Study to evaluate the need to regulate within the Framework of Regulation (EU) 305/2011 on the toxicity of smoke produced by construction products in fires

Final Report

Written by Tim Yates
October 2017

EUROPEAN COMMISSION

Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
Directorate C - Industrial Transformation and Advanced Value Chains
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Executive Summary

BRE, Ecorys, and Vito have been commissioned by Directorate-General (DG) for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) to conduct a study that aims at evaluating the need to regulate on toxicity of smoke generated by construction products in fire within the framework of Regulation (EU) No 305/2011 (Construction Products Regulation (CPR)) and the possible impacts of any such measures.

The evaluation has collected and examined available statistical and scientific data and provided factual information in order to enable a knowledge based approach. The central part of the study was the collection and analysis of existing available information and additional data collected from fire safety professionals, scientists and the main CPR actors and stakeholders.

The evaluation also needed to reflect the fact that fires, the generation of smoke, active and passive fire protection, and toxicity is a complex subject. An additional dimension that needed to be considered within the evaluation was the potential toxicity of smoke from construction products within the scope of the CPR versus the potential toxicity from the building contents including for example building contents and furnishings. Intervention logic implies that actions and the limitation of possibilities are evaluated separately, but to evaluate the responses to the research questions it is necessary to consider the complex impacts and interactions of fires in relation to fire safety

The terms of reference document provided by the European Commission included six 'main research' questions. From these main research questions, the experience of fire regulations in Europe from within the project team and the wider community of research scientists and professionals, and the EC who were consulted during the project our understanding of the key underlying points to address have been incorporated into the Table of Evidence.

Through the Steering Group and the European Commission the project team informed EU representatives, national authorities and European trade associations about the study. In all but a few exceptional circumstances it was up to the trade association to inform their Members. In addition, when confirming the appointment for an interview with a stakeholder, we provided a short letter of introduction from the Commission to provide assurance that this was a bona fide study.

At the validation workshop, those interviewed and other stakeholders have the opportunity to engage further in the project and to help build a consensus and mutual understanding based on factual data and create a constructive atmosphere where discussions took place.

The conclusions from the study were:

1. The interviews have shown a clear definition of terminology is lacking e.g fire safety engineering, injury and death. This would be needed for any future European initiative to collect data and produce coherent fire statistics at EU level.

2. Fire regulations: Member States recognise that all smoke is toxic and have a raft of regulations for the protection of occupants. Seven Member States referenced regulations on the toxicity of smoke from construction products; five of these have been notified to the EC as regulations. These regulations are from Belgium, France, Lithuania, Poland and Sweden. In each case their application is defined and limited in scope.

3. Fire statistics: The type and format of data collected varies across Member States, and, at present, statistics on smoke toxicity are not collected and therefore the effectiveness of potential measures cannot be assessed. Data shows the number of deaths per million people reducing over the last 30 years without regulations specific to smoke toxicity. The rate of reduction varies between Member States. There is general agreement that if statistics are required then collecting

them at a European level in a coordinated and harmonised system based on standardised terms and definitions would be critical

4. Although there is a lack of agreement as to what constitutes fire engineering and also that there isn't sufficient data for a fuller implementation fire engineering is seen as already delivering benefits when used as a tool for demonstrating compliance with national requirements.
5. Legislation: The responses received do not agree that regulation of toxicity of smoke from construction products is required. However, if the case for regulation were proven, then an agreed European system for testing and classification, with regulations and requirements at national level is favoured.
6. The responses to the questionnaire showed that legislation at EU level was seen as having a more positive impact than the other two options. However, greater use of existing legislation and alternative safety approaches were also seen as important in the potential impact of any additional legislation. If legislation were considered appropriate then detailed cost – benefit and impact analyses would be required and the costs and benefits of existing regulations and alternative active and passive methods, would need to be considered and would need to address the issues associated with the toxicity of smoke produced by building contents.
7. There were many comments questioning the usefulness of singling out construction products and emphasising that if legislation related to the toxicity of smoke from construction products were considered appropriate that it would need to be part of an holistic approach to fire and effectiveness of measures.
8. Legal basis: The responses indicate that interviewees believe there would be limited benefits from regulating specifically for the toxicity of smoke from construction products. Some interviewees believed that there could be greater benefits if the flammability (and hence smoke toxicity) of furnishings and fittings was addressed across all Member States.
9. The potential dangers of smoke in general, including toxic smoke, leaking into or being generated in areas that are considered to be safe zones and / or escape routes need to be considered in new or amended existing regulations.
10. Effect on the marketing of construction products: There is general agreement that regulation of toxicity of smoke of construction products could increase product costs, and potentially remove some products from the market. Additionally, it was agreed a regulation would be expected to impact products by driving improvement and developments of new products.

