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Prospects for implementation of Fire Safety Engineering approach in Europe

Support to policies and standards for sustainable construction ecosystem

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Contents

Abstract

In 2023, the JRC Technical Report "The status and needs for implementation of Fire Safety Engineering approach in Europe", presented the results of a survey carried out by the European Commission Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) and the European Commission's Joint Research Centre (DG JRC). The survey demonstrated that a safer and more fire-resilient built environment strongly depended on the availability of 1) education and training in performance-based design with fire safety engineering (FSE), to support the competency of professionals, reviewers and officers involved in FSE practice, and a proper qualification framework; 2) standards for performance-based fire design needed by professionals who undertake fire design tasks, and possibly be liable for building fire design.

In this report, the status of the ongoing standardisation work by ISO (International Organisation for Standardisation) and CEN (European Committee for Standardisation) in the field is provided, showing that the work of standardisation bodies indeed supports the widening of FSE implementation and considers the needs expressed by fire regulators, presented in the 2023 JRC Technical Report.

The analysis of data from a recent enquiry by the Society of Fire Protection Engineers (SFPE) allow to compare the views of European regulators to those of fire design professionals, as provided through the earlier GROW-JRC enquiry. Professionals confirm that the traditional prescriptive approach is still prevalent in the fire regulations of EU Member States, but FSE shows large potential for implementation in many technical areas of fire safety design, as well as in many types of buildings. Professionals consider FSE as an alternate route for compliance with regulatory or clients' requirements – as demonstrated by the SFPE enquiry and further by a case study presented (the Airport of Athens, Greece), – and are aware of methods for applying FSE, provided by different sources (standards, building codes, literature etc.).

The input from the GROW-JRC survey is further analysed for deeper understanding of the FSE-related education availability and needs, complemented by a detailed mapping of university education and training courses in EU/EFTA countries, United Kingdom and Serbia. The mapping – elaborated on the grounds of the GROW-JRC enquiry, the SFPE enquiry and information collected by the JRC FSE expert network – highlights the availability of FSE education / training offer, as well as it justifies the needs neatly expressed by fire design regulators and professionals. The mapping is compared to the status of qualification frameworks for professionals and experts to engage in FSE approach practice, and to the role of the fire engineer in specifying the main parameters of building design projects and undertaking liability for fire design. This allows for considerations on the level of implementation of FSE approach in the countries that currently allow for its application. Generally, there is potential for a wider use of FSE approach in those countries that already have defined qualification frameworks but are not yet offering substantial level of education and training. The potential of FSE education already in place could also be exploited in other countries where the qualification framework is not, defined or only partially defined.

Finally, the report explores the standardisation gaps and needs for the design of buildings at wildland-urban interfaces in Europe. The priorities highlighted are 1) pre-normative research to better understand how wildfires impact the built environment, 2) standardized tests on materials / members specific for wildfire situations, and 3) to foster a cross-border approach for countries and regions.

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1 Introduction

Fire safety in the built environment remains a major societal and sustainability issue, despite the improvements achieved over the past decades thanks to the continuous modifications and implementations of fire safety strategies in European countries. In Europe, 90% of all fire-induced fatalities are due to fires in buildings ([1]). Building fires impact society, the environment and the economy, and their consequences can affect communities, business, and families in the long period and even for a lifetime.

In the European Union (EU), the competence regarding the fire safety in the built environment is with the Member States (MS), following the subsidiarity principle and accounting for the different building traditions, climatic and geographic conditions. The MS policy makers and regulators are facing many challenges to mitigate the impact of fires, including:

— Improving the fire safety in the built environment, by ensuring the performance of buildings and spaces that cannot be addressed by prescriptive regulations (e. g. exceeding prescribed limits of height, surface area, or users' presence).

— Increasing the fire safety of many types of buildings' occupancies – including housing – through the whole process of design, assessment, review, approval and maintenance.

— Balancing the needs for sustainability and fire resilience, ensuring that energy-efficient, environment-friendly and socially responsible buildings maintain an adequate level of fire safety, and conversely that the fulfilment of fire safety requirements does not create unintended environmental impact.

— Protecting the vulnerable communities, by increasing the fire safety of informal settlements, affordable housing, schools, and retirement facilities, as well as of buildings and infrastructure in the areas where the effects of climate change are increasing the fire risk– particularly at the wildland-urban interfaces (WUI).

To face these challenges, it is crucial to enable the use of novel, sustainable technologies and products for fire safety, and of performance-based design that can address the entire building, set explicit fire safety objectives and quantifiable criteria, and consider the interaction between building components and its occupants.

According to ISO/TR 20413:2021 'Fire safety engineering — Survey of performance-based fire safety design practices in different countries', performance-based design for fire safety is design that is engineered to achieve specified fire safety objectives based on performance criteria (ISO 2021). Performance-based design is essential to FSE; it allows for advanced design methods that are quantitative, flexible, and applicable at any scale, from the detail to the whole building. The increasing sustainability requirements for buildings (including housing) bring on an increasing demand for fire safety engineering, to be provided with performance-based design methods that would grant the holistic approach needed for buildings – both existing and new – that respond to new and complex societal demands.

In particular, the implementation of a fire safety engineering (FSE) is the key enabler for rational, advanced methods in building fire safety design. As per the current ISO definition – adopted in this

([1]) https://www.firesafeeurope.eu/facts-figures report – FSE is *the application of engineering methods to the development or assessment of designs in the built environment through the analysis of specific fire scenarios or through the quantification of risk for a group of fire scenarios* (ISO 2023).

1.1 EU policy background

The construction ecosystem is a key element for the implementation of the European Single Market and for many other important strategies and initiatives. Sustainable and climate-resilient buildings and infrastructure are one of the priorities in the European Green Deal ([2]).

A noteworthy initiative under the European Green Deal, the Renovation Wave includes fire safety as one of the key principles of integrated strategy for the renovation of buildings ([3]); it launched the New European Bauhaus (NEB) ([4]), making the green transition – in built environments and beyond – sustainable, inclusive and beautiful. The NEB Self-Assessment Method – aiming to evaluate where a project stands in relation to the NEB dimensions – integrates fire safety in the assessment (Gkatzogias, Romano and Negro 2024).

Other actions proposed by the Renovation Wave have been implemented through the review of the Energy Performance of Buildings Directive (EPBD) ([5]), which takes fire safety into account for both new buildings and renovation plans ([6]). The Directive also focuses on expanding infrastructure to support Battery Electric Vehicles (BEVs) adoption by promoting pre-cabling and the installation of recharging points in residential and non-residential buildings. The European Commission is releasing guidance documents on the new provisions of the recast EPBD, covering fire safety in buildings and in car parks (European Commission: Directorate-General for Mobility and Transport, 2025) and templates to support the development of national building renovation plans in MS ([7]).

Moreover, the New Industrial Strategy for Europe ([8]) highlights the need to accelerate the green and digital transition of EU industry and its ecosystems. It proposes working together with industry, public authorities, social partners and other stakeholders. In this context, the Transition Pathway for Construction (Papadaki, Moseley, Staelens et al. 2023) proposes actions that support the transition towards safer buildings and affordable housing for all Europeans – including the recommendation for the EU MS to improve the fire safety practices and building codes.

Finally, it is worth mentioning that the recent EU Preparedness Union Strategy ([9]), aims to prevent and react to emerging threats and crises, adopts an integrated all-hazards approach taking into consideration the increasing risk of wildfires in Europe.

([2]) COM/2019/640 final, The European Green Deal, 11/12/2019

([3]) COM/2020/662 final, A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, 14/10/2020

([4]) COM/2021/573 final, New European Bauhaus - Beautiful, Sustainable, Together, 15/09/2021

([5]) Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024 on the energy performance of buildings (recast)

([6]) European Commission, Call for tenders ENER/B3/2024-517, Guidance on fire safety linked to the electrification and renovation of buildings

([7]) https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/national-building-renovation-plans_en

([8]) COM/2020/102 final, A New Industrial Strategy for Europe, 10/03/2020

([9]) JOIN/2025/130 final, European Preparedness Union Strategy, 26/03/2025

Besides the actions of national regulators and policy makers, EU level regulation on fire safety is exercised through the Construction Product Regulation (CPR) ([10]), which ensures the Internal Market for Construction Products. The CPR creates a common technical language defining the essential characteristics of construction products (e.g. reaction to fire, resistance to fire, glowing combustion, etc.) through harmonised product standards, related harmonised testing methods and European Assessment Documents (EADs). The CPR addresses fire safety as one of the "Basic Requirements for Construction Works". The revised CPR ([11]) will feature an expanded scope and explicit rules for expressing the environmental, climate, and safety performance of construction products related to their essential characteristics.

Finally, in 2017 the European Commission launched the Fire Information Exchange Platform (FIEP), to stimulate the cooperation of Member States representatives, fire safety practitioners and stakeholders by exchanging best practices and lessons learnt, sharing data and anticipating needs. FIEP is a tool to achieve a fruitful synergy among the fire safety actors, and fire safety engineering is one of its priority areas. Since its beginning, FIEP has been carrying out its activities through webinars on a range of fire safety topics – e. g. the 2024-25 webinars covered fire prevention and intervention, training and education in fire safety, installation and maintenance of products with fire performance, circularity and sustainability, and fire safety of façades.

1.2 The JRC work: assessing the FSE status and needs for further implementation in Europe

In 2019, the European Commission's Joint Research Centre (JRC) started to explore the needs and options for further harmonisation of the fire safety engineering approach and its underpinning education in the EU Member States. This activity, performed in the framework of Administrative Arrangements with the European Commission's Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW), has a direct link to FIEP's scope and activities.

To support this work, the JRC steers an expert network on fire safety engineering, which includes representatives of European institutions, technical committees, academia, professional associations, industry, research bodies and firefighters' organisations. With the support of the FSE expert network, the JRC has been collecting, analysing and assessing relevant information at European level that would facilitate the provision of guidance to the Member States for a wider application of fire safety engineering (Athanasopoulou et al. 2023). (**Figure 1**).

As a first step, DG GROW and JRC, with the support of the expert network, conceived a survey on the status and implementation needs for fire safety engineering in the European built environment, to facilitate the work of FIEP and the provision of guidance to the EU MS for a wider application of the fire safety engineering approach. The survey was launched in 2020 and consisted of a questionnaire distributed to the principal national fire regulators in Europe. The 32 countries that provided response to the questionnaire were the 27 EU MS, 3 Member States of the European Free Trade Association (EFTA, i.e. Switzerland, Iceland and Norway), the United Kingdom and Serbia. The

([10]) Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC (Text with EEA relevance), 09/03/2011

([11]) COM(2022) 144 - Proposal for a Regulation laying down harmonised conditions for the marketing of construction products, amending Regulation (EU) 2019/1020 and repealing Regulation (EU) 305/2011

JRC technical report 'The status and needs for implementation of Fire Safety Engineering approach in Europe' (Athanasopoulou et al. 2023), published in 2023, presented the results of the survey, through technical analysis intended to stimulate debate and to serve as a basis for further work towards the incorporation of fire safety engineering in the national regulatory framework.

Figure 1. European Commission activity on FSE

Source: Authors' work

The fire safety regulators of the 30 EU/EFTA countries, United Kingdom and Serbia provided useful feedback on the needs in the fields of standardisation and research for a more extended implementation of FSE in the construction practice. Of the 32 responders, 28 indicated that the application of FSE is allowed in the practice of building fire design in their countries. Such responses, in detail, show that FSE mainly applies to fulfil the following needs:

— to implement new fire safety technologies

— to provide fire safety solutions fit for innovative design of spaces

— to overcome gaps in prescriptive fire safety solutions.

On the other hand, the regulators of the remaining four countries indicate the following main factors impairing the application of FSE:

— the lack of supporting systems (legal framework, insurance, professional certification, education etc.)

— the lack of professional expertise.

Many of the targeted countries (as specified by 14 out of 28 responders) allow for the application of fire safety engineering in the framework of whole performance-based building codes, while in other countries application of FSE is permitted by national/regional regulations or by clauses within the restrictions of prescriptive building codes.

The results of the GROW-JRC survey, as well as other knowledge and investigation efforts (e.g. SFPE 2025; Torero et al. 2019; Lange et al. 2019; Moore-Bick 2019; Moore-Bick, Akbor and Istephan 2024) demonstrate that the goal of a fire-resilient built environment strongly depends on the fulfilment of the following needs:

1. *Education and training in performance-based design with fire safety engineering*, to instruct building designers, fire safety engineers, structural/civil engineers and architects – who, by regulation, are involved in fire safety – according to their responsibilities for fire safety design or peer review. As well, updated training programmes are needed for building officers and members of the fire and rescue services, whose duties include regulatory review and approval of designs with FSE, and inspection of fire safety measures in buildings.

2. *Availability of new or updated standards for fire safety design with advanced performance-based approach*, suitable for applying fire safety engineering. Such standards are particularly needed for the benefit of specialist fire safety designers, and generally for professionals (structural/civil engineers, architects …) who can undertake responsibility for building fire safety design. Standards have a key role in embracing new societal demands, namely sustainability and climate change adaptation, and enable both the passage of research to application and the collective learning of lessons, by update and improvement after the feedback of real case applications (e. g. major incidents that have historically been a stimulus to improve standards).

These conclusions have provided the basis for further developments of the JRC work, presented in this JRC Technical Report.

1.2.1 Organisation of the report

Section 1 introduces the background and policy context of the present work, as well as a summary of the previous JRC work in support of implementation of FSE approach in Europe.

Section 2 presents the status of the ISO and CEN standardisation work related to fire safety engineering, including recent updates to fire safety terminology.

Section 3 outlines the available studies on the competency framework for fire safety engineering profession.

Section 4 presents updates in the status of implementation of FSE in a selected group of European countries, obtained with the contribution of the JRC FSE expert network. This section also contains updates to national legal frameworks for building fire safety design.

Section 5 features a non-exhaustive mapping of available university education on fire safety engineering and elaborates the connections of education availability to qualification framework and fire engineer's role in the different countries.

Section 6 collects case studies of interest, and a focus on buildings at wildland-urban interface as a new field for FSE-related standardisation.

Section 7 proposes the main conclusions from the report and the way forward.

2 Fire safety engineering standardisation activities

2.1 ISO/TC 92

Within the International Organization for Standardization (ISO), fire safety standards are developed and maintained by the Technical Committee (TC) 92 'Fire Safety'. Within ISO/TC 92, Subcommittee (SC) 4 is devoted to fire safety engineering.

In 2021, the ISO technical report 'Fire safety engineering — Survey of performance-based fire safety design practices in different countries' (ISO/TR 20413:2021, ISO 2021) underlined the emergence of innovative buildings (high-rise buildings, multi-purpose large-scale facilities …) as the driving factor for fire regulations to move from prescriptive to performance-based design, and on the other hand the lack of specific education and expertise in FSE on both sides of fire design practitioners and regulators. The picture taken by ISO was later confirmed in full by the GROW-JRC survey performed in 2021 (Athanasopoulou et al. 2023). In the final remarks of the technical report, ISO/TC 92/SC 4 prioritised the development of a rational procedure to determine design fires and design fire scenarios.

2.1.1 Standards published in 2022-2024

From 2022 to 2024, ISO/TC 92/SC 4 has developed or revised 11 fire safety engineering standards and technical reports, on the following topics:

- General principles of fire safety engineering (ISO 23932-1:2018, revised and confirmed in 2024)
- Performance of structures in fire (ISO 24679-1:2019, revised and confirmed in 2024; ISO/TR 24679-5:2023 'Part 5: Example of a timber building in Canada'; ISO/TR 24679-8:2022 'Part 8: Example of a probabilistic assessment of a concrete building')
- Selection of design fire scenarios (ISO 16733-1:2024)
- Design of evacuation experiments (ISO/TS 17886:2024)
- Requirements governing algebraic formulae (ISO 24678-4:2023, ISO 24678-5:2023, ISO 24678-2:2022, ISO 24678-3:2022 and ISO 24678-9:2022)
- General principles of active fire protection systems (ISO 20710-1:2022)
- Estimating the reduction in movement speed based on visibility and irritant species concentration (ISO/TS 21602:2022)

2.1.2 Current work of ISO/TC 92

Currently, through the Working Groups of ISO/TC 92/SC 4, the following projects are under development:

1. *Reviewing the legislative and administrative bases for performance-based fire safety design* (preliminary work item PWI ISO/TR 24271)
2. *Calculation methods*, especially in reference to the use of Computational Fluid Dynamics (CFD) methods and fire zone models, and by revising the remaining parts of ISO 24678 "Requirements governing algebraic equations" (joint SC 1 - SC 4 activities are contributing to this task)

3. *Providing more examples of structural fire behaviour*, by revising ISO/TR 24679-4:2017 “Performance of structures in fire – Part 4: Example of a fifteen-storey steel-framed office building”.

Finally, the process for design and selection of evacuation systems, and the use of building information models in evacuation / pedestrian analysis, are identified by ISO/TC 92/SC 4 as potential future activities.

ISO/TC 92/SC 1 ‘Fire initiation and growth’ is managing the maintenance of reaction-to-fire testing standards, and the draft technical report ISO/DTR 22099 ‘Example for using reaction-to-fire test data for FSE’. ISO/TC 92/SC 1 is also involved in standardisation work for the fire design of façades, namely the two fire testing standards ISO 13785-1 for the intermediate scale and 13785-2 for large scale, useful to assess input for design fires. ISO/TC 92/SC 1 has also opened a Preliminary Work Item (PWI) about guidelines for testing and assessment of façades depending on the imposed fire risk.

ISO/TC 92/WG 13 ‘Fire safety – Statistical data collection’ is performing a revision of terminology, largely using input from the first European Commission project on fire statistics. ISO/TC 92/WG 14 ‘Large outdoor fires and the built environment’ is drafting a global overview of different approaches to standardization (ISO/DTR 24188) and managing working items on standardized post-fire data collection methods from large outdoor fires (ISO/AWI 24944) and harmonisation of test methods for thermal flux exposure (ISO/AWI TS 25399). A larger overview on the standardisation field of buildings at the wildfire-urban interface is given in this report at Section X). Finally, ISO/TC 92/WG 15 ‘Fire safety for tunnels’ is drafting a general overview of regulatory frameworks and research (ISO/WD TR 24488).

2.2 CEN/TC 127 ‘Fire safety in buildings’

The European (EN) standards in the field of building fire safety are under the competence of the CEN Technical Committee 127 ‘Fire safety in buildings’, which includes CEN/TC 127/WG 8 ‘Fire safety engineering’. In 2020, CEN/TC 127/WG 8 had highlighted the urgency of research efforts on the following topics to fulfil essential needs for the fire safety engineering profession (CEN/TR 17524:2020, CEN 2020): 1) Demographics data, especially in reference to vulnerable categories of users to be accounted for in the design and assessment of evacuation during fires; 2) Fire hazards of new, sustainable buildings; 3) Models for fire department response to be taken into account in FSE applications; 4) Standardised approach to enable designers taking into account the fire properties of construction materials (reaction to fire), products (fire resistance) and systems (e. g. the global behaviour of a façade) in non-standard fire conditions; 5) Models for the effect of both active and passive fire protection measures on the fire safety strategy.

2.2.1 Standards published in 2022-2024

From 2022 to 2024, TC 127 has published 17 standards, focusing on:

— Fire resistance tests for service installations (EN 1366 parts 3, 8, 9 and 10)

— Extended application of test results on different properties and types of products (e. g. durability of self-closing for fire resistance and/or smoke control of doors and windows, EN 17020 parts 1, 2, 3 and 5)

— Fire classification of construction products and building elements ((EN 13501-6:2018+A1:2022); EN 13501-2:2023)

— Fire safety - Vocabulary (EN ISO 13943:2023)

— Reaction to fire tests for building products (EN 13823:2020+A1:2022)

2.2.2 Current work of CEN/TC 127

Within CEN/TC 127, the work of WG 8 'Fire Safety Engineering' is currently progressing along two main directions:

1. *Development of a European Guideline for Performance-Based Code*. CEN/TC 127/WG 8 is aiming to provide national regulators with a guideline to effectively help the implementation of performance-based design for building fire design. The guideline will also provide links between FSE and the existing prescriptive regulations. The document is incorporating input from different countries and will feature a comprehensive view of implementation of performance-based fire safety, from the design objectives to the facility management and maintenance in use.

2. *FSE review and control*. As of September 2024, the work item CEN/TS XXXX "Fire safety engineering - review and control in the building process" is in the advanced drafting stage. This draft technical report is based on the Nordic Standards INSTA 952 "Fire Safety Engineering – Review and Control in the Building Process".

2.3 CEN/TC 250 HG "Fire"

In the area of structural fire safety, the application of performance-based approach for the design of buildings and civil works is incorporated in the framework of the EN Eurocodes (EN 1990 to EN 1999). This series of structural design standards are currently adopted in 34 countries in Europe and beyond ([12]).

The Eurocodes are developed and maintained by the CEN/TC 250 'Structural Eurocodes'. Inside CEN/TC 250, the Horizontal Group (HG) 'Fire' is in charge of the harmonization of all the fire design parts contained in the structural Eurocodes. These parts provide principles and application rules to check the fire resistance of structures on the basis of structural fire safety engineering under both standard and natural fires. However, in some cases, values for input parameters are not always available in the Eurocode fire parts to perform advanced modelling. Moreover, some principles and application rules as well as certain design data are not consistent between these fire parts.

In the evolution towards the second-generation Eurocodes ([13]), the main task of CEN/TC 250/HG 'Fire' was to harmonise the design rules of the different Eurocode fire parts, to facilitate the application of FSE – e.g. rules for concrete strength behaviour in the heating-cooling phases will be the same in EN 1992-1-2 for concrete structures and EN 1994-1-2 for steel-concrete composite structures. As well, the behaviour of loadbearing timber members can be considered on the basis of performance-based approach in structural fire resistance design through two new annexes in EN

([12]) https://eurocodes.jrc.ec.europa.eu/en-eurocodes/use-outside-euefta-member-states

([13]) https://eurocodes.jrc.ec.europa.eu/second-generation-eurocodes

1991-1-2 (Actions on structures) and EN 1995-1-2 (Timber structures). New specific FSE design methods based on global structural behaviour will also be introduced in EN 1994-1-2 for steel-concrete composite structures. All the parts of the second-generation Eurocodes will have a common date of publication of 30 September 2027.

2.4 Terminology

The ISO terms and definitions relevant for fire safety can be freely accessed through the ISO online browsing platform ([14]).

The ISO 13943 standard defines general terms to establish a vocabulary applicable to fire safety, including fire safety in buildings and civil engineering works and other elements within the built environment. This terminology is used in ISO and IEC International Standards relating to fire safety. It is periodically updated as terms and definitions for further concepts in the field of fire safety are agreed upon and developed. The last update of ISO 13943:2023 (ISO 2023) includes the revision of the following terms: fire safety engineering, prescriptive regulations, functional requirements and deemed-to-satisfy.

The JRC work in support of fire safety engineering implementation in Europe is based on these ISO definitions. However, it is worth noting that ISO acknowledges that some fire safety terms can have a different interpretation than the one used in ISO 13943, when used for regulations.

The following **Table 1** illustrates the current definitions of the above listed terms, as per the withdrawn ISO TR 13387-1:1999 (ISO 1999) and the revision proposed in 2023 (ISO 13943 – September 2023).

It is worth noting that, after the 2023 revision, CEN/TC 127/WG 8 began working at further proposals for amendment of these definitions, for the next revision of the standard.

