nurseries, and PPE is not required in this area.

4.1.2.2 Footwear

There are no fire safety requirements relating to footwear for employees working in nurseries.

4.1.2.3 House and home textiles

There are no legal regulations or minimum requirements relating to fire safety requirements for house and home textiles. Over the past few years, individual associations have published recommendations that might serve as an orientation for the operators of facilities. The Working Group on Fire Safety and Hazard Protection of the AGBF and DFV[18] published its recommendations for the risk assessment of fire loads in rescue routes ("Empfehlungen zur Risikoeinschätzung von Brandlasten in Rettungswegen") in 2014. Thus, the following applies to nurseries with a surface area of more than 200 m^2:

- In required stairwells, curtains and blinds for blocking out light are permitted; flame-retardant decorations and curtains used as wall coverings are not permitted[19].
- In a required hallway that is one of two independent structural rescue routes, flame-retardant decorations and curtains used as wall coverings are permitted along with curtains and blinds for blocking out light.
- In required hallways that are both the primary and secondary rescue route or the only structural rescue route[20], flame-retardant decorations and curtains used as wall coverings are permitted along with curtains and blinds for blocking out light.

The fire safety brochure of the Rhineland Municipal Accident Insurance Association (GUVV, 2006) states that if materials are used for decorative purposes, they should be made of non-combustible or flame-retardant materials wherever possible. *"Particularly in the area of ceilings (canopies etc.), plastics, and synthetic fibres should not be used, since they quickly catch fire when exposed to heat, drip as they burn, and thus contribute to the rapid spread of fire. In the case of large decorations, regardless of whether these are on the ceiling, wall or floor, only flame-retardant materials should be used."*
In all areas of nurseries that are not specified, no minimum requirements for house and home textiles are prescribed in law.

4.1.2.4 Furniture

The group spaces in nurseries are generally fitted out with tables and chairs. In addition, upholstered furniture, shelves, and cupboards might be found, like those in living rooms. The sleeping spaces contain beds. In general, there are no legal requirements relating to fire safety for nursery furniture. The recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV for the risk assessment of fire loads in rescue routes (2014) can be used as orientation. Details are listed in Table 10. The specifications apply to nurseries with a surface area of more than 200 m^2. The technical safety assessment of seating furniture for children is governed by the standard DIN EN 17191. Fire hazards are to be determined in

[18] German Fire Brigade Association

[19] In the case of an open staircase, max. ground floor and one storey, and if a second structural rescue route is available, then no restrictions.

[20] If under constant supervision.

accordance with DIN EN 71-2. Proof must be provided that all textile materials that are accessible on the piece of furniture cannot cause surface flaming.

Table 10: Recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV for the risk assessment of fire loads in rescue routes of nurseries with a surface area greater than 200 m² (2014) in comparison with other areas.

	Required stairwell[21]	Required hallway[22] (one of two independent structural rescue routes)	Required hallway[23] (primary and concurrent secondary rescue route or only structural rescue route)	Other areas of a nursery
Combustible furniture[24]	Not allowed	Tolerated (in the case of a flame-retardant frame and upholstery with DIN 66084 certification (class P-a) or if encased in A-material). No restrictions if inside the utilisation unit in the play hallway.	Tolerated (in the case of a flame-retardant frame and upholstery with DIN 66084 certification (class P-a) or if encased in A-material)	No restrictions known
Non-combustible furniture (fixed installation, rescue route width maintained)	Allowed	Allowed	Allowed	No restrictions known
Open coat racks	Not allowed	Tolerated (only coat hooks, no other fixtures)	Tolerated (only coat hooks, no other fixtures)	No restrictions known
Lockers, cupboards	Not allowed	Tolerated (if non-combustible and tight-closing)	Tolerated	No restrictions known

4.1.2.5 Mattresses

There are no fire safety requirements relating to mattresses for nurseries. According to Art. 22 of DGUV Regulation 82, sleeping spaces and their equipment must be designed so that children are not endangered when using them. The "Safe Nurseries" ("Sichere Kita") brochure (UK NRW 2017b) merely recommends avoiding the use of soft mattresses.

[21] In the case of an open staircase, max. ground floor and one storey, and if a second structural rescue route is available, then no restrictions.

[22] In the case of an open staircase, max. ground floor and one storey, and if a second structural rescue route is available, then no restrictions.

[23] If under constant supervision (e.g. in theatres)

[24] Arranged individually taking the width of the rescue route into account. "Combustible furniture" is any furniture that is not classified as non-combustible.

4.1.2.6 Floorings

Floorings are considered to be construction products and, as such, are governed by the MBO or the building codes of the federal states. Thus, they are subject to the requirement of being classified as at least normally flammable. The harmonised DIN EN 14041 defines parameters for laminate flooring, textile floor coverings and elastic floor coverings with which building material class E_{FL} (see Section 5.4) is achieved without testing. In this standard, DIN EN 13501-1 is stipulated as the testing and classification standard. For North Rhine-Westphalia, the regional building code (Art. 36, Para. 6, No. 3 BauO NRW 2018) states that in required hallways and open corridors, at least flame-retardant floor coverings are required. In the other federal states, there is only a general requirement that floorings must be normally flammable. According to the German Standard Building Regulations (Art. 35 Para. 5 No. 3 MBO), floorings must at the very least be made from flame-retardant building materials in required stairwells and in spaces between the required stairwell and the exit to the outside, with the exception of the anti-slip sections. The regional building codes of Lower Saxony (NBauO 2012) and Baden-Wuerttemberg (LBO BW 2010) permit the use of normally flammable materials.
According to Art. 8 Para. 1 DGUV Rule 102-002, floorings should be anti-slip and easy to clean as appropriate for use by children. Art. 24 Para. 1 states that the floors and walls of rooms and facilities for physical education must be designed in a way that ensures that the children are not endangered. However, these requirements relate to sufficient flooring elasticity to avoid injuries.

4.2 Schools

In Germany's structured schooling system, after primary school pupils attend different types of schools that are referred to collectively as "Secondary Level I". This includes Hauptschulen and Realschulen (secondary modern), Gymnasien (grammar schools), Gesamtschulen (comprehensive schools), and Förderschulen (schools for children with special needs). Secondary Level II comprises the upper grammar school along with vocational schools, evening schools, and adult education colleges. An alternative breakdown separates general education (primary schools, Secondary Levels I and II, schools for children with special needs) from vocational schools. In the field of schooling, the federal states have cultural autonomy, which means that provisions can vary across the country. The "school authorities" are the natural or legal persons who run a school and bear the space-related and material costs of running it. The technical fire safety risk of a school building depends on the user group, size of the building and its equipment (Lichtenauer 2013). The fire safety concept for a school building is therefore based on its usage, users, and the building type, among other things. Whereas in the case of new builds, the current fire safety requirements can be allowed for during advance planning, in the case of existing buildings - particularly if they are listed - conflicts of interest can occur (grandfathering). A school building can be subdivided into the following areas depending on the risk of a fire breaking out (Table 11).

Table 11: Classification of school rooms with regard to fire origin hazards (based on Lichtenauer 2013).

Rooms without an increased fire origin hazard		
Entrance area	Caretaker's office	Stairs
Secretary's office	Staff rooms	Office spaces
Classrooms	Assembly halls	Toilets
Music rooms	Sports halls/changing rooms	
Rooms with an increased fire origin hazard		
Science labs	Natural science rooms	Computer labs
Material/teaching equipment rooms	Arts/crafts rooms	Library
Storage and utility rooms	(building services)	School kitchens
Classrooms in primary schools		

Normal classrooms are classified as rooms without an increased fire origin hazard, as are the secretary's office, sports hall, changing rooms, toilets, canteen, stairs, and assembly hall. Rooms with an increased fire origin hazard or fire hazard include science labs, computer labs, teaching equipment rooms, storage and utility rooms, arts/crafts rooms, libraries, and school kitchens. In primary schools, where classrooms tend to offer a living environment with furnishings, decorations made from highly flammable materials, toys etc., the fire risk is classified as increased. Outside working hours and at night, early fire detection can be achieved using automatic fire alarm systems.

4.2.1 Requirements relating to structural fire safety

Construction law regulations for schools include the following:

- The German Standard Building Regulations (MBO)
- The regional building codes (LBO)
- The standard directive on construction inspection requirements for schools (Standard School Construction Directive - MSchulbauR)
- The Directive on Fire Safety in Existing Schools (Saarland)

Other applicable regulations include the Standard Venue Regulations (MVStättVO), Standard Piping Systems Directive (MLAR) and the Standard Ventilation Systems Directive (M-LüAR). The MVStättVO applies if, for example, events with more than 200 visitors take place in assembly rooms or halls. However, classrooms in general education and vocational schools do not fall in scope of this Directive (Art. 1 Para. 3 No. 2 MVStättVO).
The school laws of the federal states and the "Schools" accident prevention regulations (DGUV Regulation 81, 2001) govern the areas that fall outside the scope of the building regulations.
The working aids for school construction (ZNWB 2008), published by the Secretariat of the Standing Conference of the Ministers of Education and Cultural Affairs, include regulations, directives and standards on construction, operating technology and health and safety.

According to the German Standard Building Regulations (MBO 2019), schools are special buildings. The recommendation of the Secretariat of the Standing Conference of the Ministers of Education and Cultural Affairs (quoted from Lichtenauer 2013, p. 7) is that schools should not have more than four storeys, and thus belong to building class 3 or 4. In the case of school buildings for persons with a physical or mental disability, one or two storeys are recommended. The requirements and relaxations for special buildings encompass fire safety systems, equipment and precautions along with the scope, content and number of special construction documents, particularly the fire safety concept (Article 51 Clause 3 No. 7 and No. 19 MBO).
In school construction, too, the classification of building materials in accordance with their fire behaviour as non-combustible, flame-retardant, and normally flammable applies as a general rule: "*Building materials that are not at least normally flammable (highly flammable materials) may not be used; this does not apply if they are not highly flammable in conjunction with other building materials*" (Art. 26 Para. 1 MBO).
The Standard School Construction Directive (MSchulbauR 2009) applies for the requirements for general education schools and for vocational schools as long as they are not exclusively used for adult education. The requirements for building elements, fire walls, rescue routes, stairs, and doors are regulated there. Extracts are provided below.

- "For each classroom on the same storey, there must be at least two independent rescue routes to exits leading outside or to required stairwells. In the place of one of these rescue routes, there may be a rescue route that leads to the property via external stairs without a stairwell, escape balconies, terraces, and accessible roofs as long as this rescue route is not put at risk in the case of a fire; this rescue route shall be considered as an exit leading outside" (Art. 3.1 MSchulbauR).

- "The usable width of exits from classrooms and other spaces intended for occupation by pupils along with the usable width of required hallways and stairs must be at least 1.20 m for every 200 users who might need to rely upon them (Art. 3.4 MSchulbauR). Only graduations of 0.60 m are permitted. However, at least the following usable widths must be available:
  a) Exits from classrooms and other spaces intended for occupation by pupils: 0.90 m,
  b) Required hallways: 1.50 m,
  c) Required stairs: 1.20 m.

- The required usable width of the required hallways and required stairs may not be restricted by open doors, fixtures or fittings. Exits to required hallways may not be wider than the required hallway itself. Exits to required stairwells may not be wider than the required stairwell itself. Exits from required stairwells must be at least as wide as the required stairwell itself. Safety signs must be affixed to the exits to required stairwells or exits leading outside" (Art. 3.4 MSchulbauR).

Recommendations for escape routes for special science and technical labs are also given in the Directive on Safety in the Classroom of the Standing Conference of the Ministers of Education and Cultural Affairs (RiSU 2019).

4.2.2 Fire safety requirements for various product groups

Below, the fire safety requirements for the products specified in Table 7 are presented, taking into account the various areas of a school building. In accordance with the Workplaces Ordinance (Art. 3a ArbStättV 2004), the employer essentially has a duty to ensure "*that workplaces are set up and operated in a way that avoids health and safety risks to the employees to the greatest extent possible and that keeps any residual risks to a minimum*". This also applies to

classrooms in schools, since these constitute workplaces in accordance with the Guidelines on the Workplaces Ordinance for Teachers (LASI 2009).

4.2.2.1 PPE and work clothing

Work clothing in the "Schools" area includes work coats for caretakers and cleaning staff. Here, there are no fire safety requirements.
In addition, there are lab coats for use in science lessons. Most knee-length lab coats are intended to protect the clothing or skin they cover from soiling and/or from hazardous substances. Lab coats might be made from cotton or a cotton-polyester mix, for example. In accordance with the German Technical Rules for Hazardous Substances - Laboratories (TRGS 526 (2008)), "*suitable work clothing and protective clothing must be worn when performing tasks in laboratories. As a rule, the basic equipment comprises a long lab coat with long, tight-fitting sleeves and a cotton content of at least 35%.*"
The Directive on Safety in the Classroom (RiSU 2019) lists gloves as personal protective equipment for protection against thermal effects (I–3.11; I–3.11.1 Hand protection). These are generally made from special fibres.

4.2.2.2 Footwear

There are no fire safety requirements relating to footwear for caretakers and cleaning personnel.
The German Technical Rules for Hazardous Substances (TRGS 526 (2008)) apply for tasks in laboratories. Accordingly, only sturdy, closed, anti-slip footwear may be worn in laboratories.

4.2.2.3 House and home textiles

In primary schools, the classrooms are often set up to look like living rooms. This means that there may be decorative articles made of fabric, carpet, cushions or blankets in the play and rest areas that might constitute a potential fire load. In addition, classrooms are often fitted out with drapes, curtains, and black-out blinds.
The requirements for the use of textiles in public buildings with more than 200 visitors (e.g. the assembly hall) are governed by the Standard Venue Regulations [25] (MVStättVO) in Germany:

- *"At the very least, curtains on stages and in sets must be made from material that is flame-retardant"* (Art. 33 Para. 1 MVStättVO).
- *"Equipment must, at the very least, be made from material that is flame-retardant. In the case of stages and sets with automatic firefighting equipment, equipment made from normally flammable material is sufficient"* (Art. 33 Para. 3 MVStättVO).
- *"Decorations must, at the very least, be made from material that is flame-retardant. Decorations in required hallways and required stairwells must be made from non-combustible material"* (Art. 33 Para. 5 MVStättVO).

The Working Group on Fire Safety and Hazard Protection of the AGBF and DFV published its recommendations for the risk assessment of fire loads in rescue routes ("Empfehlungen zur Risikoeinschätzung von Brandlasten in Rettungswegen") in 2014. The following recommendations are given for school buildings:

- In required stairwells in schools, flame-retardant decorations and curtains as wall coverings are not allowed.

[25] In some federal states, the Standard Venue Regulations are called the Special Construction Regulations.

- In required stairwells, curtains and blinds are allowed for blocking out light.
- In required hallways, flame-retardant decorations and curtains as wall coverings and curtains and blinds for blocking out light are allowed.

No further requirements other than those above are known with regard to fire safety for house and home textiles for schools.

4.2.2.4 Furniture

Normal classroom furniture mainly consists of tables and chairs that are generally made from tubular steel frames and hardwood surfaces and are considered unobjectionable from a fire safety perspective (Lichtenauer 2013, p. 4). Shelves and cupboards are also used. In primary schools, the classrooms are often designed as play/rest areas and are set up with upholstered furniture, shelves, and cupboards like those used in living rooms.
In accordance with Art. 36 Para. 2 MBO 2019, required hallways must be wide enough to accommodate the heaviest expected traffic; furniture must therefore not constitute an obstacle in escape routes. In the Standard School Construction Directive (MSchulbauR), Art. 3.4 states that the necessary usable width of required hallways and required stairs may not be restricted by open doors, fixtures or fittings. Further, Art. 4 Para. 4 of the Workplaces Ordinance specifies that employers are responsible for ensuring that circulation areas, escape routes and emergency exits are constantly kept clear so that they are usable at all times.
Requirements for rescue routes in existing buildings are described in the Treatise on Preventative Fire Safety in Schools ("Abhandlung Vorbeugender Brandschutz an Schulen") (Gammerl 2008) in Baden-Wuerttemberg. According to the AVBG[26] instructions on fire safety precautions in schools ("Merkblatt - BVS Schulen") (2007), fire loads must be removed from hallways that act as primary rescue routes. In hallways with a minimum width of 1.25 metres, metal cupboards (with a closed surface), display cabinets (locked, unshakeable), and furniture made from non-combustible (A), flame-retardant (B1) or classified materials (DIN EN 1021 or DIN 66084, P-b) are tolerated. Copying machines and large-scale, highly flammable exhibits are not tolerated (quoted from Kolb 2017a).
The Working Group on Fire Safety and Hazard Protection of the AGBF and DFV also gives the recommendations listed in Table 12 in its recommendations for the risk assessment of fire loads in rescue routes (2014) for schools.

Table 12: Recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV for the risk assessment of fire loads in rescue routes of schools (2014) in comparison with other areas of a school building.

	Other areas of a school building	Required stairwell	Required hallway (one of two independent structural rescue routes)	Required hallway (primary and concurrent secondary rescue route or only structural rescue route)
Combustible furniture[27]	No restrictions known	Not allowed	Tolerated (in the case of a flame-retardant frame and upholstery with DIN 66084 certification (class P-a) or if encased in A-material)	

[26] Working Group on Fire Safety and Hazard Protection of the Fire Brigades of Baden-Wuerttemberg

[27] Arranged individually taking the width of the rescue route into account

	Other areas of a school building	Required stairwell	Required hallway (one of two independent structural rescue routes)	Required hallway (primary and concurrent secondary rescue route or only structural rescue route)
Non-combustible furniture (fixed installation, rescue route width maintained)	No restrictions known	Allowed	Allowed	Allowed
Open coat racks	No restrictions known	Not allowed	Tolerated (only coat hooks, no other fixtures)	Not allowed
Lockers, cupboards	No restrictions known	Not allowed	Tolerated (lockers are possible in all types of school)	Tolerated (lockers are possible in all types of school) (only in primary schools if non-combustible and tight-closing)

Further requirements relating to the fire safety of furniture for schools in areas other than rescue routes are not known at present.

4.2.2.5 Mattresses

For mattresses, where they are needed in schools, no fire safety requirements are known.

4.2.2.6 Floorings

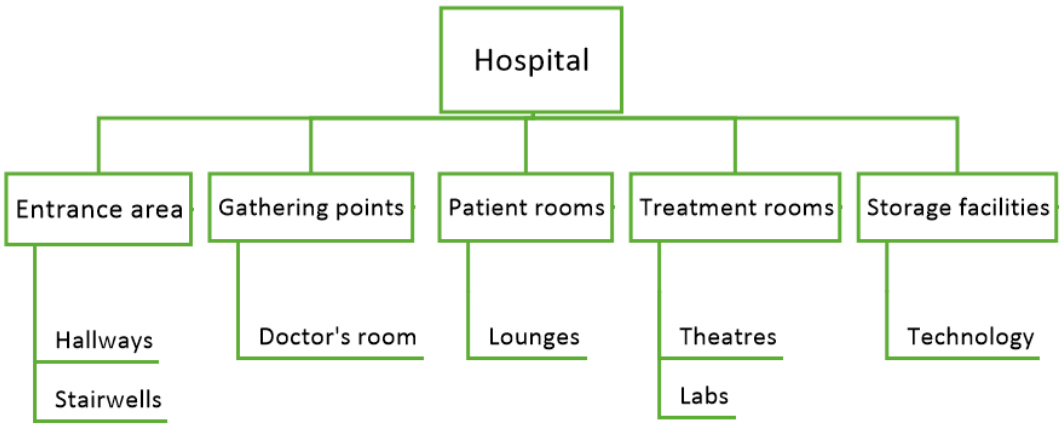
Floorings are considered to be construction products and, as such, are governed by the MBO or the building codes of the federal states. Thus, they are subject to the requirement of being classified as at least normally flammable. The harmonised DIN EN 14041 defines parameters for laminate flooring, textile floor coverings and elastic floor coverings with which building material class E_{FL} (see Section 5.4) is achieved without testing. In this standard, DIN EN 13501-1 is required as a testing and classification standard. However, in required stairwells and in spaces between the required stairwell and the exit to the outside, floorings - apart from anti-slip sections - must at the very least consist of flame-retardant building materials (Art. 35 Para. 5 No. 3 MBO). The regional building codes of Lower Saxony (NBauO 2012) and Baden-Wuerttemberg (LBO BW 2010) permit the use of normally flammable materials. For North Rhine-Westphalia, the regional building code (BauO NRW 2018, Art. 36, Para. 6, No. 3) states that in required hallways and open corridors, at least flame-retardant floor coverings must be used. In the other federal states, there is only a general requirement that floorings must be normally flammable.
In places of assembly, the requirements for floorings in escape and rescue routes are sometimes more stringent. Art. 5 Para. 7 MVStättVO states: "*In required stairwells and spaces between required stairwells and exits to the outside, floorings must be non-combustible. In required hallways and foyers through which escape routes from other assembly rooms lead, floorings must be at least flame-retardant.*"
Art. 4 Para. 7 of the Technical Rules for Workplaces ASR A1.5/1,2 (2013) states: "*If liquids or hazardous substances can come into contact with the floor, the floor is not permitted to absorb and store these substances in such a way that a hazard might result for employees through, for*

example, emissions, mould or fire risks."
In accordance with RiSU (2019), floors in science and technical labs must be "*anti-slip, impermeable to liquids, joint-tight and largely insensitive to the aggressive substances used in the vicinity.*"

4.3 Hospitals

Depending on their type and size, hospitals are building structures that are equipped with various different functional units "*where diseases, ailments or physical injuries are diagnosed, cured or alleviated by doctors or nurses, where midwifery is performed and where persons requiring care can be accommodated and catered for*" (definition of the Baden-Wuerttemberg Ministry of Economics, 2007). Due to the different sizes, uses and technical equipment of the buildings, the fire safety requirements are manifold. For example, if a fire occurs, it must be possible to evacuate immobile patients from upper storeys and to prevent the failure of technical medical equipment. Statistics on hospital fires in past years show that such fires result in damage that is not insignificant (BVFA 2019b). Preventative fire safety should reduce the likelihood of a fire occurring and minimise the consequential damages (Al-Kass 2011). The operator of a hospital is responsible for its fire safety (see e.g. BVFA 2019c). In general, hospitals can be subdivided into the following areas (Figure 7):

Figure 7: Commonly found areas in a hospital.



Source: own work, Fraunhofer WKI.

4.3.1 Requirements relating to structural fire safety

Depending on the federal state, various regulations and directives form the framework for structural fire safety in hospitals; at present, the specifications do not have a uniform status. According to the German Standard Building Regulations, hospitals are generally considered to be special buildings due to their usual height and the number and size of the utilisation units (Art. 2 Para. 4 No. 9, 10 MBO 2019).
The Hospital Construction Ordinance (KhBauVO), published in December 1976 as standard regulations on the construction and operation of hospitals, has since been withdrawn. The regulations in the various federal states are or were partially based on the KhBauVO. Only a few of the federal states have published special documents for hospitals.

- In **Berlin**, the Ordinance on the Establishment and Operation of Hospitals, Hospital Admissions, Management of Hospital Records and Nursing Documentation, and Disaster Prevention in Hospitals (Hospital Ordinance, KhsVO 2006) has been published.
- In **Brandenburg**, Art. 1 of the Ordinance on Construction Inspection Requirements for Hospitals and Care Homes (Brandenburg Ordinance on Hospital and Nursing Home Construction, BbgKPBauV 2003) governs building elements and materials; Art. 2 governs rescue routes.
- In the case of **Mecklenburg-Western Pomerania**, the action recommendations for preventative fire safety measures for the construction and operation of inpatient-only care facilities of the 4th generation have been published (Ministry for Energy, Infrastructure and Digitalisation, MV 2009).
- In **Saarland**, the Directive on the Construction and Operation of Hospitals (Hospital Construction Guidelines, KhBauR) was published in 2003. Art. 2 governs the structural requirements and Art. 3 governs the requirements for rooms and groups of rooms.
- The standard programme for hospitals in **Schleswig-Holstein** was published by the Ministry for Social Affairs, Health, Family and Equality of Schleswig-Holstein in 2012.

Para. 1 of Art. 38 ("Special Buildings") of the Regional Building Code of Baden-Wuerttemberg (LBO BW), version dated March 5 2010, states that special requirements may be imposed upon special buildings on a case-by-case basis in order to implement the general requirements of Art. 3 Para. 1. This also applies to fire safety. In **Baden-Wuerttemberg**, the directions of the Ministry of Economics on structural fire safety in hospitals and building structures with a similar purpose ("Hinweise des Wirtschaftsministeriums über den baulichen Brandschutz in Krankenhäusern und baulichen Anlagen entsprechender Zweckbestimmung") (Baden-Wuerttemberg Ministry of Economics, 2007) are intended to serve as a supplementary planning aid.
Let's turn to **Bavaria** for a further example of state-specific construction specifications. Art. 62b Para. 2 No. 1 of the Building Code of Bavaria (BayBO 2007) states that proof of fire safety must be certified by a fire safety inspection expert in the case of fire safety in special buildings or shall be tested by the building authorities.
Structural measures are in the foreground when it comes to fire safety in hospitals. The integrated planning of fire compartments and the safeguarding of escape and rescue routes are an important basis for fire safety measures during architectural design. In order to minimise the fire risk, technical systems such as fire alarm systems, sprinklers, and water/gas extinguishing systems etc. are recommended. In addition to structural and technical system fire safety, operational/organisational fire safety is also important. This includes the creation of the required plans, positioning of the required extinguishers, fire inspection visit and practical training of all employees (BVFA 2009).
Special requirements apply for the rescuing of persons in the case of a fire in a hospital due to the potential immobility of patients. For this reason, the operator of a hospital must work with the fire brigade to create an emergency action plan (along with alarm and evacuation plans) for the coordination of the required measures and the distribution of tasks (Al-Kass 2011).

4.3.2 Fire safety requirements for various product groups

Below, the fire safety requirements for PPE and work clothing, footwear, house and home textiles, furniture, mattresses and floorings are presented. The various areas of a hospital building are taken into account.

4.3.2.1 PPE and work clothing

As a rule, medical personnel wear work clothing (trousers and a tunic/t-shirt or smock); these are worn at work instead of or as well as their own clothes. This work clothing does not have any specific protective function against harmful factors; instead, it aims to protect the wearer's own clothing from contamination and allows employees to be visually distinguished from patients (see KVB 2019, for example). There are no special fire safety requirements for the work clothing.
According to TRBA[28] 250 (2014), protective clothing (personal protective equipment/PPE) must be worn if contamination of work clothing, contact with bodily fluids or excretions, or dangers arising from hazardous substances are to be expected. GUV Rule 189 (2007) states that protective clothing is personnel protective equipment that aims to protect the torso, arms and legs of the wearer from harmful factors at work. Different protective clothing designs can protect against one or more factors. According to this rule, protective clothing in the medical sector has the task of preventing clothing (including work clothing) from being contaminated with micro-organisms, leading to uncontrollable hazards due to spread. With regard to burning properties, GUV Rule 189 refers to DIN EN 533, which has now been withdrawn. According to this standard, protective clothing is suitable for fire protection if it is dimensioned in a way that prevents further burning and corresponds to fire class S-b at the very least (DIN EN 533). GUV Rule 189 states that aprons may also be used as long as the prerequisites mentioned above are met. This includes surgical textiles. DIN EN ISO 14116 (Protective clothing - Protection against flame - Limited flame spread materials, material assemblies and clothing) replaces the withdrawn DIN EN 533 and specifies (indexes 1, 2, and 3) the performance requirements for limited flame spread (see Section 5.3.1).
The DGKH has published (2016) terms and minimum requirements in tabular form with regard to clothing and protective equipment for the caring professions from a hygiene perspective.
No further fire safety requirements for work clothing for caretakers and cleaning personnel are known.

4.3.2.2 Footwear

There are no fire safety requirements for footwear for medical personnel, cleaning personnel or caretakers.

4.3.2.3 House and home textiles

The fire safety requirements for house and home textiles in hospitals are not governed centrally in Germany; instead, they are provided by the various responsible fire safety authorities. The fire safety authority that is responsible for a specific hospital specifies whether the textiles used in patient rooms and in other areas of the hospital (bedding, bedlinen, table linen, blankets, functional towels, terry towelling products) must be made from material that is flame-retardant (see e.g. the Güteausschuss der Gütegemeinschaft sachgemäße Wäschepflege e. V. 2019).
According to the guidelines for fire safety (VdS 2226 2008), "*curtains, carpets, decorations and so on should be made from non-combustible material or, at the very least, materials that are flame-retardant (building material class DIN 4102-A, at least DIN 4102-B1). The textiles must still be flame-retardant after several washes or cleaning cycles.*"
The Working Group on Fire Safety and Hazard Protection of the AGBF and DFV has published recommendations on the risk assessment of fire loads in rescue routes (2014). They state that, in required hallways in hospitals, flame-retardant decorations and curtains as wall coverings

[28] German Technical Rules for Biological Materials

and curtains and blinds for blocking out light are allowed. They are not allowed in required stairwells.