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1 Introduction

1.1 Introduction to the study and this report

BRE, Ecorys, and Vito have been commissioned by Directorate-General (DG) for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) to conduct a study that aims at evaluating the need to regulate on toxicity of smoke generated by construction products in fire within the framework of Regulation (EU) No 305/2011 (Construction Products Regulation (CPR)) and the possible impacts of any such measures.

The timetable for the delivery of the project was set out in the Technical Specification and confirmed at the Kick off meeting held 23 November 2016. The draft final report was to be delivered to the European Commission by 19 June 2017, with a final approved version completed as soon as possible.

The evaluation has collected and examined available statistical and scientific data and provided factual information in order to enable a knowledge based approach. The central part of the study was the collection and analysis of existing available information and additional data collected from fire safety professionals, scientists and the main CPR actors and stakeholders.

1.2 Short background and objectives of this study

The European Commission asked for an evaluation of the need to regulate within the framework of Regulation (EU) 305/2011 (CPR) on the toxicity of smoke produced by construction products in fires. Additional requirements were the application of intervention logic and a cost-benefit analysis if sufficient data were available.

Evaluations can be backward looking, covering existing regulations and, if it exists, the data supporting the regulation, or forward looking to the potential need for future regulation and the factual data that supports the need for regulation. The research questions to be addressed in the study indicated that both types were required. Thus the project explored both types of evaluation and aimed to clearly separate the two.

The evaluation also needed to reflect the fact that fires, the generation of smoke, active and passive fire protection, and toxicity is a complex subject. An additional dimension that needed to be considered within the evaluation was the potential toxicity of smoke from construction products within the scope of the CPR versus the potential toxicity from the building contents including for example building contents and furnishings. Intervention logic implies that actions and the limitation of possibilities are evaluated separately, but to evaluate the responses to the research questions it is necessary to consider the complex impacts and interactions of fires in relation to fire safety

1.3 Evaluation context

The study aimed to evaluate the need to regulate on toxicity of smoke generated by construction products in fire within the framework of Regulation (EU) No 305/2011 (CPR) and the possible impacts of any such measures.

The terms of reference document provided by the European Commission included six ‘main research’ questions:

i. Do Member States currently have regulations on the toxicity of smoke generated in building fires?

ii. Are there adequate fire statistics in the EU or other evidence (e.g. studies, or medical records) which reliably show that victims of building fires are due to the inhalation of toxic gases from construction products? Which are the responsible toxic gases?

iii. If the victims in building fires are mainly due to the inhalation of toxic gases from construction products, which are the available options for effectively reducing the risk (e.g. to regulate on the smoke toxicity, from constructions products at EU level, to leave Member States to regulate at national level by application of the subsidiarity principle, or to support other fire engineering measures e.g. appropriate building design, installation of alarm systems, etc.)? Which are the advantages and the disadvantages of each available option?

iv. Which would be the possible legal basis for regulating at EU level on the toxicity of smoke from fires in building? Which are the advantages and the disadvantages of each available legislative option?

v. What could be the possible effects of the above measures on the reduction of fire victims?

vi. What could be the possible effects on the marketing of construction products if regulated as above?

From these main research questions, the experience of fire regulations in Europe from within the project team and the wider community of research scientists and professionals, and the EC who were consulted during the project our understanding of the key underlying points to address have been incorporated into the Table of Evidence (see below).

1.3.1 Stakeholder process

The evaluation approach influences not only the outcome of the report, but also the potential reactions of stakeholders. In order to minimise adverse reactions to the programme of work, we considered it essential to inform stakeholders about the processes at the first contact and to affirm the potential for further involvement in later stages of the project, particularly the validation workshop. The interviews were a key part of this process as was the input from the Steering Group established by the European Commission. A list of the organisations represented on the Steering Group is given in Appendix A.

Through the Steering Group and the European Commission the project team informed EU representatives, national authorities and European trade associations about the study. In all but a few exceptional circumstances it was up to the trade association to inform their Members. In addition, when confirming the appointment for an interview with a stakeholder, we provided a short letter of introduction from the Commission to provide assurance that this was a bona fide study.

At the validation workshop, those interviewed and other stakeholders have the opportunity to engage further in the project and to help build a consensus and mutual understanding based on factual data and create a constructive atmosphere where discussions took place.

Lastly, the mix of evidence and the margin of statistical errors (not all stakeholders are interviewed or even want to be interviewed), potentially creates room for stakeholders to challenge the conclusions. To strengthen the likelihood of acceptance of the report and conclusions, the project team aimed to collect and present a mix of factual evidence and indicate the statistical uncertainties as fully as possible. The study's conclusions are based on factual evidence and logical analysis and do not attempt to weight the various aspects.