([14]) https://www.iso.org/obp/ui

Table 1. Definition of terms related to fire safety and its revision in the ISO standards

Term	ISO/TR 13387-1:1999	ISO 13943:2023
Fire Safety Engineering	The application of engineering principles, rules and expert judgment based on a scientific appreciation of the fire phenomena, of the effects of fire, and of the reaction and behaviour of people, in order to: save life, protect property and preserve the environment and heritage; quantify the hazards and risk of fire and its effects; evaluate analytically the optimum protective and preventative measures necessary to limit, within prescribed levels, the consequences of fire.	Clause 3.172: Application of engineering methods to the development or assessment of designs in the built environment (3.36) through the analysis of specific fire scenarios (3.176) or through the quantification of risk for a group of fire scenarios
Prescriptive regulations	Regulations that achieve their fire safety objectives, and/or components of those objectives, by specifying what has to be provided. In some cases, these may be on the basis of performance requirement(s) e.g. fire resistance test performance, reaction to fire performance. However, usually they will be on the basis of requirements given in physical terms e.g. maximum building height, maximum compartment size(s), length or width of escape routes, which are dependent upon the intended use of the building. In this case, the fire safety objectives are usually not explicit, and deviation from the regulatory prescription requires generally some compensating protection measures within form of relaxation or derogation.	Clause 3.349: Regulation in which the means and approach for compliance are completely or mostly specified
Deemed-to-satisfy	A provision in a regulation that is met by a specified solution without the need for providing supporting technical information. e.g. acceptance of a particular form of construction, product or material (perhaps without test data) or building design.	(*)
Functional regulations	Regulations that specify what has to be achieved in terms of qualitative fire safety objectives, but do not specify how or what level of satisfaction has to be achieved e.g. 'means shall be provided to prevent the spread of fire within the building over building surfaces.	(*)
Performance-based regulations	Regulations that specify explicitly their objectives and/ or components of these objectives, in terms of quantifiable criteria that shall be satisfied.	Clause 3.331: regulation in which compliance is specified in terms of performance criteria (3.329)

(*) A revised text is currently under definition for the next revision of ISO 13943

Source: Authors' work

3 Fire safety competency framework

3.1 Professional competency in fire safety engineering

Several studies have been conducted on the development of a competency framework for fire safety engineering professionals in Europe.

In a 2014 white paper (Jönsson and Strömgren 2014), the Society of Fire Protection Engineers (SFPE)[15] discussed the state of fire safety engineering in Europe and the need for professional recognition of fire safety engineers, as an essential element to ensure the safety of buildings and their occupants. The authors acknowledged that the profession was not yet fully recognised in Europe, arguing that this lack of recognition was especially due to the absence of a clear definition of fire safety engineering, a lack of standardised education and training programs, and a lack of certification and registration procedures. To enable these factors, SFPE highlighted the need for collaboration between different stakeholders, including fire safety engineers, architects, builders, and policymakers, to ensure that fire safety engineering is integrated into the design and construction process, and called for action in this sense.

A few years later, SFPE released recommendations to establish the minimum technical competencies required for the practice of fire protection engineering, providing a framework for ensuring that fire protection engineers possess the necessary knowledge, skills, and experience to perform their role effectively (SFPE 2018). According to the document, the minimum technical competencies for fire protection engineers entail a comprehensive understanding of:

1. Fire Science: the underlying physical principles of fire and its related mechanisms
2. Human Behaviour and Evacuation: the principles of means of egress design
3. Fire Protection Systems: fire mitigation, including water- and non-water-based suppression, fire detection and alarm systems, and smoke management systems
4. Fire Protection Analysis: principles of technical analysis related to fire protection design.

The document also identifies various knowledge areas within each core competency, such as heat transfer, fire chemistry, fire dynamics, and human behaviour and physiological response to fire. SFPE recommends that fire protection engineers obtain a university-level education in fire protection engineering and have at least four years of practical experience, three of which must be as responsible in charge of fire protection engineering work. The document also emphasises the importance of continuing professional development (CPD) to maintain the minimum level of competency needed throughout one's career. Finally, SFPE elaborated specific model curricula for Bachelor and Master level courses ([16]), which can be used as practical resources for universities and colleges.

In the last five years, the lack of accredited degree programs in fire safety engineering has again been highlighted, not only in Europe (Torero et al. 2019). The need for developing a professional qualification scheme for fire safety engineers through a suitable educational pathway and

([15]) www.sfpe.org

([16]) SFPE model curricula can be downloaded at https://www.sfpe.org/advocacy-qualifications/higher-education/modelcurr experience has been recognised. Within the fire safety engineering profession, it is important to foster a culture of safety and a commitment to continuous learning and professional development. The lack of professional recognition can lead fire safety engineers to diminished professional authority and autonomy in comparison to other engineering professionals (Lange et al. 2021).

As a profession, fire safety engineering should undergo change and development to shape up its identity and meet the societal needs (Lange et al. 2021). In particular, the development of fire safety engineering as a profession has been focusing on regulation and prescriptive solutions rather than on developing a strong professional identity. The social responsibilities should be more extensively integrated in the professional code of ethics, and a clear sense of identity or shared values should be developed, through the definition of a professional culture.

Lange et al. (2022) propose a competency framework including 12 elements of competency grouped into three categories:

1. Knowledge and skill base: technical knowledge and skills in areas such as fire dynamics, risk assessment, and fire protection systems.
2. Engineering application ability: the ability to apply technical knowledge to complex engineering problems, and to design and develop solutions that meet specified needs.
3. Professional and personal attributes: communication skills, teamwork, and project management, which are essential for effective professional practice.

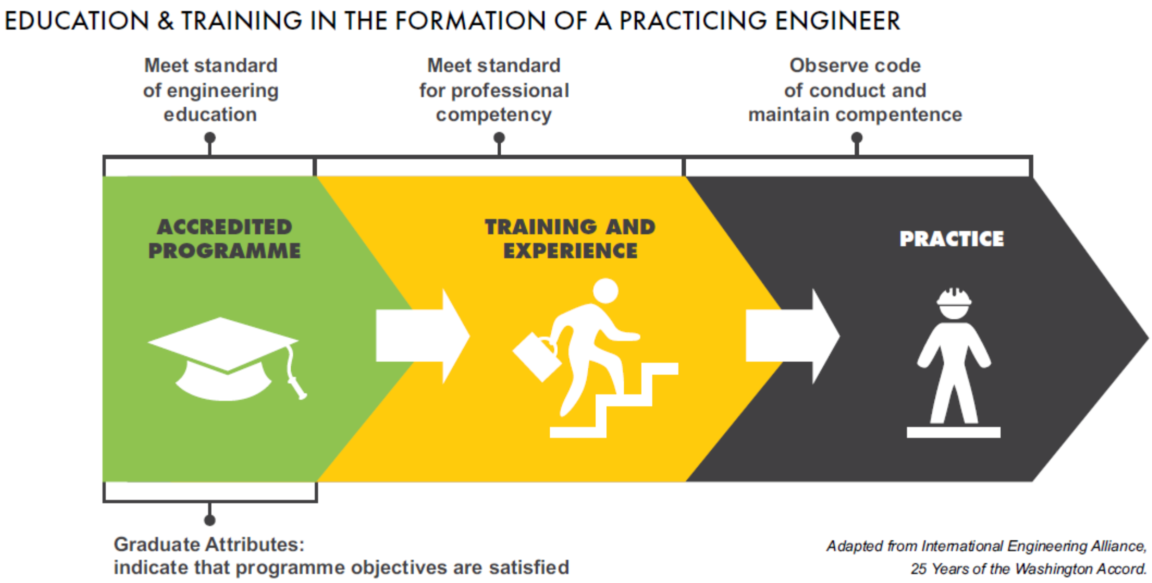
In particular, the basic knowledge and certain other professional and personal attributes can be achieved through the completion of a university program *covering not only the systematic body of theory but also the application of that theory, amongst other necessary graduate attributes*. In this framework, particular emphasis is placed on the accreditation of the institution providing the degree, and of the professional(s) supervising the application of acquired skills at the entry into professional practice. The dialogue between national professional organizations and degree-granting institutions is essential to establish how the required knowledge, skills, and attributes will be introduced into the educational process. After the graduate attributes are achieved to meet the specific standard of engineering education, training and experience allow attaining professional attributes that indicate competence to practice in a professional context. (**Figure 2**).

In 2023, the Modern Building Alliance (MBA) ([17]) discussed the importance of FSE competencies and the need for a harmonized approach for FSE in the European Union (MBA 2023). It highlighted the global call for professionalization of FSE and the need for a clear definition of the roles and responsibilities of fire safety engineers, motivated by their role in ensuring fire safety. MBA recommends analysing the short-term needs of the construction market for fire safety engineers, as well as to identify the roles and responsibilities of fire safety engineers in projects within the EU. MBA also supports the definition of a harmonized framework for the FSE profession, which would facilitate the free flow of the services within the EU. Finally, MBA agrees with the recommendations of CEN/TC 127/WG 8 (ISO 2020) and JRC (Athanasopoulou et al. 2023), as well as it promotes the EU fire safety competency, education, and training and encourages the broader implementation of FSE in MS regulations.

([17]) https://www.modernbuildingalliance.eu/

While qualification is defined as the demonstrated education, training and work experience (ISO 2018), certification ensures that a certified fire consultant has the necessary qualifications, competencies, and experience to carry out a piece of work that meets the requirements set out in the building regulations, in a consistent and satisfactory manner. As an example, **Box 1** presents the certification system currently in place in Denmark.

Figure 2. The route from engineering education to practice



Source: Torero et al. 2019

Box 1. Denmark: certification system for fire consultants

The FSE approach looks fully integrated in Denmark's regulatory framework for fire design as of 2018 (Athanasopoulou et al. 2023). In particular, the 2023 JRC report highlighted that Danish fire engineers can perform third-party regulatory review, choose fire scenarios and provide consultancy to the approval authority. On the other hand, the liability for fire design is placed on the structural engineer.

With the introduction of the Building Regulations 2018 - BR18 in Denmark, the municipalities' role in approving the documentation for technical building provisions was phased out as of January 2020. However, the municipality is still the authority having jurisdiction (AHJ) and must therefore issue building permits and commissioning permits. Instead, for buildings of a certain size or complexity, a requirement has been introduced that certified fire consultants and structural engineers must be involved. It is the certified fire consultant who must ensure that the fire safety of the building is documented and checked and that the building regulations' requirements for fire performance are complied with.

The requirements in the certification scheme for fire consultants are laid down in a separate statutory instrument (on certification schemes for documentation of technical conditions in the building regulations) based on the Danish Building Act. Personal certification is carried out and monitored by an independent certification body accredited in accordance with ISO 17024 'Conformity assessment — General requirements for bodies operating certification of persons' (ISO 2018).

In accordance with BR18, buildings are divided into fire classes 1 to 4 depending on the complexity of the building and the documentation method by which it is demonstrated that the fire safety requirements are met, e.g. by following the pre-accepted solutions or a performance-based fire safety engineering analysis. Fire class 1 is construction with the lowest complexity, where only pre-accepted solutions defined in annexes to the building regulations can be used for documentation of fire safety requirements. In contrast, fire class 4 includes construction with the highest complexity and/or a combination of methods (beyond pre-accepted solutions) is used for demonstrating that fire safety requirements are met. In fire classes 2 to 4, there are requirements for the involvement of a certified fire consultant, and in fire class 4 also a certified third-party inspector to check the documentation. With the certification scheme, it is possible to be certified for fire class 2, 3/4, or as third-party inspector. Requirements for qualifications, competencies and experience are differentiated for the three certification levels as described in **Table 2**. Finally, in connection with maintaining their certification, the certified fire consultant is obliged to:

— Operate in accordance with the requirements of the building regulations,

— Continuously update their qualifications and maintain their competency,

— Report annually on their work to the certification body and submit documentation for review of their work

— Renew certification every ten years, based on the work that has been reported annually.

Table 2. Certification levels and related requirements in the Danish Building Regulations of 2018.

<table>
<tr><th rowspan="2">Level</th><th colspan="3">Requirements</th></tr>
<tr><th>Qualification</th><th>Competence</th><th>Experience</th></tr>
<tr><td>Fire class 2</td><td>Education in building engineering at a level equivalent to at least 180 ECTS points.</td><td>Knowledge of technical fire safety requirements, preparation of technical fire safety documentation, and review of technical fire safety documentation work relevant to projects in fire class 2.</td><td>Two years' experience within the last five years of designing and managing fire safety requirements in building works or equivalent experience.</td></tr>
<tr><td>Fire classes 3-4</td><td rowspan="2">Education in building engineering at a level equivalent to 210 ECTS points, of which 60 ECTS points must relate to fire protection of buildings and performance-based fire safety engineering.</td><td rowspan="2">Knowledge of technical fire safety requirements, preparation of technical fire safety documentation, and review of technical fire safety documentation work relevant to projects in fire classes 2, 3 and 4.</td><td>Three years' experience within the last six years of designing and managing fire safety requirements in building works relevant to projects in fire classes 2, 3 and 4 or equivalent experience.</td></tr>
<tr><td>Third-party inspector</td><td>Seven years of experience within the last twelve years of designing and managing fire safety requirements in building works relevant to projects in fire classes 2, 3 and 4 or equivalent experience.</td></tr>
</table>

Source: Authors' work

3.2 Fire safety engineering for regulators and fire and rescue officials

The final report of the Grenfell Tower fire inquiry, published in 2024 (Moore-Bick, Akbor and Istephan 2024), highlights the importance of education for fire engineers in ensuring the safety of life in the built environment, but also for other construction professionals and senior members of the fire and rescue services. Such actors should have a basic understanding of the principles of fire safety engineering as they apply to the built environment. The report proposes that an authoritative statement of the skills that a fire engineer can be expected to own would assist the regulatory body, improve the definition of competences of other construction professionals and the fire and rescue services, and promote effective communication among them.

The need for regulators in the field of fire safety to understand and properly deal with fire safety engineering practices is also under concern. As already concluded by the ISO Technical Report 20413 (ISO 2021), the overall lack of specific FSE education also causes enforcers and fire safety regulators to lack understanding on FSE. Several types of expertise – firefighting, fire safety engineering, code-based expertise and building users' experience – are involved in building regulation and fire safety. A more nuanced understanding of expertise and its limitations is needed to ensure that building regulation and fire safety policy is effective and inclusive and could be attained by panels and groups bringing together diverse types of expertise. However, the risk of politicisation and the need to navigate complex and conflicting interests must be considered (Law and Spinardi 2021).

4 Implementation of fire safety engineering in Europe

This section presents the comparison between the information provided by the fire regulators (who responded to the GROW-JRC survey) and the professionals involved in fire safety design practices (who responded to the SFPE survey, through the same questionnaire as GROW-JRC)

4.1 The SFPE survey (2023)

The GROW-JRC survey on the status and implementation needs for fire safety engineering in the EU built environment was useful to assess – as explained in section 1.2 – the needs of 32 countries (EU/EFTA MS, UK and Serbia) for a wider application of fire safety engineering and its incorporation in the national regulatory frameworks and practices. The target group providing such results was selected among the main bodies involved in regulating the fire safety design of buildings at the national level in the 32 countries (see Athanasopoulou et al 2023 for details on the description of the responders).

After the dissemination of the JRC report, SFPE decided to carry out an identical survey through SFPE Europe chapters of fire design professionals. The SFPE survey was useful to provide a complementary view that would further elucidate the status and needs for FSE implementation and provide updates to the GROW-JRC survey results. The SFPE survey was launched in late 2023, and the results were handed to JRC in August 2024. SFPE distributed the questionnaire to its Europe chapters, to obtain, from each chapter, one response collectively produced by the members. The comparison presented in this report covers the 13 countries that were common to the target of the two enquiries: Austria, Switzerland, Cyprus, Germany, Denmark, Spain, Finland, Greece, United Kingdom, Italy, Malta, Portugal, and Sweden. To facilitate the comprehension of the analysis presented in the following sections, the questions of the GROW-JRC survey, fully repeated in the SFPE survey, are listed in **Table 3**. Most questions also had a comment box for details and clarifications.

Table 3. Questions of the GROW-JRC questionnaire (2020-21), distributed to SFPE European chapters (2023)

n.	Question	Responders
Q1	a) Please provide the title(s) of your current national/regional (if relevant) fire regulation(s) for construction works b) Please provide the year in which your current national/regional fire regulation was enforced	All countries
Q2	What is the nature and level of the technical detail in your fire regulation, considering the following technical details? (*)	
Q3	Who issues the approval of a construction work project from the fire safety design perspective?	
Q4	Who is liable for the fire safety design of construction works and the design compliance to the regulation?	
Q5	Is FSE approach allowed for construction works in your country/state/region?	
Q6	What are the types of construction works to which FSE approach is applied?	Countries allowing for FSE
Q7	Which fire safety technical areas are included in fire safety engineering approach applications?	

n.	Question	Responders
Q8	What are the main reasons to apply fire safety engineering approach?	
Q9	What is the regulatory framework that allows for the application of fire safety engineering approach?	
Q10	Which body/bodies perform a regulatory review of the fire safety engineering approach in projects?	
Q11	What professional qualification is required for the regulatory reviewers of the fire safety engineering approach in projects?	
Q12	What qualification is required to engage in FSE approach practices?	
Q13	Who/what specifies the fire scenarios in the project design with FSE approach?	
Q14	How are the design fires specified in the project design with FSE approach?	
Q15	How are the safety criteria determined in the project design with FSE approach?	
Q16	What assessment methods for FSE are used for the prediction of fire, smoke, structural response, evacuation, etc.?	
Q17	Which topics should be further developed by the standardisation organisations (e.g. CEN, ISO, National Standardisation Bodies, etc.) to support the fire safety engineering approach practices in your country/region?	
Q18	What are the main reasons that FSE approach is not being used in your country/region?	Countries not allowing for FSE
Q19	What official educational bodies offer FSE education and training to students?	All countries
Q20	Do you see a need for FSE post-secondary education?	
Q21	Do you see a need for FSE Continuing Professional Development courses?	
Q22	Should FSE be part of the training for fire fighters and/or other emergency responders?	
Q23	Which areas of FSE should be subject for research?	
Q24	Free space for responder's additional comments and recommendations	

(*) The technical details are the Technical Areas listed in **Table 4**.

Source: Authors' work

4.2 Allowance of FSE

Q5. Is FSE approach allowed for construction works in your country?

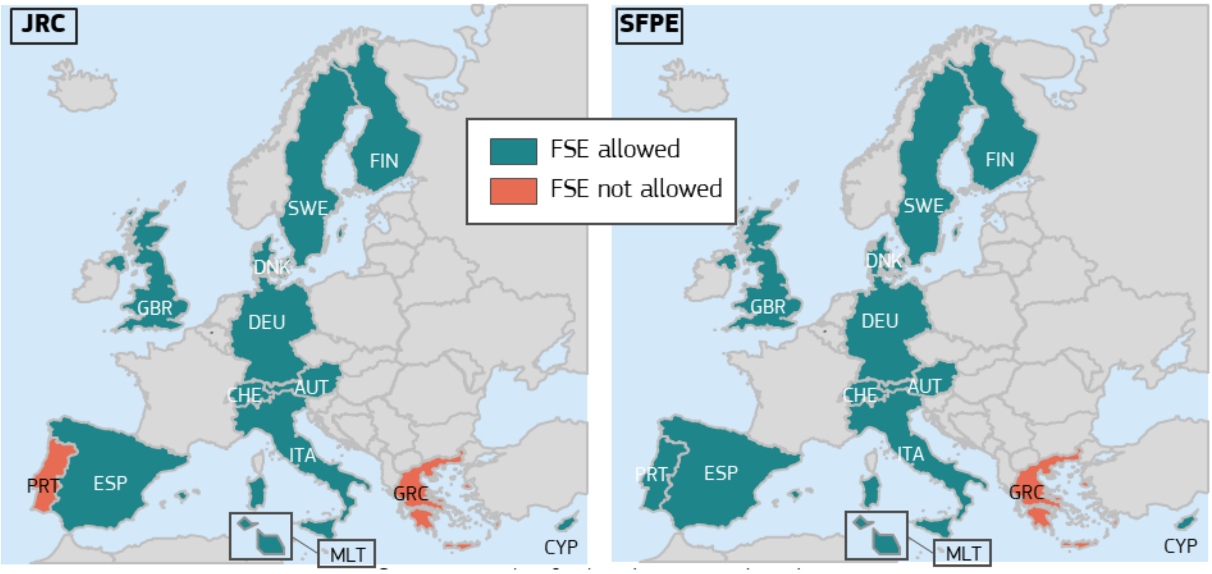
Q8. What are the main reasons to apply fire safety engineering approach?

Q18. What are the main reasons that FSE approach is not being used in your country?

The maps presented in **Figure 3**, comparing replies from the GROW-JRC and SFPE responders, show that only the professionals of Portugal have given a different answer to Q5 on the allowance of

FSE. The SFPE Portugal chapter has explained that, although the national building code allows for performance-based approach, the approval process for FSE design projects is still an issue.

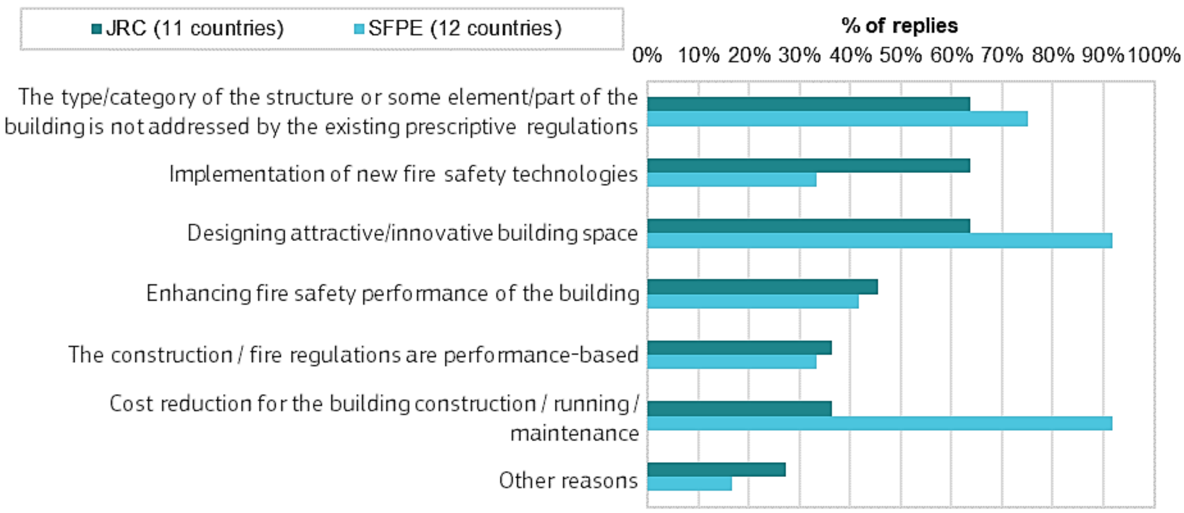
Figure 3. Allowance of FSE approach in fire design in the group of 13 countries, according to regulators (GROW-JRC), and professionals (SFPE)



Source: Authors' work (© EuroGeographics for the administrative boundaries)

Concerning the underlying reasons why FSE is applied in their countries (**Figure 4**), the professionals have fully confirmed the regulator's views on the importance of designing innovative and attractive building spaces, and on the fact that existing prescriptive regulations are insufficient to ensure the fire safety of such designs.

Figure 4. Reasons for applying FSE approach in fire design according to regulators (GROW-JRC), and professionals (SFPE)



Source: Authors' work

On the other hand, the role of new fire safety technologies in supporting the implementation of FSE approach appears not as important to the professionals as to the regulators. Finally, the professionals emphasise the cost reduction which can be attained by performance-based fire safety strategies. In the group of 13, non-allowance of FSE approach in Greece was confirmed in both GROW-JRC and SFPE enquiries. The Greek chapter of SFPE has indicated all the following reasons for non-allowance:

- Fire safety engineering is not possible to be applied due to the present legal situation
- Authority having jurisdiction is not positive to introduction of fire safety engineering approach
- The approval authorities are not qualified to review / approve fire safety engineering approach
- The enforcement authorities are not prepared to assess / inspect / enforce appropriate design and construction to performance-based methods
- There are insufficient infrastructure components (e.g., legal system, insurance systems, professional certification systems, educational programs, etc.).

It can be noticed that the professionals' view stresses the lack of legal conditions and of qualification for approval / enforcement officers, rather than the lack of professional expertise in fire safety designers to engage in FSE practice.

4.3 Fire regulations and national legal frameworks

Q1. a) Please provide the title(s) of your current national (if relevant) fire regulation(s) for construction works b) Please provide the year in which your current national fire regulation was enforced.

Q3. Who issues the approval of a construction work project from the fire safety design perspective?

Q4. Who is liable for fire safety design of construction works and design compliance to the regulation?