4.3.2.4 Furniture

No legal requirements for the fire safety of furniture (beds, desks, desk chairs, chairs/tables, upholstered furniture, cupboards) are known for the following hospital areas: Patient rooms, doctor's rooms, offices, treatment rooms. The action recommendations for preventative fire safety measures for the construction and operation of inpatient-only care facilities of the 4th generation (Ministry for Energy, Infrastructure and Digitalisation, MV 2009) indicate that fixtures and furniture in the common areas of a utilisation unit must be at least flame-retardant; solid wood furniture is an exception.
For the critical area of rescue routes in the event of a fire, the German Standard Building Regulations basically stipulate that required hallways must be arranged and designed so that they can be used for a sufficient period of time if a fire breaks out (Art. 36, Para. 1 MBO).
The Technical Rules for Workplaces ASR A2.3 (2007) also specify that escape routes, emergency exits and escape hatches must be kept clear so that they can be used at all times. However, according to Plum (2016), the requirement that rescue routes be free from fire loads in accordance with the German Standard Building Regulations does not exclude the fact that "*in individual cases, the planned fire load (e.g. furniture and monitors) and/or the rescue route system itself might be such that fire loads may be permitted in the form of a relaxation of the rules after an analysis and assessment of the risks.*" In the Fire Safety Atlas (Brandschutzatlas, 2018), Al-Kass (2011) states that furniture is not allowed to restrict rescue routes in hospitals; it must be immovable and made of non-combustible materials so that the spread of incipient fire is prevented.
The recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV on the risk assessment of fire loads in rescue routes (2014) are listed in Table 13.

Table 13: Recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV for the risk assessment of fire loads in rescue routes in hospitals (2014) in comparison with other areas of a hospital.

	Other areas such as patient rooms, common areas	**Required stairwell**	**Required hallway** (one of two independent structural rescue routes)	**Required hallway** (primary and concurrent secondary rescue route or only structural rescue route)
Combustible furniture[29]	No restrictions known	Not allowed	Tolerated (in the case of a flame-retardant frame and upholstery with DIN 66084 certification (class P-a) or if encased in A-material)	
Non-combustible furniture (fixed installation, rescue route width maintained)	No restrictions known	Allowed	Allowed	Allowed

[29] Arranged individually taking the width of the rescue route into account.

	Other areas such as patient rooms, common areas	**Required stairwell**	**Required hallway** (one of two independent structural rescue routes)	**Required hallway** (primary and concurrent secondary rescue route or only structural rescue route)
Open coat racks	No restrictions known	Not allowed	Tolerated (only coat hooks, no other fixtures)	Not allowed
Reception counters (horizontal installation flame-retardant, vertical installation non-combustible, use with low fire load)	No restrictions known	Not allowed	Tolerated	Tolerated
Lockers, cupboards	No restrictions known	Not allowed	Tolerated (if non-combustible and tight-closing)	Not allowed

In modern hospitals, gathering points are increasingly situated in places that are open to a required hallway (Al-Kass 2011). In such cases, the function of the hallway as a rescue route may not be restricted. In accordance with the recommendations above (Table 13), reception counters (horizontal installation flame-retardant, vertical installation non-combustible, use with low fire load) are tolerated in required hallways.

4.3.2.5 Mattresses

In Germany, there are no current legal requirements for the fire safety of mattresses in hospitals.

4.3.2.6 Floorings

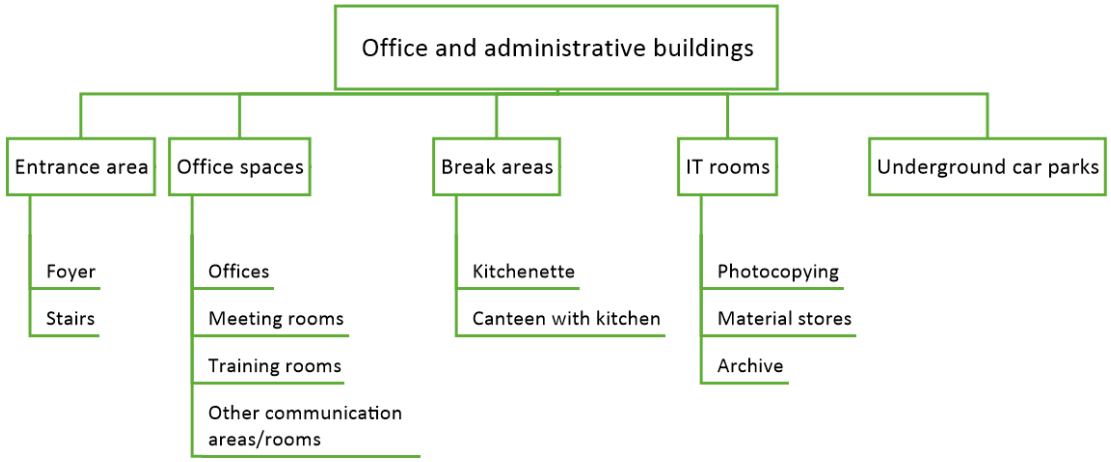
According to Art. 35 Para. 5 MBO, floorings - except for anti-slip sections - must at the very least be made from flame-retardant materials in required stairwells and in spaces between the required stairwell and the exit to the outside (Para. 3 Clause 2). Art. 6 Para. 2 of the Standard Ordinance on Accommodation (MBeVO 2000) states that floorings in required hallways must, at the very least, be made from materials that are flame-retardant. In Saarland, Art. 2.11.2 of the KhBauR (2003) specifies that floorings in generally accessible hallways must, at the very least, be flame-retardant; in stairwells, labs and similar rooms, they must be non-combustible. In all other areas, the MBO requirement that floorings must be normally flammable applies. The harmonised DIN EN 14041 defines parameters for laminate flooring, textile floor coverings and elastic floor coverings with which building material class E_{FL} (see Section 5.4) is achieved without testing. In this standard, DIN EN 13501-1 is required as a testing and classification standard.

4.4 Office and administrative buildings

Usage of office and administrative buildings is different than in residential buildings. During the day, a higher occupancy rate can be expected during normal working hours, whereas at night

and during non-working times like weekends, a building might be empty. This means that fires are more easily noticed and reported during the day. In remote rooms such as technical and installation rooms or storage rooms in the basement, for example, and at night and during non-working hours, early fire detection is possible only through the use of automatic fire alarm systems. An office or administrative building can have the areas depicted in Figure 8.

Figure 8: Common areas in office and administrative buildings.



Source: own work, Fraunhofer WKI.

4.4.1 Requirements relating to structural fire safety

The fire safety requirements depend on the size of the building, which means that the fire safety requirements for building classes 1 to 5, the requirements for special buildings, or the requirements for extremely high buildings (where the top edge of the floor of the highest storey is more than 22 m above ground level) apply.
For escape and rescue routes, MBO 2019 requires at least two separately reachable rescue routes for each storey (Art. 33); the stairwell or the exit to the outside must be accessible from every point in a room intended for occupation by employees after a distance of no more than 35 m. The width of the escape routes is not generally defined; it must be sufficient for the heaviest expected traffic (Art. 36 Para. 2 MBO 2019) and may not be restricted by furniture or similar. Escape from occupiable rooms or utilisation units with occupiable rooms to exits in required stairwells[30] or to the outside takes place via required hallways (2012). In office and administrative buildings, these serve to provide access to the individual offices; they are required for buildings in class 3 and in utilisation units with more than 400 m^2 as per MBO 2019. The walls of the required hallways[31] must be equipped with fire-retardant building elements (fire resistance of 30 minutes).

4.4.2 Fire safety requirements for various product groups

The subsection below provides the fire safety requirements for the product groups specified in Table 8. The various areas of an office or administrative building are included in the remarks.

[30] Required stairs constitute the vertical part of the structural rescue route (Art. 35 Para. 1 MBO).

[31] Required hallways are defined as the horizontal part of the structural escape and rescue route, a link between the occupiable rooms or utilisation units and the vertical part of the escape and rescue route or the exit to the outside (Art. 36 Para. 1 MBO 2019).

Requirements that fall under the scope of the Standard Venue Regulations are described in Section 4.5.

4.4.2.1 PPE and work clothing

There are no fire safety requirements relating to work clothing for caretakers and cleaning personnel. PPE is not required in office and administrative buildings.

4.4.2.2 Footwear

There are no fire safety requirements relating to footwear for caretakers and cleaning personnel.

4.4.2.3 House and home textiles

Required stairwells must be free from fire loads in order to protect life and health and to enable firefighting. For this reason, only non-combustible materials are allowed.
In non-required hallways (hallways in building classes 1 and 2 and utilisation units smaller than 400 m^2) and in all further building parts not described in more detail in this paragraph, there are no special fire safety requirements relating to house and home textiles. For this reason, even combustible materials are allowed to be used.
In all other unspecified areas, there are no fire safety requirements.

4.4.2.4 Furniture

Furniture made from combustible materials is prohibited in required hallways, since otherwise the hallways would not be free from fire loads (Battran 2010). However, such furniture can be tolerated in required hallways if it does not restrict the planned escape width. For more information, see the recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV on the risk assessment of fire loads in rescue routes (2014) in Table 14.
In the case of seating in spatially separated waiting areas, combustible furniture is allowed. In such cases, the wall, door to the hallway and any wall-high large-scale glazing must have a fire resistance of 30 minutes. If the fire load is restricted in the waiting area, glazing with a rating of G30[32] (fire resistance of 30 minutes) must be installed between the waiting area and the hallway. According to Battran (2010), the fire load can be reduced by the following:

- Pads that are flame-retardant on non-combustible frames,
- Tables and chairs made from hardwood,
- No cupboards or electrical devices.

The requirements for reception areas are similar to those for waiting areas. If the reception area is in an escape route, this is not allowed to give rise to any additional fire load.
Required stairwells must be free from fire loads in order to protect life and health and to enable firefighting. For this reason, only non-combustible materials are allowed.
In non-required hallways (hallways in building classes 1 and 2 and utilisation units smaller than 400 m^2) and in all further building parts not described in more detail in this paragraph, there are no special fire safety requirements relating to furniture. For this reason, even combustible materials are allowed to be used.

[32] G-glazing is defined as translucent building elements arranged vertically, at an incline or horizontally, with the aim of only preventing the spread of fire and smoke in accordance with their fire resistance duration. The penetration of heat radiation is merely impaired (DIN 4102-13 (1990)).

Table 14: Recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV for the risk assessment of fire loads in rescue routes in office and administrative buildings (2014) in comparison with other areas.

	Other areas of an office and administrative building	Required stairwell	Required hallway (one of two independent structural rescue routes)	Required hallway (primary and concurrent secondary rescue route or only structural rescue route)
Combustible furniture[33]	No restrictions known	Not allowed	Tolerated (in the case of a flame-retardant frame and upholstery with DIN 66084 certification (class P-a) or if encased in A-material)	
Non-combustible furniture (fixed installation, rescue route width maintained)	No restrictions known	Allowed	Allowed	Allowed
Open coat racks	No restrictions known	Not allowed	Tolerated (only coat hooks, no other fixtures)	Not allowed
Lockers, cupboards	No restrictions known	Not allowed	Tolerated (if non-combustible and tight-closing)	Tolerated (if non-combustible and tight-closing)

4.4.2.5 Mattresses

Mattresses are not relevant for this area.

4.4.2.6 Floorings

In required stairwells, all floorings with the exception of anti-slip sections must be made from materials that are flame-retardant in accordance with Art. 35 Para. 5 MBO 2019. These requirements apply only as of building class 3. The regional building codes of Lower Saxony (NBauO 2012) and Baden-Wuerttemberg (LBO BW 2010) permit the use of normally flammable materials. For North Rhine-Westphalia, the regional building code (Art. 36, Para. 6, No. 3 BauO NRW 2018) states that in required hallways and open corridors, at least flame-retardant floor coverings must be used. In the other federal states, there is only a general requirement that floorings must be normally flammable.
According to MBO 2019, floor coverings in other building areas must be made from at least normally flammable materials. The harmonised DIN EN 14041 defines parameters for laminate flooring, textile floor coverings and elastic floor coverings with which building material class E_{FL} (see Section 5.4) is achieved without testing. In this standard, DIN EN 13501-1 is required as a testing and classification standard.
If the office and administrative space is in a building that is higher than 22 m, the Standard Highrise Directive (MHHR) of 2008 must be applied. Article 3.6 requires that floorings in:

- required stairwells,

[33] Arranged individually taking the width of the rescue route into account.

- anterooms of required stairwells,
- anterooms of fire brigade lift shafts and
- spaces between the required stairwell and the exit to the outside

be non-combustible and that floorings in:

- required hallways

be flame-retardant.

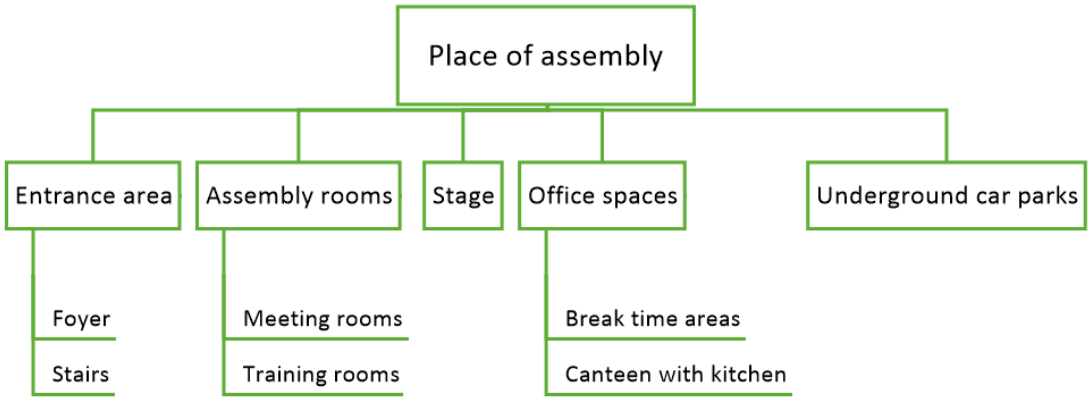
4.5 Places of assembly

Places where large numbers of people congregate for various reasons are called places of assembly (Gröger 2015); they may take the following form:

- an entire building (e.g. a multi-purpose hall),
- a set of buildings (e.g. exhibition grounds),
- building structures outside (e.g. an amphitheatre),
- rooms in buildings that are otherwise used for other purposes (e.g. a lecture hall at a hospital).

A place of assembly can have the areas shown in Figure 9.

Figure 9: Areas at a place of assembly.



Source: own work, Fraunhofer WKI.

4.5.1 Requirements relating to structural fire safety

According to the MBO (2019), places of assembly are regulated special buildings. MVStättVO 2005 governs fire safety requirements in this area and applies in the following cases (Art. 1 Para 1):

- places of assembly with assembly rooms which, individually, can hold more than 200 visitors[34],
- places of assembly with multiple assembly rooms which, in total, can hold more than 200 visitors if these assembly rooms have shared rescue routes,
- places of assembly outside with performance areas and stands that are not flying structures and can, in total, hold more than 1000 visitors,
- sports stadiums and outside sporting facilities with stands that are not flying structures and can, in total, hold more than 5000 visitors.

4.5.2 Fire safety requirements for various product groups

The subsection below provides the fire safety requirements for the product groups specified in Table 9. The various areas of a place of assembly are included in the remarks.

4.5.2.1 House and home textiles

Required stairwells must be free from fire loads in order to protect life and health and to enable firefighting according to MBO 2019. For this reason, only non-combustible materials are allowed.
House and home textiles made from combustible materials are prohibited in required hallways, since otherwise these hallways are not free from fire loads as per MBO 2019.
In non-required hallways (hallways in building classes 1 and 2 and utilisation units smaller than 400 m^2) and in all further building parts not described in more detail in this paragraph, there are no special fire safety requirements relating to house and home textiles. For this reason, combustible materials are allowed to be used.
Curtains on stages and in performance areas must, at the very least, be made from material that is flame-retardant in accordance with Art. 33 MVStättVO. Because they are firmly attached to the place of assembly, curtains on stages and in performance areas are considered to be construction products (Klode 2016).

4.5.2.2 Furniture

Furniture made from combustible materials is prohibited in required hallways, since otherwise the hallways would not be free from fire loads as per MBO 2019 (Battran 2010). Chairs are allowed in required hallways as long as they do not restrict the planned escape width. For more information, see the recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV on the risk assessment of fire loads in rescue routes (2014) in Table 15.
Required stairwells must be free from fire loads in order to protect life and health and to enable firefighting. For this reason, only non-combustible materials are allowed.
In non-required hallways (hallways in building classes 1 and 2 and utilisation units smaller than 400 m^2) and in all further building parts not described in more detail in this paragraph, there are no special fire safety requirements relating to furniture. For this reason, normally flammable materials and materials that are flame-retardant are allowed to be used there, too.
In rooms with a capacity of more than 5000 visitors, the seating must be made from material that is flame-retardant at the very least, and the substructure must be made from non-combustible material (Art. 33 Para. 2 MVStättVO 2005).

[34] The term "visitors" in this context is defined as members of the audience, so passive participants in the event.

Table 15: Recommendations of the Working Group on Fire Safety and Hazard Protection of the AGBF and DFV for the risk assessment of fire loads in rescue routes in places of assembly (2014) in comparison with other areas of a place of assembly.

	Other areas of a place of assembly	Required stairwell	Required hallway (one of two independent structural rescue routes)	Required hallway (primary and concurrent secondary rescue route or only structural rescue route)
Combustible furniture[35]	No restrictions known	Not allowed	Tolerated (in the case of a flame-retardant frame and upholstery with DIN 66084 certification (class P-a), if encased in A-material, or if a sprinkler system is present)	Tolerated (in the case of a flame-retardant frame and upholstery with DIN 66084 certification (class P-a) or if encased in A-material)
Non-combustible furniture (fixed installation, rescue route width maintained)	No restrictions known	Allowed	Allowed	Allowed
Open coat racks	No restrictions known	Not allowed	Tolerated (only coat hooks, no other fixtures, or if a sprinkler system is present)	Tolerated (only coat hooks, no fixtures, and if under constant supervision)
Lockers, cupboards	No restrictions known	Not allowed	Tolerated (if non-combustible and tight-closing)	Tolerated (if non-combustible and tight-closing)

4.5.2.3 Equipment, props, and decorations

Art. 33 MVStättVO governs fire safety requirements for items of this kind. Equipment must, at the very least, be made from material that is flame-retardant; this includes all components of a stage or set (e.g. wall, floor, and ceiling elements). If the stage has an automatic firefighting system, equipment may also be made from normally flammable material. All moving parts of stages and sets are considered to be props (e.g. tableware, furniture, lamps) and must be made from at least normally flammable material. Props are linked to the stage and sets, so there are no further fire safety requirements for these products.
The term "decorations" is defined in this context as items that are temporarily introduced to a place of assembly (such as garlands, flags, artificial plants) (Klode 2016); they must be made from at least material that is flame-retardant. Decorations in required hallways and required stairwells must be made from non-combustible material. Further, decorations made from real plant materials may only remain in the rooms while fresh.

4.5.2.4 Mattresses

Mattresses are not relevant for this area.

[35] Arranged individually taking the width of the rescue route into account.

4.5.2.5 Floorings

Floorings are considered to be construction products and, as such, are governed by the MBO or the building codes of the federal states. Thus, they are subject to the requirement of being classified as at least normally flammable. The harmonised DIN EN 14041 defines parameters for laminate flooring, textile floor coverings and elastic floor coverings with which building material class E_{FL} (see Section 5.4) is achieved without testing. In this standard, DIN EN 13501-1 is required as a testing and classification standard. Art. 5 Para. 7 MVStättVO 2005 states that in the case of required stairwells, floorings in spaces between the required stairwells and exits to the outside must be non-combustible. In required hallways and foyers through which rescue routes from other assembly rooms lead, floorings must be at least flame-retardant.

4.6 Armed forces facilities

The armed forces are subdivided into three areas with different fire safety requirements:

- Navy (fire safety requirements are governed by the IMO FTP Code 2010),
- Army (fire safety requirements are governed by the specifications of the German Standard Building Regulations),
- Air force (fire safety requirements are governed by the specifications of the ICAO).

Fire safety requirements for the navy and air force are more stringent than for the army because in the case of the navy and air force, evacuation may be required at sea or in the air in the case of a fire, which is more difficult.
The fire safety requirements for the clothing of the armed forces are defined in the Technical Terms of Supply of the Armed Forces. The following requirements apply to the three areas of the armed forces:

- Air force

All items of clothing must have been checked in accordance with DIN EN ISO 6941 (2003). For example, flight suits and jackets as per TL 8305-0337 (2010) are exposed to a 950°C flame for 15 seconds after 10 wash cycles. No melting, dripping or hole formation may be observed. The after-flame time may be max. 2 seconds and the after-glow time may be max. 5 seconds. Max. 80 x 30 mm^2 of the test specimen may be destroyed. In addition to the fire behaviour, the shrinkage behaviour as per ISO 17493 (2016) is tested at a temperature of 185°C. After five minutes, the material is not allowed to have shrunk by more than 5%.

- Navy

In this area, clothing must be flame-retardant. The tests take place in accordance with DIN EN ISO 15025 (2017) or DIN EN ISO 6941 (2003) depending on the material. Afterwards, there must be practically no after-glow or after-burn. Further, no melting, dripping or hole formation may be observed. In addition to the fire behaviour, the shrinkage behaviour as per ISO 17493 (2016) is tested at a temperature of 260°C. After five minutes, the material is not allowed to have shrunk by more than 10%.

- Army

In the case of the army, fire safety requirements exist only for the combat uniforms of soldiers. The material is required to be flame retardant as tested as per DIN 53438 (1984), DIN EN ISO 15025 (2017) or DIN EN ISO 6941 (2003). As a rule, the material is exposed to flame for 5 or 10

seconds and may then show after-glow or after-burn for 0-2 seconds and may not drip nor melt. There are fire safety requirements only for service and combat boots in TL 8430-0065 (2020). These must be tested for flame resistance as per DIN EN 15090 (2012). This involves exposing the boots to flame at the following three defined points for 5 seconds as described in Appendix E of TL 8430-0065:

1. Point of transition from leather upper to tongue with stitching, eyelet and lace.
2. Corner point of transition between leather upper and leather insert with stitching.
3. Point of transition between leather upper and midsole.

During and after the test, the material may not show after-burn and may not melt or drip. Table 16 compares the individual test methods used in the armed forces for flame retardancy.

Table 16: Comparison of standards for fire tests of textiles and combustible materials.

Standard	Material	Test method	Sample size [mm²]	Burner position	Duration of flame exposure
DIN EN ISO 6941	Textiles	Method A (surface ignition)	560 x 170	Horizontal to surface of sample	10 seconds
		Method B (lower edge ignition)	560 x 170	At an angle of 30° to surface of sample	10 seconds
DIN EN ISO 15025	Textiles (PPE)	Method A (surface ignition)	200 x 160	Horizontal to surface of sample	10 seconds
		Method B (lower edge ignition)	200 x 80	At an angle of 30° to surface of sample	10 seconds
DIN 53438-2	Combustible materials (e.g. plastics, wood, paper)	Edge ignition	190 x 90	At an angle of 45° to surface of sample, flame tip in centre of lower edge	15 seconds
DIN 53438-3		Surface ignition	230 x 90	At an angle of 45° to surface of sample, flame tip in centre of sample	15 seconds

4.7 Police and customs

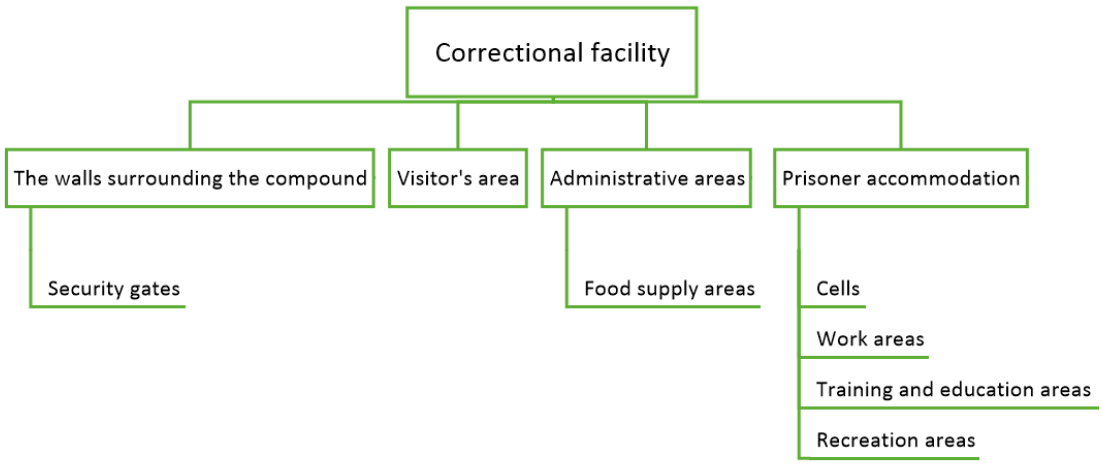
Buildings of the police force and customs authority generally fall into the "Office and administrative buildings" category. For this reason, the fire safety requirements for interior fittings are similar to those described in Section 4.4. There are no fire safety requirements for

the clothing of customs and police officers. In closed units (riot police), clothing made from flame-retardant materials should be procured, as tested in accordance with DIN EN ISO 11612.

4.8 Correctional facilities

Correctional facilities aim to enforce legally ordered custodial sentences and to provide accommodation for preventative detention orders (Otto 2012). These facilities are defined as "*...correctional authorities under full-time management in the form of lower independent administrative units in the area of the penal system*" (NRW Justice 2020). Custodial sentences, preventative detentions, juvenile sentences, pretrial detentions, civil confinements, detentions prior to deportation and detentions prior to extradition are imposed in such facilities. Due to the closed nature of these facilities, such buildings are subdivided into the areas listed in Figure 10 (Otto 2012).

Figure 10: Areas of a correctional facility.



Source: own work, Fraunhofer WKI.

4.8.1 Requirements relating to structural fire safety

The requirements placed upon correctional facilities are governed by the individual federal states through their regional building codes. Art. 2 Para. 4 Point 14 of the MBO 2019 defines correctional facilities as unregulated special buildings due to the lack of any special building regulations. This means that the fire safety of the facility must be considered in a fire safety concept with a view to ensuring adequate protection. Because a correctional facility generally consists of utilisation units that are larger than 400 m^2 with a top edge of the floor of the topmost storey that is more than 13 m above ground level, the buildings are usually classified into building class 5 (Otto 2012).

4.8.2 Fire safety requirements for various product groups

The subsection below provides the fire safety requirements for the product groups specified in Table 8. Since correctional facilities are unregulated special buildings, there are no legal requirements relating to the fire safety of house and home textiles, furniture and mattresses for many areas. Floorings - except for stairwells - are required to be normally flammable. An

individual fire safety concept might place more stringent requirements upon these product groups. Legally, the following areas are defined for correctional facilities:

- Art. 36 Para. 1 Clause 2 of the German Standard Building Regulations (MBO 2019) prescribes required hallways in correctional facilities with utilisation units of more than 200 m^2.
- In required stairwells, all floorings with the exception of anti-slip sections must be made from materials that are flame-retardant in accordance with Art. 35 Para. 5 MBO 2019.

The fire safety requirements for correctional facilities are governed by the individual federal states, too. In Bavaria, there is a recommendation for the construction of correctional facilities, and this recommendation is also implemented there (Supreme Building Authority of Bavaria 2006). This recommendation states that all furniture, mattresses and house and home textiles must be made from materials that are flame-retardant. The test takes place as per British Standard BS 5852 2006 with ignition source 5 (see Section 5.1.3). The recommendation states that tables, chairs and cupboards should be made from solid wood.

4.9 Fire brigade facilities

A modern fire station consists of one or more halls for service vehicles along with administrative areas, workshops, break rooms, training rooms and sanitary facilities. There are also sleeping quarters in fire stations that work full time.

4.9.1 Fire safety requirements for various product groups

In the "Fire brigades" area, this research project deals only with requirements for PPE and footwear.
The Occupational Health and Safety Act (ArbSchG 1996) forms the legal basis for occupational protection equipment. One of the aims of the law is to "*safeguard and improve the health and safety of employees at work through occupational health and safety measures*". The Ordinance on the Use of Personal Protective Equipment (PSA-Benutzungsverordnung 1996) applies to the provision of personal protective equipment by the employer and to the use of such equipment by employees at work. The "Fire brigade" accident prevention regulations (DGUV Regulation 49) stipulate in Art. 14 on PPE, for example, that: "*In order to protect employees from hazards during training, exercises and deployment, appropriate personal protective equipment must be selected and made available*". The minimum required equipment is: Protective firefighter clothing, firefighter's helmet with neck protection, firefighter's safety gloves and firefighter's safety boots. The requirements upon protective clothing are defined in the various accident prevention regulations of the fire brigades' accident insurance companies.