1.3.2 Background to the study

The **Construction Products Directive** (CPD) entered into force within the Member States of the European Union (EU) in December 1991. The primary purpose of the CPD was to remove technical barriers to trade for product manufacturers within Europe through the development and adoption of European Technical Specifications (harmonised product standards and European Technical Approvals) and so enable product manufacturers to sell their products throughout Europe by complying with a single common European Technical Specification recognised and accepted by all Member States, rather than having to test and comply with different national standards in each Member State.

In July 2013, the **Construction Products Regulation** (CPR) came into force and as such, for construction products covered by a harmonised product standard, CE marking became mandatory and in such cases, fire performance is declared in accordance with European fire classifications.

Although **the primary purpose of the CPD/CPR** is to enable free movement of goods using CE-marking, there is a wide range of products and constructions which are not subjected to CE-marking but benefit from having a common European classification system for fire resistance, reaction to fire, and external fire performance for roofing products and systems. These products and constructions constitute a much larger group than CE-marked construction products.

The **European classification system for reaction-to-fire** (RtF) performance of construction products excluding floorings and cables consists of six standards; a suite of four test standards, a classification standard and a standard covering specimen conditioning and substrate selection. The documents are as follows:

- BS EN 13501-1: *Fire Classification of construction products and building elements. Part 1: Classification using test data from reaction to fire tests*.
- BS EN ISO 1182: *Reaction to fire tests for building products – Non-combustibility test*
- BS EN ISO 1716: *Reaction to fire tests for building products - Determination of the heat of combustion.*
- BS EN 13823: *Reaction to fire tests for building products - Building products excluding floorings exposed to the thermal attack by a single burning item (SBI)*.
- BS EN ISO 11925-2: *Reaction to fire tests – Ignitability of building products subjected to direct impingement of flame – Part 2: Single-flame source test*
- BS EN 13238: *Reaction to fire tests for building products – Conditioning procedures and general rules for selection of substrates*.

The classifications derived from these test methods are incorporated within the Building Regulations of Member States and are used as the tools for regulating the fire safety levels within and around buildings in the event of a fire.

The basis for the development of the reaction to fire classification system for construction products was the definition of the fire hazards that needed to be controlled during the initiation and growth phases of a fire in buildings. This work was carried out by a group of fire experts in conjunction with the fire regulators from the different Member States in Europe in the 1980s. Data was collected from each Member State in terms of the hazards and test methods which were used to control fire safety and protect lives in each Member State. The findings were that all Member States regulated the use of materials in buildings to ensure that the rate at which a fire could develop was slow enough to allow sufficient time for occupants to escape safely. In some Countries there was an additional regulatory need to control the production of smoke to the extent to which the visibility of occupants escaping a building was not overly obscured.

The classification limits were defined in terms of the contribution of the construction product to flashover within the small room and additional indices for classification related to the rate of production of smoke (s1, s2, s3) and the production of burning droplets/debris (d0, d1, d2) were added for use by those Member States which had such requirements. For example, a construction product that achieves class B- s3, d2 should not cause flashover in a small room or enclosure where there is little additional fire load.

However, the reaction to fire classifications that currently exist for construction products do not consider the production and impact of toxic combustion products on people in and around buildings because at the time of defining the reaction to fire classification system, there were no regulatory requirements on toxicity in Europe.

It is also important to note that the products of combustion in a fire are dependent on a number of variables that include;

- Fuel type, quantity, distribution.
- Room size and geometry.
- Thermal characteristics of the room boundaries.
- Ventilation conditions (for example size of openings, failure of windows, location of doors and whether they are partially open or opened during a fire event, presence of a heating and ventilation system and whether operating at the time of the fire).
- Presence or not of active fire protection measures (for example fire alarm and detection systems, smoke ventilation, fire suppression).

It is important to separate the products of combustion produced by **unregulated** contents within a building such as floor coverings (rugs, mats, and carpets), curtains, upholstered furniture, televisions, white goods and other electrical equipment, and bedding from those produced by the **construction products** incorporated within the building.

The implementation of any new requirements in relation to the toxicity of products of combustion in a fire would need to consider all of the above factors and what would be a representative and meaningful scenario for bench-marking construction products.

The measurement of the toxicity of smoke produced by construction products in fire would have to define the species of specific concern and develop a repeatable and consistent test methodology that had true relevance to the threat to the life safety of building occupants.

Current data suggests that fires in European buildings injure or kill over 70,000 people every year.