Q9. What is the regulatory framework that allows for the application of fire safety engineering approach?

Q10. Which body/bodies perform a regulatory review of the fire safety engineering approach in projects?

The BeneFEU project report (Joyeux 2002) and the GROW-JRC survey (Athanasopoulou et al. 2023) provided information on the national legal frameworks for possible application of FSE in building fire safety design and approval, in the respectively targeted countries. The fire regulations of reference cited in the replies to the SFPE survey was, in most cases (8 out of 13), the same as for the GROW-JRC survey. In other 4 cases, there was partial correspondence – the SFPE chapters of Austria, Finland, Italy and Portugal reported that their regulations were revised at later dates. Finally, the German SFPE chapter referred to the 16 regional laws (Bundesländer Bauordnungen) rather than to the national (Muster-Bauordnung, reference of the response to GROW-JRC).

In the years 2022-2024, the following changes in the national regulatory systems allowing for fire safety engineering application in building design are to be mentioned:

- The reference regulation in Austria (OIB Richtlinien) was updated in 2023, as reported by the Austrian SFPE chapter.
- In Germany, new fire design regulation "Brandschutztechnische Anforderungen an Hochhäuser" (Technical Fire Safety Requirements for High-Rise Buildings) came into force on the 1st of January 2022. The overall legal framework (Model Building Code, Muster-Bauordnung - MBO) remained unchanged as per the last update (2019).

- In the Netherlands, the Dutch Building Decree (Bouwbesluit, national regulation replacing local codes) was updated in 2023, without any changes in the overall framework. In 2024, a new Environment Buildings Decree (Besluit bouwwerken leefomgeving, Bbl) was foreseen to replace both the Building Decree and the Environmental and Planning Act.
- In Spain, the fire safety regulation for industrial buildings (RSCIEI) was updated in 2024; although this category of buildings is outside the scope of the present JRC activity, it is worth noting that this updated regulation implements FSE. The full summary of the available information on the national regulatory frameworks of the EU/EFTA countries, United Kingdom and Serbia is presented in **Table 8** in **Annex 1**.

4.4 Applicability of fire safety engineering

Q2. What is the nature and level of the technical detail in your fire regulation, considering the following technical details?

Q6. What are the types of construction works to which FSE approach is applied?

Q7. Which fire safety technical areas are included in fire safety engineering approach applications?

Q16. What assessment methods for FSE are used for the prediction of fire, smoke, structural response, evacuation, etc.?

The 12 technical areas (TAs) listed in **Table 4** are descriptors of the level of implementation of FSE through the group of responding countries. The detailed description of TAs is contained in the 2023 JRC Technical Report (Athanasopoulou et al. 2023).

Table 4. The 12 technical areas (TAs) referred in the GROW-JRC survey on the FSE implementation status.

Definition of technical areas (TAs)	**Abbreviation**
Fire Detection	FireDete
Early suppression / suppression systems	EarlySup
Evacuation routes	EvacRout
Smoke control systems	SmokCoSy
Structural fire safety	StructFS
Fire compartmentation	FireComp
Smoke compartmentation	SmokComp
Prevention of fire spread to neighbouring buildings	PrFiSpre
Material / system selection for façades	MaSelFac
Material / system selection for all other relevant areas (e. g. interior finishing, cables, internal insulation, furniture etc.)	MaSelOth
Firefighting (fire brigade access and intervention)	FireFigh
Building installation (e. g. electricity, gas, lifts)	BuilInst

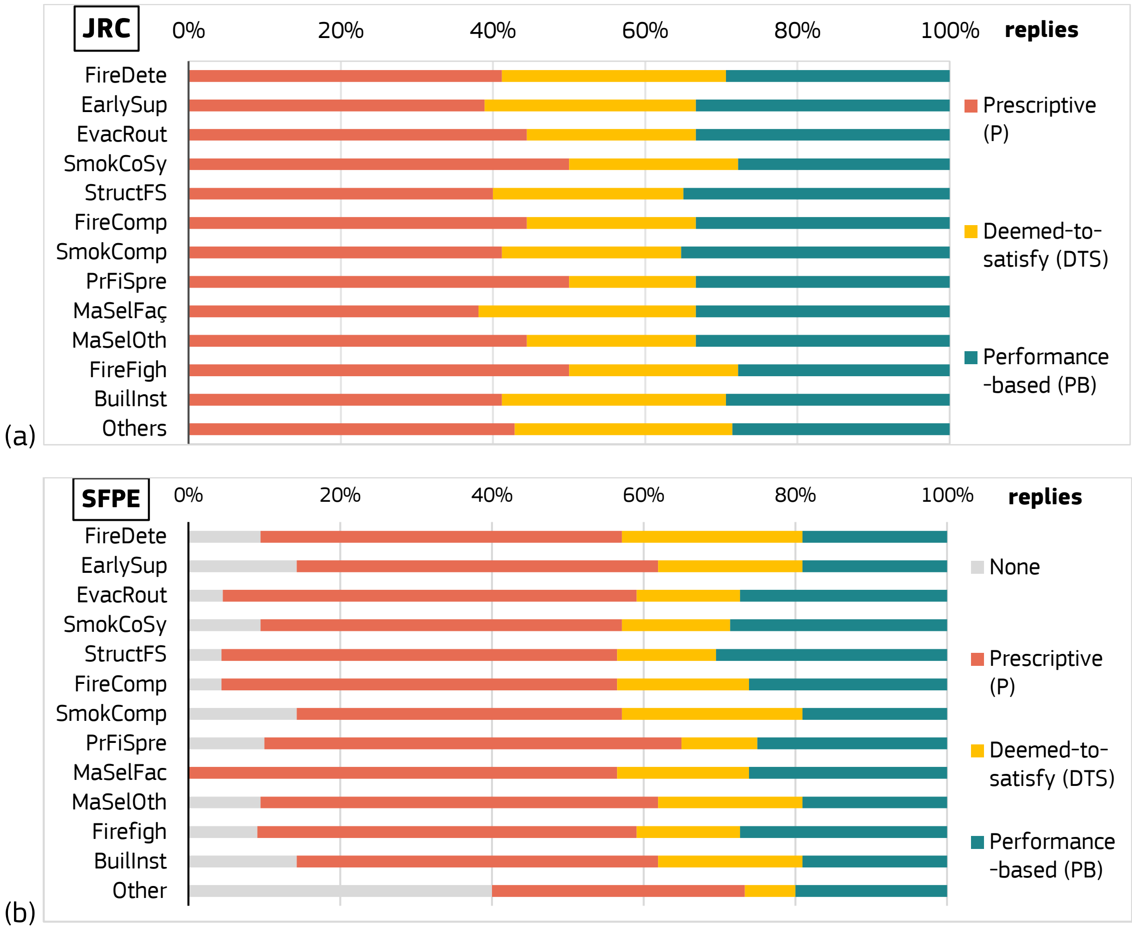
Source: Athanasopoulou et al. 2023

4.4.1 Fire safety engineering across technical areas

The responders have indicated the availability, for each TA, of technical solutions for fire design based on prescriptive (P), deemed-to-satisfy (DTS) and performance-based (PB) approaches (see **Table 1** for the full definition of the approaches). The shares of each approach P, DTS and PB are calculated over the sum of all answers P + DTS + PB and expressed in percentage.

In the GROW-JRC survey, the responses from the current group of 13 countries were in line with the general trend for all 32 countries, namely a 40-50% share for P, a 25-35% for PB, and a 20-30% for DTS solutions. The bar charts in **Figure 5** show that fire design professionals confirm the prevalence of prescriptive approach in the 13 countries, with even larger percentages than regulators.

Figure 5. Shares of P, DTS and PB approaches in fire safety regulations for the 12 TAs in the group of 13 countries, according to regulators – JRC (a) and professionals – SFPE (b)



Source: Authors' work

As a noticeable difference, professionals specified no available approach for some TAs, namely (**Figure 5b**):

— Cyprus: no available approach for Fire detection, Early suppression, Smoke control systems, Smoke compartmentation, Prevention of fire spread to neighbouring buildings, Material selection for other relevant areas, Building installations. However, in the remaining 5 TAs, all approaches P, DTS and PB are implemented in the national regulations.

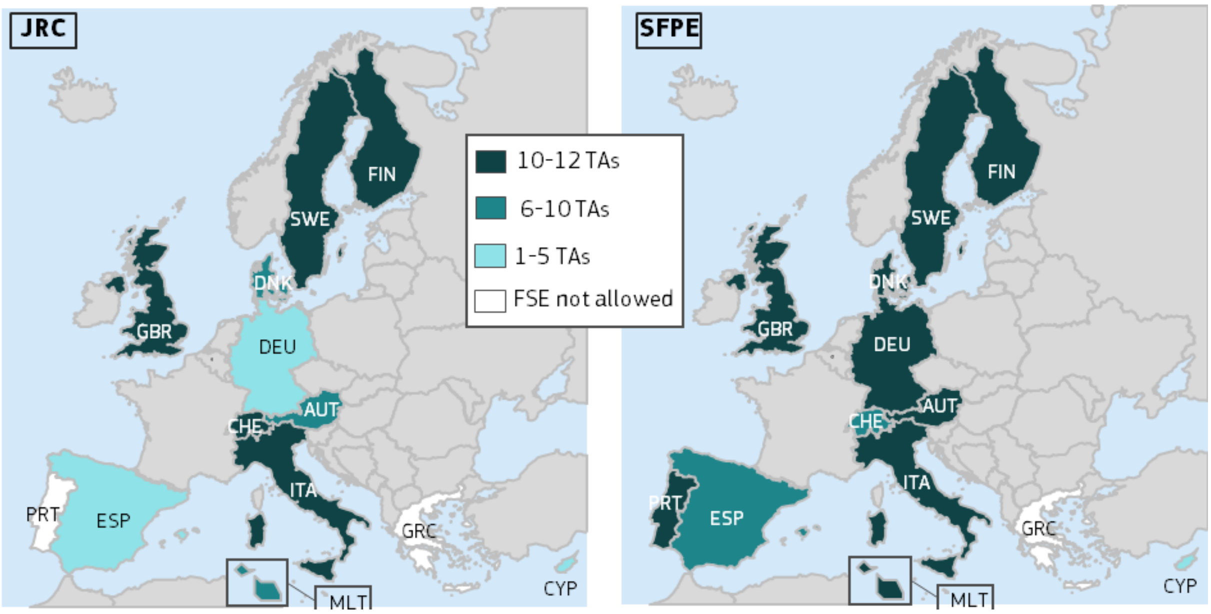
— Greece: no available approach for Early suppression, Firefighting, and Building installations.

— Switzerland: no available approach for Smoke compartmentation.

— United Kingdom: no P, DTS or PB approach is available for any TA (except P solutions in Material selection for façades and other unspecified areas). The responder explained that the building regulations are based on functional requirements, supported by guidance (e.g. other regulatory documents or national standards). Performance-based design is considered one route of compliance with the functional requirements of the building regulations.

The maps in **Figure 6** present how many of the basic 12 TAs are covered by FSE approach in the FSE-allowing countries, according to replies to Q7 'Which fire safety technical areas are included in fire safety engineering approach applications?'

Figure 6. Number of TAs included in FSE applications according to regulators (JRC) and professionals (SFPE) [note: Portugal (PRT) was not in the group of FSE-allowing countries of the GROW-JRC survey]



Source: Authors' work (© EuroGeographics for the administrative boundaries)

The SFPE information fully confirms that FSE covers a high number of TAs in Finland, United Kingdom, Italy and Sweden, where all the 12 TAs are included in FSE applications according to both regulators and professionals; on the other hand, application of FSE only to selected TAs is confirmed for Cyprus. In 4 other countries, the views of fire safety design professionals are quite different, namely:

— Austria: all the 12 TAs are included in FSE approach applications; instead of the 6 specified in the GROW-JRC survey.

— Switzerland: only 8 TAs are included, instead of the 12 specified in the GROW-JRC survey.

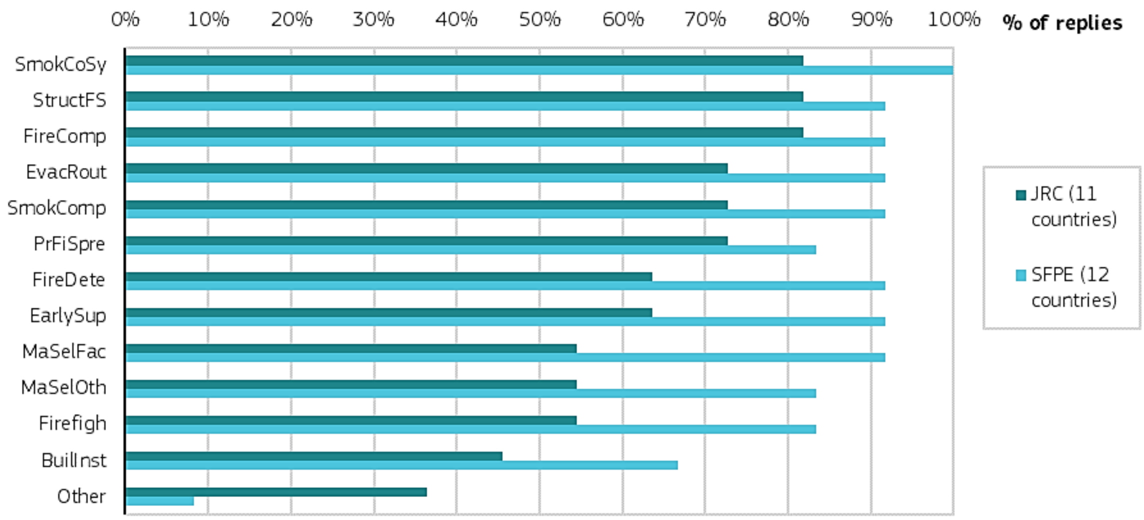
— Germany: all the 12 TAs are included in FSE approach applications; instead of the one (i. e. structural fire safety) specified in the GROW-JRC survey.

— Portugal: the FSE approach can apply to all the 12 TAs.

Finally, the SFPE responders provided partially different replies for Denmark (12 instead of 10 TAs) and Malta (11 instead of 9). For Spain, the SFPE responder replies that FSE applies to 6 TAs (with the caveat that local deviations are possible), while the JRC survey reported that no TAs are explicitly specified in the regulations.

Concerning the most indicated TAs included in FSE applications, the results of the SFPE survey are in a good agreement with the GROW-JRC survey (**Figure 7**), showing that performance-based fire design is mostly applied for designing measures of smoke control systems, structural fire safety and fire compartmentation.

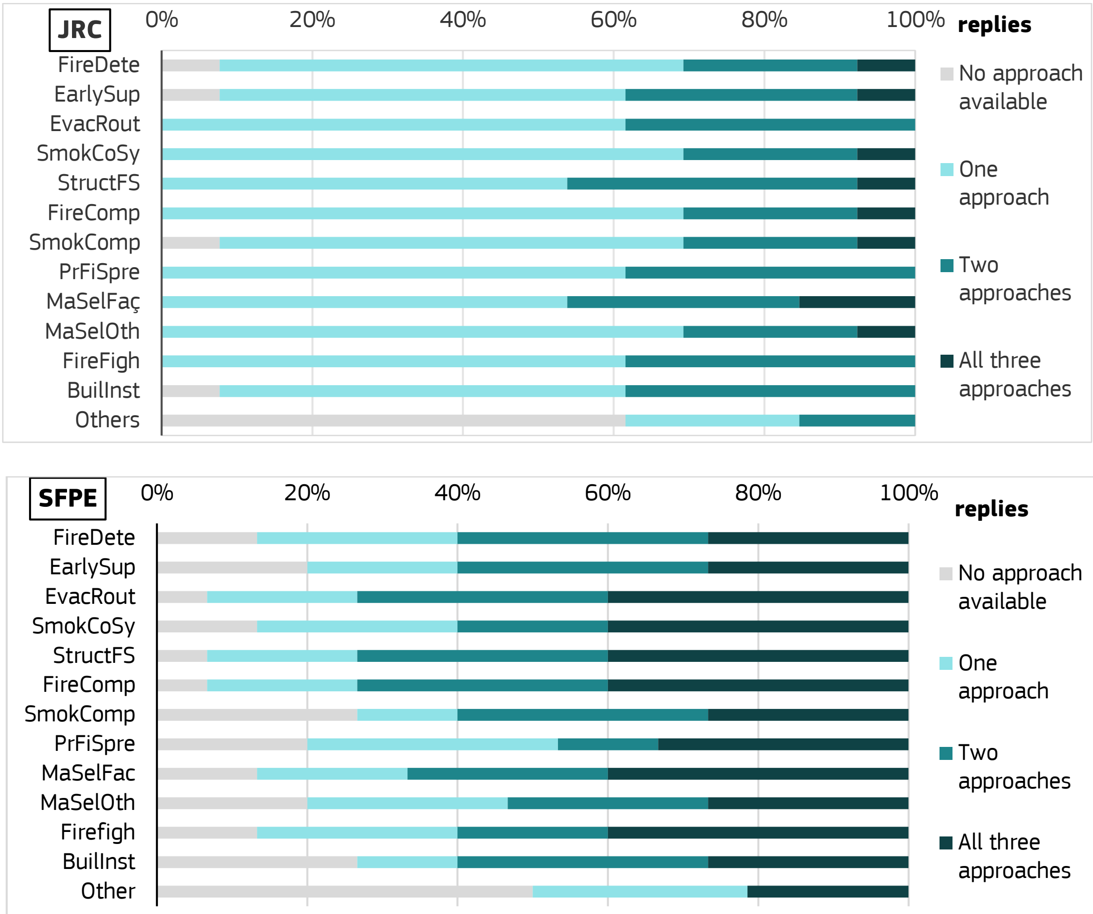
Figure 7. TAs included in FSE applications according to regulators (JRC) and professionals (SFPE)



Source: Authors' work

The possibility of adopting different approaches for the design of a technical detail can be appreciated from the responses to Q2 as illustrated by **Figure 8**. Generally, the professionals (**Figure 8b**) report a larger availability of design approaches for the same TA than the regulators (**Figure 8a**). This may reflect the fact that regulations can allow for performance-based solutions without describing them in detail, as alternate routes for compliance. However, a larger number of professionals indicate complete unavailability of a design approach across all TAs, pointing out the need for establishing design approaches especially for Smoke Compartmentation, Building Installations, Early Suppression and Material Selection for all Other relevant areas (**Figure 8b**).

Figure 8. Number of different approaches (P, DTS and PB) available for each TA, according to regulators – GROW-JRC, 11 countries (a) and professionals – SFPE, 12 countries (b)



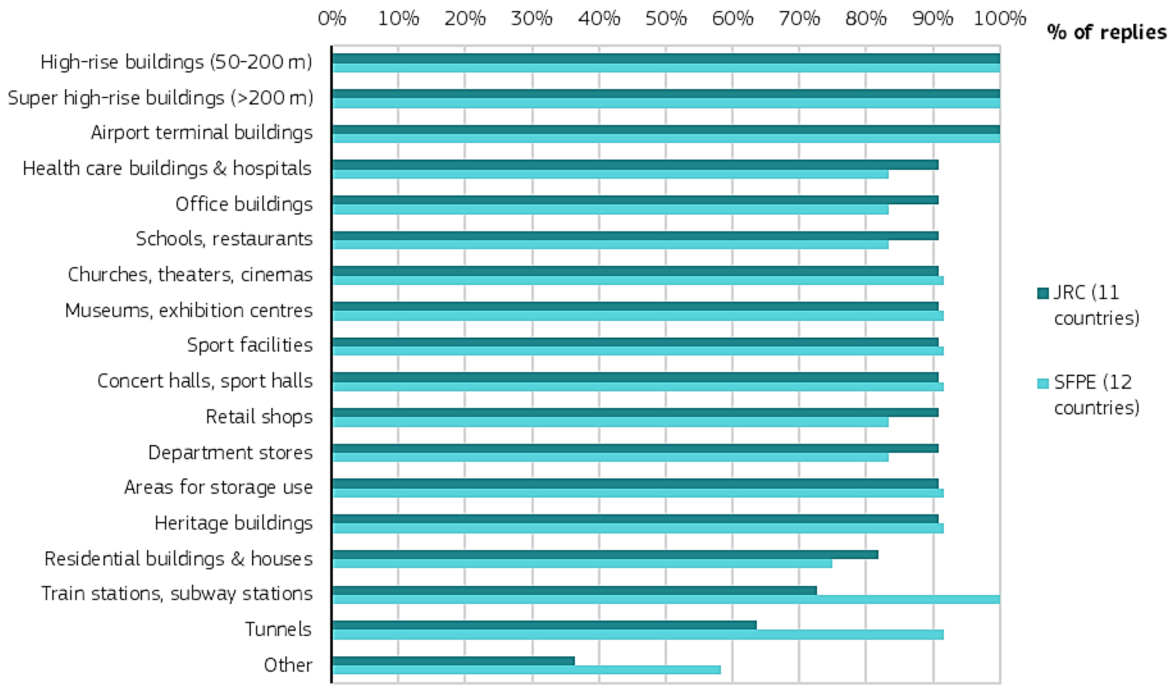
Source: Authors' work

4.4.2 Fire safety engineering across types of construction

The types of constructions that FSE can apply to (answers to Q6) are shown in the bars chart in **Figure 9**, which compares the information from GROW-JRC and SFPE enquiries given by the FSE-allowing countries (i.e. 11 out of 13 countries for GROW-JRC, and 12 for SFPE).

The replies of regulators and professionals of fire safety are in a quite good agreement for most types of buildings, especially for the three types that were the most indicated in the GROW-JRC survey, i.e. high-rise and super high-rise buildings, and airport terminals. Additionally, the lesser applicability of FSE to residential building appears confirmed. On the other hand, it is worth noting that many more professionals than regulators consider FSE applicable to train stations, subway stations and tunnels.

Figure 9. Types of constructions that FSE applies to, according to regulators (JRC, 11 countries) and professionals (SFPE, 12 countries)



Source: Authors' work

4.4.3 Assessment methods for the technical areas

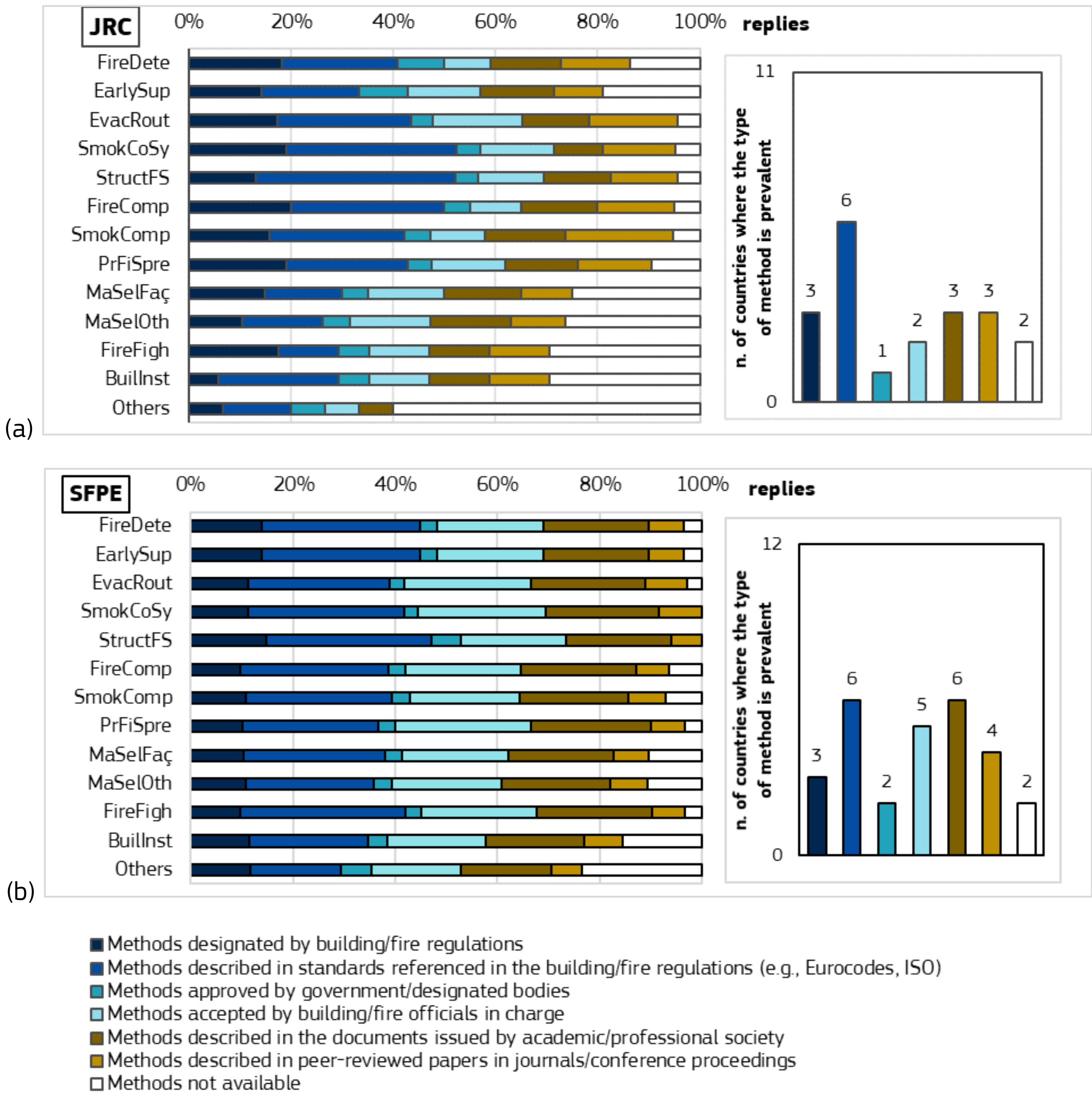
The charts proposed in **Figure 10** allow to evaluate and compare the availability of assessment methods for FSE applications through the different TAs, and the prevalent types of methods indicated by the responders, according to the replies to Q16. The methods are considered according to their sources, as follows:

1. Methods designated by building/fire regulations
2. Methods described in standards referenced in the building/fire regulations (e.g., Eurocodes, ISO standards)
3. Methods approved by government/designated bodies
4. Methods accepted by building/fire officials in charge
5. Methods described in documents issued by academic/professional society
6. Methods described in peer-reviewed papers in journals/conference proceedings.