4.9.1.1 Work clothing, PPE and footwear

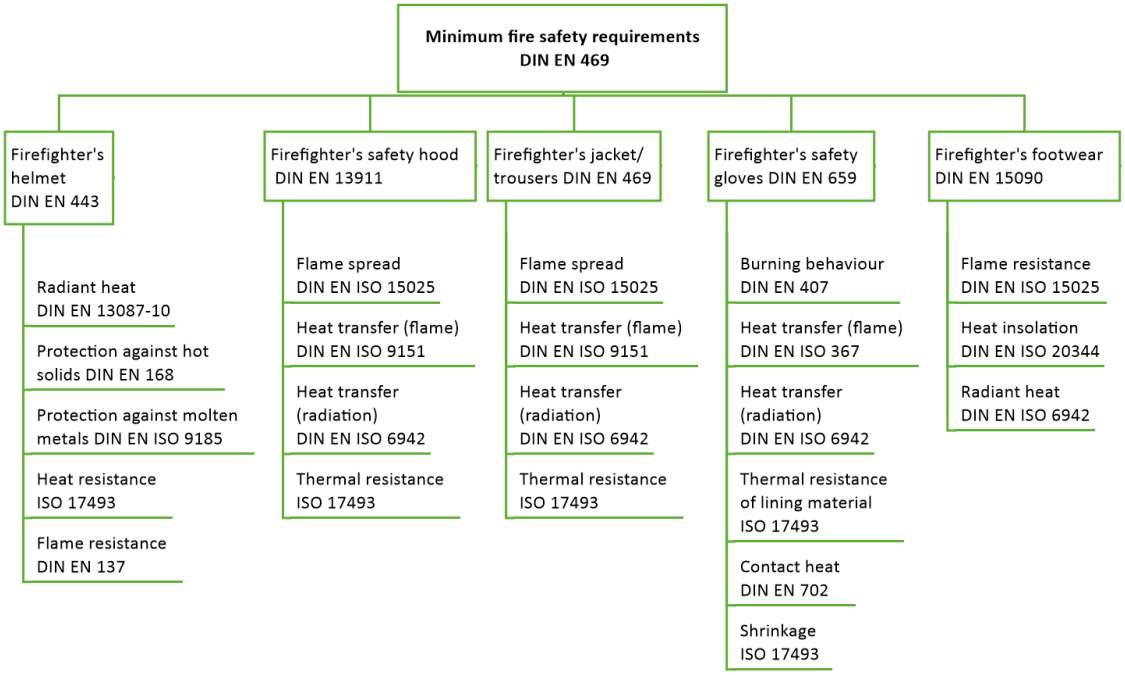
There are no fire safety requirements relating to work clothing and footwear for caretakers and cleaning personnel.
Minimum fire safety requirements for the uniforms of firefighters are governed by the following standards:

- Firefighter's safety helmet as per DIN EN 443
- Firefighter's safety hood as per DIN EN 13911
- Firefighter's safety boots as per DIN EN 15090
- Firefighter's safety gloves as per DIN EN 659

- Firefighter's jacket as per DIN EN 469
- Firefighter's trousers as per DIN EN 469

See Figure 11 for information on the corresponding standards.

Figure 11: Relevant standards for fire safety requirements upon protective clothing for firefighters.



Source: own work, Fraunhofer WKI.

For details on requirements for protective clothing for firefighters and the corresponding standards, see Section 5.3.3.

4.10 Fire safety requirements in the private sector

Sections 4.1 to 4.9 deal with the fire safety requirements upon the product groups listed in Table 7 to Table 9 for public areas. In the section below, the fire safety requirements for product groups in public areas are compared with those in the private sector. This is done using accommodation facilities as an example.

4.10.1 Accommodation facilities

Art. 2 Para. 1 of the Standard Ordinance on Accommodation (MBeVO 2000) defines accommodation facilities as "*buildings or parts of buildings that are intended in part or in whole for the accommodation of guests, except for holiday home accommodation.*"
The requirements upon fire safety in accommodation facilities are described in the MBeVO (2000) as well as in the German Standard Building Regulations (MBO 2019). As defined in the MBeVO, this Ordinance is to be applied as of 12 accommodation beds. In the federal states of Hesse and North Rhine-Westphalia only, the state-specific ordinances apply as of 30 accommodation beds. The fire safety requirements for the product groups included in this research project are extremely similar to those of the public sector; in addition to the MBO, Art.

6 of the MBeVO requires a material classification of at least "flame-retardant" for floorings in required hallways. This rule applies as of building class 3 and, contrary to the MBO (2019), also applies to utilisation units that are smaller than 200 m^2.
As is also demonstrated for the public areas, there are no legal fire safety requirements for furniture, mattresses and home textiles outside escape and rescue routes. The German Hotel Association (Hotelverband Deutschland) has published a brochure on fire safety in hotels (HOTREC 2010). This requires that all interior fittings and decorations in guest rooms, hallways, staircases and public areas - such as floorings, curtains, lampshades, suspended ceilings and light fittings - should be flame-retardant. Further, it is suggested that interior furnishings such as furniture and beds should be flame-retardant.

4.11 Summary

There are different fire safety requirements for the investigated product groups (PPE and work clothing, footwear, house and home textiles, furniture, mattresses and floorings); the requirements depend on the area where they are used (nurseries, schools, hospitals, office and administrative buildings, armed forces, correctional facilities, places of assembly, fire brigade, police/customs).
Apart from lab coats and footwear for science lessons, there are no special fire safety requirements for **work clothing, PPE and footwear** in nurseries and schools. The Association of Occupational Accident Insurance Funds (GUV) has compiled a set of guidelines for PPE in hospitals, but fire safety is dealt with only by a reference to a standard. In contrast, fire safety properties play a major role when it comes to clothing for riot police, certain parts of the armed forces (in particular the air force and navy) and the fire brigade. The minimum fire safety requirements for uniforms for firefighters are governed by the accident prevention regulations and are defined in numerous standards. No special fire safety requirements are placed upon office and administrative buildings or correctional facilities here.
No legal fire safety requirements could be found for **furniture** and **house and home textiles** in nurseries, schools, office and administrative buildings, and hospitals outside the (required) escape and rescue routes. Escape and rescue routes must be kept free from fire loads in accordance with the German Standard Building Regulations. More stringent requirements may be placed upon building equipment in individual fire safety concepts for hospitals and administrative buildings, for example. The legal provisions for correctional facilities are the responsibility of the individual federal states. There is only extremely restricted access to information relating to fire safety requirements. Thus, it was only possible to examine the state of affairs in Bavaria in this study. In Bavarian correctional facilities, materials that are flame-retardant must be used for furniture and for house and home textiles. The "Furniture" and "House and home textiles" product groups were not investigated for the "Fire brigade" and "Police/Customs" areas.
Currently, there are no statutory fire safety requirements upon **mattresses** for hospitals and nurseries in Germany. Materials that are flame-retardant are to be used for mattresses in Bavarian correctional facilities. Mattresses are not relevant in schools or in office and administrative buildings and were therefore not considered here. No more detailed investigation was performed in the "Fire brigade", "Armed forces" and "Police/Customs" areas.
The fire safety requirements upon **equipment**, **props** and **decorations** in places of assembly are described comprehensively in the Standard Venue Regulations. Equipment and decorations must at least be flame-retardant; in contrast, for props there is merely a requirement that they be normally flammable.
Floorings are considered to be building materials and must correspond to the "normally flammable" building material class. According to the German Standard Building Regulations,

floorings in required stairwells etc. must be made from at least building materials that are flame-retardant. Some regional building codes and the Standard Ordinance on Accommodation extend the requirement that floorings be flame-retardant to required hallways in the investigated areas. In office and administrative buildings, the fire safety requirements for floorings also depend on the building class. The Standard Venue Regulations place more stringent requirements upon floorings; in this case, floorings in required stairwells etc. must be non-combustible and, in required hallways etc., they must be at least flame-retardant.
Finally, it can be stated that there are far fewer legal regulations relating to fire safety requirements for the investigated product groups than was assumed at the start of the research.

5 Test methods for product fire behaviour

"Fire behaviour" is defined as the response of a test specimen when it is exposed to fire under specified conditions in a fire test (DIN EN ISO 13943). Below, the relevant test methods for the product groups "Upholstered furniture", "Mattresses", "House and home textiles", "Work clothing", "PPE", "Footwear" and "Floorings and other construction products" are described.
In the context of verification procedures, a distinction must be made between "building material tests" and "material tests". Construction products are building materials and elements that are installed permanently in building structures (structural and civil engineering) and building materials and elements of prefabricated facilities that are connected to the ground (e.g. Gabler Wirtschaftslexikon 2019). Thus, construction products are products that have a fixed connection to a building and whose position within the structure cannot be easily changed, e.g. bricks (building material), walls (building element) or even curtains on stages and sets. These products are tested and classified with regard to their fire behaviour at national level in accordance with DIN 4102 or at EU level in accordance with the harmonised standard DIN EN 13501. DIN EN 13501 offers more extensive classification features than DIN 4102, also covering the side effects of fire such as smoke development and the dripping/falling of burning materials. In the case of upholstered furniture, mattresses and house and home textiles, special testing standards providing for the testing of the product as a whole exist (e.g. DIN 66084 for upholstered composites). Despite this, the textiles making up the products are often also tested in accordance with DIN 4102 or DIN EN 13501. A direct comparison of the properties of an upholstered composite tested as per DIN 66084 with an upholstery fabric classified as flame-retardant as per DIN 40102 or DIN EN 13501 is not possible.

5.1 Test methods for upholstered furniture, mattresses and house and home textiles

5.1.1 Classification of the fire behaviour of upholstered composites and mattresses

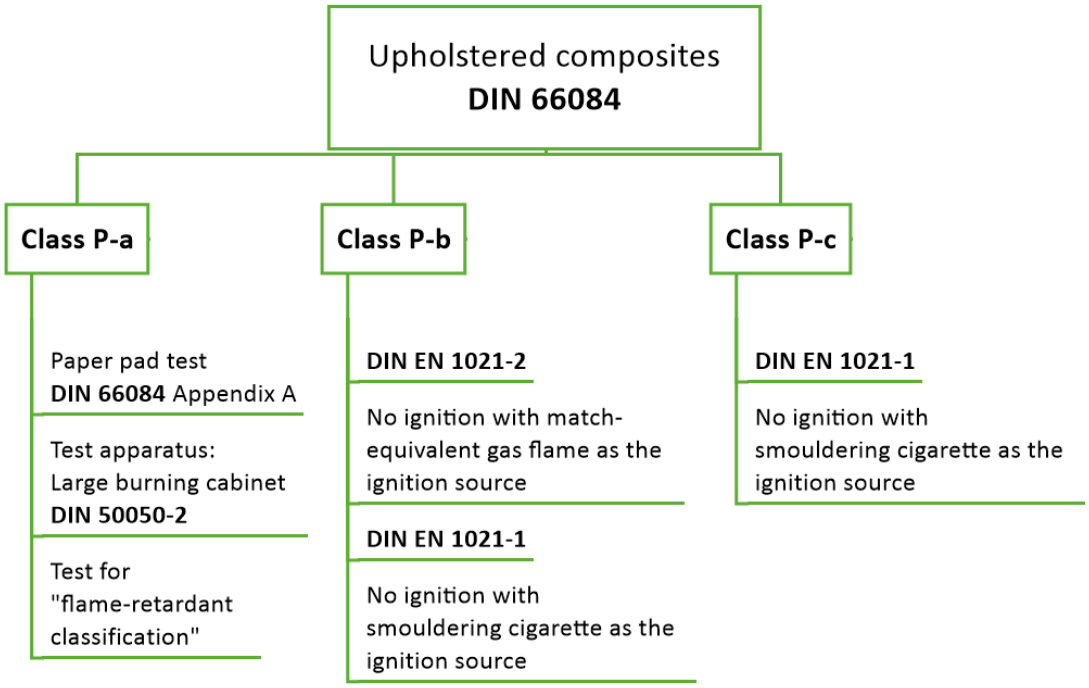
The fire behaviour of upholstered composites[36] is assessed as per DIN 66084 and is classified into the following three classes:

1. Class P-a → Material passes the paper pad test
2. Class P-b → Material passes the match flame test and the smouldering cigarette test
3. Class P-c → Material passes the smouldering cigarette test

Class P-a represents the most stringent fire safety requirements and denotes the least combustible upholstered composites. The subsections below briefly describe the individual fire test methods, starting with class P-c. Figure 12 provides an overview of the classes and the related standards.

[36] Upholstered composite as per DIN 66084: A combination of different layers and materials (e.g. upholstery cover fabric with an intermediate layer and base upholstery) as used in an end product.

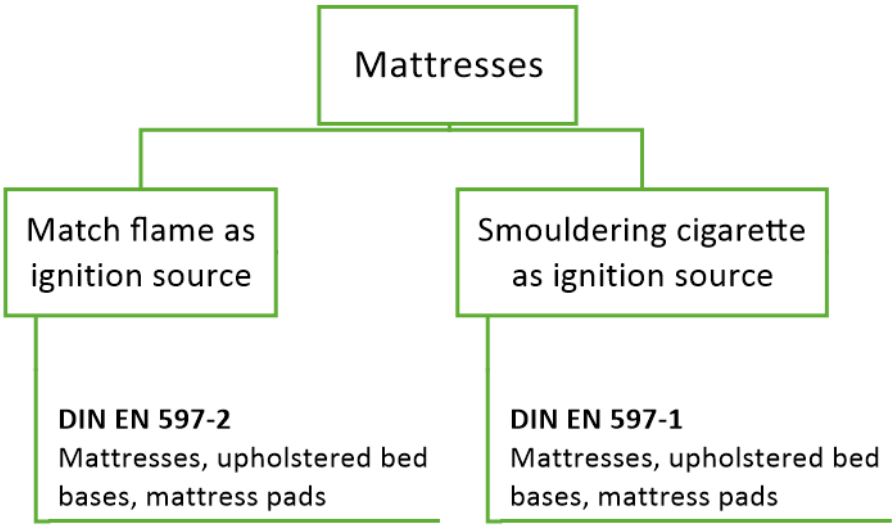
Figure 12: Classification of fire behaviour of upholstered composites.



Source: own work, Fraunhofer WKI.

For mattresses, there are two internationally recognised tests. These are shown in the diagram in Figure 13.

Figure 13: Assessment of ignitability of mattresses (mattress pads) and upholstered bed bases.



Source: own work, Fraunhofer WKI.

5.1.1.1 Assessment of ignitability of mattresses and upholstered furniture with a smouldering cigarette as the ignition source

The ignitability of mattresses, upholstered bed bases and mattress pads can be assessed with the test method described in DIN EN 597-1. The ignition source used is a smouldering cigarette (Figure 13).
DIN EN 1021-1 defines the test method for determining the ignitability of material assemblies such as covers and fillings for upholstered seating furniture. Here, again, a smouldering cigarette is used as the ignition source. However, the tests as per DIN EN 1021-1 determine the ignitability only of a combination of materials and not the ignitability of a specific finished piece of furniture consisting of these materials.

Properties of specimens

According to DIN EN 597-1, for small-scale tests, the representative test unit must be rectangular with a minimum size of 450 mm x 450 mm x the nominal thickness of the finished mattress, mattress pad or upholstered bed base. For large-scale tests, the actual product is tested.
According to DIN EN 1021-1, the test unit includes materials from representative samples of the cover, inner cover[37], filling and other components that can be used in a real seat structure. The dimensions for the testing of the outer cover[38] must be 800 mm x 650 mm. For the testing of the inner cover, the same dimensions and orientation apply as for the outer cover under which the inner cover is attached on the test frame. For each upholstery padding test, two pieces measuring 450 mm x 300 mm x 75 mm (thickness) and 450 mm x 150 mm x 75 mm (thickness) are required. Covers that have been chemically treated to reduce ignitability must be soaked and dried before conditioning. All materials to be checked and the cigarettes must be conditioned.

Test setup

The test frame for the assessment of the ignitability of mattresses as per DIN EN 597-1 consists of a support made from expanded or open mesh with a minimum size of 450 mm x 450 mm fixed at least 75 mm above a solid base.
The test frame for the assessment of upholstered furniture as per DIN EN 1021-1 must consist of two hinged rectangular frames that can be fixed at a right angle to each other.

Test execution

The test unit is placed onto the test frame for the small-scale testing of mattresses as per DIN EN 597-1. For large-scale testing, bed bases[39], mattresses or mattress pads are tested on a horizontal surface. In the specified period, two cigarettes[40] are lit and air is sucked through until the tip glows brightly. The smouldering cigarette is applied to a flat part of the top surface of the test unit so that it is at least 50 mm from the next edge or from any marks from earlier tests. The combustion process is observed and any sign of the ignition of the test unit such as progressive smouldering or incipient flames is recorded.
For the testing of upholstered furniture as per DIN EN 1021-1, the cover, inner cover and padding samples must be pulled into the test frame and secured. Two smouldering cigarettes (conditions as per DIN EN 597-1) are to be placed into the test unit along the joint between the horizontal and vertical part so that the cigarettes are at least 50 mm from one of the side edges

[37] Material layer between the outer cover and the upholstery padding with a nominal thickness equal to or less than 2 mm.

[38] Outer layer of the furniture part.

[39] The feet of the bed bases can be attached if they are present in the actual product.

[40] Cylindrical cigarettes without filters are used.

or from any other marks from earlier tests. The combustion process is observed and any sign of progressive smouldering or burning in the upholstery/cover is recorded.

Criteria for passing the test

The assessment of ignitability as per DIN EN 597-1 and DIN EN 1021-1 takes place on the basis of the burning and smouldering criteria. The smouldering criteria include the following:

a) Hazardous, escalating combustion
b) Test unit consumed
c) Smouldering to the edges (applies for DIN EN 1021-1 – upholstered furniture)
d) Smouldering through the entire thickness
e) Smouldering for more than 1 hour
f) Signs of progressive smouldering upon final examination
The burning criteria include the appearance of flames.
The test is considered to have been passed if none of the above criteria are met.

5.1.1.2 Assessment of ignitability of upholstered furniture and mattresses with a match-equivalent gas flame as ignition source

DIN EN 597-2 describes a test method for the assessment of the ignitability of mattresses, upholstered bed bases or mattress pads with a gas flame used as the ignition source. The entire upper surface or typical parts of the upper surface of the test specimens are brought into contact with a match-equivalent gas flame in a way that allows all areas with different properties to be tested.
DIN EN 1021-2 defines a test method for determining the ignitability of material assemblies such as covers and paddings for upholstered seating furniture when these, too, are exposed to a small gas flame as the ignition source. These tests provide a point of reference but cannot guarantee the ignition behaviour of the finished piece of furniture.

Properties of specimens

The specimens correspond to those from DIN EN 597-1 and DIN EN 1021-1 (see Section 5.1.1.1).

Test setup

The test setups correspond to those from DIN EN 597-1 and DIN EN 1021-1 (see Section 5.1.1.1).

Test execution

The test unit is placed onto the test frame for the small-scale testing of mattresses as per DIN EN 597-2. For large-scale testing, the specimens are tested on a horizontal surface. The burner pipe is directed at a flat part of the upper surface of the test unit for 15 seconds so that it is at least 100 mm from the nearest edge or from any burn marks from previous tests. The combustion process is observed and any sign of ignition in the upholstery and/or cover such as progressive smouldering or incipient flames is recorded.
For the testing of upholstered furniture as per DIN EN 1021-2, the cover, inner cover and padding samples must be pulled into the cleaned test frame and secured. The upholstered composite is set up so that - like in the case of a normal armchair - it represents (in stylised form) the transition between the seat and the back section. The burner pipe is to be placed along the joint between the horizontal and vertical part of the test unit so that the flame is at least 50 mm from one of the side edges. The gas must be allowed to burn for 15 seconds and the ignition process should then be ended through the careful removal of the burner pipe from the specimen. The combustion process is observed and any sign of progressive smouldering or burning in the upholstery and/or cover must be recorded.

Criteria for passing the test

The assessment of ignitability as per DIN EN 597-2 and DIN EN 1021-2 takes place on the basis of the burning and smouldering criteria. The smouldering criteria include the following:

a) Hazardous, escalating combustion

b) Test unit consumed

c) Smouldering to the edges (applies for upholstered furniture - DIN EN 1021-2)

d) Smouldering through the entire thickness

e) Smouldering for more than 1 hour

f) Signs of progressive smouldering upon final examination

The burning criteria include the following:

a) Hazardous, escalating combustion

b) Test unit consumed

c) Burning to the edges (applies for DIN EN 1021-2 - upholstered furniture)

d) Burning through the entire thickness

e) Flames for longer than 120 seconds

f) Burning for longer than 120 seconds (applies for DIN EN 1021-2 - upholstered furniture)

The test is considered to have been passed if none of the criteria listed above are met.

5.1.1.3 Determination of burning behaviour with a paper pad

Appendix A of DIN 66084 describes a method for determining the burning behaviour of upholstered compounds. The test simulates the effects of a burning piece of paper or newspaper on a seat. This allows the burning behaviour of seats during the incipient fire stage to be assessed.

Properties of specimens

The upholstery elements (moulded upholstery parts, cover fabric) are tested.

Test setup

The test is performed in a burning cabinet as per DIN 50050-2. The specimens are attached to a test frame (450 mm x 450 mm x 300 mm). The paper pads consist of 100 g of white, unprinted paper (45 to 50 g/m^2).

Test execution

The specimens and paper pads are conditioned in a normal climate before the test. Three specimens of the same type must be tested. The moulded upholstery parts are placed onto the mesh floors of the test frames; the cover fabric is pulled over the top of the frames and is stapled at the rear. The specimen is to be positioned centrally in the burning cabinet. The paper pad is placed centrally, flat on the seat, so that the unstapled long side touches the backrest. All four corners of the paper pad are ignited and the burning cabinet is closed. The following are measured:

- The maximum flame height from the surface of the seat, rounded to 10 cm
- The time until the flames extinguish themselves, in minutes or seconds

- The time until the tip of the flames reaches the top edge of the backrest, in minutes or seconds
- The time until the fire starts to abate, in minutes or seconds
- The time until the tip of the flames falls back below the top edge of the backrest, in minutes or seconds
- The time until the after-glow disappears, in minutes or seconds

The total test time is max. 15 minutes. The destroyed upholstery areas are measured.

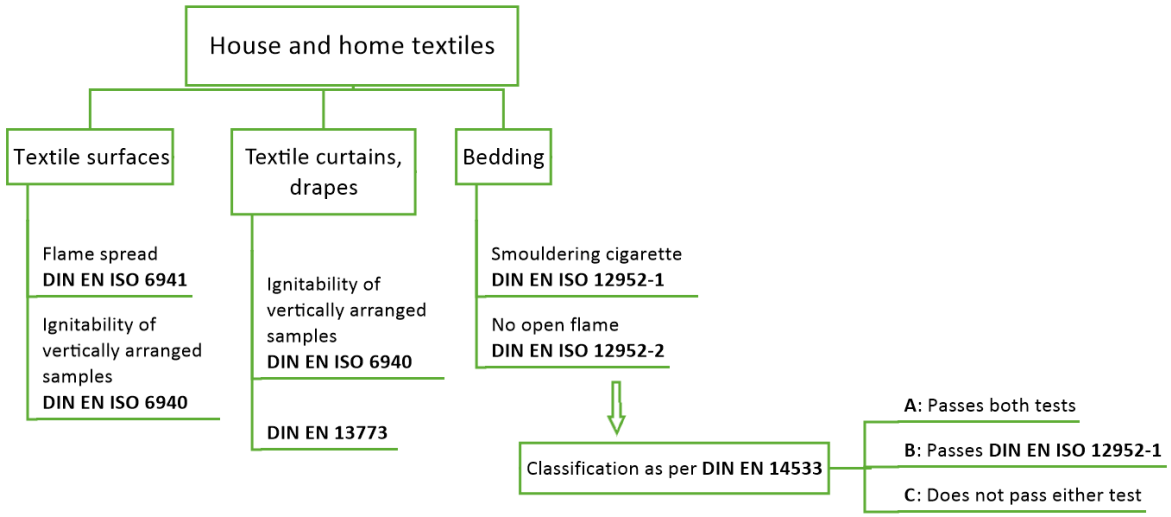
Criteria for passing the test

In order for the test to be considered to have been passed, the height of the flames may not exceed the top of the backrest of the investigated piece of upholstered furniture by more than 45 cm and the flame front may not reach the armrests or edges of the upholstered surface. The flames must go out after 15 minutes.

5.1.2 Classification of the fire behaviour of house and home textiles

House and home textiles[41] include drapes and curtains, blankets, bedlinen and table linen used for interior fittings and decoration. The burning behaviour of textiles is described by the ignitability, flame spread speed, heat development, shrinkage, melting, smoke development and formation of toxic gases (Meckel 1978). Figure 14 gives an overview of the relevant standards for the testing of fire behaviour and the classification of house and home textiles.

Figure 14: Standards for testing the burning behaviour and for the classification of house and home textiles[42].



Source: own work, Fraunhofer WKI.

[41] House and home textiles are goods that are used for interior design and fittings. This includes blankets, throws, bedlinen, table linen, kitchen linen, bathroom textiles, toilet linen, curtains, drapes, valances, passements and furniture coverings.

[42] "Bedding" is a general term for all items used on a mattress or bed for comfort, warmth and decoration (see also Section 5.1.2.3).

5.1.2.1 Test of inflammability of textile surfaces

The burning behaviour of textile surfaces is tested on the one hand with DIN EN ISO 6941 (2003) through the measurement of the flame spread properties of vertically arranged samples. On the other hand, DIN EN ISO 6940 (2004) specifies the method for the determination of the ignitability of vertically arranged samples.
DIN EN ISO 6941 describes a method for measuring the flame spread time of vertically arranged textile surfaces and industrial products in the form of individual textiles or textile composites (coated, quilted, multi-layer, composite constructions and similar combinations). In this case, a small defined flame from a specified burner acts upon the surface or lower edge of vertically arranged test samples for 10 seconds. The flame spread time required by the flame front to move between marker threads located at three distances from the ignition flame on the surface of the test sample is recorded.

Properties of specimens

The test uses six test samples. In three of these test samples, the fibres must run lengthwise, and in the other three, they must run crosswise. The test samples are cut to 560 mm x 170 mm.

Test setup
Method A (surface ignition): The test sample is attached to the support pins of a measurement sample holder so that the pins pass through the points marked with the template and so that the rear of the test sample is at least 20 mm away from the rectangular metal frame of the test sample holder. The test sample holder is attached to the mounting frame so that the test sample is in a vertical position. The burner is positioned perpendicular to the surface of the test sample so that the axis of the burner stabiliser is 20 mm above the line of the lower support pins and is aligned with the vertical centre line of the front side of the test sample. The mouth of the burner must be at least 17 mm from the surface of the test sample. The burner is brought into the horizontal stand-by position and the horizontal reach of the flame is set to 25 mm.

Method B (lower edge ignition): The test sample is attached to the support pins of a measurement sample holder so that the pins pass through the points marked with the template and so that the rear of the test sample is at least 20 mm away from the rectangular metal frame of the test sample holder. The test sample holder is attached to the mounting frame so that the test sample is in a vertical position. The burner is positioned on the front side but below the test sample so that it is aligned in a plane that passes through the vertical centre line of the test sample and is vertical to its surface. Further, its longitudinal axis slants upwards from the lower edge of the test sample at an angle of 30°. The distance to be measured between the mouth of the burner stabiliser and the lower edge of the test sample must be 20 mm. The burner must be brought into the vertical standby position. The flame height is set to 40 mm.

Test execution
For the surface ignition test (method A), the first test sample from a set of fresh test samples is attached to the test sample holder. The marker threads are applied in defined positions. The test flame is directed at the test sample for 10 seconds or for the ignition time determined as per ISO 6940. The effects must be observed and documented in accordance with the following:

a) The time in seconds from the start of the action of the test flame to the breaking of the lower (first) marker thread.

b) The time in seconds from the start of the action of the test flame to the breaking of the central (second) marker thread.

c) The time in seconds from the start of the action of the test flame to the breaking of the top (third) marker thread.

The procedure for lower edge ignition (method B) is the same as for method A except for the position of the flame.

5.1.2.2 Test of burning behaviour of textile curtains and drapes

DIN EN 1101 describes the method for determining the ignitability of vertically arranged textile samples with a small flame; the test takes place as per DIN EN ISO 6940. DIN EN 1101 describes the sampling, cleaning, nature and conditioning of the test samples along with the execution of the test and the compilation of a test report.
The detailed method for determining the flame spread properties of textiles for curtains and drapes as vertically arranged samples is defined in DIN EN 1102; the test takes place as per DIN EN ISO 6941. DIN EN 1102 describes the sampling, cleaning, nature and conditioning of the test samples along with the execution of the test and the compilation of a test report.
The method for measuring the flame spread properties of vertically arranged textile test samples with a large ignition source is described in DIN EN 13772. The test uses an electric radiant panel and the small flame defined in DIN EN ISO 6941. The criteria to be looked out for here are burning sample parts falling off the sample and flame spread measured via the breaking of the first and third marker threads[43].
DIN EN 13773 describes the classification of textiles for curtains, drapes and similar, such as blinds and textile wall hangings, for which a classification is required. The classification takes place on the basis of the assessment of ignitability and flame spread when using two different ignition sources with different heat intensities in accordance with edge ignition as per DIN EN 1101 and DIN EN 1102. The most important factor for the classification is whether or not ignition occurred.

Table 17: Definition of classes for the burning behaviour of curtains and drapes as per DIN EN 13773.