There are concerns that the pace of innovation in building design and construction materials are challenging the pace at which European test methods can evolve. For example, test methods called on by European Standards are based on the small-scale tests described above and at present there is no harmonized European standard test method to test large external facades, though one is being planned. At present, standards and regulations for construction products consider, or are expected in the near future to consider health aspects arising from (semi)volatile organic compounds emitted from construction products during normal service life (service life exposure scenario); however at present these do not take into account the health issues related to toxicity of smoke upon fires (fire exposure scenario).

The continuing development of new products and new building design could require further European regulations and, if the factual evidence supports it, this could include testing and assessing the toxicity of smoke produced by construction products in fire.

All three questionnaires make reference to **Fire Safety Engineering.** Fire Safety Engineering is the application of scientific and engineering principles based on the understanding of the effects of fire, the reaction and behaviour of people to fire and how to protect people, property and the environment.

The application of fundamental fire safety scientific and engineering principles has the potential to play a major role in freeing architects from the traditional constraints of fire safety design of buildings. Fire safety engineering has become a core discipline in fire safety and is becoming accepted both nationally and internationally through national, international, and European Standards.

As the design and construction of buildings continues to develop, using more materials and becoming more complex and innovative, the application of these fundamental scientific and engineering principles plays a key role in constantly developing and evaluating the knowledgebase that underpins fire safety design.

2 Research Methodology

The study collected and examined available statistical and scientific data and to provide factual information in order to enable a knowledge based approach. The Study Team collected and analysed existing available information and additional data collected among fire safety professionals, scientists and the main CPR actors and stakeholders related to research, regulations, and case studies of fires.

The methodological approach for the study was refined during the Inception Phase as a result of:

- Further discussions with the client that facilitated a more specific understanding of key focus areas and nature of the deliverables expected;
- Input from the Study Steering Committee, both at the meeting and subsequently; and
- Desk research undertaken on data availability which allowed the project team to discuss together the realistic and practical options for the evaluation.

2.1 Development of indicators

The two primary data sources for the evaluation are data from interviews with Member State regulators and other stakeholders, and data from published reports and studies.

The terms of reference document includes six 'main research' questions. For the interviews with Member State regulators and stakeholders much of the information collected was to be done through open questions, as well as the use of some closed questions based on a five-point Likert scale. In addition, the questionnaire was drafted to seek some specific data on information such as definitions of injury and examples of specific gases. Together, the open and closed questions formed the indicators.

The five-point Likert scale indicators were developed in the questionnaire for selected topics that suit such type of questions and facilitate a practical analysis of data. From the main research questions, the experience of fire regulations in Europe from within the project team and the wider community of research scientists and professionals, and the EC who were consulted during the project the key underlying points to address have been incorporated into the Table of Evidence (Table 1).

The questionnaires for Member State regulators is provided in (Appendix G) and the questionnaire for the other stakeholders is provided in Appendix G.

2.2 Evaluation logic applied to the research questions

The evaluation logic describes how the intervention logic is transformed into the practical approach for conducting the evaluation. In this evaluation, this transformation occurs through an "evidence table". The evidence table thus forms the evaluation logic. Alongside the evidence table are some important guiding principles that complete the evaluation logic, presented in this chapter after the evidence table.

The terms of reference (TOR) set out the main evaluation questions to be addressed. The evidence table reflects these main research questions by placing (in the first column) the evaluation questions as stipulated in the TOR.

From these evaluation questions, the evidence table includes (second column) sub-questions which form the basis for the actual questions asked in the interviews with the three stakeholder groups: Member State fire regulators, manufacturers and representatives of European organisations.

Thus, the evidence table demonstrates the link between the intervention logic and study approach, and provides the structural tool that was used for developing the questionnaires used to collect the information for the evaluation.

The evidence table was reviewed and revised during the inception phase and presented and approved by the project steering group. The version used in the study is shown below (Table 1).

Table 1 **Evidence table for the study**

Evaluation Question	**Sub questions**	**Information sources**	**Indicator**
1) Do Member States currently having regulations on the toxicity of smoke generated in building fires?	Do Member States have national regulations related to the protection of building occupants from smoke generated in building fires? Do Member States have national regulations related to the protection of building occupants from toxicity of smoke generated in building fires? If yes, do they regulate on the toxicity of smoke from construction products in fire? Do Member States have regulations related to smoke generated in non-building (e.g. transport infrastructure) fires? If yes, do they regulate on the toxicity of smoke generated by fires in structures which are not considered to be buildings (e.g. transport infrastructure)?	Primary: Interviews with MS fire regulators Existing EU regulations related to infrastructure Secondary: Interviews with organisations Literature review.	Number with / number without regulations for generation of smoke For those with regulations the scope and field of application Number with / number without regulations for generation of smoke For those with regulations the scope and field of application Number with / number without regulations for generation of smoke For those with regulations the scope and field of application