For both GROW-JRC and SFPE enquiries, the bar charts on the left present the availability of the six types of methods for each TA, for the whole group of responders (FSE-allowing countries). These charts demonstrate the high availability of fire regulations and standards referenced therein – i.e. types 1 and 2 in the above list. In fact, through all the TAs, 30-50% of responders in the GROW-JRC survey and about 40% in the SFPE survey indicate that designers can rely on such methods. The availability of methods of types 5 and 6 – or academic sources – is also indicated by both professionals and regulators (25-30% of responders in both cases). On the other hand, the availability of methods of types 3 and 4 is indicated more by professionals (20-25%) than by regulators (15-25%). The professionals indicate a greater and more homogeneous availability of assessment methods through the TAs.

The column charts on the right enlighten the most used sources over all the TAs. For some countries, various sources are equally the most used. The SFPE responders seem to give a more balanced picture of the use of the considered methods, in reference to the method sources.

Figure 10. Sources of available assessment methods for FSE applications through the TAs, according to regulators – JRC (a) and professionals – SFPE (b) of the FSE-allowing countries



Source: Authors' work

4.5 Responders' comments and recommendations

The SFPE Chapters of the 13 countries taken into consideration have provided additional comments.

The SFPE Chapter of Switzerland points out that different topics in FSE often rely on different safety philosophies (e.g. semi-probabilistic or fully probabilistic design rules as opposed to deemed-to-satisfy design scenarios or worst credible scenarios. For this reason, the SFPE Chapter of Switzerland supports a new generation of fire safety codes that have risk-based acceptance criteria, which will be the basis of both prescriptive design rules and performance-based design requirements (design fires and performance criteria). Finally, the Swiss SFPE Chapter is in favour of a consistent safety philosophy at European level alike EN 1990, beyond the mere provision of prescribed design fires.

The SFPE Chapter of Germany underlines that FSE is not only based on calculations or simulations, but also on experimental results, discussion on scientific research and other technical evidence. This applies particularly to objectives and functional requirements of fire safety designs and fire safety performance and acceptance criteria, and to the quantification of the acceptable fire risk with respect to the economic, social and cultural factors of a society.

The SFPE Chapter of Finland wishes for the establishment of formal training and education programmes, on the grounds of a national demands for FSE's professional competence, and of a national register for qualified FSE designers.

The SFPE Chapter of Greece enlightens the fact that the national law permits almost any graduate from any engineering discipline to conduct fire safety design at any level – with no requirements for relevant training, experience or assessment of qualifications – and assume all the responsibility for it. Moreover, fire safety designs are reviewed by the local fire brigade officers, who are usually not engineers, and have almost no chance to gather relevant experience in their career. Since very few European universities and educational institutes provide education based on all the SFPE core competencies, many engineers lack formal education or training at least in some of the technical areas relevant for FSE. Finally, the Greek Chapter wishes for a central FSE-supporting mechanism in EU, which could help local governments during the first period of performance=based design adoption, e. g. by reviewing performance-based designs to overcome the lack of properly qualified reviewers.

The SFPE Chapter of Portugal supports the idea of a European performance-based code, even if not mandatory in Member States, which could spread minimum core competencies and certification for performance-based design practitioners.

5 Education in fire safety engineering

The availability and needs of education and training for fire safety engineers is explored in a geographical perspective. First, the awareness of regulators and professionals of available education and training is presented (Section 5.1). Then, a detailed non-exhaustive mapping of university courses is proposed (Section 5.2), based on information provided by the JRC FSE network.

5.1 Availability and needs

For both enquiries, the reference questions are:

Q19: What official educational bodies offer FSE education and training to students?
Q20: Do you see a need for FSE post-secondary education?
Q21: Do you see a need for FSE Continuing Professional Development courses?
Q22: Should FSE be part of the training for fire fighters and/or other emergency responders?

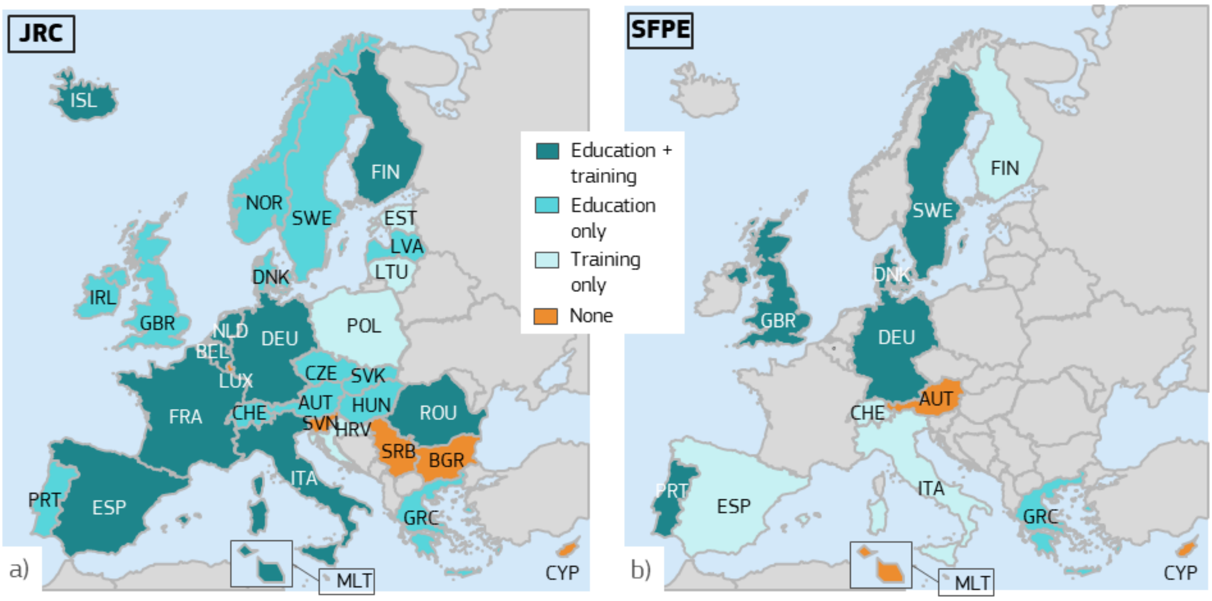
Q19 displayed the following possible answers: 1) Vocational training at higher education level / continuous professional development; 2) University (MSc); 3) University (BSc); and 4) Others. In the below analyses, it is assumed that vocational higher education, meaning PhD and post-doc courses (answer 1), belongs to the domain of training, although it is provided by universities, since it is situated out of the BSc-MSc educational path for professional engineers.

It must be noted that, for what concerned Q19, the GROW-JRC questionnaire referred to ‘fire safety engineering education’ as ‘full university courses’ (degree programmes) and ‘dedicated university courses’ (single modules within degree programmes) at BSc or MSc level, but did not rely on a strict definition, especially in terms of duration. Thus, similar responses from fire regulators might represent quite different situations – for instance, if a responder indicated FSE education provided at MSc level, this could possibly mean a MSc degree programme of 2 years or single modules of 1 semester.

To clarify this aspect, the SFPE survey relied on a definition of FSE education as fire safety engineering degree programmes given by universities at the levels of Master of Science / Engineering / Architecture (MSc/MEng/MArch) and/or Bachelor of Science / Engineering / Architecture (BSc/BEng/BArch). This choice was motivated by the idea that education shapes up the first block in the development of fire safety competency (**Figure 2**) and is expected to provide students with a complete knowledge background in FSE.

From a general point of view, the two enquiries pointed out that regulators and practitioners had different perceptions in terms of availability of education and training (**Figure 11**). The maps in **Figure 11** are constructed after the responses to Q19. Only practitioners from Cyprus, Greece and Germany provided similar responses to the regulators of the corresponding countries. The different replies are analysed in detail in the following subsections.

Figure 11. General availability of FSE education and training: JRC (a) and SFPE (b) enquiries

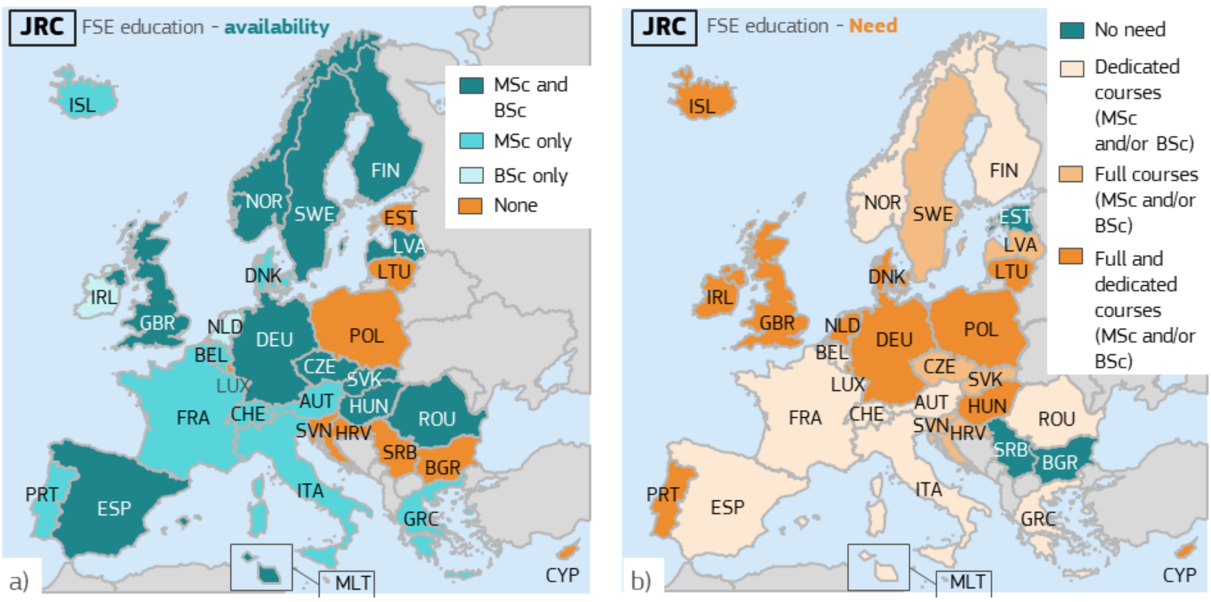


Source: Authors' work (© EuroGeographics for the administrative boundaries)

5.1.1 Regulators' views: GROW-JRC survey (2020-21)

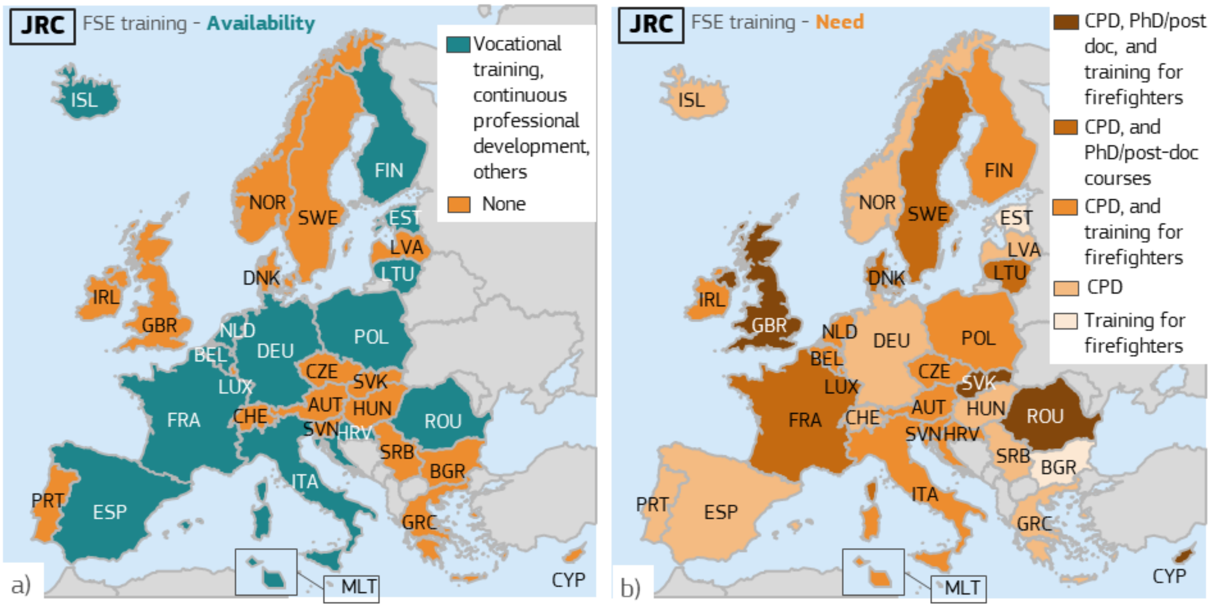
The results of the GROW-JRC survey (2020-21), shown in **Figure 12** and **Figure 13**, allow drawing a picture of the availability and needs of education and training in Fire Safety Engineering, through the perception of fire regulators in the responding countries.

Figure 12. Responses to GROW-JRC survey (2020-21): availability (left) and need (right) of FSE education



Source: Authors' work (© EuroGeographics for the administrative boundaries)

Figure 13. Responses to GROW-JRC survey (2020-21): availability (left) and need (right) of FSE training



Source: Authors' work (© EuroGeographics for the administrative boundaries)

Concerning the availability and needs of FSE post-secondary education, namely MSc and BSc degree programmes, the following considerations can be made, comparing maps (a) and (b) in **Figure 12**:

— 12 out of 32 responders (40% circa) declare that post-secondary FSE education is provided at both MSc and BSc levels in their countries: Czechia, Germany, Finland, Hungary, Latvia, Malta, Norway, Romania, Slovakia, Spain, Sweden and United Kingdom.

— However, the responders of all the 23 countries where FSE education is already available, at any level, express the need for increasing it – most frequently, the need for both degree programmes and teaching modules (12 responses); for 9 of them, more teaching modules would be sufficient.

— In 6 countries (Cyprus, Croatia, Lithuania, Luxembourg, Poland and Slovenia), responders declared no available FSE education and acknowledged need for degree programmes (BSc / MSc) at least

— In 3 countries (Bulgaria, Estonia and Serbia), responders declared no available education in FSE, and no need for it.

This picture shows that fire regulators seldom perceive the availability of FSE education at universities, at MSc and/or BSc as sufficient; they wish for a larger educational offer based on degree programmes (BSc and/or MSc).

The prevalence of need over availability also holds – and in an even more evident way – for FSE-related training; maps (a) and (b) in **Figure 13** provide the following information:

— Less than half of the responders (i.e. 14 out of 32) declare that their countries provide FSE-related vocational training, continuous professional development (CPD) and other (provided by PhD/post-doc courses, national fire brigades, international bodies, institutes and private organisations).

— All the 32 responders expressed the need for increased offer of training. 30 wish for more CPD, and 18 express the need for FSE in firefighters' training regarding fire development, fire spread and fire growth, warning of pending collapse, smoke control and handling, and other reasons.

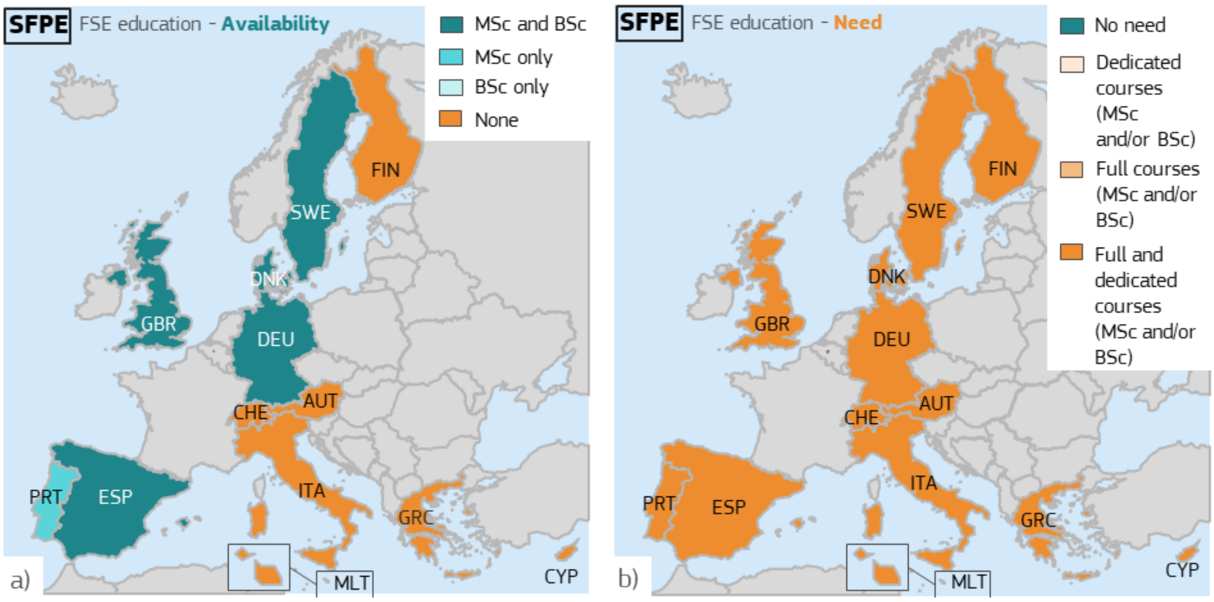
The information presented in **Figure 12** and **Figure 13** allow to conclude that, according to the responding European fire regulators, a gap exists in many countries between FSE-related educational offer and training; availability of MSc / BSc courses is greater than vocational training and CPD, and the need for increasing the training offer is more intensely perceived by the responders. In detail, the following observations can be made:

- All the responders express the need for enhancing the offer of training in FSE, regardless the availability or non-availability.
- In Austria, Switzerland, Czechia, Denmark, United Kingdom, Greece, Hungary, Ireland, Latvia, Portugal, Norway, Portugal, Slovakia, and Sweden, the availability of university-level education in FSE for engineers is not matched by an adequate offer of related training for post-university studies and professional practice.
- Vice versa, in Estonia, Croatia, Lithuania, and Poland, FSE training is available, but not backed by FSE education provided by degree programmes at university level. Responders from all these countries, except Estonia, express the need for improving the educational offer in FSE.
- Responders of Bulgaria, Cyprus, Luxembourg, Serbia, and Slovenia have indicated lack of both education and training in FSE. the regulators of Bulgaria and Serbia declare that FSE-related education is not needed.
- Finally, the regulators of Belgium, Germany, Finland, France, Iceland, Italy, Malta, the Netherlands, Romania and Spain have indicated that both FSE-related education and training are available. However, all the responders deem that the offer is not sufficient yet and should be increased.

5.1.2 Professionals' views: SFPE survey (2023)

The same analysis as in Section 5.1.1 is conducted on the professionals' responses to the same questions. **Figure 14** shows the availability (a) and perceived needs (b) of FSE-related education.

Figure 14. Responses to SFPE survey (2023): availability (left) and need (right) of FSE education



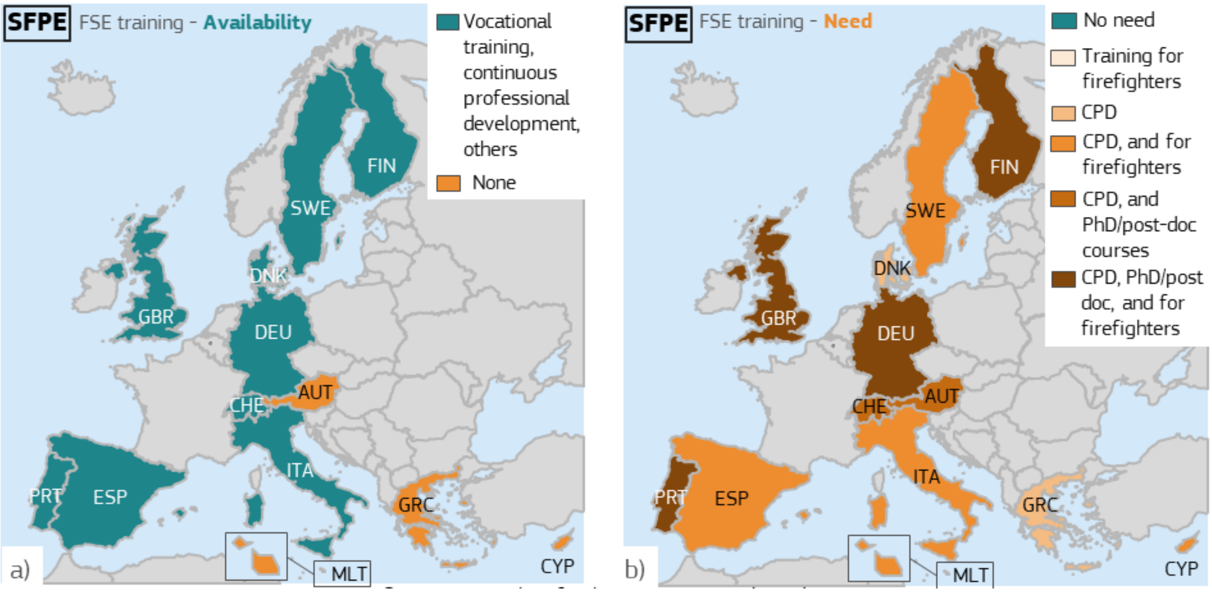
Source: Authors' work (© EuroGeographics for the administrative boundaries)

The SFPE chapters decided to consider education available if provided in degree programmes (MSc, BSc or both). This can explain why, in the 13 responding countries, the professionals' perception of the availability appears different from the regulators' (**Figure 12a**). Professionals indicate no availability of FSE-related degree programmes courses in Austria, Switzerland, Finland, Germany, Spain, Italy, Greece and Malta. On the other hand, the SFPE chapters' view on the need for education in the field of FSE is very similar to that of regulators (**Figure 12b**); in fact, all the 13 countries have indicated the need for both degree programmes and modules at MSc and BSc levels.

The replies of professionals on the availability of training in the field of FSE (**Figure 15a**) are also different from regulators' (**Figure 13a**). In fact, four of the SFPE chapters declared no training available; this corresponds to the regulators' view for Austria and Cyprus, but not for Greece and Malta. Of the 9 countries whose SFPE chapters declared that training is available, Denmark, Portugal, Sweden, Switzerland and United Kingdom do not confirm the regulators' view.