Class	Ignitability	Flame spread
1	No ignition as per DIN EN 1101	First marker thread does not break, no burning parts falling from samples as per DIN EN 13772
2	No ignition as per DIN EN 1101	Third marker thread does not break, no burning parts falling from samples as per DIN EN 13772
3	No ignition as per DIN EN 1101	Third marker thread breaks and/or burning parts fall from samples as per DIN EN 13772
4	Ignition as per DIN EN 1101	Third marker thread does not break, no burning parts falling from samples as per DIN EN 1102
5	Ignition as per DIN EN 1101	Third marker thread breaks and/or burning parts fall from samples as per DIN EN 1102

The following criteria apply for the classification as per DIN EN 13773:

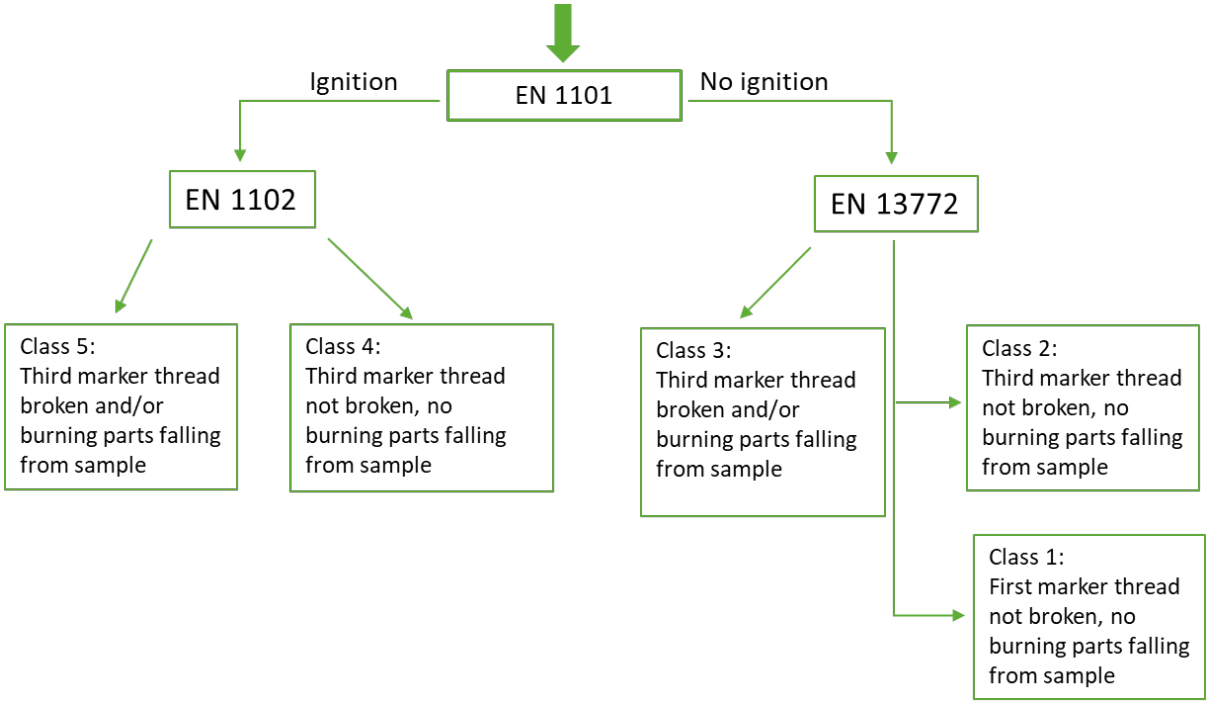
- If at least two of the six test samples show breakage of the marker thread and/or burning parts falling from the samples and if this result corresponds to the result of a higher class, the entire material must be assigned to the higher class.

[43] According to DIN EN 13772, marker threads are made from pure cotton with a fineness of 45 (± 5) tex.

- If only one of the six test samples shows ignition of the marker thread and/or burning parts falling from the samples and if this result corresponds to the result of a higher class, three new test samples must be tested.
- If none of these new test samples gives a result that is assigned to a higher class, the material must be assigned to the lower class.
- If the result of the test on one of these new test samples is assigned to a lower class, the entire material must be assigned to this class.

The main classification elements are shown in the flow chart in Figure 15.

Figure 15: Burning behaviour of curtains and drapes: Main classification elements as per DIN EN 13773.



Source: own work, Fraunhofer WKI.

5.1.2.3 Test of burning behaviour of bedding

Fires can be caused as a result of the ignition of bedding by smoking paraphernalia. For this reason, the ignitability of bedding by means of a smouldering cigarette (DIN EN ISO 12952-1) or a small open flame (DIN EN ISO 12952-2) is an important factor when assessing fire risk. The standards state that the relevant samples must be subjected to both ignitability tests, since protection against a smouldering ignition source does not necessarily protect against ignition by flame. DIN EN ISO 12952 Parts 1 and 2 apply to bedding that is usually placed on or above a mattress, such as mattress covers, underlays, incontinence sheets, bottom sheets, blankets, electric blankets, quilts (duvets) and bed covers, pillows and bolsters, and pillowcases. Both standards can be applied for the assessment for the ignitability of individual items of bedding and for combinations thereof. However, these standards are not applicable to mattresses, bed frames and mattress pads.

Properties of specimens

The components and setup of the test samples must be representative of the actual item, since the design and finish of the bedding can have a significant influence on the risk of ignition. For example, the density of pleats can have a considerable influence on the test results. Before testing, the bedding must be chemically cleaned five times in accordance with DIN EN ISO 6330, DIN EN ISO 10528 or DIN EN ISO 3175-2 depending on the materials. The materials to be tested must be conditioned first.

Test setup

The test frame consists of a platform measuring min. 450 mm × 450 mm over a solid support. It must be at least as large as the test sample, but can be larger. According to DIN EN ISO 12952-1, the ignition source must be a cylindrical cigarette without a filter that has been conditioned appropriately and, as per DIN EN ISO 12952-2, a butane gas flame. The test room must be larger than 20 m^3 and must contain sufficient oxygen for the test; alternatively, a smaller chamber with an inlet and outlet system for flowing air may be used. The flow speed on the test specimen may be no more than 0.2 m/s to ensure a sufficient flow of oxygen without disrupting the burning behaviour. The test pad on which the bedding is tested simulates a mattress. It consists of mineral wool upholstery with a defined thermal conductivity and must correspond to the size of the test frame with a thickness of 25 mm. The test pad can be replaced by the actual mattress used. The test pad and cigarettes must be conditioned before the test.

Test execution

During the test, the environment must be free from draughts and must have a temperature of between 10 and 30 °C and a relative air humidity of between 15 and 80 %. The test sample is placed on a test pad and exposed to a smouldering cigarette as per DIN EN ISO 12952-1 or a small open flame as per DIN EN ISO 12952-2 that is on and/or under the test sample. The setup of the test samples on the test frame and the positions of the ignition sources differ depending on the materials being tested. Each ignition (progressive smouldering and/or flaming) is recorded. In a final examination, the test sample is disassembled after the test and is examined inside for any signs of smouldering.

Criteria for passing the test

The ignition criteria for the assessment of bedding are shown in Table 18. The types of behaviour listed in the table are considered to be ignition through progressive smouldering or flaming.

Table 18: Bedding - ignition criteria for smouldering cigarette and small open flame as a source of ignition.

DIN EN ISO 12952-1 (smouldering cigarette)	DIN EN ISO 12952-2 (small open flame)
Ignition through progressive smouldering	
Test sample with signs of increasing combustion so that continuing the test is not safe and intensive extinguishing is required.	
Test sample that, 1 hour after the application of a smouldering cigarette, continues to smoulder until it is largely consumed.	Test sample that, within 15 minutes of the removal of the ignition source, continues to smoulder until it is consumed.

DIN EN ISO 12952-1 (smouldering cigarette)	DIN EN ISO 12952-2 (small open flame)
Test sample that, 1 hour after the application of a smouldering cigarette, has externally visible signs of smoke formation, heat development or smouldering.	Test sample that, within 15 minutes of the removal of the ignition source, has externally visible signs of smoke formation, heat development or smouldering.
Test sample that shows signs of active smouldering in the final examination.	
Flaming	
Occurrence of flames caused by a smouldering cigarette.	Test sample with signs of increasing combustion so that continuing the test is not safe and intensive extinguishing is required.
	Test setup that, within the test time, burns until it is largely consumed.
	Test sample that continues to burn with a flame for more than 120 seconds after the removal of the ignition source.

The classification scheme for the burning behaviour of bedding based on the criteria of ignition by a smouldering cigarette and a small open flame is described in DIN EN 14533 (2015). The material is considered to have passed the test if "Not Ignited" is recorded. The following classes are defined in DIN EN 14533:

Class A: **Passes** the test of ignitability through a smouldering cigarette.
Passes the test of ignitability through a small open flame.
Class B: **Passes** the test of ignitability through a smouldering cigarette.
Class C: **Does not pass** the test of ignitability through a smouldering cigarette.
Does not pass the test of ignitability through a small open flame.

5.1.3 Classification of inflammability of furniture, house and home textiles and mattresses in Great Britain

The test takes place in accordance with British Standard BS 5852 (2006). Individual components (e.g. the filler of a mattress) or a complete element (an entire sofa) can be investigated. The ignition sources are a smouldering cigarette and an open flame. In Germany, this standard applies to correctional facilities.

Test rig

The test rig consists of two rectangular frames hinged together at an angle of 90°. The vertical frame has dimensions of 450 x 450 mm^2 and the horizontal frame has dimensions of 450 x 300 mm^2.

Test execution

The test material is clamped in the test rig and exposed to one of the following ignition sources:

1. A cigarette to initiate smouldering combustion
1. A butane flame
2. A burning wooden crib

For ignition source 1, there is only one variant. The butane flame can be used with three different lengths, and there are four sizes of wooden crib.

The investigation of smouldering behaviour takes place in accordance with the specifications of DIN EN 1021-1.

The specimens are exposed to the butane flame in question for different periods of time depending on the ignition source.

The four different wooden cribs are doused with 1.4 ml of propan-2-ol and are ignited using a match or lighter.

Criteria for passing the test

To pass the test, the material may not catch fire as a result of exposure to the ignition source. The classification of the materials depends on which tests are performed. If, for example, a test is performed for ignition sources 3 to 7 and the material fails only test 7, the classification is as follows:

NI ("not ignited"): 3-6

I ("ignited"): 7

The test with the crib ignition source (5) is used in Germany to demonstrate the ignitability of some materials.

Investigation of complete pieces of furniture or mattresses

The execution of testing for entire items is like the procedure described above.

- The cigarette must be in the following position:

a) Any surface which can retain the cigarette

b) A groove, recess or junction which can retain the cigarette

- Test with a flame in the following positions:

a) At seating level or on the mattress

b) Position of the ignition source in a corner so that it touches the backrest, seat and arms (seating with back and arms)

c) Position of the ignition source so that it is closest to the backrest and seat (seating with back but without arms)

d) Ignition source must be more than 100 mm from the nearest edge (seating without back or arms)

e) Test in seat-up configuration with smallest distance to seat and backrest (tip-up seating)

f) Ignition source on floor

g) Ignition source positioned on the floor adjacent to the most vulnerable feature

5.2 Test of combustible materials

The testing of material such as plastic, wood and paper through exposure to the flame of a burner is governed by DIN 53438 (1984) Parts 1 to 3. A test takes place to determine whether and in what time the tip of the flame reaches a certain test mark on the sample. A burning cabinet as per DIN 50050 is used for the tests.
DIN 53438-2 (1984) describes the test method for determining the behaviour of materials upon **edge ignition (method K)**. For this purpose, 10 specimens measuring 190 mm x 90 mm are taken from the material to be tested. On each sample, a test mark is placed 150 mm from the

edge positioned at the bottom during the test. As a rule, five samples are tested. The conditioned specimens are placed into the test frame (DIN 53438-1) and the frame is suspended vertically in the burning cabinet. The burner flame hits the sample at an angle of 45°. The sample is exposed to the flame for 15 seconds. The burning time from the start of flaming to the extinguishing of the flame on the specimen or the time taken for the flame tip of the burning specimen to reach the test mark is measured. If the sample continues to glow after the flame has been extinguished, the after-glow time between the extinguishing of the flame on the specimen and the end of the appearance of glowing is measured. Among other things, smoke and soot formation, the falling and dripping of parts of specimens, and the after-burn of specimens are recorded in the test report.
The specimens can be assigned to the classes listed in Table 19.

Table 19: Classes for the assessment of the behaviour of combustible materials during edge ignition with a burner as per DIN 53438-2.

Class	Assessment
K 1	The test mark is not reached by the flame tip of the burning specimen (the specimen goes out of its own accord before this can happen).
K 2	The flame tip of the burning specimen reaches the test mark in 20 seconds or more.
K 3	The flame tip of the burning specimen reaches the test mark in less than 20 seconds.

In the specification of the class, a slash is used to indicate the mean value of the thickness of the test specimens rounded to 0.1 mm (or to 0.01 mm in the case of thicknesses of less than 1 mm). The following applies to the evaluation of the individual tests:

- If all of the samples are assigned to the same class, this class is to be specified for the material being tested.
- If two of five samples are assigned to a worse class, the worse class must be specified for the material being tested.
- If one of five samples is assigned to a worse class, the test is repeated on five new specimens. If one or more samples are assigned to the worse class in the repeat test, the material is to be classified in the worse class.

The burning and glowing times of the tested specimens are to be averaged out and listed in seconds in the test report.

DIN 53438-3 (1984) describes the test method for determining the behaviour of materials upon **surface ignition (method F)**. The 10 specimens measure 230 mm long by 90 mm wide. A lower test mark must be applied at 40 mm from the bottom edge of the specimen and an upper test mark must be applied at 190 mm from the bottom edge. The specimen is secured in the test frame so that the lower edge of the sample is flush with the lower edge of the frame. The flame must hit the specimen in the centre of the lower test mark. For this method, too, the sample is exposed to the flame for 15 seconds. The burning time from the start of flaming to the extinguishing of the flame on the specimen or the time taken for the flame tip of the burning specimen to reach the test mark is measured. If the sample continues to glow after the flame has been extinguished, the after-glow time between the extinguishing of the flame on the specimen and the end of the appearance of glowing is measured. Among other things, smoke and soot

formation, the falling and dripping of parts of specimens, and the after-burn of specimens are recorded in the test report. The specimens can be assigned to the classes listed in Table 20.

Table 20: Classes for the assessment of the behaviour of combustible materials during surface ignition with a burner as per DIN 53438-3.

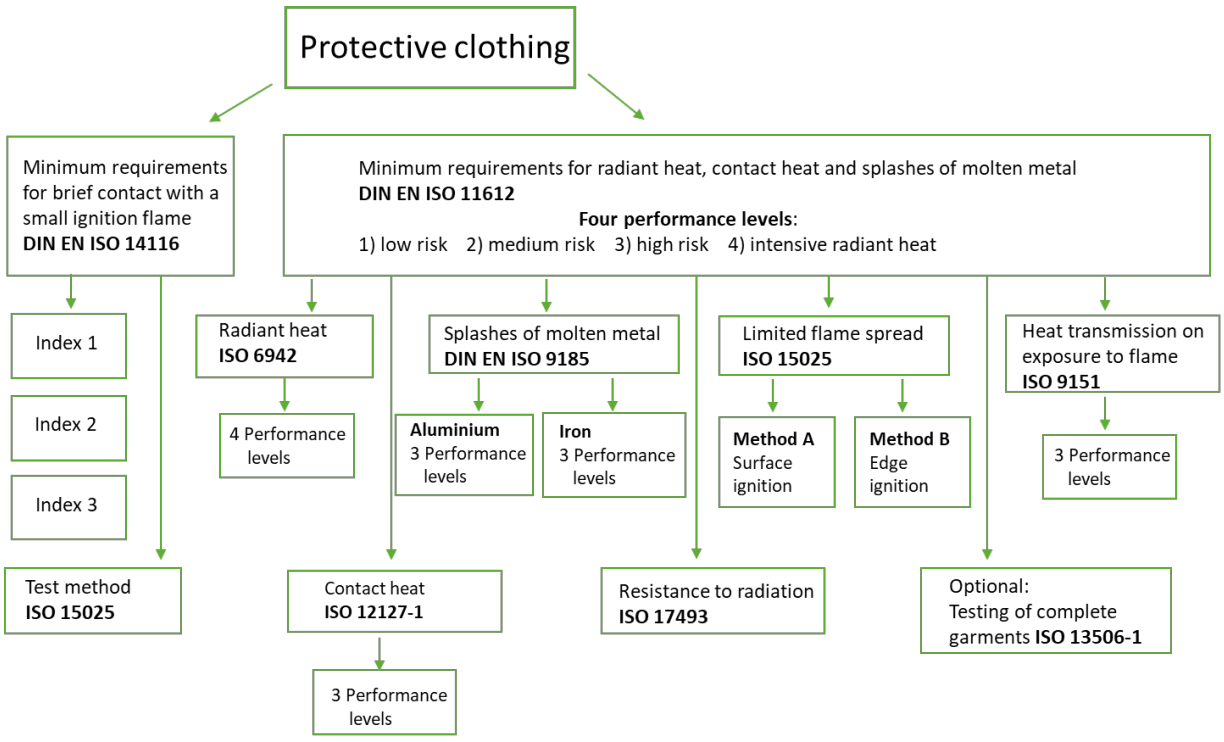
Class	Assessment
F 1	The upper test mark is not reached by the flame tip of the burning specimen (the specimen goes out of its own accord before this can happen).
F 2	The flame tip of the burning specimen reaches the upper test mark in 20 seconds or more.
F 3	The flame tip of the burning specimen reaches the upper test mark in less than 20 seconds.

The criteria as for the edge ignition test apply for the specification of the class and the evaluation of the individual tests.

5.3 Test method for PPE (protective clothing)

The section below describes the requirements and test methods for clothing intended to protect against heat and flames. According to DIN EN ISO 11612, PPE is clothing that covers or replaces the personal clothing of the user and that protects the wearer's upper and lower body, neck, arms and legs through its design. Figure 16 gives an overview of the relevant standards.

Figure 16: Standards relating to minimum requirements for PPE.



Source: own work, Fraunhofer WKI.

5.3.1 Requirements for protective clothing

DIN EN ISO 14116 (2015) specifies minimum performance requirements for the limited flame spread and burning properties of protective clothing in the case of brief accidental contact with small ignition flames. However, the standard is not suitable if protection against heat hazards is required in addition to protection against small flames. In this case, DIN EN ISO 11612 (Beuth 2020) can be applied, for example. Moreover, ISO 14116 contains additional requirements upon clothing and requirements on the design, mechanical properties, labelling and information provided by the manufacturer.

The standard defines tensile strength, tear growth resistance, bursting strength and seam strength as well as the dimensional change of textile materials and performance requirements for materials, combinations of the materials and protective clothing with limited flame spread. Sampling, pre-treatment, ageing and conditioning are also defined. Protective clothing as per this standard must achieve limited flame spread index 1, 2 or 3 in accordance with a test as defined in ISO 15025 (see Table 21, Table 22 and Table 23). Protective clothing with index 1 offers the least protection and, in accordance with manufacturers, should be worn only on top of clothing with index 2 or 3 and should not come into contact with the skin at the neck or wrist, for example (Blåkläder 2020).

Table 21: Requirements for limited flame spread index 1.

Material properties	Requirements
Flame spread	A part of the lower edge of a flame or the edge of a hole may not reach the top edge or side edge in any sample.
Burning droplets	No sample may show burning or melting droplets.
After-glow	The after-glow time must be ≤ 2 seconds. According to DIN EN ISO 15025, after-glow in a charred area is after-glow without combustion and is not considered after-glow for the purposes of this test.

Table 22: Requirements for limited flame spread index 2.

Material properties	Requirements
Flame spread	A part of the lower edge of a flame may not reach the top edge or side edge in any sample.
Burning droplets	No sample may show burning or melting droplets.
After-glow	The after-glow time must be ≤ 2 seconds. According to DIN EN ISO 15025, after-glow in a charred area is after-glow without combustion and is not considered after-glow for the purposes of this test.
Hole formation	Holes with a size of 5 mm or more in any direction are not allowed to form in any sample except in the case of interlining that has a purpose other than protection against flames.

Table 23: Requirements for limited flame spread index 3.

Material properties	Requirements
Flame spread	A part of the lower edge of a flame may not reach the top edge or side edge in any sample.
Burning droplets	No sample may show burning or melting droplets.
After-glow	The after-glow time must be ≤ 2 seconds. According to DIN EN ISO 15025, after-glow in a charred area is after-glow without combustion and is not considered after-glow for the purposes of this test.
Hole formation	Holes with a size of 5 mm or more in any direction are not allowed to form in any sample except in the case of interlining that has a purpose other than protection against flames.
After-burn	The after-burn time must be ≤ 2 seconds.

DIN EN ISO 11612 (2015) describes the minimum performance requirements for the properties of protective clothing with an extensive range of use for end applications in which clothing with limited flame spread is required and in which the wearer is exposed to radiant heat, convective or contact heat, or splashes of molten metal. It relates to protective clothing made from flexible material for the protection of the body with the exception of the hands. Three performance levels are defined for many of the hazards listed in the standard:

- Level 1 to indicate exposure to low risk
- Level 2 to indicate exposure to medium risk
- Level 3 to indicate exposure to high risk

A fourth performance level exists for high-performance materials for protection against intensive radiant heat.
The general performance requirements concern the following criteria:

- Thermal resistance at temperatures of 180°C, tested in accordance with ISO 17493; the samples are not allowed to ignite or melt, and fabric/leather samples are not allowed to shrink by more than 5%. There is an optional requirement of thermal resistance at 260°C. The samples are not allowed to ignite or melt and may not shrink by more than 10%.
- Limited flame spread (test as per 15025, method A and method B, see Section 5.3.2); Table 24 lists the performance requirements for limited flame spread for method A, Table 25 shows the equivalent performance requirements for method B.

Table 24: Performance requirements for limited flame spread in test of samples of single-layer items of clothing as per ISO 15025, method A (code letter A1).

Property	Requirement
Flame spread	A part of the lower edge of a flame may not reach the top edge or side edge in any sample.
Burning droplets	No sample may show burning or melting droplets.

Property	Requirement
Hole formation	Holes with a size of 5 mm or more in any direction are not allowed to form in any sample except in the case of interlining that has a purpose other than protection against heat and flames.
After-glow	The after-glow time must be ≤ 2 seconds. According to DIN EN ISO 15025, after-glow in a charred area is after-glow without combustion and is not considered after-glow for the purposes of this test.
After-burn	The after-burn time must be ≤ 2 seconds.

Table 25: Performance requirements for limited flame spread in test of samples of hemmed single-layer items of clothing as per ISO 15025, method B (code letter A2).

Property	Requirement
Flame spread	A part of the lower edge of a flame may not reach the top edge or side edge in any sample.
Burning droplets	No sample may show burning or melting droplets.
After-glow	The after-glow time must be ≤ 2 seconds. According to DIN EN ISO 15025, after-glow in a charred area is after-glow without combustion and is not considered after-glow for the purposes of this test.
After-burn	The after-burn time must be ≤ 2 seconds.

- Dimension change of textile materials as per ISO 5077
- Physical requirements such as tensile strength, tear growth resistance and bursting strength of machine-knitted materials and seams, seam strength and leather fat content

In addition to these obligatory minimum performance requirements, the minimum performance requirement for all end applications must be at least one of the code letters for heat transmission. The application of the performance requirements here is oriented towards the intended usage purpose of the clothing in accordance with the specifications of the manufacturer.

- Convective heat - code letter B

In the test as per ISO 9151, single-layer or multi-layer items of clothing and/or clothing compositions intended to protect against convective heat must at least comply with performance level B1 in Table 26. If the item of clothing has multiple layers, the entire material composition must be tested.

Table 26: Performance levels as per DIN EN ISO 11612 for convective heat testing.

Performance level	Range of HTI[a] 24 values [seconds]	
	Min.	Max.
B1	4.0	< 10.0
B2	10.0	< 20.0
B3	20.0	

[a] Heat transfer index as defined in ISO 9151

- Radiant heat - code letter C

In the case of testing as per ISO 6942 (method B) using a heat flux density of 20 kW/m², single-layer or multi-layer items of clothing and or clothing compositions that are intended to protect against radiant heat must at least comply with performance level C1 (see Table 27). Tests on metallised materials must be carried out after the pre-treatment specified in Appendix A. If the item of clothing has multiple layers, the entire material composition must be tested.

Table 27: Performance levels as per DIN EN ISO 11612 for radiant heat testing.

Performance level	Radiant heat transfer index RHTI[44] 24 [seconds]	
	Min.	Max.
C1	7.0	< 20.0
C2	20.0	< 50.0
C3	50.0	< 95.0
C4	95.0	

- Liquid aluminium splashes - code letter D

In the test as per ISO 9185 with molten aluminium, single-layer or multi-layer items of clothing and/or clothing compositions intended to protect against liquid aluminium splashes must at least comply with performance level D1 (Table 28). The test is not considered to have been passed if materials or material assemblies ignite.

[44] Radiant heat transfer index as defined in ISO 6942

Table 28: Performance levels as per DIN EN ISO 11612 for liquid aluminium splashes.

Performance level	Liquid aluminium splashes [grams]	
	Min.	Max.
D1	100	< 200
D2	200	< 350
D3	350	

- Liquid iron splashes - code letter E

In the test as per ISO 9185 with molten iron, single-layer or multi-layer items of clothing and/or clothing composition intended to protect against liquid iron splashes must at least comply with performance level E1 (Table 29). The test is not considered to have been passed if materials or material assemblies ignite.

Table 29: Performance levels as per DIN EN ISO 11612 for liquid iron splashes.

Performance level	Liquid iron splashes [grams]	
	Min.	Max.
E1	60	< 120
E2	120	< 200
E3	200	

- Contact heat - code letter F

In the case of testing as per ISO 12127-1 at a temperature of 250°C, single-layer or multi-layer items of clothing and/or clothing compositions that are intended to protect against contact heat must at least comply with performance level F1 (Table 30).

Table 30: Performance levels as per DIN EN ISO 11612 for contact heat.

Performance level	Threshold value time [seconds]	
	Min.	Max.
F1	5.0	< 10.0
F2	10.0	< 15.0
F3	15.0	

Table 31 provides an overview of the test methods for assessing the heat transmission performance of the various code letters.

Table 31: Methods for testing heat transmission (from DIN EN ISO 11612).

Heat transmission performance	Code letter	Test method
Limited flame spread	A1 or (A1 and A2)	ISO 15025
Convective heat	B1 to B3	ISO 9151
Radiant heat	C1 to C4	ISO 6942
Liquid aluminium splashes	D1 to D3	ISO 9185
Liquid iron splashes	E1 to E3	ISO 9185
Contact heat	F1 to F3	ISO 12127-1

As an optional test, DIN EN ISO 11612 specifies the testing of a complete item of clothing by measuring the thermal transfer using a sensor-equipped test manikin as per ISO 13506-1 (2017). Further, DIN EN ISO 11612 defines requirements for the labelling of items of clothing and information from manufacturers.

The **Technical Rule ISO/TR 2801** (2007) contains general recommendations on selecting, caring for and using protective clothing intended to protect against heat and flames.

5.3.2 Test methods for limited flame spread

DIN EN ISO 15025 describes two methods for determining flame spread behaviour on vertically arranged flexible materials. Single-component and multi-component textiles (e.g. coated, quilted, multi-layer, sandwich composites) are tested. The two test methods test surface ignition (method A) and the edge ignition of the lower edge (method B). A defined burner flame is directed at the upper surface or lower edge of the vertically arranged textile samples for 10 seconds. However, the test standard does not apply to situations with a restricted air supply or extreme heat, it is not suitable for materials subject to significant melting or shrinkage.

Properties of specimens

In method A (surface ignition), cut-out samples (two rows of three samples positioned perpendicular to each other) measuring 200 mm × 160 mm are used; for method B (edge ignition of the lower edge), cut-out samples measuring 200 mm × 80 mm are used. In the case of samples consisting of multiple layers or materials that do not extend over the entire sample and in the case of seams, special positions must be observed when the materials are placed into the test equipment. The samples are conditioned.

Test setup

For each method, the sample is placed onto the pins of the sample holder. The pins should penetrate the holes marked out using the template and the rear of the sample should be at least 20 mm from the rectangular metal frame of the sample holder. The sample holder with the sample in the vertical position is attached to the mounting frame. No sagging, wrinkles or folds are allowed. Samples showing wrinkles or sagging must be pulled taut but not stretched. Samples with a seam must be attached so that the seam is exposed to the flame.
In the case of surface ignition (method A), the burner is aligned perpendicular to the surface of the sample. The axis of the burner must lie 20 mm above the lower retaining pins and must point to the vertical centre line of the sample surface.
In the case of method B (ignition of the lower edge), the burner is attached centrally beneath the sample so that, as a result of the inclined position of the longitudinal axis, an upwards angle of 30° to the vertical lower edge of the sample is maintained.

Test execution

For both methods, there must be a temperature of 23°C, a relative air humidity of between 15 and 80 %, and an air flow of less than 0.2 m/s at the start of the tests. The first in a series of six samples is attached to the sample holder as described above. In the case of woven or knitted materials, a record is made as to whether the machine direction or transverse direction of the fabric is positioned vertically. Then, the sample is exposed to the test flame for 10 seconds. The following observations must be made:

Whether any part of the flame reaches the top edge or one of the side edges of the sample

- The after-burn time in seconds
- Whether the after-glow spreads past the area exposed to the flame (usually the charred area) into the undamaged area
- The after-glow time in seconds
- Any occurrence of particle detachment
- Whether detached particles ignite the filter paper (detachment of burning particles) or melt, if particle detachment occurs
- Any occurrence of melting
- Hole formation is recorded with sufficient lighting from above or behind the sample. The number of holes, size of the largest hole and affected layer(s) in the case of a multi-layer sample are recorded. In the case of the testing of multi-layer samples, the formation of a hole or of holes in each separable layer along with the number of holes that penetrate all of the layers of the multi-layer sample must be specified.

This procedure applies to both methods with the exception of hole formation, which does not apply to method B (lower edge ignition).

Criteria for passing the test

The criteria for passing the test in accordance with the test method from DIN EN ISO 15025 are described in DIN EN ISO 14116 (see Section 5.3.1).

5.3.3 Protective clothing for firefighters

5.3.3.1 Jackets and trousers for firefighters as per DIN EN 469

For both items of clothing, DIN EN 469 prescribes two performance levels. Level 1 represents compliance with a lower set of material requirements and level 2 compliance with more stringent requirements.
One requirement upon the material used is limited flame spread as tested in accordance with DIN EN ISO 15025 Part A. During the 10 seconds of flame exposure, the following may not occur:

- Reaching of the upper or side edge of the sample by the flame
- Burning or melting droplets
- After-glow time of more than 2 seconds
- Holes larger than 5 mm in the outer layers of the protective clothing

- Opening of seams

As a further parameter, the heat transfer of the protective clothing material is determined using a flame as per DIN EN ISO 9151. This involves exposing a horizontally positioned sample to a burner flame from below. During the test, the heat transfer index (HTI) is determined. This is an indicator of relative protection against the action of heat (DGUV Information 205-020, 2012). The following values play an important part in the assessment:

- HTI 12 → Temperature increase of 12 Kelvin (skin pain threshold)
- HTI 24 → Temperature increase of 24 Kelvin (second degree burn)
- HTI 12-24: Time from the first sensation of pain to the occurrence of a second degree burn

Table 32 specifies the times for the indexes for the two performance levels.