	Do Member States have regulations that prescribe or promote the use of fire resistant construction products in building? If yes, do these regulation stipulate application domain (for example type of buildings)? If yes, is toxicity of smoke explicitly or implicitly taken into account in the regulation?		Number with / number without regulations for generation of smoke For those with regulations the scope and field of application
	Do Member States have regulations that prohibit, or restrict the use of combustible construction products in buildings? If yes, do these regulation stipulate application domain (for example type of buildings)? If yes, is toxicity of smoke explicitly or implicitly taken into account in the regulation?		Number with / number without regulations for generation of smoke For those with regulations the scope and field of application

Evaluation Question	Sub questions	Information sources	Indicator
2) Are there adequate fire statistics in the EU or other evidence (e.g. studies, or medical records) which reliably show that victims of building fires are due to the inhalation of toxic gases from construction products? Which are the responsible toxic gases?	Do Member States have fire statistics? Do Member States have a common definition of "injury"? Do Member States have records related to fire victims? Is there information available on the building that was on fire?	Contact with MS fire regulators Research studies Medical records	Numbers of fires Number of fire deaths. Number of fire injuries Number of deaths in building fires Number of deaths - other types of fire (e.g. vehicle fires) Number of deaths in fires that involve construction products Number of deaths in other types of building fire (e.g. those just involving contents such as furniture) The nature of the injury / cause of death (e.g. smoke inhalation, burns, physical injury, etc.) The proportion of deaths from smoke inhalation. Type of building; (dwelling, public building, office, old or new building) Main construction products used for the building (bricks, concrete, wood, etc.); Were fire resistant products used indoors?

	Is there evidence that victims died from inhalation of toxic gases specifically from construction products? If 'yes' what form does the evidence take it? If 'yes' are gases routinely monitored in deceased fire victims? If 'yes' which toxicants are considered in the treatment of smoke inhalation victims? Is there evidence of the gases which are commonly responsible?		Is the presence of combustible furniture in the building recorded? For example asphyxiant gases (carbon monoxide, hydrogen cyanide, etc.), incapacitating or irritant gases (including acidic gases such as hydrochloric acid) and also various organic compounds. Evaluation from the study contractor Note: the availability of this data will need to be confirmed as part of Q1.

Evaluation Question	Sub questions	Information sources	Indicator
3) If the victims in building fires are mainly due to the inhalation of toxic gases from construction products, which are the available options for effectively reducing the risk (e.g. to regulate on the smoke toxicity, from construction products at EU level, to leave Member States to regulate at national level by application of the subsidiarity principle, or to support other fire engineering measures e.g. appropriate building design, installation of alarm systems, etc.)? Which are the advantages and the disadvantages of each available option? (Information on options to be provided)	Is fire engineering is an accepted fire safety approach in my country? Is all the information needed to implement fire engineering available? Could fire engineering deliver effective benefits? Is regulation of smoke toxicity from construction products at a European level more effective than regulation at a national level? Is regulation at a national level directly or indirectly related to construction products acceptable? Could robust and meaningful smoke toxicity data be used in regulations?	Interviews with MS fire regulators Interviews with experts and fire professionals	Number of Yes/No responses and evaluation from the study contractor Evaluation from the study contractor 5 point Likert scale examining potential for introducing regulation

Evaluation Question	Sub questions	Information sources	Indicator
4) Which would be the possible legal basis for regulating at EU level on the toxicity of smoke from fires in buildings? Which are the advantages and the disadvantages of each available legislative option?	Is there any possible legal basis for regulating at EU level? If yes, would that be the CPR or another piece of EU legislation (e.g. DG EMPL, DG JUST)? What are the costs and benefits for each option? Are they quantifiable? • Legislation at EU level • Legislation at national level (subsidiarity) • Using fire engineering Which option is the most effective? Why?	Interviews with EC officials; MS fire regulators; fire safety engineering experts	Number of Yes/No responses and elaboration, plus evaluation from the study contractor 5 point Likert scale examining potential cost-benefits for each option

Evaluation Question	Sub questions	Information sources	Indicator
5) What could be the possible effects of the above measures on the reduction of fire victims?	Would there be reductions in the number of fire victims (taking into account the available options)? How would the reduction of fire victims be measured at EU and/or national levels? Which option is the most effective? Why? To what extent is elimination of smoke inhalation in fires achievable?	Interviews MS fire regulators; fire safety engineering experts	Number of Yes/No responses and evaluation from the study contractor 5 point Likert scale examining potential each option 5 point Likert scale examining potential for achieving elimination
6) What could be the possible effects on the marketing of construction products if regulated as above?	Would the introduction of regulations related to the toxicity of smoke increase barriers to trade? Would regulation for toxicity of smoke lead to disappearance from the market of some typical construction product families (e.g. thermal insulation, wood, PVC)?	Interviews with EC officials; MS fire regulators; trade associations and manufacturers	Number of Yes/No responses and evaluation from the study contractor 5 point Likert scale examining potential for each option

	Would regulation for toxicity of smoke lead to increases in the prices of some typical construction product families (e.g. thermal insulation, wood, PVC)?		