On the other hand, just like in the GROW-JRC survey (**Figure 13b**), every responder declared that there is need for more FSE-related training (**Figure 15b**). The 13 SFPE chapters indicated the need for at least one type of training, with prevalence of CPD (100% of responses) and FSE training for firefighters (70%). The need for more post-doc courses is perceived by nearly 50% of responders.

Figure 15. Responses to SFPE survey (2023): availability (left) and need (right) of FSE training



Source: Authors' work (© EuroGeographics for the administrative boundaries)

From the information collected by GROW-JRC and SFPE, it is possible to observe:

— The need for education is more intensely perceived by professionals than regulators.

— There are discrepancies between replies of regulators and professionals about the availability of education and training in FSE. The former can be explained by the professionals' assumption that FSE education corresponds to degree programmes in FSE. On the other hand, the reasons for the latter discrepancy are not clear, based on the available information.

- However, regardless the availability, all the responding SFPE chapters express a need for enhancing the offer of FSE training in their countries and emphasise CPD as the most desirable development, followed by FSE training for firefighter. Regulators have expressed the same.

5.2 Mapping of fire safety engineering education and training

This section presents the detailed mapping (**Figure 16**) of available FSE education and training for professionals, on the grounds of information collected by the JRC FSE network experts after the GROW-JRC survey results were published. Such information adds to the picture of education availability from the views of fire regulators (GROW-JRC survey, section 3.1.1) and professionals (SFPE survey, section 3.1.2) who responded to question Q19 'What official educational bodies offer FSE education and training to students?'. The mapping focuses on the education and training offer that specifically provide competencies in fire design of buildings with FSE.

The proposed mapping also includes programmes of PhD, Master of Advanced Studies, or specialist / postgraduate studies, as vocational training in FSE provided by universities. Finally, 1-year vocational training, and single modules (1-2 semesters) in BSc/MSc level curricula were noted in some countries where minimum 2-year programmes of FSE education / training were available.

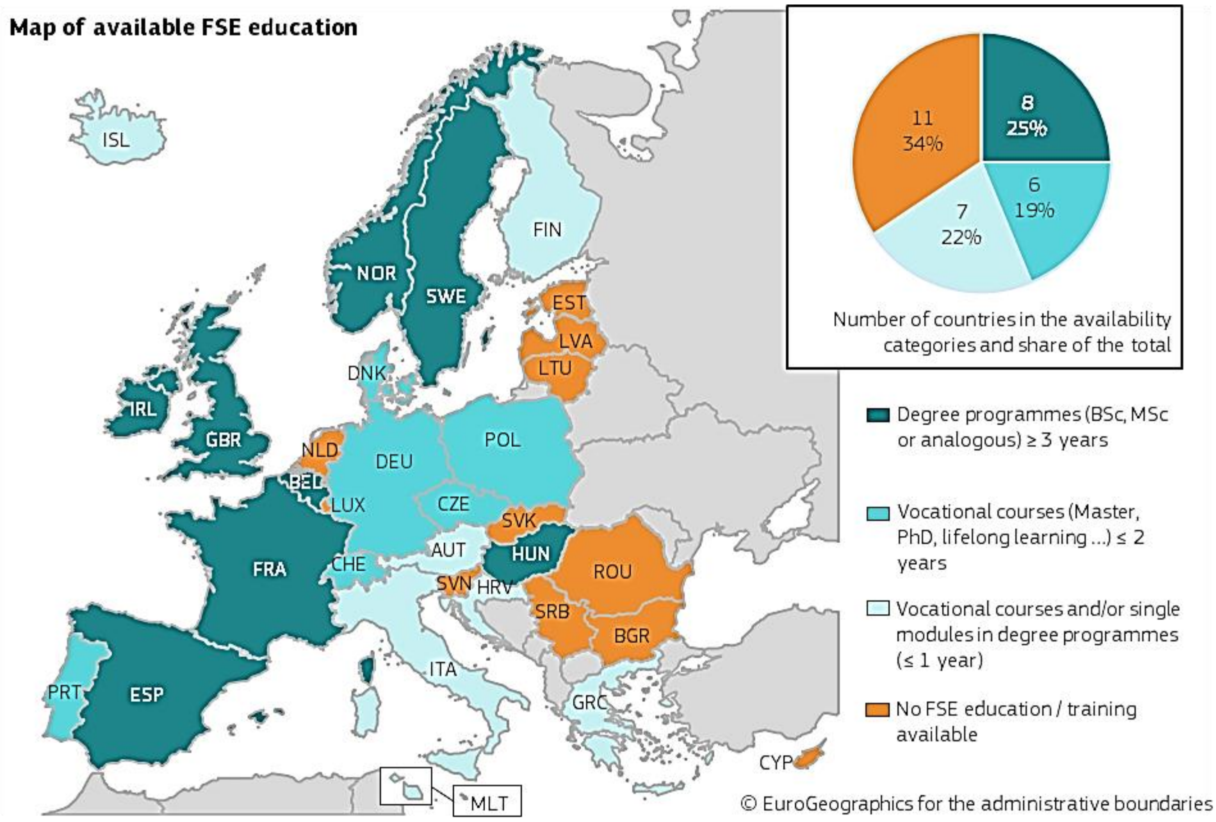
5.2.1 Education and professionals' training

The mapping (**Figure 16**) was performed based on the information from the two enquiries as well as from the JRC FSE experts, according to the following categories, and to duration: (i) degree programmes (MSc and/or BSc), (ii) vocational courses provided by universities, (iii) single modules, and (iv) no educational offer at university. All the university courses are specified in **Table 5**, while **Annex 2** provides the full details of each mapped course (description, duration, requirements for enrolment, etc.).

As for the single European countries, the map (**Figure 16**) allows to determine the following groups:

1. Countries where a fire safety engineer can be fully educated through the BSc and/or MSc levels (at least 3 years study): 8 out of 32 countries (Belgium, Spain, France, United Kingdom, Hungary, Ireland, Norway, and Sweden).
2. Countries where fire safety engineers can be trained by university through at least 2 years of vocational courses (postgraduate studies, PhD): 6 out of 32 countries (Switzerland, Czechia, Germany, Denmark, Poland, and Portugal).
3. Countries where universities provide vocational training in FSE for maximum 1 year, and/or where students in engineering and/or architecture can attain a basic level of knowledge on fire safety engineering, by attending modules of 1-2 semesters during their BSc and/or MSc study programmes: 7 out of 32 countries (Austria, Finland, Greece, Croatia, Iceland, Italy, and Malta).
4. Countries where universities do not provide any fire safety engineering education: 11 out of 32 countries (Bulgaria, Cyprus, Estonia, Lithuania, Luxembourg, Latvia, the Netherlands, Romania, Serbia, Slovakia, and Slovenia).

Figure 16. Map of FSE education in EU/EFTA countries



Source: Authors' work (© EuroGeographics for the administrative boundaries)

Table 5. European universities providing programmes of education and vocational training in FSE

Country	University	FSE education / training
Belgium	University of Ghent	• International Master in Fire Safety Engineering (IMFSE) (*) • MSc in Fire Safety Engineering • Postgraduate studies in Fire Safety Engineering (vocational)
Croatia	University of Zagreb	• Specialist Study in Fire Engineering (vocational, 1 year)
Czechia	Technical University of Ostrava	• PhD in Fire Protection and Safety (vocational)
Denmark	Technical University of Denmark	• MAS in Fire Safety (vocational)
France	University of Aix-Marseille	• MEng in Fires & Fire Safety Engineering (available both as initial education and as vocational training)
	National Institute of Applied Sciences of Rouen	• Postgraduate studies in Fire Safety Engineering (vocational)
Germany	University of Dresden	• MEng in Preventive Fire Protection (vocational)
Hungary	Ludovika University	• BSc in Fire Protection Engineering

Country	University	FSE education / training
Ireland	Atlantic Technological University	• BEng/BSc in Fire Safety Engineering
Italy	Free University of Bolzano	• Master in Fire Safety Engineering (vocational, 1 year)
Norway	Western Norway University of Applied Sciences	• BSc in Fire Safety Engineering • MSc in Fire Safety Engineering
Poland	Fire Academy of Warsaw	• BEng in Safety Engineering • MEng in Safety Engineering • Postgraduate diploma in Fire Safety Engineering (vocational training)
Portugal	University of Coimbra	• Lifelong Learning Master Programme in Urban Fire Safety Engineering (vocational training) • PhD in Fire Safety Engineering (vocational training)
Spain	Polytechnic of Catalunya	• International Master in Fire Safety Engineering (IMFSE)
Sweden	University of Lund	• International Master in Fire Safety Engineering (IMFSE) • BSc in Fire Safety Engineering • MSc in Fire Safety Engineering
	Luleå University of Technology	• BSc in Fire Engineering
Switzerland	Swiss Federal Institute of Technology	• MAS in Fire Safety Engineering (vocational)
United Kingdom	University College of London	• MArch in Fire Safe Design
	University of Central Lancashire	• BSc in Fire Safety Engineering • MSc in Fire Safety Engineering
	University of Edinburgh	• International Master in Fire Safety Engineering (IMFSE) • BEng in Structural and Fire Safety Engineering • MEng in Structural and Fire Safety Engineering • MSc in Fire Engineering Science
	University of Ulster	• Postgraduate diploma in Fire Safety Engineering (vocational)

(*) See **Box 2**

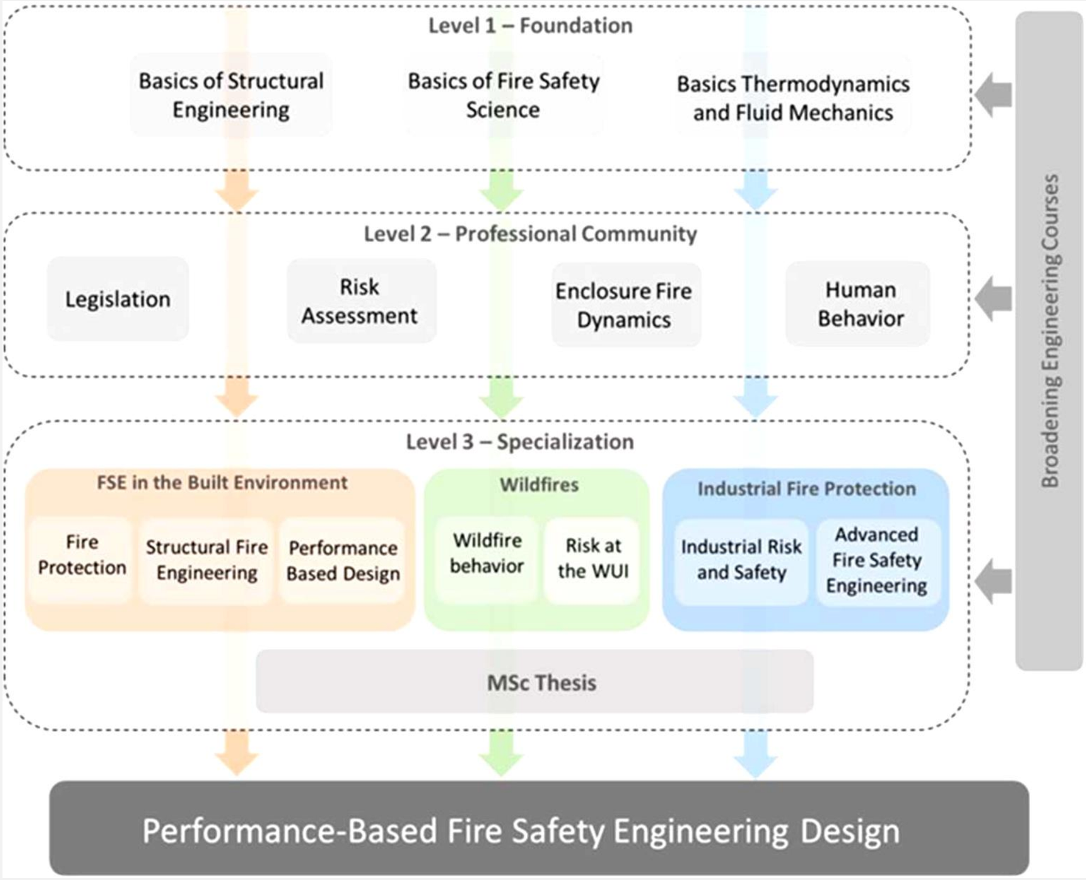
Source: Authors' work

The European education for FSE benefits of an international master course, IMFSE (International Master in Fire Safety Engineering), participated by 4 universities of Belgium, Spain, United Kingdom and Sweden as full partners, and co-funded by the EU in the Erasmus+ programme. A short description of this course is given in **Box 2** below, and some more details are given at point 1 of **Annex 2.**

Box 2. Characteristics of the IMFSE programme

The strong need for competency in FSE is recognised on the grounds of the increasingly challenging and complex fire safety practice, in front of the European strive for sustainability of the built environment, energy efficiency and adaptation to climate change effects – considering e. g. wildfires / fires at wildland-urban interface (WUI). To this regard, FSE should take advantage of the opportunities of advanced experimental and computational methods, risk- and resilience-based design approaches, multidisciplinary design interactions, and digitalisation – which education should embrace and convey to students. As well, acknowledging the importance of designs based on first principles is essential for the sustained future of the fire safe engineer profession.

The IMFSE programme



Source: courtesy of B. Merci

The IMFSE consortium, coordinated by the University of Ghent (Belgium), includes the Universities of Edinburgh (United Kingdom), Lund (Sweden), and Polytechnic of Catalunya (Spain) as full partners. There are currently 7 associated partners: University of Queensland (Australia), University of Maryland (USA), the Swiss Federal Institute of Technology (ETH), University of Poitiers (France), the Slovenian National Building and Civil Engineering Institute, the Worcester Polytechnic Institute (USA), and the University of Science and Technology of China.

The IMFSE programme strongly aligns with the SFPE model curriculum for MSc. The IMFSE key principle for academic choices is to create strong technical competencies (based on in-depth theoretical knowledge) and communication skills, embedded in an ethical and critical thinking attitude.

5.2.2 Training for firefighters

As examples, the following firefighters' academies in Europe include FSE in their programmes:

- Fire University of Warsaw
- Fire Safety and Civil Protection College, Riga
- The French National Fire Officers Academy (ENSOSP).

The courses provided by these academies are also open to professionals, as vocational training.

5.3 Education, qualification framework, and role of fire engineer

Q11. What professional qualification is required for the regulatory reviewers of the fire safety engineering approach in projects?

Q12. What qualification is required to engage in FSE approach practices?

Q13. Who/what specifies the fire scenarios in the project design with FSE approach?

Q14. How are the design fires specified in the project design with FSE approach?

Q15. How are the safety criteria determined in the project design with FSE approach?

The questions in this group help defining the qualification of actors abled to apply / to review FSE in building design, and the way(s) they should or may perform the main design tasks. The categories considered to define qualification frameworks are explained in **Table 6**.

Table 6. Types of qualifications for regulatory reviewers and professionals engaged in FSE projects

Qualification type	**Category**
Certification / license in relevant category issued by the government or by a body designated by the government	Qualification issued by government
Set of minimum educational / professional experience acknowledged by the government (e. g. graduate of recognised engineering programme, a certain number of years of practice)	
Certification issued by recognised professional society	Qualification issued by professional societies
Qualification not explicitly defined	Not defined

Source: Authors' work

The graph in **Figure 17** presents the picture of qualification requirements from the responses to the GROW-JRC survey, by specifying qualification categories for reviewers along the horizontal axis and for practitioners along the vertical axis. The countries along the dashed lines have expressed two possible categories for regulatory-reviewers (Switzerland), practitioners (Finland) or both (Croatia, Malta, the Netherlands and Romania). Such cases may reflect complex frameworks.

In relation to the above options, it is possible to assess if a country sets symmetric qualification, which is the same qualification type is in place for both reviewers and practitioners involved in FSE projects. The countries setting symmetric qualification are located along the diagonal (**Figure 17**). The fragmented picture emerging from **Figure 17** inspires the following considerations:

— Most countries where qualification is defined set symmetric requirements for regulatory reviewers and professionals. In the largest group (Germany, Denmark, Estonia, Hungary, Iceland, Italy, Lithuania, Luxembourg, Latvia, and Serbia), qualification is issued by the government. In Malta, Romania and Slovenia it can also be, or is (in the case of Slovenia) issued by professional societies. In all these countries, the qualification can be considered *fully defined and symmetric*.

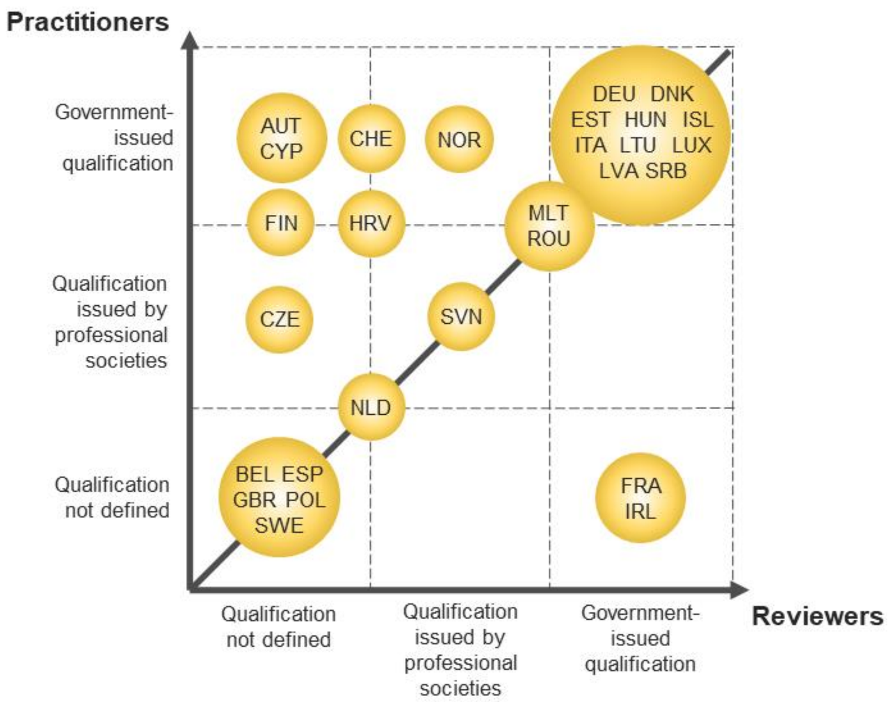
— Among the countries where asymmetric qualification is in place, it is possible to note that:

- In Norway, qualification is defined for both practitioners and reviewers but is released by different bodies (qualification *fully defined and asymmetric*).

- In France and Ireland qualification is government-issued for reviewers, while it is not defined for practitioners. Vice versa, in Austria, Cyprus, Finland and Czechia, the qualification frameworks are defined for practitioners, but not for reviewers. In Switzerland and Croatia, qualification appears less precisely defined for reviewers (due to multiple replies selected by the responder) than for practitioners. All these countries have thus *partially defined* qualification, which can possibly hold for the Netherlands too (where multiple replies selected denote a symmetric, not fully defined situation).

— In Belgium, Spain, United Kingdom, Poland and Sweden, qualification neither is explicitly defined for reviewers nor for practitioners of FSE approach projects (qualification *not defined*).

Figure 17. Qualification framework for practitioners and reviewers of FSE design – GROW-JRC survey



Source: Authors' work

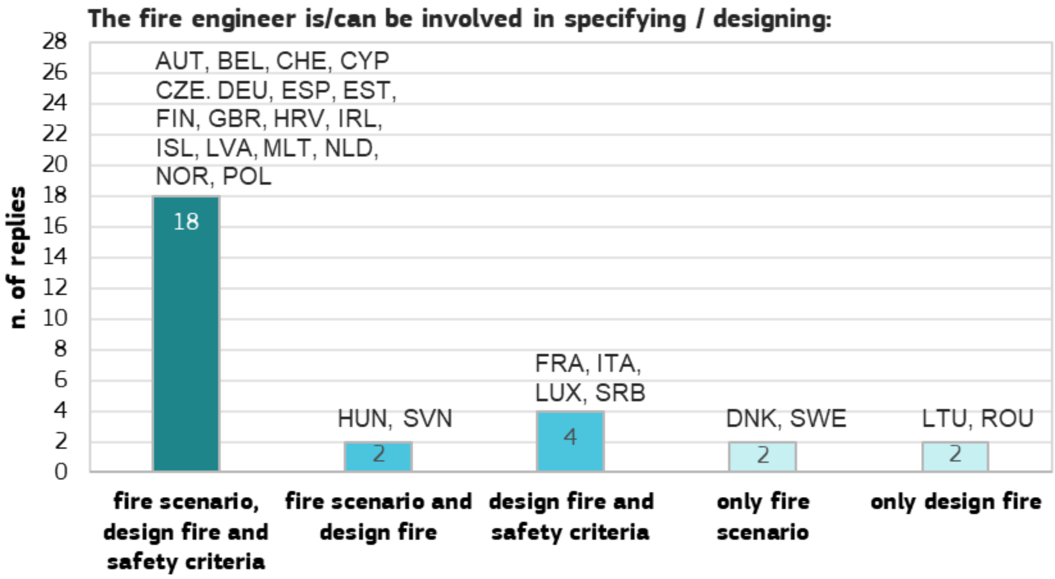
The replies to Q13, Q14 and Q15 demonstrate that the fire engineer is by far the most frequent designer / specifier of the main parameters of a project with FSE approach in the countries covered by the GROW-JRC survey. From the collected data (**Figure 18**), it is possible to assess that:

— In 18 out of 28 countries allowing for FSE application in fire design practice (Austria, Belgium, Switzerland, Cyprus, Czechia, Germany, Spain, Estonia, Finland, United Kingdom, Croatia, Ireland, Iceland, Latvia, Malta, the Netherlands, Norway, and Poland) the fire engineer specifies all the main 3 parameters, namely fire scenario, design fire and safety criteria.

— In 6 out of 28 countries, the fire engineer specifies 2 of the 3 main parameters, namely fire scenario and design fire in Hungary and Slovenia, and design fire and safety criteria in France, Italy, Luxembourg and Serbia.

— Only in 4 out of 28 countries the involvement of the fire engineer in the design choices for FSE projects is limited to one parameter only (Denmark, Sweden, Lithuania and Romania).

Figure 18. Building fire safety design parameters that can be specified or designed by the fire engineer (replies of fire regulators to the GROW-JRC survey, FSE-allowing countries)



Source: Authors' work

Finally, it is appropriate to mention the liability profiles for fire safety design, based on the data obtained through the GROW-JRC survey (Athanasopoulou et al., 2023). The questionnaire allowed to assess if the fire safety engineer is or can be (depending on certain characteristics of the project) liable for building fire safety design. This information, when crossing with the availability of FSE education and of a defined qualification framework, in a country, is helpful in evaluating the level of FSE competences of the actor on which the liability for fire design is placed. The fire engineer is or can be liable for fire design in all the considered countries, except Cyprus, Denmark, France, Latvia and Portugal (where another technical actor is liable, mainly the architect or structural engineer), as well as in Switzerland, the Netherlands and Sweden (where the owner or the builder is liable).

The FSE-related education mapping, analysed together with the picture of qualification frameworks for designers and regulatory reviewers of FSE projects, and with the role of the fire engineer in specifying / designing the main parameters of building design projects with FSE approach, allow for further considerations on the level of implementation of fire safety engineering in the countries that currently allow for its application. In particular, the level of exploitation of – and conversely the need for – the available education and qualification infrastructure could be better understood. The synthesis is presented in **Table 7**.