Table 32: Heat transfer requirements for jackets and trousers for firefighters during exposure to flame.

Heat transfer index	Performance level 1	Performance level 2
HTI_{24}	≥ 9.0 seconds	≥ 13.0 seconds
$HTI_{24} – HTI_{12}$	≥ 3.0 seconds	≥ 4.0 seconds

The heat transition using a source of radiant heat is determined in accordance with DIN EN ISO 6942 by exposing a sample to a 40 W radiant heater. This method also determines the HTI (see Table 33 for limit values).

Table 33: Heat transfer requirements for jackets and trousers for firefighters during exposure to radiant heat.

Heat transfer index	Performance level 1	Performance level 2
HTI_{24}	≥ 10.0 seconds	≥ 18.0 seconds
$HTI_{24} – HTI_{12}$	≥ 3.0 seconds	≥ 4.0 seconds

In order to determine the thermal resistance as per ISO 17493, each material in the clothing composition is tested at a temperature of 180°C for an exposure time of 5 minutes. During this time, the material is not allowed to ignite, melt, or shrink by more than 5% lengthwise or crosswise.

The minimum requirements of DIN EN 469 are governed in Germany by the manufacturing and testing description for universal protective clothing for firefighters (HuPF) (Bach 2009). Equipment for firefighters consists of four elements that can be combined with each other:

- Outer jacket (part 1)
- Firefighter's trousers (part 2)
- Firefighter's jacket (part 3)
- Firefighter's overtrousers (part 4)

5.3.3.2 Requirements upon helmets for firefighters as per DIN EN 443

Helmets for firefighters must meet the following fire safety requirements:

- Radiant heat

In the test as per DIN EN 13087-10, a helmet is exposed to a flow of heat of 14 kW/m² for 480 seconds. The following conditions must be met for the test to be passed:

a) Increase of lab temperature (20°C) by max. 25 K

b) No softening or ignition of materials during the test

c) Following exposure to the radiant heat, the helmet must still meet requirements relating to shock absorption and penetration resistance.

At least performance level 1 must be reached in the tests as per DIN EN 469**.**

- Protection against hot solids

In this test (DIN EN 168), the material is exposed to a 900°C steel ball. The requirements for passing the test are as stipulated in DIN EN 166. The latter states that the ball may not fully penetrate the material within 5 to 7 seconds.

- Protection against molten metals

The protection of a helmet against molten metal is tested similarly to DIN EN ISO 9185. In a deviation from the standard, 150 g of liquid iron (requirement of DIN EN 443) is poured onto the helmet. The metal is not allowed to burn through the helmet within 30 seconds. The requirements apply to the area from the eyes to the top of the head. Materials used beneath protection zones 1a and 1b (as per DIN EN 443) are tested using liquid aluminium instead of liquid iron.

- Heat resistance

For the analysis of heat resistance, the helmet is placed in a furnace at a temperature of 90°C for 20 minutes in accordance with ISO 17493. The neck protection test takes place at a temperature of 180°C for 5 minutes. Afterwards, the helmet may not show any of the following:

1. Deformation in a way that causes it to touch the head at points other than those required to ensure a good fit
2. Separation, melting or dripping (including the product name)
3. Helmet elements that no longer work (e.g. chin strap)
4. Ignition (including the product name)

- Flame resistance

In order to determine flame resistance as per DIN EN 137, a firefighter's helmet is placed onto a test torso along with a firefighter's outer jacket, firefighter's safety hood, and a full respiratory protection mask. The test specimen is then exposed to a 950°C flame for 10 seconds. This scenario simulates flashover during firefighting. During the test, the helmet is not allowed to drip or show after-burn/after-glow for longer than 5 seconds. These criteria are defined in EN 443.

5.3.3.3 Brief descriptions of individual standards for helmets for firefighters

DIN EN 13087-10 (2012) supplements the specific product standards for protective helmets. This standard defines a test method for determining resistance to radiant heat. Radiant heat from an infrared source is applied to the outer surface of a helmet with a defined intensity for 180 seconds during the test. The helmet is attached to a test head. The helmet is attached to the test head in the same way as it would be worn on the head of a firefighter. The temperature of the surface of the test head is measured via an attached temperature sensor and recorded.

DIN EN 168 (2001) describes the non-optical test methods for eye protection equipment. The fire-safety test specifications of this standard include the following:

- Test of resistance to high temperature: The sample is placed in a heating cabinet in the normal position of use for 60 minutes at a temperature of 55°C. It is then removed and allowed to rest at 23°C for at least 60 minutes to allow its temperature to stabilise before being subjected to a visual inspection.
- Test of inflammability: At least 50 mm of the end of a defined steel rod is heated to a temperature of 650°C. The heated area of the rod (held vertically in the longitudinal axis) is pressed against the surface of the specimen for 5 seconds and is then removed. During the test, observations are made to determine whether specimens ignite or show after-glow.
- Test of resistant to high-speed particles at extreme temperatures: The eye protector to be tested is placed on a test head. A sheet of carbon paper lying on a white paper sheet is placed between the eye protector and the test head. The test head and eye protector are arranged at a defined distance in front of the propulsion device. The ball is shot at a defined speed. The impact of the ball takes place in the following conditions:
  a) The ocular is heated to 55°C and is kept at this temperature for at least 1 hour.
  b) The ocular is cooled to a temperature of -5°C and is kept at this temperature for at least 1 hour.
  New oculars must be used for each impact point and temperature condition.
- Test of protection against molten metal: For this test, molten metal is hurled at an eye protector. An ejection device with a plate-shaped ejection head in the centre that can hold a crucible with molten metal is used. The eye protector is arranged over the opening so that the area to be tested is immediately over the centre of the ejection head. The ejection head is loaded with a crucible containing grey cast iron at a temperature of 1450°C. The crucible with the molten metal is hurled against the eye protector. The test is repeated with a second eye protector; in this case, aluminium at a temperature of 750°C is used. The tests take place at an ambient temperature of 23°C. The tester records whether molten metal has adhered to any part of the eye protector.
- Test of resistance to penetration by hot solids: The sample to be tested is placed on a defined cylinder. A funnel of heat insulating material is placed on the sample in order to centre a steel ball there. A steel ball is heated to 900°C and is then dropped into the funnel. If the ball drops, this indicates the complete penetration of the test material. The time taken to penetrate the material is recorded.

The result of the test is "passed" or "failed".

DIN EN ISO 9185 (2007) is used for the assessment of the material resistance of protective clothing to molten metal splash. In this test, defined amounts of molten metal are poured onto

the sample, which is held in a mounting frame. A PVC film is attached immediately behind the sample and in contact with it. Damage is assessed by recording the changes to the PVC film. The changes to the PVC film after the pouring process are recorded along with any adhesion of metal to the surface of the sample. Depending on the result, the test is repeated with either a larger or a smaller amount of metal until the minimal amount that damages the PVC film is determined.

ISO 17493 (2016) describes a test method for determining the resistance of clothing and equipment to heat. The test method tests convective heat resistance using a hot air circulating furnace. The samples are exposed to the hot air at a temperature of 180°C or 260°C for 5 minutes. All visible changes such as charring, deformation, degradation, hole formation, ignition and melting are recorded. The standard applies to gloves, footwear, helmets and eye protectors, for example.

DIN EN 137 (2006) governs the requirements, testing and labelling for respiratory protective devices (self-contained open-circuit compressed air breathing apparatus with full face mask). Self-contained compressed air devices are subdivided into devices for industrial usage (type 1) and devices for firefighting (type 2).
With regard to fire safety, the requirements relating to temperature resistance, inflammability, flaming and resistance to radiant heat are relevant. The device must work without interference in a temperature range of −30 to 60°C. "*Devices designed specially for temperatures outside these limits must be tested and the temperatures must be marked on the device.*" In addition, the material of the straps and buckles must not burn or must not continue to burn for more than 5 seconds after having been removed from the flame. *"The breathing tubes leading to the full face mask, the medium pressure line(s) and the breathing regulator must be self-extinguishing, so the material must not be highly flammable and the parts must not continue to burn for more than 5 seconds after having been removed from the flame. Type 2 breathing apparatus must be subjected to a flame test. There must not be any after-burning for more than 5 seconds. In the case of type 2 breathing apparatus, the breathing tubes leading to the full face mask, the medium pressure line(s) and the breathing regulator must be tested for resistance to radiant heat. The components may be considered to be resistant to radiant heat if they remain leak-proof after a test time of 20 min...".*

5.3.3.4 Requirements upon safety hoods for firefighters as per DIN EN 13911

Safety hoods for firefighters must meet the following fire safety requirements:

- Flame spread

In order to determine flame spread, the surface of the used material is exposed to a burner flame for 10 seconds in accordance with the specifications of DIN EN ISO 15025. In order for the material to meet the requirements of DIN EN 13911, no seam may open during or after the test and the conditions of index 3 of DIN EN ISO 14116 must be met (see Section 5.3.1).

- Thermal transfer

As described for trousers and jackets for firefighters, thermal transfer is again tested with a flame as per DIN EN ISO 9151 here. The following limit values apply:

HTI 24	≥ 8 seconds
HTI 24-HTI 12	≥ 3 seconds

Heat transfer tests using radiant heat take place in accordance with EN ISO 6942 with a heat flux density of 20 kW/m^2. The following limit values apply to passing the test:

RHTI 24 ≥ 11 seconds

RHTI 24-RHTI 12 ≥ 3 seconds

- Thermal resistance

This test takes place like for the thermal resistance test for helmets for firefighters as per ISO 17492. The test takes place for 5 minutes at a temperature of 180°C. Afterwards, the materials may show shrinkage of no more than 5%.

5.3.3.5 Requirements upon footwear for firefighters as per DIN EN 15090

From a fire safety point of view, footwear for firefighters must meet the following requirements:

- Heat insulation

This test takes place in accordance with the specifications of DIN EN ISO 20344. A boot is placed on a hot plate for a certain period of time. Table 34 and Table 35 summarise the test conditions and requirements for heat insulation in accordance with DIN EN 15090. Following the test, the boot may not have any large cracks, any separation of the upper material and outsole, or any sole deformation.

Table 34: Heat insulation: Requirements for inner temperature of boot.

Heat insulation level	HI 1	HI 2	HI 3
HTI_{24}	150°C	250°C	250°C
Inner temperature of boot	< 42°C after 30 minutes	< 42°C after 10 minutes	

Table 35: Heat insulation: Requirements for boot degradation.

Heat insulation level	HI 1	HI 2	HI 3
HTI_{24}	150°C	250°C	250°C
Full duration of test	30 minutes	20 minutes	40 minutes

- Radiant heat

Boots for firefighters must pass the test as per DIN EN ISO 6942 with a heat flux density of 20 kW/m^2 for 40 seconds. The measured temperature rise may not exceed 24°C. Following the end of the test, no crack reaching half the material thickness may be present and the upper leather may not ignite or melt. Finally, the closing mechanism must still be functional.

- Flame resistance

For this test, a certain area of a boot positioned at an incline of 45° is exposed to flame for 10 seconds in accordance with DIN EN ISO 15025. Following the removal of the flame, this surface may continue to burn or glow for no more than 2 seconds. The following events also result in the failure of the test:

- Defined, deep cracking beyond half of the material thickness of the upper leather
- Ignition and melting of the upper leather
- Unravelling of seams

- Cracks in the outsole
- Separation of the upper material and outsole
- Failure of the closing mechanism

5.3.3.6 Requirements upon protective gloves for firefighters as per DIN EN 659

From a fire safety point of view, protective gloves for firefighters must meet the following requirements:

- Burning behaviour

To investigate the burning behaviour of protective gloves for firefighters in accordance with DIN EN 407, the lower tip of the glove (position of the middle finger) is exposed to flame for 15 seconds. The after-burn time must be ≤ 2 seconds and the after-glow time must be ≤ 5 seconds. In addition, melting droplets and any opening of seams result in the failure of the test.

- Convective heat

For this test, the glove material is exposed to radiant heat with a heat flux density of 80 kW/m² in accordance with DIN EN 367. To pass the test, the heat transfer index must not fall below the following value:

HTI 24 ≥ 13 seconds

- Radiant heat

Heat transfer tests using radiant heat take place in accordance with EN ISO 6942 with a heat flux density of 40 kW/m². The following limit values apply to passing the test:

RHTI 24 ≥ 20 seconds

- Contact heat

The determination of resistance to contact heat takes place in accordance with EN 702 in a calorimeter with a moving aluminium disk. This is moved in the direction of the glove material at 250°C and the time it takes for the disk temperature to increase by 10°C is measured. In accordance with DIN EN 659, this must be at least 10 seconds.

- Thermal resistance of lining material

For the analysis of heat resistance, the lining material that lies closest to the skin is placed in a furnace at a temperature of 180°C for 5 minutes in accordance with ISO 17493. The lining material is not allowed to melt, drip or ignite during or after the test.

- Shrinkage

The analysis of shrinking behaviour also takes place in accordance with ISO 17493; the material is allowed to shrink by no more than 5%.

5.4 Test method for floorings and other construction products

According to the definition of the German Standard Building Regulations (Art. 2 Para. 10 MBO 2019), construction products are building materials, building elements, systems and construction kits for permanent installation in structural and civil engineering. Their use may affect the requirements for building structures (DIBt 2019). Further, construction products

include prefabricated facilities made from building materials and building elements, such as prefabricated houses and garages, that are connected to the ground. All (construction) products that are connected to a building and cannot be disturbed without further ado are tested in accordance with the national standard DIN 4102-1 or the harmonised EU standard DIN EN 13501-1. It is intended for all standards to undergo European harmonisation. It is not yet known when this will take place in Germany for DIN EN 13501-1. The standards are presented below.

5.4.1 Building material testing as per DIN 4102-1

This standard can be used to classify the fire behaviour of all building materials in Germany. Unlike in the case of DIN EN 13501-1, this classification is not accepted in other countries as a rule. It enables an assessment of the risk of a material in its own accord and in conjunction with other building materials. According to DIN 4102-1, building materials are classified as non-combustible, flame-retardant, normally flammable, and highly flammable (Table 36).

Table 36: Overview of building material classes as per DIN 4102-1.

Building material class	Description
A A 1 A 2	Non-combustible building materials
B	Combustible building materials
B 1	Flame-retardant building materials
B 2	Normally flammable building materials
B 3	Highly flammable building materials

5.4.2 “Non-combustible” building material classes (A1 and A2)

The following tests must be passed in order to achieve a "non-combustible" building class:

- Furnace test as per DIN 4102-1 (A1 and A2)
- Fire shaft ("Brandschacht") test as per DIN 4102-16 (A2)
- Smoke generation test as per Appendices A and B of DIN 4102-1 (A2)

5.4.2.1 Non-combustibility/furnace test

The furnace test as per DIN 4102-1 simulates an advanced fire that is transitioning towards fully developed. In this situation, for building material class A1, the tested material must not give off any heat and the ignitable gases must not be released. For building material class A2, extremely low heat release and fire spread are permitted. Likewise, the development of a limited amount of ignitable gases and harmless smoke development are allowed.

Test specimens

For each test, five specimens measuring 40 mm x 40 mm x 50 mm are required. Building materials with surface coatings are tested with these coatings and must meet the requirements.

Before testing, the specimens are dried at a temperature of 105°C for 6 hours.

For the test, the samples are inserted into a wire rack that keeps them in the same position in the furnace.

Test apparatus

The test is performed in a cylindrical electrical furnace with heating conductors that are applied evenly to the outer jacket of the ceramic heating conductor support. An ignition flame with a height of 20 mm is to be positioned above the lid opening in the axis of the heating tube. A slanted mirror is placed above the furnace to enable the direct observation of the specimen's fire behaviour.

Test execution

First, the furnace is heated to a temperature of 750°C. Then, the specimen is placed in the centre of the furnace. The duration of the test is 30 minutes for A1 classification and 15 minutes for A2 classification. If the maximum temperature increase has not occurred after 30 minutes (A1 classification), the test of just one sample up to the maximum temperature (max. 90 minutes) is sufficient. The energy supply remains constant during the test. Five tests are required for a classification.

Criteria for passing the test

A1 classification

The test is considered to have been passed if no sample shows signs of inflammation. Signs of inflammation include an increase in the size of the ignition flame, flames in the furnace and/or glowing combustion of the specimens. In addition, the temperature in the furnace must not reach more than 50°C above the initial value as a result of the heat given off.

A2 classification

The test is considered to have been passed if there is no inflammation with a total duration of more than 20 seconds in any sample. The flames are not allowed to exceed a height of 100 mm and must not extend beyond the heating tube. In addition, the temperature in the furnace must not reach more than 50 Kelvin above the initial value as a result of the heat given off.

5.4.2.2 Fire shaft test

The type of the specimens, test apparatus and test execution are described in Section 5.4.3.1.

Criteria for passing the test

The test is considered to have been passed if:

- The mean residual length of the four specimens is at least 35 cm and no specimen has a residual length of less than 20 cm
- Mean flue gas temperature: ≥ 125°C
- No inflammation of the rear side
- No flame higher than the top edge of the sample
- No falling or dripping burning matter

5.4.2.3 Smoke generation test

This test takes place in accordance with the specifications of Appendixes A and B of DIN 4102-1. In part A, the determination of smoke generation takes place in smouldering conditions and in part B the determination of smoke generation takes place in flame conditions.

Test specimens

Determination of the smoke generation of building materials in smouldering conditions

For the test in smouldering conditions as per DIN 4102-1 Appendix A, 18 specimens are required for homogeneous materials and 24 specimens are required for composite materials (parallel to the surface and vertical to the surface). The specimens are sized 5 x 2 x 27 mm^3. The specimens are conditioned until they reach constant mass.

Determination of the smoke generation of building materials in flame conditions

Five or ten specimens are required for testing. Specimens shall measure 30 mm x 30 mm and have the same thickness as in service as long as this is no greater than 15 mm. The specimens are conditioned until they reach constant mass before the test starts.

Test apparatus

Determination of the smoke generation of building materials in smouldering conditions

The test apparatus consists of a quartz glass tube in which the specimen is positioned. This tube is heated from the outside using a moving tube furnace. A light measuring system is used to determine the light attenuation during the test.

Determination of the smoke generation of building materials in flame conditions

For this test, a propane burner, sample holder and flue gas density meter are placed into a closing test chamber.

Test execution

Determination of the smoke generation of building materials in smouldering conditions

The specimen is placed into the quartz glass tube and the tube furnace, heated to the test temperature, is moved over the sample. In parallel, the light attenuation (smoke density) is measured. The test is performed at the following temperatures:

1. 250°C
2. 300°C
3. 350°C
4. 400°C
5. 550°C
6. 600°C

Determination of the smoke generation of building materials in flame conditions

The sample is placed onto the sample holder with the surface that will be exposed in use face down and is exposed to the flame for 4 minutes. During this time, the light absorptance is recorded.

Criteria for passing the test

When testing as in Appendix A (smouldering conditions), the mean light absorptance may not exceed 30% in any experiment. When testing as in Appendix B (combustion with flame exposure), the light absorptance may not exceed 15% for experiments without a supply of air.

5.4.3 Building material class “Flame-retardant” (B1)

The prerequisites for the classification "flame-retardant" (B1) are:

- Passing the "Brandschacht" test as per DIN 4102-16 or DIN 4102-14 for floorings

- Meeting the requirements of building material class B2 (flame exposure in burning cabinet)

5.4.3.1 "Brandschacht" test

The "Brandschacht" test is performed in accordance with DIN 4102-16 in a "Brandschacht" apparatus as specified in DIN 4102-15. The prerequisites for B1 classification are listed in DIN 4102-1. There, the test is depicted as a fire model describing an object on fire in a room (e.g. a wastebasket). In the case of a material that passes the test, it is ensured that the extent of the combustion of the material does not reach beyond the primary fire area and the heat released is minimal.

Test specimens

Specimens with a height of 1000 mm and a width of 190 mm are used for the "Brandschacht" test. The maximum thickness of the specimens is 80 mm. The specimens are conditioned until they reach constant mass.

Test apparatus

The "Brandschacht" apparatus consists of the following:

- Vertical housing
- Sample holder for arranging the 4 specimens to form a flue (the attachment of the specimens depends on the later use of the materials)
- A supply of air from below
- Flue gas discharge above the specimens
- Square gas burner with 8 nozzles per side
- Thermocouples above the specimens to measure the flue gas temperature

Test execution

The specimen is positioned in the "Brandschacht" apparatus and the air supply is adjusted. Once the burner has been ignited, the samples are flamed for 10 minutes. In comparison with the lab, there must be a differential pressure of -15 Pascal inside the shaft during the test.

The specimen is left in the shaft until the fire test has finished, including after-burn, smouldering, and after-glow. The supply air volume flow remains constant for the entire time. The test is performed three times.

Criteria for passing the test

- Mean residual length of the four specimens of at least 15 cm and no specimen with a residual length of 0 cm
- The mean flue gas temperature may not exceed 200°C in any test.
- The specimens may only continue to burn, smoulder or glow to an extent that still allows the mean residual length requirements to be met.

5.4.3.2 Determination of flame spread after exposure to radiant heat source

The test as per DIN 4102-14 simulates a fire situation in which the flames enter a neighbouring room through a door opening. The horizontal flame spread and smoke development of the tested material must be harmless.

Test specimens

For a test, specimens measuring 1050 x 230 mm^2 are placed or glued onto a specimen plate. In the former case, the test is performed four times; in the latter case, it is performed three times. Each specimen is conditioned until it reaches constant mass.

Test apparatus

The test apparatus consists of a test chamber, gas-fired radiant panel, moving pilot burner, sample holder, extraction device and measuring/calibration device. The propane-fired radiant panel is inclined at 30° to the horizontal (position of the samples) and is located near to the short edge of the specimen.

Test execution

The sample holder is placed along with the sample in the test chamber and is exposed to the heat of the preheated radiant panel for max. 30 minutes. Between the third and twelfth minute, a pilot burner is used to attempt to ignite the sample. The critical radiation intensity is determined from the measurement of the burning distance and the radiation profile of the radiant heater.

Criteria for passing the test

A flooring passes this 30-minute test if, during this time, the critical radiation intensity is at least 0.45 W/cm^2 and if the light attenuation integral does not exceed 750 %•min.

5.4.3.3 Burning cabinet test for building material class “normally flammable” (B2)

This test simulates the exposure of a building material to a match flame. In order for the material to pass the test, the ignitability and flame spread of the material must be limited.

Test specimens

A test consists of five specimens measuring 90 mm x 190 mm (edge ignition) or 90 mm x 230 mm (surface ignition). The specimens are conditioned until they reach constant mass.

Test apparatus

The test takes place in a burning cabinet as per DIN 50050-1. To ensure free ventilation, the floor consists of a grating. The burning cabinet contains a propane gas burner as per DIN 50051 and a holder (vertical) for the specimens.

Test execution

The specimen, clamped into the test frame, is exposed to a burner flame at an angle of 45°. Depending on whether edges will be present in the material's later use, the specimen is exposed to flame at its narrow edge or on its surface. In both cases, the sample is exposed to flame for 15 seconds. The time from the start of flaming to the reaching of the 150 mm mark (edge ignition) or 190 mm mark (surface ignition) is measured unless the flame goes out of its own accord. In addition to flame spread, burning droplets are investigated in the test. There are two layers of filter paper under the specimen for this purpose.

Criteria for passing the test

In order for the test to be passed, the tip of the flame must not reach the upper marking (150 mm for edge ignition and 190 mm for surface ignition) in the first 20 seconds after the start of flaming, and the filter paper must not ignite due to burning droplets.

5.4.4 Building material testing as per DIN EN 13501-1

In accordance with the EU standard, building materials - with the exception of floorings and pipe insulation materials (the latter not being relevant for this work) - are classified into seven classes. These are depicted in Table 37 along with the corresponding test methods.

Table 37: Overview of building material classes as per DIN EN 13501-1 with exception of floorings and pipe insulation materials.

Building material class	Description	Test method	Test standard
A1	Non-combustible building materials	Non-combustibility test Gross heat of combustion	DIN EN ISO 1182 DIN EN ISO 1716
A2	Non-combustible building materials	Non-combustibility test Gross heat of combustion SBI[45] test	DIN EN ISO 1182 DIN EN ISO 1716 DIN EN 13823
B	Flame-retardant building materials	SBI test Single-flame source test	DIN EN 13823 DIN EN ISO 11925-2
C	Flame-retardant building materials	SBI test Single-flame source test	DIN EN 13823 DIN EN ISO 11925-2
D	Normally flammable building materials	SBI test Single-flame source test	DIN EN 13823 DIN EN ISO 11925-2
E	Normally flammable building materials	Single-flame source test	DIN EN ISO 11925-2
F	Highly flammable building materials	None	

The criteria for achieving the various building material classes are defined in DIN EN 13501-1; Table 38 provides a summary.

Table 38: Overview of requirements for achieving construction product building classes as per DIN EN 13501-1; floorings and pipe insulation materials are not taken into account.

Building material class	Test method	Classification criteria
A1	DIN EN ISO 1182 and DIN EN ISO 1716	ΔT ≤ 30°C and Δm ≤ 50% and No inflammation PCS ≤ 2 MJ/kg →Homogeneous components and substantial components PCS ≤ 2 MJ/m² →External non-substantial components PCS ≤ 1.4 MJ/m² →Internal non-substantial components PCS ≤ 2 MJ/kg →Whole product
A2	DIN EN ISO 1182 or	ΔT ≤ 50°C and Δm ≤ 50% and Inflammation: Max. 20 s

[45] SBI: Single burning item test

Building material class	Test method	Classification criteria
	DIN EN ISO 1716 and	PCS ≤ 3 MJ/kg →Homogeneous components and substantial components PCS ≤ 4 MJ/m² →External non-substantial components PCS ≤ 4 MJ/m² →Internal non-substantial components PCS ≤ 3 MJ/kg →Whole product
	DIN EN 13823	FIGRA ≤ 120 W/s and LFS < edge of specimen THR (after 600 s) ≤ 7.5 MJ
B	DIN EN 13823 and	FIGRA ≤ 120 W/s and LFS < edge of specimen THR (after 600 s) ≤ 7.5 MJ
	DIN EN ISO 11925-2 30 s exposure time	Vertical flame spread ≤ 150 mm (after 60 s)
C	DIN EN 13823 and	FIGRA ≤ 250 W/s and LFS < edge of specimen THR (after 600 s) ≤ 15 MJ
	DIN EN ISO 11925-2 30 s exposure time	Vertical flame spread ≤ 150 mm (after 60 s)
D	DIN EN 13823 and	FIGRA ≤ 250 W/s and
	DIN EN ISO 11925-2 30 s exposure time	Vertical flame spread ≤ 150 mm (after 60 s)
E	DIN EN ISO 11925-2 15 s exposure time	Vertical flame spread ≤ 150 mm (after 20 s)
F	None	None

For the building material classification of floorings, DIN EN 13501-1 defines seven classes, which are summarised in Table 39. The criteria for achieving the various building material classes are summarised in Table 40.

Table 39: Overview of building classes for floorings as per DIN EN 13501-1.

Building material class	Description	Test method	Test standard
$A1_{fl}$	Non-combustible building materials	Non-combustibility test Gross heat of combustion	DIN EN ISO 1182 DIN EN ISO 1716
$A2_{fl}$	Non-combustible building materials	Non-combustibility test Gross heat of combustion Exposure to radiant heat source	DIN EN ISO 1182 DIN EN ISO 1716 DIN EN ISO 9239-1
B_{fl}	Flame-retardant building materials	Exposure to radiant heat source Single-flame source test	DIN EN ISO 9239-1 DIN EN ISO 11925-2

Building material class	Description	Test method	Test standard
C_{fl}	Flame-retardant building materials	Exposure to radiant heat source Single-flame source test	DIN EN ISO 9239-1 DIN EN ISO 11925-2
D_{fl}	Normally flammable building materials	Exposure to radiant heat source Single-flame source test	DIN EN ISO 9239-1 DIN EN ISO 11925-2
E_{fl}	Normally flammable building materials	Single-flame source test	DIN EN ISO 11925-2
F_{fl}	Highly flammable building materials	None	

Table 40: Overview of requirements for achieving construction product building classes for floorings as per DIN EN 13501-1.

Building material class	Test method	Classification criteria
$A1_{fl}$	DIN EN ISO 1182 and	$\Delta T \leq 30°C$ and $\Delta m \leq 50\%$ and No inflammation
	DIN EN ISO 1716	PCS ≤ 2 MJ/kg →Homogeneous components and substantial components PCS ≤ 2 MJ/m² →External non-substantial components PCS ≤ 1.4 MJ/m² →Internal non-substantial components PCS ≤ 2 MJ/kg →Whole product
$A2_{fl}$	DIN EN ISO 1182 or	$\Delta T \leq 50°C$ and $\Delta m \leq 50\%$ and Inflammation: Max. 20 s
	DIN EN ISO 1716 and	PCS ≤ 3 MJ/kg →Homogeneous components and substantial components PCS ≤ 4 MJ/m² →External non-substantial components PCS ≤ 4 MJ/m² →Internal non-substantial components PCS ≤ 3 MJ/kg →Whole product
	DIN EN ISO 9239-1	Critical heat flux[46] ≥ 8 kW/m²
B_{fl}	DIN EN ISO 9239-1 and	Critical heat flux ≥ 8 kW/m²
	DIN EN ISO 11925-2 30 s exposure time	Vertical flame spread ≤ 150 mm (after 60 s)
C_{fl}	DIN EN ISO 9239-1 and	Critical heat flux ≥ 4.5 kW/m²
	DIN EN ISO 11925-2 30 s exposure time	Vertical flame spread ≤ 150 mm (after 60 s)

[46] Heat flux at which the flames extinguish or heat flux after a test period of 30 minutes (so the heat flux at the most distant spread of flame within 30 minutes), whichever is the lower value (definition as per DIN EN 9239-1).