2.3 Guiding principles in the evaluation process

In refining the evaluation logic during the inception phase, we have clarified a number of considerations relevant for the evaluation logic.

2.3.1 Backward and forward looking evaluation

Evaluations can be backward looking, covering existing regulations and, if it exists, the data supporting the regulation, or forward looking to the potential need for future regulation and the factual data that supports the need for regulation. The research questions indicate that both types are required. This study has sought to explore both types of evaluation and clearly separate the two. Of course a focus on one or other type of evaluation can set the tone of the report:

2.3.2 Quantitative versus qualitative

We have reviewed factual data about fire statistics and smoke, and so where this data exists, the evaluation is based on quantitative data.

With regard to the results for the representatives and Member State fire regulators, interviews were the main source of information, implying a qualitative evaluation of results. The project team asked representatives and Member State fire regulators about any supporting data for their arguments which would add occasional quantitative support to the evaluation of results whenever such data was provided. Where this was not provided the evaluation was mainly qualitative.

With regard to impacts on manufacturers, interviews supported by research data, were the main source of information and thus this part of the evaluation was qualitative. All stakeholders were asked for relevant statistics that might support the evaluation of impacts.

2.3.3 Transparency and replicability

With respect to transparency, the project team consulted the Commission on interview guidelines and questionnaires before starting the interviews. The interview reports have been shared with the Commission, in an anonymized form for interviews with Member State fire regulators and representatives of European organisations. The questionnaires have been included in the final report as this ensures transparency to the wider public about the questions which have been asked. According to academic standards a report needs not include all underlying data as long as it is possible to provide the underlying data, which is ensured by the above approach. In the report, the project team have clearly separate what respondents said from our interpretations.

With respect to replicability, the development of the evidence tables and resultant questionnaires assists in replicability as these can be used again. In addition, because the views of respondents and of the researchers are separated in the report, the results of the evaluation (the analysis) are replicable to the extent that the views of the respondents can be clearly identified. This is particularly the case for the Member State fire regulators of which the majority (if not all) were interviewed. For representatives of European organisation, replicability further depends on the representativeness of the selection that are interviewed and here the study team consulted with the Steering Group.

2.4 Literature review

The review of existing literature related to smoke and smoke toxicity has focused on 175 papers identified through databases searches and papers and reports provided by members of the Study Steering Group. All of the papers, reports and other documentation were reviewed and the key findings related to each of the main research questions identified. A table listing the papers and documents reviewed is included in Appendix B and those referred to are in Appendix C.

2.5 Interviews

The study involved the preparation of questionnaires and carrying out of interviews with 17 Representatives of European Organisations (face-to-face) and 26 National Fire Regulators from EU Member States (face-to-face; phone),

2.5.1 Member State Fire Regulators

With assistance of the European Commission and Steering Group Members contact details were identified for 31 Member State fire regulators and interviews were held with 26 Member States. The list of countries, indicating those that did not respond, is given in Appendix E. In the case of Austria and Poland additional alternative contacts were identified as the initial contacts either had insufficient expertise or were unwilling to contribute to the study. In the case of the UK, contact details were provided for the devolved government department in Northern Ireland, Scotland and Wales as well as in England – all were contacted and responses collated to give a single reply.

All replies were uploaded to a spreadsheet for analysis.

2.5.2 European Organisations

An initial list of 12 European Organisations was compiled based on the discussions and suggestions from the Steering Group and a review by the team to ensure that a balance of interests and sectors was maintained. Following the second steering group meeting a further six organisations were contacted and five of these interviewed (one questionnaire is still outstanding). The list of organisations interviewed is given in Appendix E. Construction Products Europe (CPE) contacted many of their members and as a result the response from CPE is based on replies from 28 associations representing 15 product sectors. The sectors are listed in Appendix E.

All replies were uploaded to a spreadsheet for analysis.

2.5.3 Manufacturers

The terms of reference require interviews to be with the European Commission services; authorities of Member States; scientists and professionals from fire associations; and industry representatives (including those from SMEs and micro-enterprises).

Following discussions at the second steering group it was agreed to increase the number of European organisations interviewed (see 2.5.2 above) and to not include any individual producers.