Table 7. Synthesis of FSE education mapping, qualification framework, and role of the fire engineer in specifying the main design parameters and undertaking liability in FSE approach projects

(1) Education / training available (Figure 16)		**(2) Qualification framework (Figure 17)**	**(3) Role of the fire engineer**	
			(i) Specification of fire design parameters (Figure 18)	**(ii) Liability for fire safety design**
Degree programmes in FSE (at least 3 years duration)	BEL	Not defined	3 parameters	yes
	ESP	Not defined	3 parameters	yes
	FRA	Partially defined, asymmetric	2 parameters	no
	GBR	Not defined	3 parameters	yes
	HUN	Fully defined, symmetric	2 parameters	yes
	IRL	Partially defined, asymmetric	3 parameters	yes
	NOR	Fully defined, asymmetric	3 parameters	yes
	SWE	Not defined	1 parameter	no
Vocational courses in FSE (at least 2 years duration)	CHE	Partially defined, asymmetric	3 parameters	no
	CZE	Partially defined, asymmetric	3 parameters	yes
	DNK	Fully defined, symmetric	1 parameter	no
	DEU	Fully defined, symmetric	3 parameters	yes
	POL	Not defined	3 parameters	yes
Vocational training in FSE (max 1 year duration), and/or single modules	AUT	Partially defined, asymmetric	3 parameters	yes
	FIN	Partially defined, asymmetric	3 parameters	yes
	HRV	Partially defined, asymmetric	3 parameters	yes
	ISL	Fully defined, symmetric	3 parameters	yes
	ITA	Fully defined, symmetric	2 parameters	yes
	MLT	Fully defined, symmetric	3 parameters	yes
No fire safety engineering education	CYP	Partially defined, asymmetric	3 parameters	no
	EST	Fully defined, symmetric	3 parameters	yes
	LTU	Fully defined, symmetric	1 parameter	yes
	LUX	Fully defined, symmetric	2 parameters	yes
	LVA	Fully defined, symmetric	3 parameters	no
	NLD	Partially defined, symmetric	3 parameters	no
	ROU	Fully defined, symmetric	1 parameter	yes
	SRB	Fully defined, symmetric	2 parameters	yes
	SVN	Fully defined, symmetric	2 parameters	yes

Source: Authors' work

In **Table 7**:

- Column (1) lists the FSE-allowing countries by the groups established in section **5.2.1** (**Figure 16**) based on the availability of FSE education and training, in alphabetic order of abbreviations.
- Column (2) lists the type of qualification frameworks according to the considerations proposed above (**Figure 17**) Namely, qualification frameworks can be (i) fully defined and symmetric; (ii) fully defined and asymmetric; (iii) partially defined; (iv) not defined.
- Column (3) adds the information about the relevance of the fire engineer's role in (i) the specification / design of fire design parameters, i. e. scenarios, design fires and safety criteria, as shown in **Figure 18**, and (ii) liability of the engineer for building fire safety design.

Based on the information collected in **Table 7**, the synthesis of the aspects of education, qualification, and role of the fire engineer allows to get an insight in the specific situation of each country:

- First group (BSc/MSc degree programmes in FSE are available):
    - This group includes 4 out of the 5 countries where the qualification framework for reviewers and professionals involved in FSE approach designs is not defined: Belgium, Spain, Sweden and United Kingdom. In these countries, except Sweden, professionals perform all the main fire design tasks and are liable for fire safety design.
    - Within the same group, only in Hungary and Norway the qualification framework is fully defined and supports professionals in undertaking the main design tasks and the related liability.
    - France and Ireland do not define qualification for professionals; in France, professionals manage 2 of the 3 main tasks without liability for fire design, while in Ireland they undertake higher responsibilities.
- Second group (maximum 2-years courses available):
    - Only in Denmark and Germany the qualification framework is fully defined, while fire engineers have low responsibilities in Denmark (only specification of scenario and no liability) and high in Germany (all parameters and liability).
    - In Czechia and Switzerland there is partial definition of qualification frameworks, in front of many tasks to be performed by fire engineers (however, in Switzerland they are not liable for fire design).
    - In Poland, where the qualification framework is not defined, the fire engineer has high responsibilities, thus there is a similar situation to Belgium, Spain and United Kingdom.
- Third group (maximum 1-year courses available):
    - In Iceland, Malta and Italy, the qualification is fully defined for both reviewers and professionals involved in FSE approach designs, and the professionals are committed to perform all the main design tasks and undertake liability.
    - In Austria, Croatia and Finland the definition of qualification frameworks is only partial and covering the competency of professionals more than reviewers; in all these countries, professionals perform all the main design tasks and undertake liability.

— Fourth group (no FSE education available):

- This group includes most of the countries where qualification frameworks are fully defined, i. e. Estonia, Latvia, Lithuania, Luxembourg, Romania, Serbia and Slovenia. In these countries, fire engineers are involved at different levels in specifying the main parameters and are liable for fire design (except in Latvia).
- In Cyprus and the Netherlands, the qualification framework is only partially defined, and fire engineers are not liable for fire design although they specify all the main parameters.

6 Case study: recent progress towards FSE approach implementation in Greece

The Greek responders to both GROW-JRC and SFPE enquiries declared that application of FSE approach was currently not possible in their country because of insufficient legal framework, insurance, professional certification and education, lack of proper expertise in designers as well as in approval and enforcement authorities, lack of supporting data as calculation input parameters and low demand for FSE in construction projects. However, the following subsections describe recent progress towards the implementation of FSE approach in Greece:

- Section **6.1** presents an example of FSE application, namely the analysis of specific fire scenarios and the quantification of risk for a group of fire scenarios in the design of the Athens international Airport.
- Section **6.2** presents the first modules on FSE included in the curriculum of the Civil Engineering degree programme at the University of Patras.

6.1 FSE in the design of the Athens International Airport

The green field project of the Athens International Airport dates to the mid-1990s; the infrastructure was built between years 1997 and 2000. The airport is a dual-use infrastructure, switching from commercial to military in case of conflict, based on NATO designations.

For the design of the new international airport, the Greek State mandated the Hellenic Civil Aviation Authority (HCAA) to be the authority having jurisdiction and releasing building permits – including fire design approvals – instead of the local building authority or the Greek Fire Brigade as in the usual procedure. The HCAA keeps a high-level oversight on the airport facilities' fire safety, based on the approvals of a qualified fire protection engineer who acts as the AHJ for everyday operations.

In absence of national code provisions for fire design of airports, the choice of reference codes and standards was left to the construction company. Thus, German building codes (the Building Ordinance of Northrhine-Westfalen and other federal and federal state regulations), German (DIN) and USA (NFPA) standards were used, while designers and installers of fire protection systems were certified by the German Association of Property Insurers. The fire design strategy was predominantly based on prescriptive requirements, with very limited application of FSE. However, after the airport had opened, significant challenges emerged – due to changes of use, modifications in compartmentation, increase in passengers' flows, increasing demand for security measures, etc. To introduce the necessary changes, fire design with FSE approach was applied, mainly because codes and standards were unclear or too restrictive. This case study showcases the two most recent applications.

6.1.1 Aircraft Maintenance Hangars, deviation on floor finish minimum requirements

The Athens International Airport has three aircraft maintenance hangars, ranging from 4,200 to 77,000 m^2 in floorspace (**Figure 19**).

Figure 19. Maintenance hangar at the Athens International Airport

Source: courtesy of P. Samaras

FSE-based analysis was applied in the fire safety design of such buildings to tackle the problem of combustibility of epoxy floor systems, used to safeguard concrete floors against corrosion from liquids used in aircraft maintenance, contamination, and mechanical wear during routine operations. In fact, the NFPA 409 (NFPA 2022) - Standard on Aircraft Hangars, applied to the hangars' design, required floors to be non-combustible. Thus, the Airport Company requested a fire risk assessment of applying specific epoxy floor systems to the airport hangars, based on i) combustibility and fire spread, ii) heat content and fire loading, and iii) compliance with fire standards.

Epoxy coating systems applied to concrete floors generally pose minimal fire risks. Their use is consistent with best practices across numerous aircraft hangars. Concerning combustibility and fire spread, the epoxy coatings to be applied at a nominal thickness of approximately 3 mm are flame-retardant, as evidenced by their BFL-S1 classification per EN 13501 (CEN 2019). This designation indicates minimal smoke production and limited flame spread, making the product suitable for fire-critical settings. In the particular application to the hangar floors, the epoxy material is supported by a non-combustible concrete substrate, further reducing the potential for ignition or flame propagation.

The heat content value for the epoxy floor coating is typically around 20-25 MJ/kg depending on the specific formulation and additives, with most sources citing a value closer to 22 MJ/kg. For the hangar floor analysis, a value of 30.37 MJ/kg was conservatively assumed, as well as a 1400 kg/m^3 density. Given a manufacturer-recommended application rate of 2.7 kg/m^2, the estimated fire loading contribution to any hangar area is approximately 82.11 MJ/m^2. This equates to a fire severity of approximately 5 minutes per coat, based on the linear relationship between fire load and fire severity indicated in the NFPA Handbook (National Fire Protection Association, 2023). Therefore, even conservatively assuming the epoxy floor coating, when fully cured, is combustible, the contribution to the overall fire loading in any area would be insignificant.

The analytical assessment demonstrated the suitability of the flooring solution even though it did not completely meet the requirements of the applied fire protection standard; the existing fire protection measures (e. g., detection, suppression and barriers) were sufficient to address any residual fire risks associated with the epoxy coatings.

6.2 First steps of fire safety engineering education in Greece

The Civil Engineering department of the University of Patras in Greece offers new modules in FSE included in the curriculum of the Civil Engineering degree programme. The courses are taught by academics that belong to the Fire Testing Facility (FireUP) of the Structural Materials Lab. Some high-level updates in this space are provided below:

— An undergraduate module in “Fire Engineering and Fire Protection” was introduced in September 2024. The course is elective to final year students (ninth semester) and was selected by 82 students. The course introduces the fundamental principles of a fire safety strategy and structural fire design in accordance with the Eurocodes.

— A postgraduate module is also offered, “Introduction to Structural Fire Engineering”, that was introduced in February 2019. Thus far, the module has been selected by 25 students of the postgraduate civil engineering programme and provides a more thorough understanding of fire dynamics, heat transfer and the fundamental response of materials and structures under fire conditions. The module includes lab visits to the FireUP unit linking theory with hands-on experience.

— More than 20 undergraduate and postgraduate students are currently working on dissertations in fire safety engineering, either experimental, numerical or combined across different topics such as fire resistance testing of heritage timber beams, fire resistance testing of fire doors, testing the response of fibre-reinforced polymers and textile-reinforced mortars under elevated temperatures, modelling of fire doors using LS-DYNA, modelling steel or timber structures using software LS-DYNA or OpenSees among other topics. The planning and organisation of Erasmus placements has started too, providing opportunities for joint supervision of the research training of students and their involvement in research publications.

7 A new field for standardisation in fire safety: buildings in wildfire-prone areas

7.1 Need for adaptation to wildfires

Wildfires are undergoing significant changes worldwide in terms of increased frequency, intensity, and geographical spread. The emergence of wildfires in regions previously unaffected, along with prolonged fire seasons, is becoming increasingly prevalent. Extreme wildfires characterized by unprecedented rates of spread, higher burn intensities, and erratic behaviour, pose novel challenges to traditional firefighting and management strategies. These changes are primarily driven by climate variability, and projections by the Intergovernmental Panel on Climate Change (IPCC 2022) suggest a likely escalation of these events in the coming years.

In Europe, wildfire-related damages amounted approximately €4.1 billion in 2023, impacting around 120,000 individuals (JRC 2023). Recent assessment by the European Climate Risk Assessment (EUCRA Report, EEA 2024) highlights that Europe is witnessing worse-than-anticipated wildfire events. The assessment highlights the expanding reach of wildfires into areas historically not considered fire-prone, posing significant threats to forests and nearby human settlements. Moreover, large-scale wildfires have the potential to hinder evacuation and overwhelm rescue and recovery operations, significantly straining emergency response capacities (Kalogeropoulos et al. 2024).

The prevailing strategy of wildfire management, primarily focused on suppression, is proving to be insufficient in the long term (Arango et al 2023). Recent experiences with the evolving wildfire regime suggest a pressing need to pivot towards preventive fire management, preparedness and adaptation. These strategies are essential for coexisting with these increasingly frequent and intense events (Duane, Castellnou and Brotons 2021). Despite the escalating risk, there is a gap in the tools available for supporting decision-making in wildfire management and the adaptation strategies needed for the built environment (COM/2024/91 final, 2024). Current tools may not fully address the complexities of wildfire behaviour under changing climatic conditions, nor are they sufficiently integrated into the planning and design of buildings and infrastructure to enhance resilience. An emphasis on adaptation is critical for ensuring the continuity of social and economic activities in wildfire-prone regions.

The study of wildfires examines this natural phenomenon by focusing on various aspects such as ecology, topography, meteorology, and fire-atmosphere interactions that occur in wildland areas. In contrast, structural fire safety is concerned with preventing and mitigating fire-related incidents within buildings and infrastructure to ensure the safety of occupants and minimize property damage during a fire. The zone where natural wilderness areas intersect with human-developed areas is known as the Wildland-Urban Interface (WUI). This interface is highly susceptible to wildfires. With the evolving characteristics of wildfires, which are expanding in affected areas and exhibiting more severe behaviours, it becomes imperative to reconsider the delimitation of this interface to enhance resilience and safety measures effectively.

7.2 Regulatory developments

In response to this situation, various governments worldwide have implemented distinct building codes and guidelines for dwellings in fire-prone areas.

In the United States, only four states have implemented building codes specifically addressing the challenges of the WUI. These codes, e.g., California Fire Code (IFC 2021), are designed to enhance the resilience of buildings against wildfires through specific requirements on construction materials, building methods, and the testing of external elements. However, despite these tailored codes, the enforcement across the states remains a significant challenge (IBHS 2025a).

In Canada, the approach to managing wildfire risks in building construction is less prescriptive. The National Guide for Wildland-Urban-Interface Fires, (Bénichou et al. 2021), developed in 2021, serves as a voluntary guideline rather than a mandatory code. Developed by the National Research Council, this guideline provides comprehensive advice on minimizing wildfire impact through hazard and exposure assessment, property protection, and community resilience, and it is available for any government entity to consider.

Meanwhile, Australia has adopted a more formalized approach with the Australian Standard for the Construction of Buildings in Bushfire-Prone Areas, AS 3959 (AS 2018), which was officially adopted in 2020. This standard is enforced in all the Australian federal states and territories. It focuses on improving the ability of buildings in designated wildfire-prone areas to withstand wildfires, thereby offering a measure of protection to the building occupants until the fire front passes. AS3959-2018 is underpinned by a national map that identifies bushfire-prone areas (BPAs) and incorporates an assessment of the bushfire attack level (BAL) tailored to local code provisions. Construction requirements vary for buildings situated within BPAs, contingent on the specified BAL. Notably, AS3959-2018 accommodates the unique regulations and specificities of each Australian state and territory. Additionally, the BPAs map is dynamic, undergoing continuous updates to reflect evolving conditions.

In Europe, Portugal has recently introduced a significant regulatory framework titled "Base for Project Requirements in Passive Fire Protection Against Forest Fires in Buildings," which was established on May 5, 2024. This new framework lays down comprehensive wildfire-specific building requirements focusing on passive fire protection measures for structures in fire-prone zones. It adopts a risk-based approach – using factors such as the distance from surrounding vegetation and a defined rural fire exposure class (similar in concept to Australia's BAL) – to tailor the required fire-resistant construction features for each building. This Portuguese framework has been integrated into the national building safety code (RJ-SCIE), making its provisions mandatory for new constructions in designated wildfire-risk areas. Portugal's initiative represents a pioneering step in enhancing structural resilience against wildfires in Europe.

To correctly identify needs and opportunities for wildfire safety standardization across the EU, it is important to recall that fire safety in the construction sector in the EU is implemented by providing a framework to classify products as per their fire resistance and their reaction to fire. This allows having products with recognized performance across the EEA. However, it is then the responsibility of each authority to require a specific performance in each specific situation. The framework through which construction products are classified is the CPR, the Construction Products Regulation (Regulation (EU) 2024/3110). Commission Decision 2000/367/EC established a European classification system regarding resistance to fire performance of construction products based upon standard fire curves to design up to a given fire resistance (standard temperature-time curves as defined in EN1991-1-2 §3.2.1 or EN 1363-1) and harmonized standards to classify the fire resistance of a given element based on the results of recognized tests, which are defined in EN 13501 part 2 to part 4. The Eurocodes provide technical design rules for the load-bearing capacity.

The Euroclasses system for reaction to fire is described in Commission Decision 2000/147/EC. This Commission Decision became fully operational with the publication of the Single Burning Item (SBI) test method EN 13823 and the classification standard for reaction to fire EN13501-1 in February 2002. The pathway followed was:

- Harmonization of the classification stated in EN 13501-1 known as Euroclasses.
- Assessment by results of multiple harmonized tests that adapt to different products and configurations, as described in EN 13501.

This framework may also be applied to the WUI case with necessary adaptations. To lower the burden for manufacturers of roofing materials/solutions, the European Commission (Commission Decision 2000/553/EC) has composed a list of materials which is deemed to satisfy the requirements for the external fire performance of many roof covering products/materials. This list comprises materials with a fire performance which is well established and sufficiently well known to fire regulators in the Member States that they do not require testing for this particular performance characteristic. Since this approach is general for external fires, it can be used as a basis to combat the spreading risk of wildfires to structures. This is for example explicitly mentioned as a protective measure for wildfires according to the Swedish building authority (Boverket 2023). Given the preliminary status of CEN/TS 1187:2012 (CEN 2012), which specifies the test methods for assessing the external fire performance of roofs, more efforts could lead to a harmonized approach within the European Economic Area for a classification system of roof materials/systems which are exposed to wildfires or other external fires.

An extensive literature review revealed that no harmonized standards exist for the fire performance of façades. The national safety objectives for façades are commonly evaluated on a case-by-case basis by accredited test institutions, based on national non-harmonized standards. Considering this gap, 2024, a new European standard for full-scale façade fire-testing was finalized and is now awaiting formal publication under the EU Construction Products Regulation 305/2011 as a harmonised European standard (hEN).

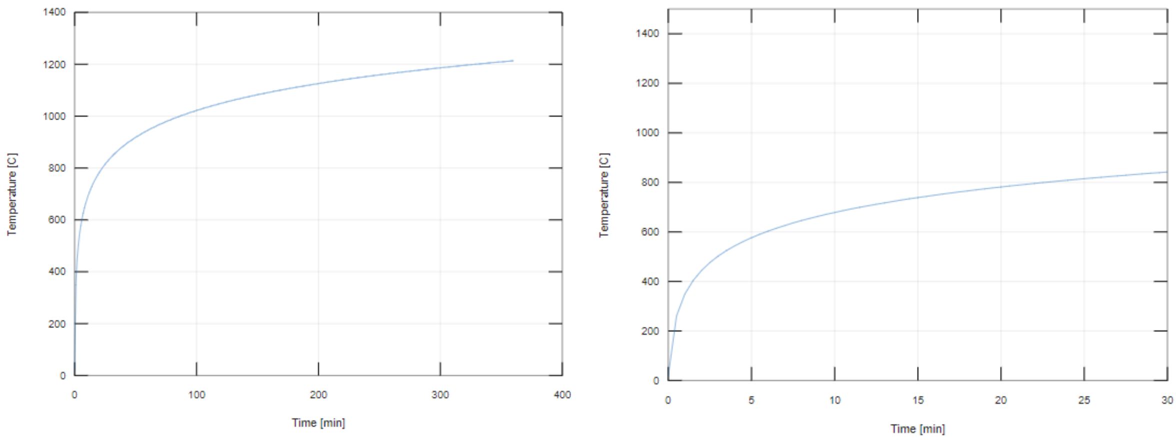
Thus, there is need to better understand the key mechanisms how wildfire impacts the built environment (traditional heat transfer, hot embers or firebrands and direct flame contact, Filkov et al. 2023) and adapt the standard CEN/TS 1187:2012 accordingly, as well as harmonizing the classification systems further using those specific ignition mechanisms. A harmonization effort is needed for the fire performance of facades and façade systems, which leaves the option to incorporate the mechanisms in which wildfires impact the built environment.

Some initial ideas being developed in the US (NIST 2025, Manzello and Suzuki 2013) show the need to create new tests for roof, facades and auxiliary equipment on those parts of buildings. Those tests aim at simulating the shower of fire embers (flying particles of glowing wood) as well the transient direct flame impingement.

7.3 Technical considerations

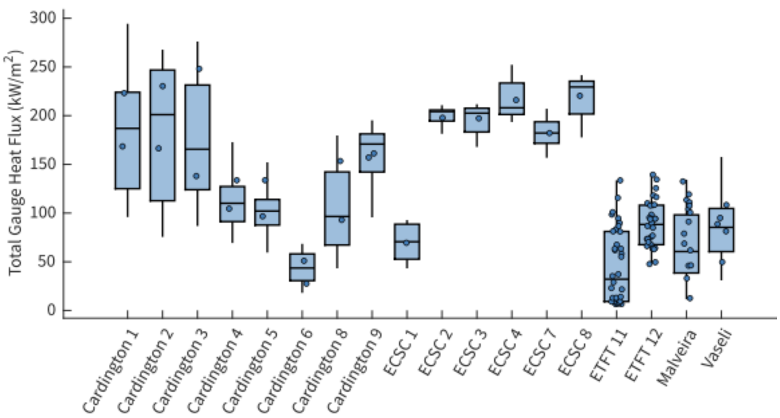
Regarding the fire resistance property, the first relevant reflection to make is if the standardized fire curve used for most of the load bearing structures' fire resistance performance (EN 1363-1, EN 1991-1-2 §3.2.1, EN 13501-2 sec. 4.5, the so-called ISO 834 standard fire curve) is also applicable to wildfire case. This curve sets the time-temperature evolution inside an oven (where the element is tested under loading conditions or without them). The profile is a logarithmic curve with an initial steep growing phase and later stabilization over 100 min (see **Figure 20**). This mimics a compartment fire in flashover conditions. However, a real time-temperature curve depends on the structural element's size, shape, orientation, and thermal exposure environment—factors that affect how heat is absorbed, distributed, and dissipated. The first consideration is that a wildfire front may increase the surrounding gas temperature faster than the abovementioned standardized curve as this is a fast and moving phenomenon in which a fully developed fire moves over the land. However, a wildfire would expose the structure in an open environment for a shorter time than a typical compartment fire in flashover conditions, which is what the ISO 834 standard fire curve mimics (ISO 2025). A wildfire is by definition a transient front, and the impact is normally shorter in time than a compartment fire in flashover conditions. Finally, heat losses are higher in a non-compartmentalized environment and thus, lower temperatures might be expected for wildfires than for compartment fires in flashover conditions. Heat fluxes recorded from wildfires can reach up to 300 kW/m2 in given slope and wind conditions (according to Manzello 2020; Filkov et al. 2023) which is of a similar order of magnitude of those reported for fully developed flashover compartment fires, see **Figure 21** (Gupta et al 2021; Pope et al. 2023). Although additional research to characterize WUI events would shed light on the need of revisiting this curve, it seems reasonable to consider that fire resistance as characterized in the European standards and implemented in design via the Eurocodes, is conservative enough for design for wildfires.

Figure 20. Standard temperature-time curve as per EN-1363-1 §5.1. Zoom to first 30 min (right)



Source: Authors' work

Figure 21. Experimental heat flux recorded during multiple compartment fires



Source: Gupta et al. 2021

The second element to characterize the performance of construction materials in fire is the reaction to fire. One of the current existing approaches within Europe to protect buildings from exterior fires, such as wildfires, is through fire classification on the roof structure. These requirements exist on a national level and most often refer to the classifications B_{ROOF} (t1 – t4) to F_{ROOF} (t1 – t4) based on different test methods:

— t1: test using a firebrand.

— t2: test using a firebrand and wind.

— t3: test using a firebrand, wind and external radiating panels.

— t4: two-tiered test using a firebrand, wind and external radiating panels.

These test methods form the basis of CEN/TS 1187:2012**.** However, their application varies significantly across Europe; countries often select test levels according to national regulations. Belgium and the Netherlands chose to enforce X_{ROOF}(t1), the Nordic countries chose to enforce an X_{ROOF}(t2) classification, France chose to enforce X_{ROOF}(t3) whereas Ireland enforces X_{ROOF}(t4). Moreover, the acceptance criteria for these different tests are also different.