Building material class	Test method	Classification criteria
D_{fl}	DIN EN ISO 9239-1 and DIN EN ISO 11925-2 30 s exposure time	Critical heat flux ≥ 3 kW/m² Vertical flame spread ≤ 150 mm (after 60 s)
E_{fl}	DIN EN ISO 11925-2 15 s exposure time	Vertical flame spread ≤ 150 mm (after 20 s)
F_{fl}	None	None

5.4.4.1 Non-combustibility test

Construction products that pass the non-combustibility test as per DIN EN ISO 1182 make no contribution to a fire or make no significant contribution to a fire because they are not fully inert and develop a limited amount of heat and flames at a temperature of 750°C. The practical use of the materials is not considered.

Test specimens

For a test, representative cylindrical test specimens with a diameter of 45 mm and a height of 50 mm are required.

The conditioning of the specimens generally takes place in accordance with the rules of DIN EN 13238 as:

a) Conditioning with a defined duration

or

b) Conditioning to constant mass

Following conditioning, the samples are stored for 20 to 24 hours in a circulating air drying cabinet at a temperature of 60°C.

Test apparatus

The test apparatus consists of an electrically heated cylindrical furnace and a cylindrical sample holder with which the samples can be precisely positioned in the centre axis of the furnace. For a test, three thermocouples are required for:

1. Measuring the furnace temperature
2. Measuring the temperature on the surface of the specimen
3. Measuring the temperature inside (in the centre) of the specimen

Test execution

The furnace is heated to 750°C and the specimen is inserted. The temperature development at the three measurement points is recorded for 30 minutes. If no stabilisation of the temperature occurs within 30 minutes, the test is extended in steps of 5 minutes until temperature equilibrium is reached. The test ends after 60 minutes at the latest. The test is performed five times.

Criteria for passing the test

The classification criteria are summarised in Table 38 and Table 40.

5.4.4.2 Determination of gross heat of combustion

This test method as per DIN EN ISO 1716 determines the maximum heat release of a construction product upon full combustion in a bomb calorimeter. Like in the case of the non-combustibility test, this test method does not take practical usage into account.

Test specimens

For the test, both the substantial[47] and the non-substantial[48] components of a product are investigated individually. The samples are ground to a fine powder and are conditioned in accordance with the specifications of DIN EN 13238, as described in Section 5.4.4.1.

Test apparatus

This test uses a bomb calorimeter into which a calorimetric bomb can be placed.

Test execution

The sample is placed in the calorimetric bomb, sealed and filled with oxygen until the pressure reaches 3 to 3.5 MPa. The calorimeter is filled with water until the bomb is covered. The bomb is then heated electrically to bring about the combustion of the sample. The gross heat of combustion is calculated from the initial temperature and the maximum temperature. The test is performed five times.

Criteria for passing the test

The classification criteria are summarised in Table 38 and Table 40.

5.4.4.3 Thermal attack by a single burning item

The test takes place in accordance with the specifications of DIN EN 13823 and represents the exposure of the test material to a single burning item.

Test specimen

The specimen consists of two sample wings with the following dimensions that are arranged to form a corner:

- Wing 1: (495 x 1500) mm^2
- Wing 2: (1000 x 1500) mm^2

The maximum thickness of the samples must not exceed 200 mm. The samples are installed in the same way as in their later practical application, so building materials that are back-ventilated in reality are installed with a cavity for the test. If the construction products have joints, a horizontal joint must be made at a height of 500 mm above the lower sample edge and a vertical joint must be installed at 200 mm from the corner on wing 2. The samples must be conditioned as per DIN EN 13238 as described in Section 5.4.4.1.

Test apparatus

The test apparatus consists of a non-combustible test chamber and a test device (specimen trolley, frame, burner, exhaust hood, collector and exhaust pipe), a smoke extractor and various measuring devices. The test specimens are flamed using two sandbox burners (main and

[47] Definition of substantial component as per DIN EN ISO 13943:
Material that constitutes a significant part of a non-homogeneous product with a mass/unit area ≥ 1.0 kg/m^2 or a thickness ≥ 1.0 mm.

[48] Definition of non-substantial component as per DIN EN ISO 13943:
Material that does not constitute a significant part of a non-homogeneous product and that has a mass/unit area < 1.0 kg/m^2 and a thickness of < 1.0 mm.

auxiliary burners) located at the bottom on the corner of the specimen. In addition, the following measuring devices are required:

- Type K sheathed thermocouple
- Gas measuring probe to determine the concentration of oxygen and carbon dioxide
- Light measuring system to determine the smoke density

Test execution

At the start of the test, the specimen is moved into the test chamber and the ignition flames of the two burners are ignited. After 120 seconds, the auxiliary burner is ignited and after 300 seconds the gas supply is switched from the auxiliary burner to the main burner. The test must then be performed for a period of 1260 seconds. During the test, the lateral flame spread must be observed. Further, burning droplets must be observed for the first 600 seconds. The oxygen and carbon dioxide concentrations and the transmission of light in the exhaust pipe are measured online during the test. The measured values can be used to determine the fire growth rate (FIGRA), total heat release (THR) and smoke growth rate (SMOGRA). Each material is subjected to an SBI test three times.

Criteria for passing the test

The classification criteria are summarised in Table 38.

The smoke development is classified into the following three classes in accordance with the TSP (after 600 seconds) and the SMOGRA values:

1. s1: SMOGRA ≤ 30 m^2/s^2; TSP ≤ 50 m^2
2. s2: SMOGRA ≤ 180 m^2/s^2; TSP ≤ 200 m^2
3. s3: No requirements

The burning droplet behaviour of the materials is determined during the first 600 seconds and is classified into the following three classes:

1. d0: No falling or dripping burning matter
2. d1: Falling or dripping burning matter for less than 10 seconds
3. d2: No requirements; if a paper ignites during the test as per DIN EN ISO 11952-2 (see Section 5.4.4.4), the material is classified as d2.

5.4.4.4 Ignitability of products subjected to direct impingement of flame – Single-flame source test

With this test as per DIN EN ISO 11925-2, the ignitability of a sample surface or edge is tested with a match equivalent flame.

Test specimens

According to DIN EN ISO 11925-2 the specimens must have a length of 250 mm and a width of 90 mm; the maximum thickness is 60 mm. A test consists of 6 specimens conditioned as per DIN EN 13238 as described in Section 5.4.4.1.

Test apparatus

The test apparatus is like that for the test as per DIN 4102, described in Section 5.4.3.3. As per DIN EN ISO 11925-2, the test takes place at a flow velocity of 0.7 m/s in an exhaust stack. During the test, the specimen is clamped vertically in the holder and is flamed with a propane gas flame at an angle of 45°. A special wire basket is used for loose material. Filter paper is placed under the sample to enable an analysis of burning droplets.

Test execution

The samples are placed into the holder and flamed for 15 or 30 seconds. The progress of the flame is then observed for a further 5 or 30 seconds. A distinction is made between surface and edge ignition. The filter paper under the specimens during the test enables an assessment of burning droplets.

Criteria for passing the test

The classification criteria are summarised in Table 38 and Table 40.

5.4.4.5 Determination of burning behaviour using a radiant heat source

The test as per DIN EN ISO 9239-1 simulates the exposure of a floor to heat during the early stages of a fire in an adjacent room or compartment under wind-opposed flame-spread conditions.

Test specimens

For a test, six representative samples measuring 1050 x 230 mm^2 and conditioned to constant mass are required.

Test apparatus

The test apparatus consists of a test chamber containing a sample holder, a gas-fired radiant panel attached at an angle of 30° to the horizontal, and a pilot burner.

Test execution

The sample holder and sample are pushed into the preheated test chamber and the test chamber is exposed to radiant heat for 30 minutes. In the first 10 minutes, the flame of the pilot burner touches the sample. During the test, the progression of the flame front is recorded every 10 minutes. The test is performed twice. The critical heat flux is determined from the developed frame front and the calibrated heat flux profiles in accordance with the radiant heat source.

Criteria for passing the test

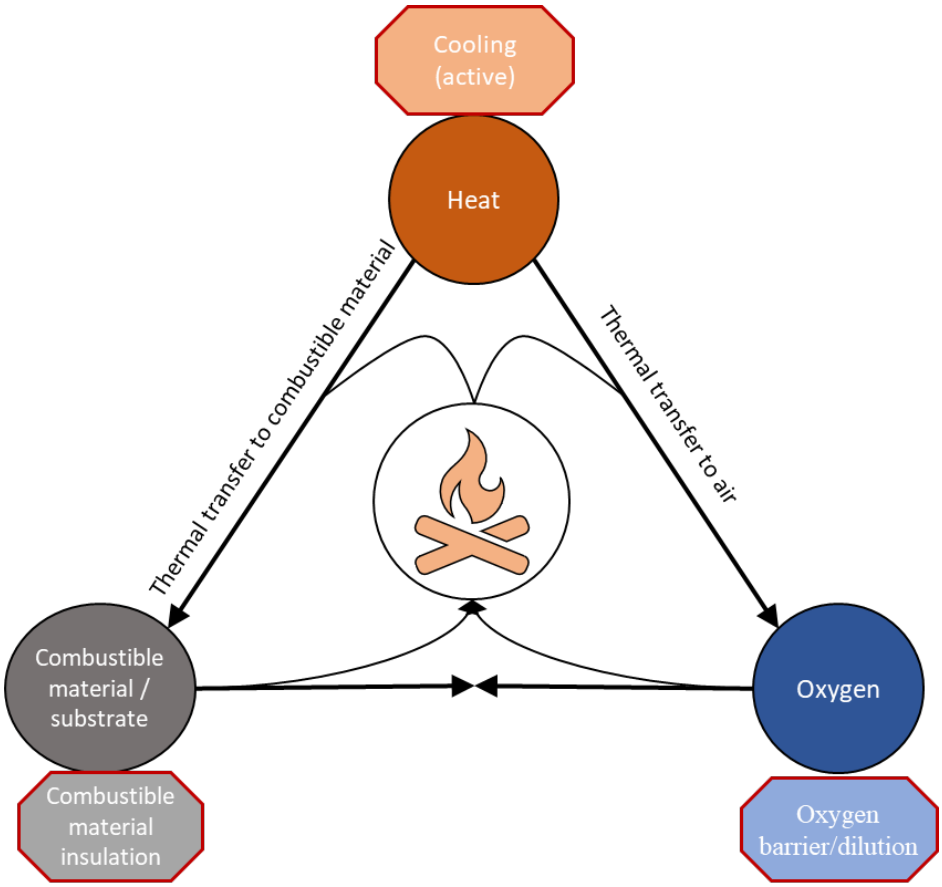
The classification criteria are summarised in Table 40.

6 Options for meeting the fire protection requirements

6.1 Introduction

Due to their chemical and physical effects, flame retardants (FRs) can intervene at various different points in the combustion process (Figure 17) by suppressing or delaying inflammation and/or by reducing the flame spread speed (DIN EN ISO 13943). Substances of this kind aim to limit, slow down, or ideally prevent flame spread. The use of flame retardants in flammable materials can strengthen the properties of such materials so that they meet technical fire protection requirements. The way in which they work is primarily dependent on the used flame retardant and can result from chemical or physical principles.

Figure 17: Fire triangle with possible points of attack.



Source: own work, Fraunhofer WKI, Piatkowsky, according to Simon 2006; Jeske 2012.

The active cooling of the system can be brought about through endothermic reactions as well as through chemical and physical effects (Simon 2006). In the case of chemical cooling, the flame retardant releases radicals if a fire occurs. These intervene in the radical chain mechanism and slow it down (Drohmann 2001). Halogenated flame retardants with bromine or chlorine compounds can be used for this. The fire-retardant effect of brominated flame retardants is greater than that of chlorinated flame retardants (Leisewitz et al. 2001). However, if a fire occurs or if they are disposed of incorrectly, brominated flame retardants can release highly toxic, bioaccumulative dioxins (UBA 2008). As a result of Regulation (EC) No. 1907/2006, only two of the four main classes (TBBPA and PBB) are allowed for the use of brominated flame retardants

in insulating material. Since 2016, the use of HBCD (hexabromocyclododecane) is also no longer allowed in EPS insulation, and the use of PBDE (polybrominated diphenyl ethers) is completely prohibited.

Physical cooling takes place when endothermic (energy-consuming) processes are triggered, for example through the decomposition of compounds and the associated chemical release of water. Frequently, inorganic aluminium hydroxide (ATH), which has a decomposition temperature of around 200°C, and magnesium hydroxide (MDH), which has a decomposition temperature of around 300°C, are used. Less frequently, boric compounds and zinc compounds are used. In both cases, the system cools down and the supply of flammable gases is gradually reduced until the temperature required to maintain the combustion processes is no longer reached (EFRA 2014).

A further physical mode of action involves the dilution of the oxygen required to maintain a fire with inert, non-combustible gases. In this case, a sufficient amount of inert gases must be released to displace the oxygen in the air, reducing it to below 15 vol% in order to "suffocate" the combustion process (Battran 2011). Nitrogen compounds such as melamine, melamine cyanurate, and other homologous compounds that release nitrogen and ammonia[49], among other substances, when exposed to heat are suitable for this dilution process (EFRA 2014).

In addition, the combustion process can be influenced by the material insulation of the substrate as a result of chemical or physical effects. In both cases, the flame retardant brings about the formation of a protective layer around the combustible material to insulate the material against the heat and oxygen that are required for the continuation of the combustion process. Organophosphorous flame retardants and inorganic phosphorous compounds such as red phosphorous and ammonium polyphosphate (APP) primarily act through releasing phosphoric acid upon decomposition. This results in the carbonisation of the organic substrate, and an insulating carbon layer forms. Expandable graphite, which can be used as an alternative, expands greatly when exposed to heat, thus forming a resistant protective layer around the polymer (EFRA 2014); see also Section 6.2.

Many of the mentioned flame retardants do not simply act in one of the described ways; instead, they also bring about secondary fire-retardant effects in combination with other substances. This enables the establishment of intumescent systems which, if the components are precisely tailored to each other, can bring about the formation of an extremely effective intumescent coating. In addition to the existing polymers, these intumescent systems generally consist of a binding agent, gas source, carbon source, and acid source. In the presence of a thermal load, an acid is first released; in turn, this releases carbon from the carbon source. At the same time, the decomposition of the propellant gives rise to the formation of gases that cause the accruing carbon to foam up and create an insulating carbon foam. As long as the sequence of reactions is timed correctly, the substrate is protected by the non-combustible insulating layer from further contact with flames and thus from ignition (Simon 2006). The gas source is often a nitrogen compound such as melamine or melamine phosphate. Organic hydrocarbons such as polyalcohol and carbohydrates can be used as carbon sources whereas inorganic phosphorous compounds such as phosphoric acid, APP, or even sulphuric acid can be used as the acid source. In order to be suitable for use as an acid source, a substance must release its acids in a temperature range of 100 to 250°C (Jeske 2012).

Materials and products can be protected from flames at three different levels:

[49] Ammonia is not an inert gas but it does have very low flammability.

- Additive flame retardancy: In this case, flame retardants are added to combustible materials (mixed with the materials) as additives or are applied to the materials from the outside as a flame-retardant coating [see Section 6.2].
- Inherent flame retardancy: In this case, substances (fibres) acquire a permanent flame-retardant property through a chemical reaction that makes the material created from them flame-resistant [see Section 6.3].
- Alternative flame retardancy: This refers to materials and products whose protection is ensured even without the use of flame retardants because, for example, they are non-combustible [see Section 6.4].

In particular in the case of additive flame retardants in textiles, it is also important to remember that these retardants can sometimes be washed out of the textiles when the clothing, upholstery, mattress covers etc. are washed. This gives rise to both ecological and technological hazards, since as the proportion of flame retardants in the textiles decreases, the resistance of the textiles to flames also drops. Flame retardants can be categorised as follows in accordance with their wash resistance (pinfa 2017):

- Non-durable (the flame retardant is not resistant at all to washing),
- Semi-durable (the flame retardancy treatment can survive a limited number of washing/soaking cycles),
- Durable (the flame retardancy treatment remains when subject to at least 50 wash cycles).

6.2 Additive flame retardants

Flame retardants can be placed into the following categories depending on their chemical composition:

- Halogenated FRs,
- Inorganic phosphorous-based FRs,
- Organic phosphorous-based FRs,
- Nitrogen-based FRs,
- Other inorganic FRs,
- Other FRs.

Halogenated flame retardants act through a chemical reaction in the gas phase that results in the formation of free radicals that interrupt the radical chain mechanism of the combustion process, cool it down, and thus prevent spread. The best-known halogenated flame retardants are polybrominated diphenyl ethers (PBDE), hexabromocyclododecane (HBCD), tris(2-chloroethyl)phosphate (TCEP), tris(2-chloro-1-methylethyl)phosphate (TCPP), decabromodiphenyl ethane (DBDPE), and tris(1,3-dichloroisopropyl)phosphate (TDCPP)[50]. Although halogenated flame retardants are particularly effective, their use is increasingly restricted or prohibited by the REACH regulation (Regulation (EC) No. 1907/2006) due to their

[50] TCEP and TCPP can also be categorised as organophosphorous flame retardants. However, for the sake of consistency, these substances are categorised only as halogenated flame retardants below.

high toxicity, bioaccumulation, and persistence[51] (Drohmann 2001). In the discussion below, substances whose use is prohibited or greatly restricted by European law are not considered further.

Phosphorous-based flame retardants (both organic and inorganic) primarily take effect in the solid phase. During their thermal decomposition, phosphoric acid is released. This brings about the carbonisation of the combustible material, which obstructs the further supply of oxygen or oxidation at the ignition source. Ammonium phosphate (AP), ammonium polyphosphate (APP), red phosphorous, and diammonium hydrogen phosphate are the best-known inorganic phosphorous-based flame retardants. Because red phosphorous has a strong odour, it cannot be used universally. Frequently used organic phosphorous-based flame retardants include N-hydroxymethyl(3-dimethyl phosphono)propionamide (DMPPA), tricresyl phosphate (TCP), triethyl phosphate (TEP), diphenyl tolyl phosphate, resorcinol bis(diphenyl phosphate) (RDP), methylphosphonic acid, a mixture of cyclic phosphonates, and tetrakis(hydroxymethyl)phosphonium chloride (THPC) (Leisewitz et al. 2001). The mixture of cyclical phosphonates, THPC, and DMPPA are wash resistant, although in the case of the last of these, wash resistance applies only once the FR has reacted with a fibre.

The effect of *flame retardants containing nitrogen* is based on the dilution of the oxygen-containing air and combustible pyrolysis gases or on the promoted carbonisation of the substrate. Melamine, melamine cyanurate (MC), melamine phosphate (MP), melamine polyphosphate (MPP), and thiourea are the most frequently used nitrogen flame retardants (EFRA 2014).

Other inorganic flame retardants such as aluminium hydroxide (ATH), magnesium hydroxide (MDH), and disodium tetraborate (Borax) primarily act through the separation of water under a thermal load, which cools the combustion process. Antimony trioxide (ATO), which is also a mineral substance, acts as a synergist for halogenated and organic flame retardants. The reactions underlying the synergism of antimony trioxide and halogens are not absolutely clear. It is generally agreed (Leisewitz et al. 2001) that synergism in flame retardancy is primarily based upon gas phase mechanisms but also involves the promotion of carbonisation in the solid phase, the repression of oxygen access to the fire zone by superimposing it with heavy vapour, and the cooling of the flammable material through the gradual formation of antimony-halogen products.

The use of ATO alone has no flame-retardant effect (Leisewitz et al. 2001). Expandable graphite is also a mineral-based flame retardant that is incorporated into the polymer matrix (e.g. polyurethane foam, polyamides) in accordance with the specifications of the manufacturer and can be used in textiles (Luh 2021). The flame retardancy of expandable graphite is based on its physical properties, since the black graphite flakes demonstrate a large increase in volume at temperatures of around 300°C. As heat takes effect, an intumescent layer forms on the surface of

[51] Restrictions as per Regulation (EC) No. 1907/2006:
- Pentabromodiphenyl ether (PentaBDE): Prohibition on placing on the market; more than 0.1% w/w not permitted as an ingredient of preparations.
- Octabromodiphenyl ether (OctaBDE): Prohibition on placing on the market; more than 0.1% w/w not permitted as an ingredient of preparations.
- Decabromodiphenyl ether (DecaBDE): Prohibition on manufacturing and placing on the market.
- Hexabromocyclododecane (HBCD): Subject to authorisation.
- Tris(2-chloroethyl) phosphate (TCEP): Subject to authorisation.
- Short-chain chlorinated paraffins (SCCP): Prohibition on placing on the market; more than 1.0% w/w not permitted as an ingredient of preparations.

materials. One important possible application of expandable graphite is as fire protection for soft polyurethane foam in aeroplane seats (Troitzsch 2016).

Zirconium acetate could not be placed into any of the categories named above and is therefore included in the "Other" category. According to statements from the flame retardants industry, this salt is not wash resistant.

The following Sections below list commonly used flame retardants for various product groups. The information comes from the following literature sources: Borukaev and Alakaeva (2019), EFRA (2014), Hörold (2014), Leisewitz et al. (2001), Leisewitz and Schwarz (2001), Mather and Wardman (2015), Rothon and Hornsby (2014), SAM (2017), UBA (2003), van der Veen and de Boer (2012), and from Regulations (EC) No. 1907/2006 (2020) and (EC) No. 1272/2008 (2020). These are not specified again below.

6.2.1 Protective work clothing

Commonly used additive flame retardants for protective work clothing are shown in Table 41. Because items of clothing are subjected to multiple wash cycles during their lifetime and because additive flame retardants are not generally permanent, inherent flame retardants are preferred here. These are described in more detail in Section 6.3.

Table 41: Common additive FRs for protective work clothing.

Organic halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
		N-hydroxymethyl(3-dimethyl phosphono)propionamide (DMPPA)			
		Tetrakis(hydroxymethyl)phosphonium chloride (THPC)			

6.2.2 House and home textiles

Commonly used additive flame retardants for house and home textiles are shown in Table 42. House and home textiles are goods that are used for interior design and decor. This includes blankets, throws, bedlinen, table linen, kitchen linen, bathroom textiles, toilet linen, curtains, drapes, valances, passements, and furniture coverings. The additive flame retardants for furniture coverings are dealt with separately in Section 6.2.3.

Table 42: Common additive FRs for house and home textiles.

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
Decabromodiphenyl ethane (DBDPE)	Ammonium polyphosphate (APP)	N-hydroxymethyl(3-dimethyl phosphono)propionamide (DMPPA)	Melamine	Ammonium hydroxide (ATH)	Zirconium acetate
	Diammonium hydrogen phosphate	Tricresyl phosphate (TCP)	Melamine cyanurate (MC)	Ammonium sulphate	
	Red phosphorous	Tetrakis(hydroxymethyl)phosphonium chloride (THPC)	Melamine phosphate (MP)	Ammonium sulphamate	
		Resorcinol bis(diphenyl phosphate) (RDP)	Thiourea	Ammonium bromide	
		Methylphosphonic acid		Dipotassium hexafluorotitanate	
		Mixture of cyclical phosphonates		Antimony trioxide (ATO) only as synergist	
				Expandable graphite	

6.2.3 Upholstered furniture (fabric)

Table 43 shows commonly used additive flame retardants for upholstered furniture with fabric coverings. The product group "Upholstered furniture (fabric)" includes furniture coverings made from textiles, woollen textiles, and synthetic fibres. Wooden composites and/or upholstery foam that are or can be parts of furniture of this kind are dealt with separately.

Table 43: Common additive FRs for upholstered furniture (fabric).

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
Tetrabromobisphenol A (TBBPA)	Ammonium polyphosphate (APP)	N-hydroxymethyl(3-dimethyl phosphono)propionamide (DMPPA)	Melamine	Disodium tetraborate (Borax)	

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
Decabromodiphenyl ethane (DBDPE)	Diammonium hydrogen phosphate	Tricresyl phosphate (TCP)	Melamine cyanurate (MC)	Ammonium sulphate	
	Red phosphorous	Tetrakis(hydroxymethyl)phosphonium chloride (THPC)	Melamine phosphate (MP)	Ammonium sulphamate	
		Resorcinol bis(diphenyl phosphate) (RDP)	Melamine polyphosphate (MPP)	Ammonium bromide	
		Methylphosphonic acid		Potassium hexafluorozirconate	
		Mixture of cyclical phosphonates		Antimony trioxide (ATO) as a synergist	

6.2.4 Upholstered furniture (leather)

Current commonly used additive flame retardants for upholstered material with leather coverings are shown in Table 44. The product group "Upholstered furniture (leather)" includes furniture coverings made from leather. Wooden composites and/or upholstery foam that are or can be parts of furniture of this kind are dealt with separately. Because leather does not burn easily, it can be made flame-retardant more easily than other materials according to statements from the leather sector (e.g. Leder-Info 2021).

Table 44: Common additive FRs for upholstered furniture (leather).

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
	Ammonium phosphate (AP)	Methylphosphonic acid	Melamine cyanurate (MC)	Ammonium bromide	
	Ammonium polyphosphate (APP)		Melamine polyphosphate (MPP)		
	Red phosphorous				

6.2.5 Mattress materials

Table 45 provides an overview of commonly used additive flame retardants for mattress materials. Upholstery foam that is or can be part of mattresses of this kind is dealt with separately.

Table 45: Common additive FRs for mattress fabrics.

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
	Ammonium polyphosphate (APP)	N-hydroxymethyl(3-dimethyl phosphono)propionamide (DMPPA)	Melamine cyanurate (MC)	Ammonium sulphate	
	Red phosphorous	Tetrakis(hydroxymethyl)phosphonium chloride (THPC)	Melamine phosphate (MP)	Ammonium sulphamate	
		Methylphosphonic acid			
		Mixture of cyclical phosphonates			

6.2.6 Foams (mattress and upholstery)

Table 46 shows current commonly used additive flame retardants for foam used in mattresses and upholstery.

Table 46: Common additive FRs for mattress and upholstery foam.

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
Tris(2-chloro-1-methylethyl) phosphate (TCPP)	Ammonium polyphosphate (APP)	Triethyl phosphate (TEP)	Melamine cyanurate (MC)	Aluminium hydroxide (ATH)	
Tris(1,3-dichloroisopropyl)phosphate (TDCPP)	Red phosphorous	Resorcinol bis(diphenyl phosphate) (RDP)	Melamine polyphosphate (MPP)	Magnesium hydroxide (MDH)	
				Expandable graphite	

6.2.7 Carpets

The tables below list the additive flame retardants that are generally used for carpets. The product group "Carpets" is further broken down into "Carpet back coatings" [Table 47] and "Carpet fibres" [Table 48], which can be natural or synthetic.

Table 47: Common additive FRs for carpet back coatings.

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
Decabromodiphenyl ethane (DBDPE)	Ammonium polyphosphate (APP)	N-hydroxymethyl(3-dimethyl phosphono)propionamide (DMPPA)	Melamine	Aluminium hydroxide (ATH)	Zirconium acetate
	Diammonium hydrogen phosphate	Tricresyl phosphate (TCP)	Melamine cyanurate (MC)	Magnesium hydroxide (MDH)	
	Red phosphorous	Triethyl phosphate (TEP)	Melamine phosphate (MP)	Ammonium sulphamate	
		Resorcinol bis(diphenyl phosphate) (RDP)	Melamine polyphosphate (MPP)	Dipotassium hexafluorotitanate	
		Mixture of cyclical phosphonates		Antimony trioxide (ATO)	
				Expandable graphite	

Table 48: Common additive FRs for carpet fibres.

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
	Red phosphorous	Methylphosphonic acid	Melamine cyanurate (MC)	Aluminium hydroxide (ATH)	
		Mixture of cyclical phosphonates	Melamine phosphate (MP)	Magnesium hydroxide (MDH)	
			Thiourea	Dipotassium hexafluorotitanate	

6.2.8 Wood and wooden composites

Table 49 shows commonly used additive flame retardants for wood and wooden composites. Wooden composites include plywood, laminated veneer lumber, particle board, fibreboard, and oriented strand board (OSB) that are used to make entire pieces of furniture or that are incorporated into other pieces of furniture such as upholstered furniture. FRs for wood and wooden composites can be categorised as fire-smothering, charring-promoting, barrier-layer-

forming, and intumescent (www.wecobis.de/service/lexikon/flammschutzmittel-lex.html - German only).

Table 49: Common additive FRs for wood and wooden composites.

Halogenated FRs	Inorganic phosphorous-based FRs	Organic phosphorous-based FRs	Nitrogen-containing FRs	Other inorganic FRs	Other
	Ammonium polyphosphate (APP)		Melamine	Aluminium hydroxide (ATH)	
	Diammonium hydrogen phosphate			Magnesium hydroxide (MDH)	
	Red phosphorous			Disodium tetraborate (Borax)	
				Ammonium sulphate	

6.3 Inherent flame retardancy

The flame resistance of a textile/fabric does not only depend on the type of components and flame retardancy treatment; it is also dependent on the areal density of the fabric, its structure, air permeability, and moisture content. In this regard, non-woven fabrics should have better properties than woven or machine-knitted structures, even if all other parameters are the same (DEFRA 2010, Lee and Barker 1987).
Numerous fibres and the textiles made from them have inherent flame resistance. In many usage areas, wash resistance is the primary advantage here.
In the case of inherently flame-retardant products, problematic substances are often released as a result of improper recycling of the flame-retardant fibres (German Federal Environment Agency 2016, pinfa 2017, Kruecken 2021). A further aspect that is particularly relevant for flame-retardant plastics is the difficulty of recycling; much of the world's stock of polymer recyclates is said to be contaminated with brominated flame retardants and their degradation products (Hull et al. 2014). However, the recycling and reusability of heat-resistant and fire-resistant fibres, which often consist of complex blends and compound structures, also pose a technical challenge (Horrocks 2016).
Below, we briefly present known materials from literature and the Internet along with example uses.