2.6 Cost-Benefit Study

Different methodologies are available to conduct this comparison: Compliance Cost Assessment, Cost-Effectiveness Analysis (e.g. expressed by cost per victim reduced), Cost-Benefit Analysis, Multi-Criteria Analysis, etc.

However, due to difficulties in quantifying effects health impacts and some cost impacts it was decided that it would not be possible in general to quantify costs or benefits. This means that the overall results are expressed in quantitative ways with the exact form depending on the impacts and the robustness of the information that could be gathered.

- An overview is given of the costs and benefits for each policy option for each relevant stakeholder group as far as specific information was available.

For each policy option, it is identified which of these impacts were relevant. A semi-quantitative comparison is made of the net additional impacts (compared to the baseline option base on the present situation) for the various options.

3 Findings – Literature Review

3.1 Introduction

The purpose of the literature review was to supplement the questionnaire responses by looking for published sources of information (primarily from academic and peer reviewed literature) that address the same topics as the questionnaire. However, as an introduction, some basic features of fire toxicity are reviewed.

Two important sources are Purser's chapter in the SFPE Handbook (Purser 2008) and the book "Fire Toxicity" edited by Stec and Hull (Stec and Hull 2010).

3.1.1 Toxic species produced in fires

There are eight compounds known to make a significant contribution to toxicity, either by contributing directly to asphyxia or by contributing to incapacitation due to irritant effects, identified in ISO 13571 (International Organization for Standardization 2007) and ISO 13344 (International Organization for Standardization 2004).

Asphyxia arises chiefly from exposure to carbon monoxide (CO) and hydrogen cyanide (HCN) as well as lack of oxygen (O_2) (exposure to an oxygen depleted atmosphere). Carbon dioxide (CO_2) also contributes to asphyxia, but only due to its presence in elevated concentrations increasing respiration rate (Purser 2008).

Carbon monoxide is quantified via the proportion of haemoglobin to which it has bound to form carboxyhaemoglobin (COHb). 40% COHb is reported to result in unconsciousness in an adult. Quantification of hydrogen cyanide (HCN) exposure is complicated due to it not remaining persistent in the blood.

The chemical species giving rise to irritant effects which are commonly considered are the halogenated acid gases hydrogen chloride (HCl), hydrogen bromide (HBr) and hydrogen fluoride (HF), nitrogen oxides (NO and NO_2), sulphur dioxide (SO_2), acrolein and formaldehyde. Sensory irritation may not be dangerous in itself, but can impede escape, thereby increasing the dose of asphyxiant gases to which a person attempting to escape a fire is exposed. Where damage to the respiratory tract does occur, this can be fatal, although death can be delayed some hours after exposure has ceased.

One study of flame retardants and the associated toxicity of fire effluent (Hirschler 2015) takes the view that death is overwhelmingly correlated with COHb concentration and therefore, it is not necessary to test for an entire cocktail of toxic fire gases. Heat release rate (HRR) and smoke production are correlated and therefore controlling HRR is more beneficial than controlling toxicity of combustion products (Hirschler 2015). Any discussion of the toxicity and/or health effects of flame retardants needs to address the specific material of potential concern. Published data overwhelmingly shows that flame retardants do not contribute significantly to either acute or chronic fire toxicity in real fires.

In a study carried out by UL in the USA, synthetic materials produced more smoke than natural materials (Fabian *et al* 2010). As the fraction of synthetic compound was increased in a wood product (either in the form of adhesive or mixture such as for wood-plastic composites), smoke production increased. For a given particle size, synthetic materials will generate approximately 12.5 times more particles per mass of consumed material than wood based materials. 99+ % of smoke particles collected during damping down after fire-fighting were less than 1 micron in diameter. Of these 97+ % were too small to be visible by the naked eye suggesting that "clean" air was not really that clean.

The physiological effects of HCN or CO exposure are reported by Penney (Penney 2009) where the specific chemical species are not specific to construction products.

Dhabbah (Dhabbah 2015) focussed on mainly organic compounds, their effects and how to measure the presence of the following compounds in fire gases:

- Organo-irritants
- Polycyclic Aromatic Hydrocarbons (PAHs)
- Isocyanates
- Dioxins
- Organophosphates
- Aerosols/particulates.

The detection of a small number of "supertoxicants," materials whose smoke was orders of magnitude more harmful to laboratory animals than most smoke, sparked the development of over 20 laboratory test apparatus according to Gann (Gann 2001). Few of these "supertoxicants" have been identified in the laboratory and no commercial products have been found to behave in this way.