7.4 Development of international standards ([18])

While Europe is being exposed to the growing issue of wildland fires spreading into urban areas, known as wildland-urban interface (WUI) fires, WUI fires have been a challenge in the USA for a significant amount of time. WUI fires are distinct from wildland fires. WUI fires consist of the combustion of vegetative fuels and human-made fuels whereas wildland fires consist of the combustion of vegetative fuels and are present in uninhabited areas   The plethora of fuels present in WUI fires, such as vehicles in addition to homes, is more complex than the vegetative fuels present in wildland fires.

Before the development of testing standards and building codes, the USA, and the entire world, witnessed massive destruction during the outbreak of urban or city fires. After significant losses in the USA in the late 1800s and early 1900s, such as the Great Baltimore Fire and the Great Chicago Fire, the USA embarked on a path to develop standard test methods and building codes to lessen the destruction from urban fires. The urban fire codes and standards provide the basis for fire resistant construction in many countries throughout the world.

As California continued to be ravaged from WUI fires, the Office of the State Fire Marshal of California embarked on a course to develop standard test methods and building codes for WUI communities, in a similar manner to the development of such methods for urban fires, decades earlier (California Building Code 2019a and 2019b). When these developments began in earnest around the early 2000s, there was little scientific research on WUI fires. For these reasons, the California State Fire Marshal test standards and building codes were based on best guess estimates of WUI fire exposures. As research began to progress on WUI fires, it was becoming apparent that current WUI test standards and building codes may be constrained and should begin to incorporate

[18] This section is developed from Manzello S. L. (2024), 'Progress to develop globally harmonized international testing standards for large outdoor fires, including Wildland-Urban Interface fires', *Fire and Materials*, Vol. 0, pp. 1-5

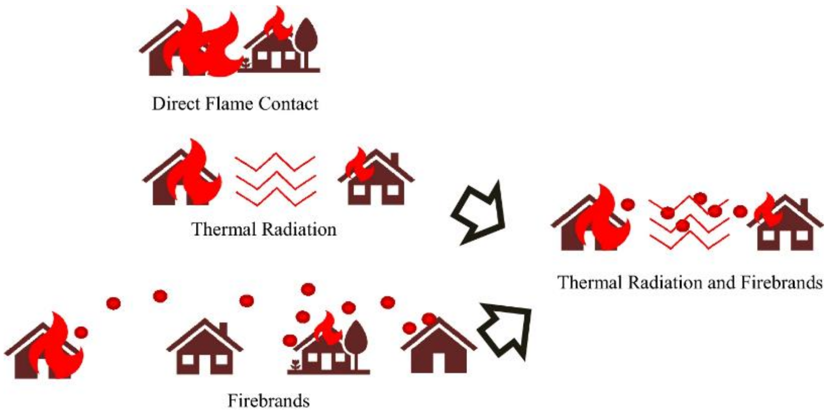
improved scientific understanding on how buildings are ignited in WUI fires, and what are the specific mechanisms of building ignition in WUI fires.

For these reasons, ASTM International sponsored a workshop to bring researchers together with building code officials and industrial building code representatives in 2015 (Manzello and Quarles 2017). The workshop found that current WUI test standards and codes are not adequate considering improved scientific understanding of the problem. In particular, firebrands, discussed in detail below, were noted as not being properly included in WUI test methods. It was also found that a major disconnect was present between the WUI research community and those in the WUI standards and codes community.

ISO/TC 92 'Fire Safety' and the International Association for Fire Safety Science sponsored two workshops in 2017 to look at the WUI fire problem in a more global manner (). Subsequently, the International FORUM of Fire Research Directors issued a position paper on the increasing global WUI fire threat that was being seen in many countries (Manzello *et al*. 2018). ISO/TC 92/TG 03 'Large Outdoor Fires and the Built Environment' Task Group developed a roadmap and published a collection of papers (Manzello 2020) showing a clear need to address large outdoor fires, including WUI fires, from a global standpoint. ISO TR/24188 'Large Outdoor Fires and the Built Environment – Global Overview of Different Approaches to Standardization' (ISO 2022) provides an overview of global testing methodologies related to the vulnerabilities of buildings from large outdoor fire exposures. Some of these test methods have been developed in the context of indoor building fires and extrapolated to external fires. It also provides information on land use management practices, definitions of key terms, and basic knowledge of large outdoor fire propagation mechanisms. The second edition was published in 2025 (ISO TR24188,2025).

Large outdoor fires differ from fires inside buildings in several ways; most notably the fire spread processes are not limited to well-defined boundaries, as is the case in fires inside buildings. Large outdoor fires must consider the interaction of topography, weather, vegetation, and structures. Ignition could occur by three ways (and in combination) (see **Figure 22**).

Figure 22. Exposure threats to buildings in WUI communities



Source: ISO/TR 24188, 2022 (from Suzuki and Manzello 2021)

Direct flame contact refers to the situation where a structural component is in direct contact with flaming combustion from an adjacent combusting fuel source. In wildland-urban interface (WUI) fires, this could be ornamental vegetation, such as mulch, shrubs, or trees, or other fuel types, such as a burning vehicle or a neighbouring structure.

Thermal radiation is a form of electromagnetic radiation that is emitted from any object whose temperature is above absolute zero. Due to the combustion of vegetative and structural fuels in WUI fires, any fuel type in proximity to these combustion processes will experience radiation. The probability of ignition is a function of the distance and depends on the time of exposure.

Firebrands are the production or generation of new, far smaller combustible fragments from the original fire source. Firebrands are similar to embers but with a slight distinction: ember refers to any small, hot, carbonaceous particle and when airborne embers have the capability of setting additional fires, they become firebrands (ISO 2022). Firebrands are produced or generated from the combustion of vegetative and structural fuels. Firebrand processes include generation, transport, deposition, and ignition of various fuel types, leading to fire spread processes at distances far removed from the original fire source (Manzello *et al.*, 2020).

A combination of any of the above mechanisms is possible. Direct flame contact and thermal radiation act in combination as a flame exists and emits thermal radiation. Direct flame contact and firebrands may also act in combination while direct flame contact is likely dominant. Thermal radiation and firebrands may also act in combination.

ISO/TC 92/WG 14 developed the ISO standard firebrand generator (ISO 6021 standard, ISO 2024), a combustion device that develops continuous firebrand showers seen in wildland-urban interface fires, wildland fires, and urban fires. The ISO firebrand generator is a laboratory-scale version of the full-scale firebrand generator developed for large-scale experimentation (Manzello 2014). The ISO Firebrand Generator represents the first and only internationally harmonized device for generating firebrand showers (**Figure 23**).

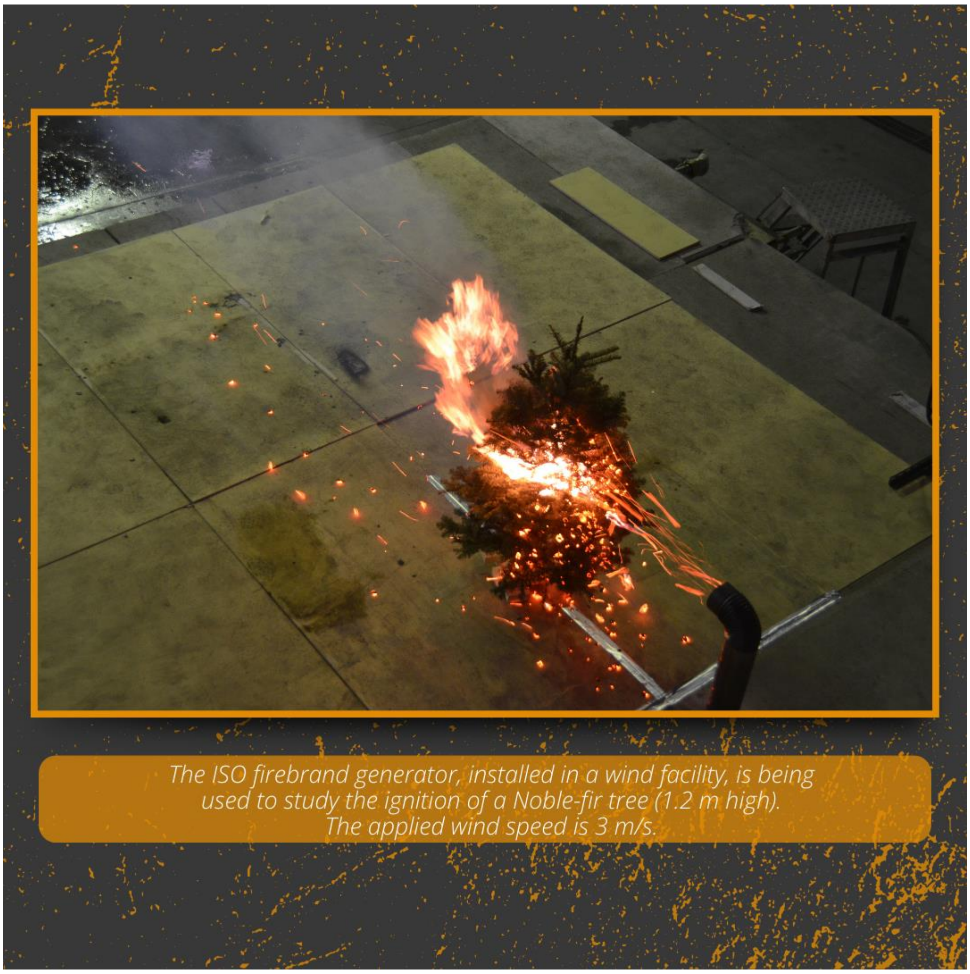
ISO TC92/WG14 will be developing an international standard for post-fire data collection methods from large outdoor fires, based on available studies for wildland-urban interface fires, urban fires, including post-earthquake urban fires, and informal settlement fires. A standardized approach, at the international level, is required to assess and compare fire spread and damage across all these large outdoor fire types.

In ISO/TC 92/WG 14, committee discussions are currently underway as to how to best address direct flame contact and radiant heat exposures in new global test methods. Firebrand shower test methods are also required for both ornamental vegetation, mulch, and various construction components. Another legacy area from the building fire side is the use of performance-based design methods using standard fire exposures.

Performance-based design approaches for WUI fires are another interesting topic that has been discussed in ISO TC92/WG14, but the major challenge is there does not exist a large experimental database of building component behaviour exposed to WUI fire exposures. For indoor building fires, there exists a massive experimental database from nearly 100 years of fire testing to the standard furnace exposure of ASTM E119 (ASTM International 2024) and ISO 834 (ISO 2025).

It is important to note that other key standards organizations, such as the National Fire Protection Association (NFPA) (NFPA 2018 and 2022), the International Code Council (ICC) (ICC, 2021), ASTM International (ASTM International 2024) and Standards Australia (NCC 2019), have also been working on WUI fire standards.

Figure 23. ISO Firebrand Generator



Source: ©Combustion Institute News, 2024.

8 Conclusions

The recent ISO and CEN standardisation work related to fire safety engineering indeed supports a further implementation of FSE approach. The proposed revision of the term 'Fire safety engineering' as per ISO 13943:2023 stresses and enlightens the scientifical basis of FSE, while at the same time puts FSE in a non-contrasting position to prescriptive fire design. The relevant technical committees take into account the needs expressed by fire safety regulators and professionals, by developing standardisation work on design fire scenarios and other topics (ISO/TC 92/SC 4), performance-based codes, FSE review and control process (CEN/TC 127/WG 8), and harmonising the design rules of the Eurocode fire parts to facilitate the application of FSE (CEN/TC 250/HG 'Fire').

The available studies on the competency framework for fire safety engineering professionals in Europe highlight the need for professional recognition as an essential element to ensure the safety of buildings and their occupants. A harmonised European approach to FSE competencies, with a clear definition of the roles and responsibilities of fire safety engineers, would facilitate the free flow of the services within the EU.

The information collected from professionals in FSE design confirmed that the traditional prescriptive approach is still prevalent in fire regulations of EU Member States, but FSE shows large potential through many technical areas of fire safety design, as well as through many types of buildings – particularly high-rise and super-high-rise buildings, and airport terminals. Compared to the regulators, professionals see a wider application of FSE design for each technical area, especially seeing FSE as a frequent alternate route for compliance with regulatory or clients' requirements, as demonstrated by the case study here presented. However, many professionals point out the need for establishing design approaches especially for smoke compartmentation, building installations, early suppression and material selection. Professionals are aware of many assessment methods for FSE across various sources (e.g. standards, literature…).

The mapping of education on fire safety engineering was conducted on the 32 countries that responded to the GROW-JRC survey through their fire regulators: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Serbia and the United Kingdom. The map enlightens that 11 out of 32 countries lack any education and training, 7 countries have a limited offer of modules or vocational training, and 14 provide courses of at least 2-years duration. This justifies the needs for increasing the education / training offer neatly expressed by fire design regulators and professionals.

Education provides fire engineers with the knowledge required to perform fire design and obtain formal qualification. Of the 8 countries providing full university degree programmes in FSE, only 2 have fully defined qualification frameworks for fire engineers. There is potential to improve the wider use of FSE in 10 countries that already have defined qualification frameworks, which are – however – not backed yet by substantial offer of education and training (i. e. provide no education, or maximum 1-year courses). Vice versa, the potential of FSE education already in place (BSc/MSc or vocational courses) could also be exploited in other 9 countries where the qualification framework is not defined or only partially defined. Moreover, in most of the countries where qualification for professionals to engage in FSE practice is not, or only partially, defined - irrespectively of available education and training - the regulators point out that fire engineers are highly involved in the main choices of fire design, i.e. they specify all the main parameters, and in most cases are liable. In making the proposed considerations, it was assumed that university education consisting of at least 3-year courses in FSE fully supports graduates in making key decisions in building fire design projects with FSE approach and undertaking the liability for building fire design. Conversely, the absence of any FSE education in a country is considered a critical lack for the implementation of FSE approach in the concerned country.

Finally, buildings and infrastructure at wildland-urban interfaces are a new field for standardisation. This report highlights the need for 1) pre-normative research to better understand how wildfires impact the built environment, and 2) standardized tests on materials / building members specific for wildfire situations. It is worth stressing that a cross-border approach involving both country and region borders is essential to enhance the resilience of wildfire-prone regions.

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Annexes

Annex 1. National legal frameworks

Table 8 lists the available information on the legal frameworks for the 30 EU/EFTA countries, United Kingdom and Serbia, i. e. the countries targeted by the 2021 JRC survey on the status and needs for the implementation of fire safety engineering approach.

The rows with grey background indicate the countries that responded ‘No’ to the question ‘Is a FSE approach allowed for construction works in your country?’. FSE is frequently applied also under prescriptive frameworks, e. g. through a specific clause allowing for design out of rules (e. g. in Croatia, Cyprus, France). Column 8 indicates the national institutional level at which any change must be introduced to facilitate FSE.

The JRC report (JRC 2023) was the source for columns 2 and 3 and 6 of **Table 8**, and the BeneFEU project (TC/127, 2002) for columns 4, 5, 6, 7 and 8. The table notes indicate where both sources, and/or the last updates mentioned in **Section 4.3** (for Germany, Denmark and Spain), provided information.

In the seventh column of **Table 8**, calculations, ad hoc tests and expert judgement are intended as alternative means of compliance; different means are specified in some cases. The following abbreviations, also specified in the table footnotes, are used in the table: LA = Local Authority; RA = Regional Authority; NA = National Authority; FB = Fire Brigade, NCP = National Civil Protection, NSB = National Standardisation Body. Other bodies or subjects are specified in full. The table highlights many cases where the information is scarce, and many instances where the JRC report provided slightly different information from the BeneFEU report, especially about the approving authorities and approval mechanism.

Table 8. Legal framework of building fire regulations in EU/EFTA countries, United Kingdom and Serbia (grey background: not allowing for FSE, according to GROW-JRC enquiry)

1 **Country ID**	2 **Performance-based legislative framework**	3 **Year of last update of fire regulation**	4 **Regional/local regulations connected**	5 **Phases when national regulations are enforced**	6 **Approving authority/-ies (*)**	7 **Alternative means of compliance (*)**	8 **At which level are changes needed to allow use of FSE? (**)**
AUT	Yes	2019	The building regulations are regional laws	Planning, building and use (for some types)	RA with advice of FB in specific cases (1) RA with advice of FB (2)	Yes, authorised by LA	Parliament (law)
BEL	No	2011	Yes, complementary	Planning, building and use (enforcement is not systematic)	LA and FB or others (technical commission) (1) LA, FB and NA (2)	Yes, subject to acceptance by NA	Government (decree)
BUL	No	2010	-	-	FB (1)	-	-
CHE	No	2015	No [by inference]	Planning, building and use	LA (1) Local Fire Police (2)	Yes, + Swiss fire safety evaluation method	-
CYP	No	2020	-	-	LA and FB (1)	-	-
CZE	Yes	2020	-	-	FB, only in specific cases (1)	-	-
DEU	Yes	2022	Regional laws may overrule the national	Planning, building and use	LA or fire safety engineer, depending on local regulations (1) LA in agreement with FB (2)	Yes, authorised by LA	Parliament (law), Government (decree) or NSB (standards)
DNK	Yes	2018	No	Planning, building (for some types), use (for some types, and with different regulations)	LA (1) (2)	Yes	Government (decree), NSB (standards)

1 Country ID	2 Performance-based legislative framework	3 Year of last update of fire regulation	4 Regional/local regulations connected	5 Phases when national regulations are enforced	6 Approving authority/-ies (*)	7 Alternative means of compliance (*)	8 At which level are changes needed to allow use of FSE? (**)
ESP	No	2006 ([1])	Yes, but mostly not connected to the national one ([2])	Planning, building and use	LA of FB ([1]) LA; in some cities RA / FB ([2])	Expert or authority judgement	Government (decree)
		2019 ([3])	Yes, additional ([3])	-	LA and local FB ([3])	-	-
EST	No	2017	-	-	Rescue Board (Surveillance Department) ([1])	-	-
FIN	Yes	2018	-	Planning and building	LA ([1]) ([2])	Yes	-
FRA	No	2004	No	Planning, building and use (public buildings). Environmental legislation: No enforcement	LA ([1]) LA including FB (main legislation); ([2]) Environmental legislation: RA with advice of LA and FB ([2])	Yes, authorised by LA or NA, or official laboratory. Environmental legislation: FSE assessment agreed by LA; LA often requires peer review	Government (decree), NSB (standards)
GBR	Yes	1985	Local laws in England and Wales	Planning, building and use; additional regulations for use	LA ([1]) Main legislation: LA or in some cases 'approved inspectors' as an alternative; Additional Fire Safety legislation: several bodies including	Yes	-

1 Country ID	2 Performance-based legislative framework	3 Year of last update of fire regulation	4 Regional/local regulations connected	5 Phases when national regulations are enforced	6 Approving authority/-ies (*)	7 Alternative means of compliance (*)	8 At which level are changes needed to allow use of FSE? (**)
					LA, FB and Health & Safety Executive (2)		
GRC	No	2018	No	Planning, building and use	LA and FB in specific cases (1) LA and FB, referring to the NA (2)	Yes, after authorisation by the LA or NA	Government (decree), NSB (standards)
HRV	No	2015	-	-	LA and others in specific cases (historic build) (1)	-	-
HUN	No	2015	-	-	LA and FB (1)	-	-
IRL	Yes	1992	No	Planning and building; use (in some cases)	LA (1) FB, on behalf of NA (2)	Yes	Government (decree), NSB (standards)
ISL	Yes	2012	No	Planning, building and use	LA (1) LA and FB (2)	Yes, authorised by LA or third-party	Government (decree)
ITA	Yes	2019	No	Planning only	FB, only in specific cases (1) Local FB (2)	Yes, authorised by regional FB	Government (decree)
LTU	No	2010	-	-	LA and others (certified expert) in specific cases (1)	-	-
LUX	No	2017	Not specified	Planning, building and use	FB or others (unspecified) in specific cases (1) LA with NA inspection (2)	Yes	Parliament (law), Government (decree)

1 Country ID	2 Performance-based legislative framework	3 Year of last update of fire regulation	4 Regional/local regulations connected	5 Phases when national regulations are enforced	6 Approving authority/-ies (*)	7 Alternative means of compliance (*)	8 At which level are changes needed to allow use of FSE? (**)
LVA	No	2015	-	-	LA and FB in specific cases (1)	-	-
MLT	No	No fire regulations	-	-	NCP (1)	-	-
NLD	Yes	2023 (3)	No [by inference]	Planning, building and use	LA or others (private companies) in specific cases (1) LA (2)	Yes, generally authorised by LA	Government (decree), NSB (standards)
		2024 (3)	No [by inference] (3)	Planning, building, environment and use (3)	LA (3)	Yes, generally authorised by LA (3)	Government (decree), NSB (standards) (3)
NOR	Yes	2017	No	Planning. The FB normally inspects during use	No approval required; independent control only in specific cases (1)	Yes, authorised by LA or third-party	-
POL	Yes	2019	-	-	LA and fire safety expert in specific cases (1)	-	-
PRT	No	2008	No	-	LA, or NCP in specific cases (1) LA: in some cases, additional approval from regional or national FB (2)	Expert or authority judgement	Government (decree)
ROU	Yes	1999	-	-	FB or NA in specific cases (1)	-	-
SRB	Yes	2019	-	-	NA (1)	-	-
SVK	No	2019	-	-	LA and FB in specific cases (1)	-	-

1 Country ID	2 Performance-based legislative framework	3 Year of last update of fire regulation	4 Regional/local regulations connected	5 Phases when national regulations are enforced	6 Approving authority/-ies (*)	7 Alternative means of compliance (*)	8 At which level are changes needed to allow use of FSE? (**)
SVN	No	2020	-	-	No approval required ([1])	-	-
SWE	Yes	2012	No	Planning, building and use	No approval required (some surveillance by LA) ([1]) LA ([2])	Yes, authorised by LA or third-party	-

Sources: Athanasopoulou et al. 2023; Joyeux 2002

(*) Abbreviations: LA = Local Authority; RA = Regional Authority; NA = National Authority; FB = Fire Brigade, NCP = National Civil Protection
(**) NSB = National Standardisation Body
([1]) from the JRC report (Athanasopoulou et al. 2023)
([2]) from BeneFEU report (Joyeux 2002)
([3]) from last updates, see **Section 4.3**

Annex 2. Full information on available FSE university programmes

This Annex offers the complete details of the university courses in fire safety engineering at MSc and BSc levels (education and training) provided by European universities and summarised in **Table 5**. The course titles also provide the links to the related institutional websites, where more information and updates can be found.

1. *International MSc course in Fire Safety Engineering (ERASMUS+ framework)*

Course title: International Master of Science in Fire Safety Engineering (IMFSE)

Host institutions: Ghent University, Belgium (coordinator); University of Edinburgh, United Kingdom; University of Lund, Sweden; Polytechnic University of Catalunya, Spain

Language: English

Level: MSc

Duration: 2 years

Requirements to enrol: BSc (or MSc) degree or recognised equivalent from an accredited institution (minimum 3 years full-time study or 180 ECTS credits) in selected disciplines – e. g. architecture, civil/mechanical engineering – or a related discipline.

First edition: 2010

Course contents or learning outcomes: 1) Physics, chemistry, thermodynamics, heat and mass transfer to critically analyse the development of fires in the built environment, or explosions. **2)** Element methods and dynamics of structures. **3)** Advanced dynamics of fire or explosion, smoke dynamics, risk assessment, fire safety legislation and regulations, human behaviour, active and passive fire protection measures**. 4)** Integration of knowledge to develop a fire safety strategy or performance-based fire safety design in the built environment (which can include wildland – urban interface) or for industry fire protection. **5)** Computer simulations of the development of fires or explosions in the built environment and of the behaviour of structures in case of fire. **6)** Fire risk assessment and management, even based on limited, incomplete, contradictory or redundant data. **7)** Professional behaviour and ethics when developing and presenting a performance-based fire safety design.

Link to qualification framework(s): The MSc degree is signed by all host institutions involved as full partner and is internationally recognized.

Involved stakeholders: There is a consortium of contributors, which constitutes an Industry Advisory Board giving feedback to the IMFSE Management Board on the curriculum. This consortium also provides positions for internships during the summer break, guest lectures, and teachers for some IMFSE courses at Ghent University.