6.3.1 Wool

As a keratin-based protein fibre, wool is inherently flame-retardant; the ignition temperature of sheep's wool is around 560°C (Korjenic et al. 2014). The LOI value of wool is 25%; the LOI values[52] of cotton (18.4%), viscose (18.9%), and polyester (20-21%) are lower. As a general rule, fibres with an LOI value of more than 26% are considered to be not readily ignitable (Mather and Wardman 2015). Wool can extinguish small sparks itself; it has a tendency towards charring, and the carbon layer is an effective heat barrier that impedes further fire (Mather and

[52] The LOI value specifies the oxygen concentration at which a material starts to burn under test conditions. The higher the value, the better the resistance of the material to burning.

Wardman 2015). However, this inherent property of wool is not sufficient for certain application areas (e.g. for the aircraft sector), and flame retardancy treatment is therefore required (Posner 2004). Typical products made from wool include home textiles such as blankets and cushion covers, furnishing cover materials, and carpets.

6.3.2 Cellulose and viscose

The product Visil® (Sateri, Finland) is an inherent flame retardancy solution for (regenerated) cellulose and viscose fibres. To produce it, a viscose solution is mixed with sodium silicate and is then spun to create fibres. Its permanent fire resistance is achieved through its high polysilicic acid content (30±33%); the silicic acid penetrates the fibres during the production process (e.g. Burrow 2013). Its flame retardancy property is based on endothermic water separation and the formation of a charred layer (Weil and Levchik 2016) which means that the material does not melt or run during a fire and that, as a rule, no smoke or toxic vapours form. Visil® can also be combined with natural fibres such as wool and cotton.

Phosphorous-based Lenzing™FR (Lenzing™) is a special cellulose/viscose fibre for flame retardancy applications. Like Visil®, it is a regenerated cellulose fibre that is obtained from wood pulp and contains an organophosphorous additive that is introduced during the fibre production process. During a fire, these fibres increase carbonisation, thus providing heat and flame protection for a wide range of applications. The fibres have a heat-insulating property in combination with permanent flame resistance. Unlike flame-retardant cotton, Lenzing™FR fibres can be mixed with other inherent FR fibres such as aramid and modacrylic fibres (Wakelyn 2008). Fibre combinations of the Modal fibre Lenzing™FR along with e.g. aramid fibres, wool, nylon, modacrylic fibres, polybenzimidazole (PBI) fibres and others are used to produce protective clothing for the fire brigade, police, military services, and industry (Lenzing™ 2021). These textiles can also be used for applications such as covering polyurethane foam in upholstered furniture or mattresses (Weil and Levchik 2016).

6.3.3 Polyester

Polyester fibres such as PET are copolymerised with a phosphorous monomer during production for improved fire safety (Freudenberger and Jakob 1982). During the last 30 years, numerous inherently flame-retardant polyester fibres have been developed; of these, Trevira CS has seen commercial success (Wakelyn 2008). According to the manufacturer, textiles made from Trevira CS are not readily ignitable due to the chemical composition of the polyester fibres, since they contain an organophosphorous compound as a comonomer (Trevira 2021). The usage areas of Trevira CS include drapes, decorative fabrics, stage curtains, furniture fabrics, window shades, bedding, and table linen. The use of Trevira CS in upholstered furniture enables compliance with all international flame retardancy standards (Wakelyn 2008).

The Zeroxy™ fibres produced by Huvis are also based on polyester and a phosphorous compound (polyester FR). This product provides semi-permanent flame retardancy that is largely retained after 50 wash cycles (pinfa 2017).

6.3.4 Polyamides/aramids

Flame-retardant polyamides include aramids (aromatic polyamides) known under the tradenames Nomex® (DuPont), Kermel® (Kermel SA), and Kevlar® (DuPont).

Nomex® is the registered tradename of a flame-retardant meta-aramid material. This is an aromatic polyamide, the meta variant of the para-aramid Kevlar®, produced from poly(*para*-phenylene terephthalamide). The material is used as a textile in applications that require

resistance to heat and flames along with acceptable aesthetic and wear properties. All aramids are heat-resistant and not readily ignitable, but Kevlar®, thanks to its *para* substitution pattern, can be molecularly guided to offer increased strength and a better modulus of elasticity[53].

The polyamide-imide fibre Kermel® (Kermel SA) is highly resistant to heat and is also used in clothing for the fire brigade and police when mixed with other fibres (e.g. TTI 2021).
Aramid blends are used as fire-retardant fabrics in aeroplane seats and can also be found in other upholstered seats between the outer fabric and foam core as protection for the foam (Erb et al. 2002).

In addition, an intrinsically flame-retardant polyamide has been developed by the German Institute of Textile Technology and Process Engineering (DITF 2021). In a new procedure, small quantities of flame-retardant phosphorous compounds are incorporated into the polymer chains during the plastic synthesis reaction. At the time of writing, this material is not yet available on the market.

6.3.5 Polymelamine fibres

Basofil® fibre (BASF) is resistant to heat and flames and is based on the patented melamine technology. Basofil® fibre has similar properties to those typical of other common materials based on melamine formaldehyde: Heat stability, low inflammability, high wear resistance, and resistance to solvents and UV rays. It has an LOI value of 32%, low heat conductivity, excellent dimensional stability, and does not shrink; no melting or burning droplets are seen when the fibres are exposed to flame. Machines for woven, knitted, and non-woven materials can be used to produce fire protection barriers made from wadding or to produce fabric for mattresses and upholstered furniture. Basofil® fibres are also found in aeroplane seats and protective clothing, e.g. as flame arresters (Weil and Levchik 2016).

6.3.6 Polyetherimides

Chemically, polyetherimides are polyimides that are highly temperature resistant and can be used to produce woven and non-woven fabrics such as the fibre variant Ultem™ 9011 (SABIC) (e.g. US8940209B2 2006; Weil und Levchik 2016; Kalayci et al. 2016). Ultem™ is an amorphous polyimide with good thermoplastic processability thanks to the incorporation of aromatic ether groups into its molecular chain. The material is not readily ignitable and produces only small amounts of smoke if a fire occurs.

6.3.7 Other fibre and material variants

Modacrylic (MAC) fibres are produced using halogenated comonomers such as vinylidene chloride or vinyl chloride in the polymer (Mather and Wardman 2015). They are not readily ignitable and are self-extinguishing; the inherently flame-retardant acrylic fibres do not melt or drip when ignited and carbonise in combination with cotton (Rofa Bekleidungswerk 2021). MAC can be used in protective clothing, drapes, furnishings, carpeting, and areas where flame retardancy is important (Mather und Wardman 2015).

PyroTex® is a fibre based on acrylonitrile. Along with other properties, it is permanently flame-resistant and heat-resistant. This fibre has an LOI of 43% and is used in protective work clothing and in the seats of public transport vehicles (PyroTex 2021).

[53] In materials engineering, the "modulus of elasticity" denotes a material characteristic value describing the linear elastic behaviour of a solid body as a proportional relationship between stress and strain during deformation.

Polyphenylene sulphide (PPS) is a highly temperature-resistant thermoplastic that is primarily used for plastic parts subject to high thermal, mechanical, and/or chemical loads, mainly in the automotive sector (e.g. Celanese 2021). PPS fibres have high thermostability. They are not readily ignitable (LOI of 39 to 41%), are self-extinguishing, and melt at 285 °C (Parker et al. 2012). Diofort® is a multi-filament yarn with a high tensile strength that can be used in woven goods, non-woven materials, and for reinforcement (Textile World 2021).

Proban® is a chemical solution created by Solvay (formerly called Rhodia) that gives textiles with a high cotton content flame-retardant properties. According to the manufacturer, the fire retardancy is resistant to frequent washing (Rofa Bekleidungswerk 2021) and is therefore used to manufacture protective work clothing. The procedure impregnates the fully woven cotton or cotton blend with the Proban chemicals. The material is then dried and gassed with ammonia using a licensed technology (Alsko 2021).

Melamine resin foam (e.g. Basotect®) is used as a non-combustible upholstery material in aeroplane and cinema seating and as a sound absorber, among other things (BASF 2021). The flame-resistant properties of the material are due to the high nitrogen content of the melamine resin. The foam is particularly suitable for applications with increased fire protection requirements (FSK 2021).

6.3.8 Table with overview of inherent flame retardants

Table 50 shows inherently flame-retardant materials with their usage areas by product group.

Table 50: Possible uses of inherently flame-retardant materials by product group.

Material	Products/product names	Product group					
		Protective work clothing	House and home textiles	Upholstered furniture (fabric)	Mattress materials	Foams (mattresses and upholstery)	Carpets
Wool	-		x	x	x		x
Cellulose and viscose	Visil®				x[54]		
	Lenzing™FR	x		x	x	x	
Polyester	Trevira CS		x	x	x		
	Zeroxy™	x	x	x			
Polyamides/aramids	Nomex®	x					
	Twaron®	x					

[54] E.g. as covers for mattresses (see e.g. https://patents.google.com/patent/US7484256B2/en).

Material	Products/product names	Product group					
		Protective work clothing	House and home textiles	Upholstered furniture (fabric)	Mattress materials	Foams (mattresses and upholstery)	Carpets
	Kevlar®	x					
	Kermel®	x					
Polymelamine fibres	Basofil®	x		x	x		
Polyetherimides	Ultem™ 9011	x	x	x	x		
Other	Modacrylic (MAC) fibres	x	x				x
	PyroTex®	x		x[55]			
	Diofort®		x	x			
	Proban®	x	x	x	x		
	Melamine resin foam					x	

6.4 Alternative flame retardancy

With regard to alternative flame retardancy, the following section presents product-group-specific materials whose flame retardancy is ensured or that are non-combustible without the use of flame retardants. These include fibreglass, basalt fibre, gypsum materials, and concrete materials.

6.4.1 Textiles for protective work clothing

- The very fine fibres of a basalt variant composed of minerals in the plagioclase, pyroxene, and olivine groups resemble fibreglass. The spun fibres can be processed to produce woven materials and insulating materials (e.g. Suter Kunststoffe AG 2021). According to the manufacturer, basalt roving and textile fabrics made from it can be used to create fire-resistant woven materials for protective work clothing (Deutsche Basaltfaser GmbH 2021).

6.4.2 House and home textiles

- Weave constructions made from non-combustible glass filaments are used in applications such as glare protection (window shades, sun blinds, awnings) and for decorative applications such as drapes and wall/ceiling coverings (A2Textiles 2021).

[55] Used for seats in e.g. trains, aeroplanes, cinemas, and theatres.

- Nowetex® is a glass fabric classified as a non-combustible material in building material class A2. This material is used to make covers for quilts and cushions, shower curtains, drapes, and table cloths (e.g. GEFA 2021).
- Endless basalt fibres can be used to make home and interior design textiles such as wall coverings and base textiles. For Basaltex® (Masureel), the basalt fibres are given a primer and a silicone coating (Weil and Levchik 2016). One possible use of Basaltex® is as a fire barrier in industrial fabrics and composites for public transport (air, sea, and rail).

6.4.3 Furniture

In the furniture sector, there are various possible ways of avoiding the use of flame retardants. For example, it is common practice to make the underframe or substructure from non-combustible materials such as tubular steel or aluminium.

- Concrete furniture is classed as non-combustible. Concrete tables, benches, stools, reception desks, and wall brackets are available on the market (e.g. efecto.de, Oggi-beton.de, Betoniu.com). The relatively high dead weight of concrete furniture can be advantageous in escape routes, since they are difficult to move and therefore remain in their intended position. A few manufacturers offer complete solutions for furniture that is not readily ignitable, is certified as per DIN 66084 P a, and can be placed in rescue routes. This furniture is certified as a whole and is not allowed to be simply modified as desired.
- Gypsum fibreboards are available on the market as substrates with various coating materials. They can be further processed for use in interior design and to make furniture. Gypsum fibreboards are covered with aluminium sheet, lacquer coatings, paper surfaces, and veneer, for example. The furniture and furnishing items made from them (e.g. cupboards, shelves, sideboards, tables, benches, chairs, wardrobes, counters) can be classified as building material class A1 or A2 according to the vendors (Weigand und Wiederschein 2021).
- High-pressure laminate coated with melamine resin on gypsum fibreboard is classed as non-combustible and can be used for interior design and to make furniture according to the manufacturers (Dekodur 2021).
- Unupholstered and non-combustible furniture (e.g. made from concrete, gypsum, or metal) can be customised with non-combustible upholstery and textiles if desired. This can be done using fabric made from fibreglass with a polymer coating that can serve as a barrier layer for furniture (e.g. VersaShield®). The endless filament fabric Flamline® is made from 95% fibreglass with a 5% finish (polyvinyl alcohol, acrylic binder, and pigments) (Porcher Industries 2021) and is non-combustible in accordance with the applicable standards (DIN EN 13501; A2-s1, d0 (EU); DIN 4102-A2). This material is used as a separating layer on upholstery foam in furniture production, for example.
- Nowetex® is a glass fabric classified as a non-combustible material in building material class A2. This material is used to make non-combustible chairs (e.g. GEFA 2021).

6.4.4 Floorings

- Textile floorings for living quarters are classed as normally flammable; this means that they meet the minimum requirements for construction products and generally are not treated with FRs (Baunetz-Wissen 2020a).

- A floor panel with a fire-resistant coating has been described in a patent (https://patents.google.com/patent/US20090214832). The laminate has a fire-retardant layer made from non-combustible material (preferably a fibreglass mat) and is impregnated with melamine resin. It is not currently available commercially. The fire-retardant layer is situated between the core and the decorative layer, and the edges are formed from fire-retardant kaolin and sodium silicate.
- Linoleum is used to make elastic floor coverings. Essentially, it is made from linseed oil, natural resin, powdered cork, wood flour, powdered limestone, titanium(IV) oxide, and colourants. Jute fabric acts as the carrier layer. Linoleum can be classified as not readily ignitable (DIN 4102, B1) or normally flammable (B2). Due to its properties, linoleum is also used in hospitals and nurseries (Tarkett 2021).
- The various flooring variants made from PVC should also be mentioned as "alternatives" in the sense of FR-free possibilities. These generally consist of the thermoplastic polyvinyl chloride, plasticisers, and additives. PVC floorings are not readily ignitable and are generally in building material class B1 (DIN 4102) with regard to their fire behaviour (Baunetz-Wissen 2020b).

6.5 Summary

In order to meet fire safety requirements, it might be necessary to strengthen the properties of the used materials using flame retardants. The following methods are used for this:

- Additive flame retardancy: In this case, flame retardants are added to combustible materials (mixed with the materials) as additives or are applied to the materials from the outside as a flame-retardant coating. The following types of FR are discussed in more detail in this paper: Halogenated FRs, inorganic phosphorous-based FRs, organic phosphorous-based FRs, nitrogen-based FRs, other inorganic FRs, and other FRs. It can be clearly seen that these are used differently in the various product areas [protective work clothing, house and home textiles, upholstered furniture (fabric/leather), mattress materials, foams (mattresses and upholstery), carpets, and wood/wooden composites]. Flame retardancy solutions that are prohibited as per the REACH regulation [Regulation (EC) No. 1907/2006] are not considered further here.
- Inherent flame retardancy: In this case, substances (fibres) acquire a permanent flame-retardant property through a chemical reaction that makes the material created from them flame-resistant. The following materials have been investigated in more detail and have had possible usage in the various product groups tested: Wool, cellulose and viscose, polyester, polyamides/aramids, polymelamine fibres, polyetherimides, and other fibre/material variants.
- Alternative flame retardancy: This refers to materials and products whose protection is ensured even without the use of flame retardants because, for example, they are non-combustible. A closer consideration of alternative flame retardancy was performed for the following product groups: Textiles for protective work clothing, house and home textiles, furniture, and floorings.

The choice of the most suitable solution is always dependent on the usage area of the materials and the method-dependent costs. In the case of additive flame retardancy, there is generally a risk that the flame retardants will be washed out of the products during cleaning. This danger exists for protective work clothing and some house and home textiles. As a rule, inherent flame

retardants or alternative fire retardancy solutions are used in such cases. To sum up, there is no solution that can be applied for all materials. Each flame retardancy solution was developed for a specific application area. These aspects are presented in detail in this section.

7 Assessment of flame retardants

Diverse types of flame retardants and flame retardancy solutions are available for use in the various product groups. Their precise application depends mainly upon the product to be protected. The use of traditional (additive) flame retardants is not associated with advantages only. On the one hand, due to their diverse modes of action, they can positively influence the fire behaviour of substances and/or products, thus contributing to sound technical fire safety. The use of fire retardants can increase the safety of people and animals as well as extending the usage areas of many substances and/or products. The development and use of synthetic materials was associated with the increased use of flame retardants. Synthetic polymers such as polyethylene, polypropylene, polyurethane, and polystyrene burn better than natural materials such as wool, cotton, and leather, and can generate more smoke and toxic fumes, particularly in open structures and with low density, like in fabrics and foams (Stec and Hull 2014).

On the other hand, in an objective consideration of these flame-retardant substances, their negative properties should not be ignored, because flame retardants can pose a significant risk to the environment and the health of many creatures. In particular, the extremely effective and therefore frequently used halogenated flame retardants often have significantly problematic health and environmental properties as well as having a long lifetime in the environment (persistence) and the ability to accumulate in organisms (bioaccumulation). In addition to the intrinsic properties of the substance in question, the hazard posed by certain substances is due to their (uncontrolled) release into the environment. For example, additive flame retardants can enter the environment through the use of everyday objects (e.g. during the washing of flame-retardant clothing). Hull et al. (2014) and others describe the global spread of brominated flame retardants. These compounds have been found in remote areas from the Arctic to the Antarctic, since the transport processes also take place via the atmosphere. Brominated flame retardants are also spread via the food chain.
Similarly, combustion products and the gases that are produced during a fire can have adverse effects on the environment and on health. In particular, there is a risk that persistent, bioaccumulative, toxic products (PBTs) such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated and polybrominated dibenzodioxins and dibenzofurans (PCDDs/PCDFs and PBDDs/PBDFs) can be formed from halogen-containing materials during real fires (e.g. Stec and Hull 2014). PCDDs and PBDDs are extremely toxic, chemically and thermally stable, and can be adsorbed on the surface of particulate matter (Stec and Hull 2014).
The following section therefore subjects "traditional" (additive) flame retardants to an ecological assessment with the ultimate objective of providing recommendations for purchasers. For this purpose, the hazard statement codes in accordance with the CLP Regulation (2021) are used in an initial step. In a second step, the remaining flame retardants are assessed on the basis of the following criteria: Persistence, bioaccumulation, wash resistance, combustion products, and costs. Further, the GreenScreen assessment method and its individual assessment criteria are presented in an excursus. In relation to this, we explain why - from the point of view of the researcher - the application of this method is not sufficient when applied to flame retardants at present.

7.1 Assessment criteria

In a first step, the assessment of the flame retardants is based on their HS codes. Subsequently, the following criteria are used:

- Persistence

- Bioaccumulation
- Wash resistance
- Combustion products
- Costs

The individual criteria are presented in the sections below.

7.1.1 CLP Regulation

The classification of a substance or mixture is regulated by the CLP Regulation (2021), which ensures a high level of protection for human health and for the environment and for the free movement of substances, mixtures, and articles. This EU regulation harmonises the criteria for the classification of substances and mixtures along with the provisions for the labelling and packaging of hazardous substances and mixtures. It also governs the HS codes that must be used to identify a substance or mixture.

Below, we perform an assessment of flame retardants in the product groups under consideration (see Section 6.2). To simplify the assessment, all substances with HS codes that are not permitted in accordance with the Blue Angel award criteria are excluded from further assessment. Table 51 lists the HS codes that are used in accordance with the product groups that are relevant for this research project; the meaning of these HS codes is briefly explained. The relevant award criteria here are Low-Emission Panel-Shaped Materials (Construction and Furnishing Panels for Interior Construction) (DE-UZ 76 (2016)), Low-Emission Upholstered Furniture (DE-UZ 117 (2018)), Mattresses (DE-UZ 119 (2018)), Elastic Floor Coverings (DE-UZ 120 (2011)), Low-Emission Textile Floor Coverings (DE-UZ 128 (2016)), Leather (DE-UZ 148 (2015)), Textiles (DE-UZ 154 (2017)), and Shoes (DE-UZ 155 (2018))[56]. In addition, more individual HS codes may lead to substance exclusion in the aforementioned product groups.

The HS code assignments were taken from the ECHA database of the C&L (Classification & Labelling) inventory[57]. This contains harmonised classifications of the Member States along with self-classifications in accordance with the CLP Regulation.

Note that not every HS code constitutes an exclusion in all Blue Angel product groups. The appraisal as to which HS codes lead to an exclusion in each product group is always performed on a scientific basis by various experts from the German Federal Environment Agency and external research institutes. These results are then discussed in expert hearings. All interested parties can take part in these expert hearings. As a rule, participants include companies, associations, testing institutes, non-governmental organisations, and scientific institutions. The criteria for the various product groups are then finalised by the participants. Next, these criteria are presented to the ecolabel jury, which makes the final decision about the presented criteria. The jury consists of a wide range of stakeholders[58].

[56] See also https://www.blauer-engel.de/en/certification/basic-award-criteria.

[57] https://echa.europa.eu/information-on-chemicals/cl-inventory-database

[58] In 2021, the ecolabel jury consisted of representatives of Stiftung Warentest, Deutscher Städtetag, Handelsverband Deutschland – HDE e.V., the General Students' Committee of the Rhenish Friedrich Wilhelm University of Bonn, the United Nations University, the Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES), NABU – Naturschutzbund Deutschland e.V., der Verbraucherzentrale Bundesverband e. V. (vzbv), the State Office for the Environment, Natural Protection, and Geology of Mecklenburg-Vorpommern, the Board of the German Trade Union Confederation (DGB), the Zentralverband des Deutschen Handwerks e.V. Chamber of Skilled Crafts Berlin, the Forschungsstätte der Evangelischen Studiengemeinschaft e.V., the Bund für Umwelt und Naturschutz Deutschland e. V. (BUND), the Federation of German Industries (BDI), and the Hessian Ministry for the Environment, Climate Protection, Agriculture, and Consumer Protection.

Table 51: HS codes leading to exclusion from the Blue Angel award in accordance with the relevant award criteria[59].

HS code	Meaning
H300	Fatal if swallowed
H301	Toxic if swallowed
H310	Fatal in contact with skin
H311	Toxic in contact with skin
H330	Fatal if inhaled
H331	Toxic if inhaled
H340	May cause genetic defects
H350	May cause cancer
H350i	May cause cancer by inhalation
H360D	May damage the unborn child
H360Df	May damage the unborn child. Suspected of damaging fertility
H360F	May damage fertility
H360FD	May damage fertility. May damage the unborn child.
H360Fd	May damage fertility. Suspected of damaging the unborn child.
H370	Causes damage to organs
H372	Causes damage to organs through prolonged or repeated exposure

31 flame retardants, already named in Section 6.2 (see Table 41 to Table 49), form the basis for the investigation.

The following Table 52 shows the assessment of the flame retardants and states the exclusion hazard statement codes. We can see that 20 of the substances have at least one HS code and are not suitable for further consideration.

[59] DE-UZ 76 (2016): Low-Emission Panel-Shaped Materials (Construction and Furnishing Panels for Interior Construction); DE-UZ 117 (2018): Low-Emission Upholstered Furniture; DE-UZ 119 (2018): Mattresses; DE-UZ 120 (2011): Elastic Floor Coverings; DE-UZ 128 (2016): Low-Emission Textile Floor Coverings; DE-UZ 148 (2015): Leather; DE-UZ 154 (2017): Textiles; DE-UZ 155 (2018): Shoes (see also https://www.blauer-engel.de/en/certification/basic-award-criteria).

Table 52: Substances that are excluded from Blue Angel[60] due to their HS code(s).

Substance	CAS RN	Excluding HS codes
Hexabromobenzene (HBB)	87-82-1	H413
Tris(2-chloro-1-methylethyl) phosphate (TCPP)	13674-84-5	H412, H413
Di-Ammonium hydrogen phosphate	7783-28-0	H311, H412
Red phosphorous	7723-14-0	H412
Dimethyl [3-[(hydroxymethyl)amino]-3-oxopropyl]phosphonate (DMPPA)	20120-33-6	H317, H350
Tris(methylphenyl) phosphate (TCP)	1330-78-5	H317, H361d, H370, H371, H372, H373, H400, H410, H411
Trimethyl phosphate (TMP)	512-56-1	H340, H350, H351, H361, H373
Triethyl phosphate (TEP)	78-40-0	H341, H350
Tetrakis(hydroxymethyl)phosphonium chloride (THPC)	124-64-1	H301, H311, H317, H330, H334, H350, H360, H400, H410, H411
Tetrakis(hydroxymethyl)phosphonium chloride, oligomeric reaction products with urea (THPC)	27104-30-9	H317, H341, H350, H361d, H373, H410, H412
Diphenyl tolyl phosphate (cresyl diphenyl phosphate)	26444-49-5	H371, H400, H410, H411, H412
Melamine	108-78-1	H317, H351, H361f, H361fd, H372, H373, H400, H410
Thiourea	62-56-6	H317, H331, H351, H361d, H373, H411
Magnesium hydroxide (MDH)	1309-42-8	H372
Sodium tetraborate decahydrate (Borax)	1303-96-4	H360FD, H370, H412
Ammonium sulphate	7783-20-2	H331, H371, H400, H411
Dipotassium hexafluorotitanate	16919-27-0	H301, H317
Dipotassium hexafluorozirconate	16923-95-8	H300, H301, H311, H331, H412
Diantimony trioxide (ATO)	1309-64-4	H317, H350, H351, H360Df, H370, H372, H373, H411, H412
Diantimony pentoxide	1314-60-9	H411, H413

According to this assessment, 14 of the flame retardants under consideration can be used in the investigated products/product groups:

- Phosphoric acid, ammonium phosphate (CAS RN 10124-31-9)
- Polyphosphoric acids, ammonium polyphosphate (CAS RN 68333-79-9)

[60] DE-UZ 76 (2016), DE-UZ 117 (2018), DE-UZ 119 (2018), DE-UZ 120 (2011), DE-UZ 128 (2016), DE-UZ 148 (2015), DE-UZ 154 (2017), DE-UZ 155 (2018) (see also https://www.blauer-engel.de/en/certification/basic-award-criteria).

- 1,3,5-triazine-2,4,6-triamine phosphate, melamine phosphate (CAS RN 41583-09-9)
- 1,3,5-triazine-2,4,6-triamine monophosphate, melamine polyphosphate (CAS RN 218768-84-4)
- Ammonium sulphamate (CAS RN 13765-36-1)
- Sulphuric acid, compound with graphite, expandable graphite (CAS RN 12777-87-6)
- Graphite, acid-treated, expandable graphite (CAS RN 90387-90-9)
- Zirconium acetate (CAS RN 7585-20-8)
- 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol, tetrabromobisphenol A (TBBPA, CAS RN 79-94-7) in upholstered furniture
- 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene], decabromodiphenyl ethane (DBDPE, CAS RN 84852-53-9) in upholstered furniture and in carpet back coatings
- Tetraphenyl m-phenylene bis(phosphate), resorcinol bis(diphenyl phosphate) (RDP, CAS RN 57583-54-7) in upholstered furniture, mattresses, and textile floors
- 1,3,5-triazine-2,4,6(1H,3H,5H)-trione, compound with 1,3,5-triazine-2,4,6-triamine (1:1), melamine cyanurate (MC, CAS RN 37640-57-6) in floorings and textiles
- Aluminium hydroxide (ATH; CAS RN 21645-51-2) in textile floorings
- Ammonium bromide (CAS RN 12124-97-9) in textiles

These 14 flame retardants are now assessed on the basis of further criteria in a second step.

7.1.2 Further assessment criteria

The following criteria were used for the further assessment of the flame retardants: Persistence, bioaccumulation, wash resistance, combustion products, and costs. These criteria were included in the assessment method because they represent important aspects for the usage area of the products. Washing resistance, which should be considered only for materials that are intended to be washed, provides lifecycle and environmental impact information. The combustion products provide information about hazards in the event of a fire, and costs are important in order to enable the planning of budgets in procurement. The bioaccumulation and persistence criteria look at degradability and the accumulation of the substances in the environment.

The list of the 14 flame retardants should be put to the test again, where possible, on the basis of these selected criteria. The objective is to determine whether a recommendation can be made for public purchasers with regard to these flame retardants.

Persistence

Persistence relates to the amount of time that a chemical substance can exist in the environment before it is destroyed by natural processes (so transformed) (US EPA 2011). A substance that is "persistent" is broken down by microbial enzymes or mineralised only slowly or not at all. From one point of view, this property is technologically desirable (because durability is a quality feature); on the other hand, it is not desirable from an ecological viewpoint for environmental contamination to result in an accumulation of a substance in environmental media and for its concentration in the environment to have an adverse effect on the living and non-living world (Leonhäuser 2006). This parameter depends greatly upon the ambient and test conditions. The

accumulation of persistent substances in water, soil, and the air is primarily a major environmental hazard if these substances reach the food chain due to their lipophile properties (Leonhäuser 2006).

The persistence of the flame retardants was checked on the pages of the European Chemicals Agency (https://echa.europa.eu/en/home) by entering their CAS RNs. Of the 14 flame retardants, TBBPA and DBDPE are classified as persistent, and as a result these two substances are not considered further.

Bioaccumulation

Bioaccumulation refers to the potential of a substance or certain substances of a mixture to accumulate in the environment and thus enter the food chain (Employer's Liability Insurance Association for the Construction Industry (BG BAU) 2021). In aquatic organisms, the substances enter from the surrounding medium via the gills and skin and when sediment particles or other contaminated organisms are eaten (Mackay and Fraser 2000). In the case of land animals, the substances are ingested in food and drinking water. This bioaccumulation of a substance can, on the one hand, harm the ingesting organism itself if the substance reaches a concentration that is harmful for that organism. However, it can also lead to the transfer of the substance via the food chain if the contaminated organism is eaten. Creatures at the top of a food chain are particularly endangered by this (UBA 2021).

Generally, the ratio between the concentration of a chemical substance in an organism and its concentration in the environment is used to describe the extent of bioaccumulation. The determination of the bioaccumulation factor (BAF) takes place in accordance with OECD 315 (2008) and OECD 317 (2010) and the determination of the bioconcentration factor (BCF) takes place in accordance with OECD 305 (2012). The octanol water partition coefficient (K_{OW}) is calculated using the shake flask method as per OECD 107 (1995) and high-performance liquid chromatography (HPLC) as per OECD 123 (2006). It is generally specified in the form of a decimal logarithm.

The bioaccumulation of flame retardants was checked on the pages of the European Chemicals Agency (https://echa.europa.eu/en/home) by entering their CAS RNs. This research found that of the 14 flame retardants, TBBPA and DBDPE are classed as bioaccumulative, and as a result these two substances are not considered further.

Wash resistance

The wash resistance of textiles was described in brief in Section 6.1 The assessment of wash resistance is not easily possible, since:

- An assessment only really makes sense for textiles that are actually washed. Despite this, in the case of products for which no washing is intended for their entire usage duration (e.g. sofas with a permanent cover, mattresses with the exception of the mattress cover etc.), this lack of washing resistance would have unjustified negative effects on the assessment.
- The washability of flame retardants is greatly dependent on the carrier (the substance to which they are added). For example, a flame retardant might be semi-durable in combination with textile A but not offer any wash resistance when applied to textile B.

Here, it might be possible to fall back upon general information from literature - where it exists - in which, for example, additive flame retardants are classified as not wash-resistant or as semi-wash-resistant.

Of the 14 flame retardants that, in accordance with Section 7.1.1, meet the award criteria of the Blue Angel ecolabel, none is used in protective work clothing. Some products in the "House and home textiles" area also need to be wash-resistant. There, all of the flame retardants listed in Section 7.1.1 are used with the exception of expandable graphite. These flame retardants are either semi-wash-resistant (APP, melamine polyphosphate, ammonium sulphamate) or not wash-resistant (ammonium phosphate, melamine phosphate, zirconium acetate) in the various areas of use and can therefore not be used for wash-resistant applications (EFRA 2012 and pinfa 2017). The flame retardants that are used only in certain products are either not wash-resistant (ammonium bromide) or are used only in products for which the issue of wash resistance is not relevant.

Combustion products

In the case of a fire, the thermal decomposition of the burning materials takes place. Depending on whether combustion is full or incomplete, different gaseous, liquid, or solid products are created. The creation of products of this kind depends on:

- the concentration of oxygen,
- the temperature and
- the original material.

Different combustion products are produced depending on the combination of these parameters. During the hot phase (incipient fire or full fire) high concentrations of toxic or irritant gases or vapours form, such as carbon monoxide, hydrogen halides (hydrogen chloride, hydrogen fluoride, or hydrogen bromide), acrolein, sulphur dioxide, nitrogen oxides, or hydrogen cyanide (condensed: prussic acid). These pose a potential hazard for living beings (German Association of Property Insurers - VdS 2357 2014).

The concentrations of decomposition products released during the burning of substances are determined in accordance with ISO 19702:2015-08. To do so, a sample with a defined size is burned in a chamber and the concentration of the substance being investigated is then determined by means of Fourier-transform infrared (FTIR) spectroscopy. The limit values are shown in Table 53.

Table 53: Combustion product limit values (IMO FTP Code 2010).

Substance	Limit value
Carbon monoxide	1450 ppm
Hydrogen fluoride	600 ppm
Nitrogen oxides	350 ppm
Hydrogen chloride	600 ppm
Hydrogen bromide	600 ppm
Sulphur dioxide	120 ppm

The limit values above are taken from the IMO FTP Code 2010. This assessment criterion has restrictions with regard to the assessment of flame retardants. The combustion products that are produced during thermal decomposition depend greatly on the additive-containing substance, which is thermally decomposed at the same time and also releases certain reaction products.

Costs

In addition to the ecological requirements upon flame retardants, economic factors, so the cost effectiveness of purchasing the products (here products with flame retardancy), are also relevant. An economic consideration of the purchase of products with appropriate flame retardancy might, for example, involve (where possible) a comparison of the costs, potentially lifecycle costs, of products with inherent flame retardancy and products with additive flame retardancy. Naturally, products with different additive flame retardants might also be compared with each other. In general, there are three possible methods, each of which is more or less suitable depending on the scenario:

- **Costs per unit of weight:** This comparison *would* only be suitable for additive flame retardants. However, since manufacturers rarely sell the pure substances and instead sell products, extensive data collection is probably not effective. For example, the manufacturer Clariant alone has 13 flame retardants with ammonium polyphosphate as a major ingredient in its portfolio (https://www.clariant.com/en/Corporate/Search?tab=products).
- **Costs per unit of area:** This comparison *would* only be suitable for (inherently) flame retardant fibres and not for additive flame retardants. The data could be obtained from manufacturers.
- **Costs per unit of area to achieve a certain level of flame retardancy:** This comparison *would* be suitable for additive flame retardants and flame-retardant fibres etc. However, the data collection required to perform a sound comparison would seem to be practically impossible. Especially in the case of additive flame retardants, the required quantity to meet certain requirements depends primarily on the carrier material (e.g. cotton, hemp, sheep's wool, leather, hardwood, softwood, wood fibres, wood chippings etc.). In conjunction with the different products of the manufacturers (see point 1), this gives rise to numerous possible combinations that could only be applied to a specific example, if at all.

A differentiated and precise economic comparison of alternatives would seem to be impossible, since the exact data required can probably be obtained only with high research efforts or a lot of inquiries. Ultimately, purchasers must apply a "traditional" economic assessment, meaning that their decision is based upon the lowest price or lowest lifecycle costs while still meeting the ecological requirements.

7.2 Excursus: GreenScreen assessment criteria

Below, we present the GreenScreen® for Safer Chemicals ("GreenScreen") method of the Clean Production Action organisation. This is a free and transparent method that has been reviewed by experts for the assessment of hazards posed by chemicals and the identification of chemicals of concern and of safer alternatives. The method uses various assessment criteria (Table 54) that are assigned one of the following five hazard levels on the basis of defined limit values and/or classifications:

- Very high hazard/pollution level (vH),
- High hazard/pollution level (H),
- Moderate hazard/pollution level (M),
- Low hazard/pollution level (L),
- Very low hazard/pollution level (vL).

Various data sources from all over the world are available for the assessment, e.g. measured values from recognised test methods, Globally Harmonized System (GHS) classifications (EU and non-EU), HS codes[61], and other internationally recognised listings. Then, one of four benchmarks is determined and assigned to the chemical substance in question as the final result on the basis of the results for the individual assessments of the various criteria:

- Benchmark 1: Avoid – Chemical of High Concern,
- Benchmark 2: Use but Search for Safer Substitute,
- Benchmark 3: Use but Still Opportunity for Improvement,
- Benchmark 4: Use – Safer Chemical.

Table 54: Assessment Criteria of GreenScreen (Clean Production Action 2018).

Environmental behaviour	T (Ecotox)	T (Group I Human)	T (Group II Human)	T (Group III Human)	Physical
Persistence (P)	Acute Aquatic Toxicity (AA)	Mutagenicity/Genotoxicity (M)	Systemic Toxicity and Organ Effects (ST-single)	Systemic Toxicity and Organ Effects (ST-repeated)	Physical Reactivity (Rx)
Bioaccumulation (B)	Chronic Aquatic Toxicity (CA)	Carcinogenicity (C)	Neurotoxicity (N-single)	Neurotoxicity (N-repeated)	Flammability (F)
		Developmental (Neuro-)Toxicity (D)	Skin Irritation (IrS)	Skin Sensitisation (SnS)	
		Reproductive Toxicity (R)	Eye Irritation (IrE)	Respiratory Sensitisation (SnR)	
		Endocrine Activity (E)	Acute Mammalian Toxicity (AT)		

7.2.1 Benchmark determination

Following the assessment of the individual criteria, a benchmark is determined for the organic or inorganic substance being investigated. The most negative assessment results for the individual criteria or groups of criteria are always decisive here.

Table 55 shows the assessment criteria for the benchmarks for **organic** chemicals. Similarly, Table 56 lists the assessment criteria for the benchmarks for **inorganic** chemicals.

[61] HS code: Hazard statement code for a chemical substance.

Table 55: Benchmarks for organic chemicals.

Benchmark	Explanation	P	B	T (Ecotox)	T (Group II Human)	T (Group III Human)
1 (PBT)	High P **and** high B **and** very high T (Ecotox)	H	H	vH		
	High P **and** high B **and** very high T (Group II Human)	H	H		vH	
	High P **and** high B **and** high T (Group III Human)	H	H			H
1 (vPvB)	Very high P **and** very high B	vH	vH			
1 (vPT)	Very high P **and** very high T (Ecotox)	vH		vH		
	Very high P **and** very high T (Group II Human)	vH			vH	
	Very high P **and** high T (Group III Human)	vH				H
1 (vBT)	Very high B **and** very high T (Ecotox)		vH	vH		
	Very high B **and** very high T (Group II Human)		vH		vH	
	Very high P **and** high T (Group III Human)		vH			H
2	Moderate P **and** moderate B **and** moderate T (Ecotox)	M	M	M		
	Moderate P **and** moderate B **and** moderate T (Group II Human)	M	M		M	
	Moderate P **and** moderate B **and** moderate T (Group III Human)	M	M			M
	High P **and** high B	H	H			
	High P **and** moderate T (Ecotox)	H		M		
	High P **and** moderate T (Group II Human)	H			M	
	High P **and** moderate T (Group III Human)	H				M
	High B **and** moderate T (Ecotox)		H	M		
	High B **and** moderate T (Group II Human)		H		M	
	High B **and** moderate T (Group III Human)		H			M
	Very high T (Ecotox)			vH		
	Very high T (Group II Human)				vH	
	High T (Group III Human)					H

Benchmark	Explanation	P	B	T (Ecotox)	T (Group II Human)	T (Group III Human)
3	Moderate P	M				
	Moderate B		M			
	Moderate T (Ecotox)			M		
	Moderate T (Group II Human)				M	
	Moderate T (Group III Human)					M
4	Low P **and** low B **and** low T (Ecotox **and** Group II Human **and** Group III Human)	L	L	L	L	L

Table 56: Benchmark for inorganic chemicals.

Benchmark	Explanation	P	B	T (Ecotox – only CA)	T (Ecotox)	T (Group II Human)	T (Group III Human)
1 (PBT)	High P **and** high B **and** very high T (CA)	H	H	vH			
	High P **and** high B **and** high T (Group III Human)	H	H				H
1 (vPT)	Very high P **and** very high T (CA)	vH		vH			
	Very high P **and** very high T (Group III Human)	vH					H
1 (vBT)	Very high B **and** very high T (CA)		vH	vH			
	Very high B **and** very high T (Group III Human)		vH				H
2	Moderate P **and** moderate B **and** moderate T (CA)	M	M	M			
	Moderate P **and** moderate B **and** moderate T (Group II Human)	M	M			M	
	Moderate P **and** moderate B **and** moderate T (Group III Human)	M	M				M
	High P **and** moderate T (CA)	H		M			
	High P **and** moderate T (Group II Human)	H				M	
	High P **and** moderate T (Group III Human)	H					M

Benchmark	Explanation	P	B	T (Ecotox – only CA)	T (Ecotox)	T (Group II Human)	T (Group III Human)
	High B **and** moderate T (Ecotox)		H		M		
	High B **and** moderate T (Group II Human)		H			M	
	High B **and** moderate T (Group III Human)		H				M
	Very high T (Ecotox)				vH		
	Very high T (Group II Human)					vH	
	High T (Group III Human)						H
3	Moderate B		M				
	Moderate T (Ecotox)				M		
	Moderate T (Group II Human)					M	
	Moderate T (Group III Human)						M
4	Low B **and** low T (Ecotox **and** Group II Human **and** Group III Human)		L		L	L	L

The GreenScreen assessment criteria are explained below. The data is taken from Annex I of the GreenScreen guide (Clean Production Action 2018). Limit values, data, classifications, and listings from non-EU countries were not taken into account.

Persistence (P)

Persistence relates to the amount of time that a chemical can exist in the environment before it is destroyed by natural processes (so transformed) (US EPA 2011). A substance that is "persistent" is broken down by microbial enzymes or mineralised only slowly or not at all. From one point of view, this property is technologically desirable (because durability is a quality feature); on the other hand, it is not desirable from an ecological viewpoint for environmental contamination to result in an accumulation of a substance in environmental media and for its concentration in the environment to have an adverse effect on the living and non-living world (Leonhäuser 2006). This parameter depends greatly upon the ambient and test conditions. The accumulation of persistent substances in water, soil, and the air is primarily a major environmental hazard if these substances reach the food chain due to their lipophile properties (Leonhäuser 2006).

Table 57 contains the limit values for half-life time in different media, determined using the test methods OECD 307 (2002), OECD 308 (2002), and OECD 309 (2004), and other assessment criteria for the persistence of substances.

In the GreenScreen method, persistence is assessed only for organic substances.

Table 57: Persistence – limit values and classifications.

Information type	Value	vH	H	M	L	vL
Data	Half-life time in soil or sediment	> 180 d or GHS recalcitrant	61 to 180 d	16 to 60 d[62]	< 16 d or GHS rapid degradability	Meets 10-day window in "Ready Biodegradation Test"[63]
	Half-life time in water	> 60 d or GHS recalcitrant	41 to 60 d	16 to 40 d	< 16 d or GHS rapid degradability	Meets 10-day window in "Ready Biodegradation Test"[63]
	Half-life time in air	> 5 d or GHS recalcitrant	2 to 5 d	-	< 2 d	-

Bioaccumulation (B)

Bioaccumulation refers to the potential of a substance or certain substances of a mixture to accumulate in the environment and thus enter the food chain (Employer's Liability Insurance Association for the Construction Industry (BG BAU) 2021). In aquatic organisms, the substances enter from the surrounding medium via the gills and skin and when sediment particles or other contaminated organisms are eaten (Mackay and Fraser 2000). In the case of land animals, the substances are ingested in food and drinking water. This bioaccumulation of a substance can, on the one hand, harm the ingesting organism itself if the substance reaches a concentration that is harmful for that organism. However, it can also lead to the transfer of the substance via the food chain if the contaminated organism is eaten. Creatures at the top of a food chain are particularly endangered by this (UBA 2021).

Generally, the ratio between the concentration of a chemical substance in an organism and its concentration in the environment is used to describe the extent of bioaccumulation. The determination of the bioaccumulation factor (BAF) takes place in accordance with OECD 315 (2008) and OECD 317 (2010) and the determination of the bioconcentration factor (BCF) takes place in accordance with OECD 305 (2012). The octanol water partition coefficient (K_{OW}) is calculated using the shake flask method as per OECD 107 (1995) and high-performance liquid chromatography (HPLC) as per OECD 123 (2006). It is generally specified in the form of a decimal logarithm. The limit values are shown in Table 58

[62] In contrast to the GreenScreen method, substances are classified as persistent as of a half-life time of > 120 days in accordance with Annex XIII of the REACH Regulation. For consistency reasons, only the GreenScreen values are presented here.

[63] Ready Biodegradation Test as per OECD 301 (1992).

Table 58: Bioaccumulation limit values.

Information type	Value	vH	H	M	L	vL
Data	Bioaccumulation Factor (BAF)	> 5000	> 1000 to 5000	> 500 to 1000	> 100 to 500	≤ 100
	Bioconcentration Factor (BCF)	> 5000	> 1000 to 5000	> 500 to 1000	> 100 to 500	≤ 100
	Log K_{ow}	> 5.0	4.5 to 5.0	4.0 to 4.5	-	≤ 4

Acute aquatic toxicity (AA)

Acute aquatic toxicity means the intrinsic property of a substance to be injurious to an organism in a short-term exposure to that substance (Regulation (EC) No 1272/2008). Acute aquatic toxicity is determined by experiments on fish, Daphnia[64], algae, and Lemna[65]. The test takes place in accordance with Regulation (EC) No 440/2008 with different concentrations of the test substance as follows:

- Fish as per Method C.1 (p. 944 et seq.) for a test duration of 96 hours with the criterion "mortality"
- Daphnia as per Method C.2 (p. 955 et seq.) for a test duration of 48 hours with the criterion "immobilisation"
- Algae as per Method C.3 (p. 966 et seq.) for a test duration of 72 hours with the criterion "growth inhibition"
- Lemna as per Method C.26 (p. 1378 et seq.) for a test duration of 7 days with the criterion "growth inhibition"

Table 59: Acute aquatic toxicity – limit values and classifications.

Information type	Value	vH	H	M	L
GHS cat.	-	1	2	3	GHS not classified and negative studies
Data	LC_{50} or EC_{50} [mg/l]	≤ 1	> 1 to 10	> 10 to 100	> 100
HS codes	-	H400	-	-	-

Chronic aquatic toxicity (CA)

Chronic aquatic toxicity means the intrinsic property of a substance to cause adverse effects to aquatic organisms during exposures which are determined in relation to the life-cycle of the organism (Regulation (EC) No 1272/2008).

[64] Genus of crustaceans.

[65] Genus of the arum family, also known as duckweed.

Chronic aquatic toxicity is determined by experiments on fish, Daphnia, and algae in accordance with OECD 202 (2004), OECD 210 (2013), and OECD 211 (2012).

Table 60: Chronic aquatic toxicity – limit values.

Information type	Value	vH	H	M	L
Data	LC_{50} or EC_{50} [mg/l]	≤ 0.1	> 0.1 to 1.0	> 1.0 to 10	> 10

Acute mammalian toxicity (AT)

Acute mammalian toxicity denotes the adverse effects that occur after oral or dermal administration of a single dose of a substance or after the administration of multiple doses within 24 hours or after inhalation exposure of four hours (US EPA 2011). Acute toxicity is determined in experiments on animals in accordance with Regulation (EC) 440/2008 with the criterion "mortality" as follows:

- Oral toxicity as per OECD 420 (2001) and OECD 423 (2001)
- Dermal toxicity as per Method B.3 (p. 248 et seq.)
- Inhalation toxicity as per OECD 403 (2009) and OECD 436 (2009)

Table 61: Acute mammalian toxicity – limit values and classifications.

Information type	Value	vH	H	M	L
GHS cat.	-	1 or 2	3	4	5 or GHS not classified and negative studies
Data (guidance values for animal data)	LD_{50} oral [mg/kg]	≤ 50	> 50 to 300	> 300 to 2000	> 2000
	LD_{50} dermal [mg/kg]	≤ 200	> 200 to 1000	> 1000 to 2000	> 2000
	LC_{50} gas [mg/l]	≤ 2	> 2 to 10	> 10 to 20	> 20
	LC_{50} mist [mg/l]	≤ 0.5	> 0.5 to 1.0	> 1 to 5	> 5
HS codes	-	H300, H310, or H330	H301, H311, or H331	H302, H312, or H332	-

Systemic Toxicity/Organ Effects (ST_{single} and $ST_{repeated}$)

Systemic toxicity and organ effects include all significant non-lethal effects in a single organ that can impair function, both reversible and irreversible, immediate and/or delayed, not otherwise covered by any other endpoint; or generalized changes of a less severe nature involving several organs (Clean Production Action 2018). Determination takes place in accordance with OECD 452 (2018).

Table 62: Systemic toxicity/organ effects ST_{single} – limit values and classifications (single exposure).

Information type	Value	vH	H	M	L
GHS cat.	-	1	2	3	GHS not classified and negative studies
Data (guidance values for animal data)	$NOAEL^{66}_{oral}$ [mg/kg-bw]	≤ 300	> 300 to 2000	-	-
	$NOAEL_{dermal}$ [mg/kg-bw]	≤ 1000	> 1000 to 2000	-	-
	$NOAEL_{Inhal., Gas}$ [mg/l/4h]	≤ 10	> 10 to 20	-	-
	$NOAEL_{Inhal., Mist}$ [mg/l/4h]	≤ 1.0	> 1.0 to 5.0	-	-
HS codes	-	-	-	H335	-

Table 63: Systemic toxicity/organ effects ST_{single} – limit values and classifications (single exposure – aspiration hazards).

Information type	Value	vH	H	M	L
GHS cat.	-	-	1	2	GHS not classified and negative studies
HS codes	-	-	H304	-	-

Table 64: Systemic toxicity/organ effects – limit values and classifications (repeated exposure $ST_{repeated}$).

Information type	Value	vH	H	M	L
GHS cat.	-	-	1	2	GHS not classified and negative studies
Data (guidance values for animal data)	$NOAEL_{oral}$ [mg/kg-bw/d]	-	≤ 10	> 10 to 100	> 100
	$NOAEL_{dermal}$ [mg/kg-bw/d]	-	≤ 20	> 20 to 200	> 200

[66] The greatest concentration or amount of a substance at which no detectable adverse effects occur in an exposed population (https://www.efsa.europa.eu/en/glossary/no-observed-adverse-effect-level-noael).

Information type	Value	vH	H	M	L
	$NOAEL_{Inhal., Gas}$ [mg/l/6h/d]	-	≤ 0.2	> 0.2 to 1.0	> 1.0
	$NOAEL_{Inhal., Mist}$ [mg/l/6h/d]	-	≤ 0.02	> 0.02 to 0.2	> 0.2

Neurotoxicity (N_{single} and $N_{repeated}$)

Neurotoxicity describes an adverse change in the structure or function of the central and/or peripheral nervous system after exposure to a chemical, physical, or biological agent (US EPA 2011). Determination takes place in accordance with OECD 407 (2008), OECD 424 (1997), and Methods B.37 (p. 559 et seq.) and B.38 (p. 564 et seq.) of Regulation (EC) No 440/2008.

Table 65: Neurotoxicity N_{single} – limit values and classifications (single exposure).

Information type	Value	vH	H	M	L
GHS cat.	-	1	2	3	GHS not classified and negative studies
Data (guidance values for animal data)	Oral [mg/kg-bw]	≤ 300	> 300 to 2000	-	-
	Dermal [mg/kg-bw]	≤ 1000	> 1000 to 2000	-	-
	Inhalation-gas [mg/l/4h]	≤ 10	> 10 to 20	-	-
	Inhalation-mist [mg/l/4h]	≤ 1.0	> 1.0 to 5.0	-	-
HS codes	-	-	-	H336	H336

Table 66: Neurotoxicity $N_{repeated}$ – limit values and classifications (repeated exposure).

Information type	Value	vH	H	M	L
GHS cat.	-	-	1	2	GHS not classified and negative studies
Data (guidance values for animal data)	Oral [mg/kg-bw/d]	-	≤ 10	> 10 to 100	> 100
	Dermal [mg/kg-bw/d]	-	≤ 20	> 20 to 200	> 200
	Inhalation-gas [mg/l/6h/d]	-	≤ 0.2	> 0.2 to 1.0	> 1.0

Information type	Value	vH	H	M	L
	Inhalation-mist [mg/l/6h/d]	-	≤ 0.02	> 0.02 to 0.2	> 0.2

Skin sensitisation (SnS)

Skin sensitisation refers to an allergic response occurring after skin contact with a substance (UN 2019). Determination takes place in accordance with Methods B.6 (p. 278 et seq.) and B.43 (p. 635 et seq.) of Regulation (EC) No 440/2008.

Table 67: Skin sensitisation – limit values and classifications.

Information type	Value	H	M	L
GHS cat.	-	1A	1B	GHS not classified and negative studies
HS codes	-	H317	H317	-

Respiratory sensitisation (SnR)

Respiratory sensitisation refers to hypersensitivity of the airways occurring after inhalation of a substance (UN 2019). Determination takes place in accordance with OECD 429 (2010).

Table 68: Respiratory sensitisation – limit values and classifications.

Information type	Value	H	M	L
GHS cat.	-	1A	1B	GHS not classified and negative studies
HS codes	-	H334	H334	-

Skin irritation (IrS)

Skin irritation is reversible damage to the skin following exposure to a substance (US EPA 2011). Determination takes place in accordance with OECD 404 (2015), OECD 430 (2015) and OECD 431 (2019).

Table 69: Skin irritation – limit values and classifications.

Information type	Value	vH	H	M	L
GHS cat.	-	1	2	3	GHS not classified and negative studies
HS codes	-	H314	H315	-	-

Eye irritation (IrE)

Eye irritation is defined as changes to the eyes following exposure to a substance (US EPA 2011). Determination takes place in accordance with OECD 405 (2021) and Methods B.47 (p. 684 et seq.) and B.48 (p. 702 et seq.) of Regulation (EC) No 440/2008.

Table 70: Eye irritation – limit values and classifications.

Information type	Value	vH	H	M	L
GHS cat.	-	1	2A	2B	GHS not classified and negative studies
HS codes	-	H318	H319	H320	-

From the perspective of the authors of this study, the GreenScreen assessment system and thus the variant adapted during the project are too complex for the assessment sought here. Further, the available data is extremely patchy in some cases. They therefore recommend that flame retardants be assessed only using the normal HS codes. For products that are required to be wash-resistant, the wash resistance aspect must also be analysed.

7.3 Summary

The evaluation of the 31 flame retardants took place on the basis of excluded HS codes from the Blue Angel award criteria. 14 flame retardants were identified that may be used in the products or product groups relevant here. There are:

- Phosphoric acid, ammonium phosphate (CAS RN 10124-31-9)
- Polyphosphoric acids, ammonium polyphosphate (CAS RN 68333-79-9)
- 1,3,5-triazine-2,4,6-triamine phosphate, melamine phosphate (CAS RN 41583-09-9)
- 1,3,5-triazine-2,4,6-triamine monophosphate, melamine polyphosphate (CAS RN 218768-84-4)
- Ammonium sulphamate (CAS RN 13765-36-1)
- Graphite, acid-treated, expandable graphite (CAS RN 12777-87-6)
- Graphite, acid-treated, expandable graphite (CAS RN 90387-90-9)
- Zirconium acetate (CAS RN 7585-20-8)
- 2,2',6,6'-tetrabromo-4,4'-isopropylidenediphenol, tetrabromobisphenol A (TBBPA, CAS RN 79-94-7)
- 1,1'-(ethane-1,2-diyl)bis[pentabromobenzene], decabromodiphenyl ethane (DBDPE, CAS RN 84852-53-9)
- Tetraphenyl m-phenylene bis(phosphate), resorcinol bis(diphenyl phosphate) (RDP; CAS RN 57583-54-7)
- Melamine cyanurate (MC; CAS RN 37640-57-6)
- Aluminium hydroxide (ATH; CAS RN 21645-51-2)
- Ammonium bromide (CAS RN 12124-97-9)

In addition to the HS codes as per the CLP Regulation, the flame retardants were assessed in accordance with the following criteria:

- Bioaccumulation
- Persistence
- Wash resistance
- Combustion products
- Costs

During the course of this study, we were able to demonstrate that the FRs TBBPA and DBDPE do not meet the requirements for bioaccumulation and persistence, and thus both must be excluded. The FRs melamine phosphate and melamine cyanurate do not meet the persistence requirements and are unsuitable for this reason. The remaining 10 FRs are not wash-resistant, and can therefore not be used in products that need to be cleaned, e.g. textiles. This does not apply to upholstery with a fixed cover: This does not need to be wash-resistant and therefore these flame retardants could be used as long as legal prerequisites are met. On this basis, if other solutions are not feasible, these 10 flame retardants are to be recommended to purchasers for products that do not need to be washed. Possible usage areas include shoes, furniture, floorings, and house and home textiles that do not need to be washed.

The assessment criteria "Combustion products" and "Costs" could not be used in a meaningful manner. For the assessment criteria "Combustion products", this is because it is impossible to make a general statement for any one FR; instead, the products are always dependent on the textile that requires fire protection. For the criteria "Costs", we attempted to investigate various costs but it became clear that without extremely specific references to a concrete (potential) contract item, a cost comparison is ineffective, since the variation in costs is so high that it is not possible to derive any recommendation.

In the future, further FRs might be added if they meet the criteria developed in this study.

Purchasers are recommended to first ask themselves whether fire protection is at all necessary for the products to be acquired. Then, they should check whether fire protection can be realized via inherent flame retardancy or via alternative flame retardancy. Finally, the use of FRs should be checked. Here, the 10 FRs listed here should be selected if required (see Table 71).

Table 71: Commonly used additive FRs for the five investigated product groups

FR group	FR	Used in product group				
		PPE	House and home textiles	Furniture	Mattresses	Floorings
Inorganic phosphorous-based	Ammonium polyphosphate (APP)		x	x	x	x
	Ammonium phosphate			x		
Organophosphorous	Resorcinol bis(diphenyl phosphate) (RDP)		x	x	x	x

FR group	FR	Used in product group				
		PPE	House and home textiles	Furniture	Mattresses	Floorings
Nitrogenous	Melamine polyphosphate (MPP)		x	x	x	x
Other organic	Ammonium bromide		x	x		
	Aluminium hydroxide (ATH)		x	x	x	x
	Ammonium sulphamate		x	x	x	x
	Expandable graphite[67]		x	x	x	x
Other	Zirconium acetate					x

[67] Expandable graphite with CAS RNs 12777-87-6 and 90387-90-9.

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