Enrolled students / year: ≈25

2. *Belgium*

a) Course title: Master of Science in Fire Safety Engineering (MFSE)

Host institution: Ghent University

Language: English

Level: MSc

Duration: 2 years

Requirements to enrol: BSc or MSc in selected disciplines (e. g. architecture, civil/mechanical engineering). Other degrees based on a study of individual skills (e.g. fire safety consultants, fire prevention officers, fire brigade officers, building designers, building services engineers, architectural practitioners).

First edition: 2015

Course contents or learning outcomes: 1) Physics, chemistry, thermodynamics, heat and mass transfer to critically analyse the development of fires in the built environment, or explosions. **2)** Element methods and dynamics of structures. **3)** Advanced dynamics of fire or explosion, smoke dynamics, risk assessment, fire safety legislation and regulations, human behaviour, active and passive fire protection measures. **4)** Integration of knowledge to develop a fire safety strategy or performance-based fire safety design in the built environment or for industry fire protection. **5)** Computer simulations of the development of fires or explosions in the built environment and of the behaviour of structures in case of fire. **6)** Fire risk assessment and management, even based on limited, incomplete, contradictory or redundant data. **7)** Professional behaviour and ethics when developing and presenting a performance-based fire safety design.

Link to qualification framework(s): This MSc degree is internationally recognized.

Involved stakeholders: There is an Industry Advisory Board, giving feedback to the MFSE Management Board on the curriculum. This consortium also provides positions for internships during the summer break, guest lectures, and teachers for some courses.

Enrolled students / year: 5-10

b) Course title: Postgraduate Studies in Fire Safety Engineering (vocational training)

Host institution: Ghent University

This vocational course has similar language, level, requirements, contents and involved stakeholders as the above; it is intended for people who are professionally active in FSE.

Duration: 2 years (part time)

First edition: 2007

Link to qualification framework(s): This Postgraduate Studies degree signed by is formally recognized in Belgium only. However, the moral value is internationally recognised.

Enrolled students / year: 5-10

3. Switzerland

Course title: Master of Advanced Studies in Fire Safety Engineering

Host institution: ETH Zürich

Language: German (80%), English (20%)

Level: MAS (Continuing education programme, parallel to job)

Duration: 2 years

Requirements to enrol: BSc / MSc

First edition: 2020

Course contents or learning outcomes: This MAS is structured into 5 modules, based on the SFPE curriculum and in cooperation with IMFSE (see **Box 2** above). **1)** Fire science: physical and chemical fundamentals for the fire action **2)** Fire safety design **3)** Human behaviour and evacuation **4)** Structural fire design **5)** Fire protection systems

Link to qualification framework(s): -

Involved stakeholders: Engineering companies from the private sector encouraged ETH to make use of its broad competences and become active in teaching fire safety. During the development of the MAS FSE, ETH conducted a broad market survey on current needs in Switzerland, Germany and Austria; in such countries, a large consensus was found that fire safety must be increasingly operated according to first principles and that ETH should train engineers for this purpose.

Enrolled students / year: -

4. Czechia

Course title: PhD in Fire Protection and Safety

Host institution: Technical University of Ostrava

Language: English

Level: PhD (vocational)

Duration: 4 years (full or part-time options)

Requirements to enrol: BSc (minimum) + entrance examination; possibly English proficiency certificate for non-native speakers

First edition: -

Course contents or learning outcomes: Theories and practical applications of fire safety. Research in areas like fire dynamics, risk assessment, and the development of safety protocols. Career outcomes cover fire safety engineering, risk management, regulatory compliance, and research within governmental and private sectors. Potential roles include safety consultant, fire investigator, and academic positions in universities.

Link to qualification framework(s): -

Involved stakeholders: -

Enrolled students / year: -

5. Germany

Course title: MEng in Preventive Fire Protection

Host institutions: International University of Dresden, in cooperation with European Institute for Postgraduate Education (EIPOS)

Language: German

Level: Master of Engineering, M.Eng. (vocational)

Duration: 5 semesters (part-time, 90 ECTS)

Requirements to enrol: BSc or MSc degree in civil engineering or architecture, or a related discipline, for at least 210 ECTS credits + minimum 1 year professional experience, or at least 180 ECTS + minimum 2 year professional experience.

First edition: 2003

Course contents or learning outcomes: 1) Scientific basics, risk and security; fire causes and fire damage assessment, thermodynamics and fluid mechanics, **2)** Fire protection in building regulations, fire safety certification of building materials and components **3)** Building installations, extinguishing systems, smoke and heat extraction systems, smoke protection, alarm systems, ventilation systems, interaction of safety systems, fire protection for photovoltaic systems **4)** Fire scenarios and fire simulation models, methods and calculations for fire and smoke propagation, basics of fire safety engineering calculations **5)** Fire protection during construction, interdisciplinary quality management, BIM in fire protection, professional liability.

Link to qualification framework(s): The course is nationally accredited.

Involved stakeholders: Representatives of science and professional practice as well as the university are in the Scientific Advisory Board

Enrolled students / year: -

6. Denmark

Course title: Master in Fire Safety

Host institution: Technical University of Denmark

Language: Danish

Level: Postgraduate master (vocational)

Duration: Typically, 2 years with 3 course week per semester (60 ECTS)

Requirements to enrol: To be a trained civil engineer or building designer with passed admissions course and 2 years of full-time working experience after graduation. Admission course is offered for building designers and others who do not have mathematics, physics and chemistry on par with an engineering degree.

First edition: -

Course contents or learning outcomes: **1)** Fire chemistry, **2)** Building fire technology, **3)** Fire dynamics, **4)** Construction fire technology, **5)** Industrial fires, **6)** Fire technical sizing, **7)** Fire risk management, **8)** Fire modelling, **9)** Complex buildings.

Link to qualification framework(s): After completing the training, the graduated can apply for certification as a fire consultant in fire class 3 (BK3), fire class 4 (BK4) and third-party control.

Involved stakeholders: -

Enrolled students / year: -

7. France

a) Course title: Master in Fire and Fire Safety Engineering

Host institution: University of Aix-Marseille

Language: French

Level: Master of Engineering in Fires & Fire Safety Engineering (available both as initial education and as vocational training in partnership with the National School for Firefighters - ENSOSP)

Duration: 4 years (as initial education); 2 years (as vocational training)

Requirements to enrol: BSc (for students only); previous knowledge in fluids mechanics, material strength, numerical methods, notions on fluids' turbulence.

First edition: -

Course contents or learning outcomes: **1)** Analyse, understand and model a mechanical system, and predict its evolution by applying multidisciplinary knowledge and fundamental methods in fluid mechanics and solid mechanics, applied mathematics, numerical calculation and physics. **2)** Develop a strategy for studying a mechanical system in its environment, extract its relevant spatial-temporal characteristics, develop a theoretical, numerical or experimental study strategy, then interpret and exploit the results. **3)** Communicate easily in written and spoken French, adapting to the audience, using structured, relevant and critical argumentation. **4)** Conduct engineering projects in various fields of mechanics, either independently or within teams that they will need to integrate, support or lead. **5)** Respond to the needs and solve technical problems in the professional world by applying and adapting fundamental disciplinary knowledge. **6)** Develop a project that facilitates integration into a professional organisation and an ethic that promotes accountability.

Link to qualification framework(s): -

Involved stakeholders: National School for Firefighters - ENSOSP

Enrolled students / year: -

b) Course title: Civil and Urban Engineering – 3rd year specialisation in Fire Safety Engineering and Structures

Host institution: National Institute of Applied Sciences (INSA) of Rouen

Language: French

Level: MSc

Duration: 1 semester (specialisation)

Requirements to enrol: Postgraduate degree or two years of higher education in sciences.

First edition: -

Course contents or learning outcomes: **1)** Safety of buildings in their environment **2)** Fire Safety Engineering **3)** Structural safety of buildings **4)** Urban planning and risks.

Link to qualification framework(s): -

Involved stakeholders: Some courses are offered in university exchanges for foreign students.

Enrolled students / year: -

8. Croatia

Course title: Specialist Study in Fire Engineering

Host institutions: University of Zagreb

Language: English

Level: Postgraduate studies (vocational training)

Duration: 1 year (activated every other year). Classes are held on weekends.

Requirements to enrol: MSc or BSc in a technical discipline, or professional graduate with at least 5 years of experience after admission exam. The course is open to all technical professions (civil engineers, architects, mechanical and electrical engineers, etc.) involved in the design, construction, and maintenance of buildings from the perspective of fire safety.

First edition: 2006

Course contents or learning outcomes: **1)** Active fire safety measures **2)** Architectural-building and urban planning fire safety measures **3)** Behaviour of building materials and elements in fire **4)** Fire safety of load-bearing structures **5)** Thermodynamics of fire **6)** Fire development modelling **7)** Fire protection Regulation **8)** Methodology of research work **9)** Principles of load-bearing structures.

Link to qualification framework(s): -

Involved stakeholders: -

Enrolled students / year: -

9. Hungary

Course title: Bachelor of Fire Protection Engineering

Host institution: Ludovika University (National University of Public Service)

Language: Hungarian

Level: BSc

Duration: 3 years (8 semesters)

Requirements to enrol: -

First edition: -

Course contents or learning outcomes: Students acquire knowledge in fire safety engineering (design, authorisation) and fire protection expertise in the field of fire protection of buildings, firefighting tools, industrial fire protection and fire investigation. This is complemented by the preparation of students in higher education for technical planning, organization, analysis and evaluation tasks related to disaster management, civil protection, industrial safety and fire protection. In addition, students receive trainings in the fields of fire prevention, fire investigation, firefighting and operations management of the professional disaster management and they will also be able to perform technical engineering tasks in the fire protection specialties of the Municipal Fire Department, Industrial Fire Stations and Voluntary Fire Department.

Link to qualification framework(s): The course provides the pre-qualification required to obtain a fire protection certificate for designers and installers of built-in fire protection equipment (automatic fire alarm and fire extinguishers). Graduates are eligible for the Fire Protection section of the Hungarian Chamber of Engineers.

Involved stakeholders: -

Enrolled students / year: -

10. Ireland

a) Course title: Bachelor of Engineering in Fire Safety Engineering

Host institution: Atlantic Technological University, Donegal

Language: English

Level: BEng (Honours degree), BSc (Honours degree)

Duration: 4 years

Requirements to enrol: Minimum grades in selected technical subjects

First edition: 2023

Course contents or learning outcomes: The aim of the programme is to deliver engineers who have scientific and practical skills to undertake both prescriptive and performance-based fire safety design. In the first two years, learners gain an understanding of fire, general construction and engineering principles and technology before being immersed in fire safety-specific subjects. Theoretical and practical modules provide the graduate fire safety engineer with a skill set unique to this country and in demand internationally.

Link to qualification framework(s): The programme is fully accredited by Engineers Ireland as meeting the educational requirement to enable graduates to become 'Chartered Engineer' with further study. It is also recognised by the Chartered Association of Building Engineers (CABE).

Involved stakeholders: -

Enrolled students / year: -

b) Course title: Bachelor of Engineering in Fire Engineering

Host institution: South-East Technological University, Waterford

Language: English

Level: BEng

Duration: 1 year part-time

Requirements to enrol: 1) to have completed a specified minimum level programme in fire engineering or in a cognate area of study, or 2) senior trades apprenticeship qualification with a minimum of 2 years relevant experience, or 3) to be fire officers with a minimum of 7 years' experience or full-time fire officers with a minimum of 5 years' experience. Additionally, minimum proficiency in English is mandatory for non-native speakers.

First edition: -

Course contents or learning outcomes: On successful completion of the programme the student will be able to: **1)** Investigate the phenomena and effects of fire and of the reaction and behaviour of people to fire, and to apply this knowledge to protect people, property and the environment from the destructive effects. **2)** Generalise the scientific and technical principles underlying fire and firefighting systems and design requirements of engineering projects. **3)**

Research and successfully complete fire engineering projects, both technical and managerial, within time and cost constraints and relevant national and international directives and effectively communicate their resolution. **4)** Solve common fire engineering problems through systematic analysis and design methods. **5)** Apply their knowledge of fire safety and fire safety systems legislation to evaluate its impact on the design and approval of building designs and fire safety systems. **6)** Define the responsibilities of an engineering technologist and exercise independent technical judgement with significant autonomy. **7)** Explore the wider social, political, business and economic context of the fire engineering professionalism.

Link to qualification framework(s): -

Involved stakeholders: -

Enrolled students / year: -

11. Italy

Course title: Master in Fire Safety Engineering

Host institution: Free University of Bolzano

Language: Italian and English

Level: Postgraduate studies (vocational training)

Duration: 1 year

Requirements to enrol: MSc or BSc in selected technical disciplines, or other discipline with adequate working experience. Good command of Italian and English.

First edition: -

Course contents or learning outcomes: The course covers the main four areas of FSE, namely 1) Fire science, 2) Human behaviour and evacuation, 3) Fire protection systems 4) Fire protection analysis. Particular attention is paid to calculation and simulation methods, advanced active and passive protection system, integrated design and timber construction. In addition to these, there are legislation and regulations and proper building design, with a focus on prevention and not just reaction to fire.

Link to qualification framework(s): -

Involved stakeholders: -

Enrolled students / year: minimum 26, maximum 35

12. Norway

Course title: Master in Fire Safety

Host institutions: Western Norway University of Applied Science

Language: English

Level: MSc

Duration: 2 years (activated every year), part-time option is available

Requirements to enrol: Applicants to the program are required to have a BSc in Fire Safety Engineering. Applicants with another technological bachelor's degree may also be considered for admission, if they in addition have passed courses of Fire Dynamics and Active and Passive Fire Protection from Western Norway University of Applied Sciences, or equivalent from other institutions, with a minimum grade point average. Applicants from outside the Nordic countries must provide evidence of their academic achievements and proficiency in English.

First edition: -

Course contents or learning outcomes: 1) Measures (barriers) to prevent ignition and fire. **2)** Understanding of different scenarios for fire- and smoke development **3)** Modelling of fire- and smoke development, egress and risk to people, property and the environment **4)** Fire safety design **5)** Fire safety risk assessment **6)** Human behaviour in fire and evacuation **7)** Contingency **8)** Fire prevention in businesses and municipality **9)** Communication and accident investigation.

Link to qualification framework(s): -

Involved stakeholders: -

Enrolled students / year: ≈

13. Poland

Course title: Building and Construction Fire Engineering / Building and Fire Engineering

Host institution: Fire Academy of Warsaw

Language: Polish

Level: Postgraduate studies

Duration: -

Requirements to enrol: -

First edition: -

Course contents or learning outcomes: The course aims to provide advanced training in various areas of fire safety and train specialists, at professional level, in matters linked to the technological development. It transmits a training allowing to whom attend the courses make a self-learning along life and at a self-orientated mode. The curriculum reflects the most advanced knowledge in the field. After the course, students are expected to plan and manage specialized project tasks by applying fire safety engineering, becoming agents of innovation and optimization of resources.

Link to qualification framework(s): -

Involved stakeholders: -

Enrolled students / year: -

14. Portugal

a) **Course title:** Urban Fire Safety Engineering (vocational training)

Host institutions: University of Coimbra

Language: Portuguese and English

Level: Lifelong Learning Master Programme

Duration: 1,5 years

Requirements to enrol: BSc or higher degree

First edition: -

Course contents or learning outcomes: -

Link to qualification framework(s): The course is nationally accredited.

Involved stakeholders: -

Enrolled students / year: -

b) **Course title:** Fire Safety Engineering (vocational training)

Host institutions: University of Coimbra

Language: Portuguese and English

Level: PhD

Duration: 3 years

Requirements to enrol:

First edition:

Course contents or learning outcomes: The objective of the course is to provide doctoral students and national, or foreign, a solid institutional framework, methodological and scientific training in advanced fire safety for buildings that can enable them to carry out quality scientific work and integrate them into international networks of knowledge.

Link to qualification framework(s): The course is nationally accredited.

Involved stakeholders: -

Enrolled students / year: -

15. *Sweden*

a) Course title: Master of Science in Fire Safety Engineering and Bachelor of Science in Fire Protection Engineering

Host institution: Lund University

Language: Swedish

Level: MSc and BSc (currently there is no separate enrolment of students)

Duration: MSc: full course of 5 years. Students apply to the MSc program in Fire Safety Engineering and can after 3.5 years receive a BSc degree in Fire Protection Engineering.

Requirements to enrol: The number of students accepted is limited, and part of a selection process based on previous study results at secondary school level and professional experience

First edition: The MSc programme started in 2023. It is a development of the previous BSc in Fire Protection Engineering program that started in 1986 and was extended from 2.5 years to 3.5 years in 1994.

Course contents or learning outcomes: a) MSc. 1) Basic engineering competences such as courses in physics, mathematics (calculus in one and several variables, linear algebra, mechanics, sustainable development, building materials, thermodynamics, mathematical statistics, and programming. **2)** Related engineering competences such as courses in construction sciences, building processes, building physics, economy, leadership and group dynamics, law, CAD/BIM, and engineering practice. **3)** Specific competences such as courses in fire chemistry, fire physics, room fire dynamics, passive systems, active systems, risk assessment, human behaviour in fires, fire safety evaluation, advanced computational fluid dynamics, consequences during large scale accidents, industrial fire accidents, building evacuation modelling, wildfire evacuation modelling, performance based fire safety design, building structure fire safety design, rescue services methods, risk based land use planning, environmental aspects during rescue services interventions, preparedness and planning, advanced fire investigation, and societal safety and resilience. **b) BSc. 1)** Basic engineering competences such as courses in physics, mathematics (calculus in one and several variables, linear algebra, mechanics, sustainable development, building materials, thermodynamics, statistics, and programming. **2)** Related engineering competences such as courses in construction sciences, building processes, building physics, and engineering practice. **3)** Specific competences such as courses in fire chemistry, fire physics, room fire dynamics, passive systems, active systems, risk assessment, human behaviour in fires and evacuation modelling, fire safety evaluation, advanced computational fluid dynamics, consequences during large scale accidents, industrial fire accidents, risk-based land use planning.

Link to qualification framework(s): The MSc or BSc degree is issued by Lund University and approved by the Swedish Government

Involved stakeholders: Professionals participate in different courses as guest lecturers. In some courses, professionals act as informal external examiners, providing feedback to students on e.g. assessment reports. Students drafting their final dissertation usually have an assistant supervisor at the organisation or company where they do the work.

Enrolled students / year: ≈50 students enrol in the full course.

b) Course title: Fire Protection Engineering

Host institution: Luleå University of Technology

Language: Swedish

Level: BSc

Duration: 3,5 years

Requirements to enrol: -

First edition: -

Course contents or learning outcomes: Knowledge in fire engineering, risk management, building technology, behavioural science and emergency services.

Link to qualification framework(s): -

Involved stakeholders: Companies and authorities, such as Brandskyddslaget, Säkerhetspartner, SWECO, Briab, as well as the rescue services in Luleå and Boden.

Enrolled students / year: -

16. United Kingdom

a) Course title: Bachelor of Engineering in Structural and Fire Safety Engineering (Hons) and Master of Engineering in Structural and Fire Safety Engineering (Hons)

Host institution: University of Edinburgh

Language: English

Level: BEng and MEng

Duration: 4-5 years (activated every year)

Requirements to enrol: High School Diploma plus good grades depending on student's home country

First edition: -

Course contents or learning outcomes: 1) Develop critical thinking, teamworking, and problem-solving skills in interdisciplinary engineering design tasks; learn the fundamental mathematics that underpins engineering science and design **2)** Fire science and fundamental topics of civil and environmental engineering **3)** Specialist courses linking civil engineering knowledge and fire safety engineering**.**

Link to qualification framework: This course is accredited to provide the requirements for registration as Incorporated Engineer in the UK; it partially provides the requirements for accreditation as Chartered Engineer (candidates must also hold a masters' degree or doctorate accredited as further learning).

Involved stakeholders: Strong industrial engagement through the Industrial Advisory Board and industrial input to teaching, including design projects. Students also have opportunities to interact with recent graduates working in industry.

Enrolled students / year: -

b) Course title: Master of Science in Fire Engineering Science

Host institution: University of Edinburgh

Language: English

Level: MSc

Duration: 1 year (activated every year)

Requirements to enrol: A UK 2:1 honours degree, or its international equivalent, in engineering or applied physics.

First edition: -

Course contents or learning outcomes: 1) Create, identify and evaluate fire safety engineering options to solve complex (multiparameter) problems. **2)** Analyse experimental evidence and design situations and apply creative thinking to develop the appropriate solutions within the context of fire safety. **3)** Conduct research and survey into fire safety science and engineering issues through research design, the collection and analysis of quantitative and qualitative data, synthesising and reporting. **4)** Understand the complexity and multidisciplinary nature of many fire safety challenges and handle the complexity associated with ambiguity. **5)** Evaluate fire safety information thoroughly, identifying assumptions, detecting false logic or reasoning and defining terms accurately to make an informed judgement about appropriate actions.

Link to qualification framework: -

Involved stakeholders: -

Enrolled students / year: -

c) **Course title:** Bachelor of Engineering in Fire Engineering

Host institution: University of Central Lancashire

Language: English

Level: BEng

Duration: 3 years (activated every year)

Requirements to enrol: Educational achievements, predicted grades, work experience and personal statement.

First edition: -

Course contents or learning outcomes:

Link to qualification framework:

Involved stakeholders: This course is supported by an industrial liaison group, which involves leading companies in fire safety engineering and management, as well as the Fire and Rescue Service; this group reviews the aspects of the course to ensure it meets industry needs.

Enrolled students / year: -

d) **Course title:** Master of Science in Fire Safety Engineering

Host institution: University of Central Lancashire

Language: English

Level: MSc

Duration: 1 year (activated every year)

Requirements to enrol: Honours Degree in Fire Safety or Fire Engineering, or 2:2 degree in Architecture or Engineering, or a degree or Higher National Diploma in an appropriate discipline combined with professional experience.

First edition: -

Course contents or learning outcomes: This postgraduate degree emphasises Fire Safety Engineering in the context of buildings and infrastructure and is designed for those who will eventually hold senior positions within the fire-related professions. This involves skills and knowledge crossing all areas of learning including fire chemistry, physics of heat transfer, biology and toxicity, structures, law and legislation, environmental impact, risk management and design. The course is intended to provide both skills and knowledge relevant to the management of private and public sector services.

Link to qualification framework: -

Involved stakeholders: -

Enrolled students / year: -

e) **Course title:** Master of Architecture in Fire Safe Design

Host institution: University College London

Language: English

Level: MArch

Duration: 1 year (activated every year)

Requirements to enrol: UK bachelor's degree in architecture, with at least 2.1; or equivalent; or 5+ years of employment in an architecture firm.

First edition: -

Course contents or learning outcomes: 1) Develop your own unique designs, with an emphasis on fire safety as a design variable and one of the core strategic considerations for architecture. **2)** Gain advanced knowledge and skills in fire safe design, informed by multidisciplinary theories taken from architectural design, human behaviour and fundamentals of fire science. **3)** Access specialist facilities for drawing and prototyping, in close proximity to complimentary disciplines and expertise in civil engineering, computer science, architectural computation, environmental design and performance design.

Link to qualification framework: -

Involved stakeholders: -

Enrolled students / year: -

f) **Course title:** Master of Science in Fire Safety Engineering

Host institution: University of Ulster

Language: English

Level: Postgraduate Diploma, MSc

Duration: 1 year (activated every year)

Requirements to enrol: BSc degree

First edition: -

Course contents or learning outcomes: This programme is offered by the Fire Safety Engineering Research and Technology Centre (FireSERT), which is internationally recognised for research in fire dynamics, structural fire engineering, and human behaviour in fire. Learning and teaching are research led, closely with practitioners in developing fire safety strategies for real buildings. Learning outcomes: **1)** To gain a comprehensive understanding of fire science and the technological principles and techniques relevant to the discipline of fire safety engineering; **2)** To benefit from the expertise and resources of FireSERT, including world-leading teaching staff and state-of-the art experimental facilities.

Link to qualification framework: Course accredited by the Institution of Fire Engineers (IFE), Chartered Institution of Building Services Engineers (CIBSE) and the Energy Institute (EI) on behalf of the Engineering Council as Further Learning for registration as a Chartered Engineer

Involved stakeholders: -

Enrolled students / year:

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