The Fire Protection Handbook (Gann and Bryner 2008) states that gases produced in fires include CO, CO_2, HCN, halogen acids, organic irritants and others depending on the fuel source (e.g. fire retardants containing phosphorus will produce phosphoric acid, polymers containing sulphur will produce SO_2).

Of the organic irritants, the most important toxicologically are formaldehyde, unsaturated aldehydes (especially acrolein), and isocyanates (from nitrogen-containing polymers) (Herzberg *et al* 2003). The first two result from partial oxidation of the carbon in the material. (Further oxidation leads to the formation of CO and then CO_2). Acrolein, in particular, has been demonstrated to be present in many fire atmospheres (Burgess *et al* 1979). It is also formed from the smouldering of all cellulosic materials and from the oxidative pyrolysis of polyethylenes (Potts *et al* 1978).

Chapter 3 of the Fire toxicity book (Table 3.2 of 131) details the effects of irritants. It discusses the extent to which Haber's rule, essentially the product of concentration and time = constant, is obeyed (for irritants). Exposure to irritants from fires will impact on a person's ability to escape and can result ultimately in incapacitation. Individual Fractional Effective Concentrations (FEC's) are assumed to be additive.

Chapter 4 of the Fire toxicity book (Stec and Hull 2010) covers asphyxiants and the detailed effects on the body. COHb is lethal at 50% concentration, and causes incapacitation at 30%. A study in Scotland, UK (Nelson and Harland 1981) had 50%+ in 54% of all fatalities, 30%+ at 69%. This distribution of % COHb shows that COHb is not the only factor affecting toxicity (Nelson 1998).

One of the findings of the SEFS project (Gann *et al* 2001), an international study of the sub-lethal effects of fire smoke on survival and health, carried out by NIST in the USA, found that far more people are exposed to fire smoke than are suffering consequences, either immediate to the fire incident or afterwards. Therefore, the study concluded that nearly all of the smoke exposures are inconsequential. The likely reason being attributed to the remoteness of the people from the fire, and therefore, their exposure is to dilute smoke whether from the building products or furnishings (Gann 2001).

3.1.2 The impact of fire conditions on species production

Flammability of materials and toxicity of fire effluent must be considered in relation to the stage at which a fire has reached. Fire stages are defined within ISO 19706 (International Organization for Standardization 2012), which outlines three principal stages of fire growth;

- Non-flaming (stage 1)
- Well-ventilated flaming (stage 2) and
- Under-ventilated flaming (stage 3).

Stage 1 is broken down into three sub-stages; self-sustaining smouldering, oxidative pyrolysis and anaerobic pyrolysis. Stage 3 is broken down into two sub-stages; a small localised fire in a poorly ventilated compartment and a post-flashover fire. Each of these stages/sub-stages is described by an expected surface heat flux, temperatures (fuel surface and upper compartment smoke layer), atmospheric oxygen concentration, equivalence ratio and relative quantities of effluent gases indicating completeness of combustion (given in terms of CO and CO_2).

Toxic gas production was measured in an air-starved enclosure of volume 1.6m^3 receiving 2.7 air changes per hour by Andrews *et al* (Andrews *et al* 2005). This ventilation rate was typical for a store cupboard with a closed door, rather than an under ventilated fire with an open door. Most fire tests in rooms, such as the ISO 9705, fall into the latter category and are characterised by high heat release rates and temperatures, large volumes of smoke production and high levels of CO.

In this study (Andrews *et al* 2005), the fires were two pool fires (for repeatability) and a third fire which involved a wood crib 1.6kg, fire load 27MJ. This third fire had a peak heat release rate of 28kW, and a ceiling temperature of 340^{o}C. The period after flaming combustion ceases due to oxygen starvation can lead to significant production of toxic gases. In the case of the wood crib fire, it was reported that smouldering continued for about 1 hour. Fourier Transform Infrared (FTIR) spectroscopy was used to measure 51 gas species, of which 23 were toxic. In addition to the usual products, HCN was detected in the wood fire (thought to come from the N_2 in the air), also SO_2 (with S possibly coming from wood preservatives) and a variety of partially oxidised hydrocarbons (POHCs) which it was concluded survived due to the relatively low compartment temperature (with more ventilation the HRR and temperature would increase and the POHC would be fully oxidised, leaving CO to be the dominant toxic component of the effluent).

This study is particularly interesting since it used a slightly unusual approach to the determination of the importance of different toxic species. The measured concentrations were compared to the limiting concentrations permitted for a 15-minute exposure under the EC COSHH regulations (EC COSHH Regulations 2002). This was justified on the grounds that the COSHH regulations set limits for more compounds than the generally-accepted FED/FEC methodology (Purser 2008, International Organization for Standardization 2012) and the authors considered the COSHH data was "much more reliable since part of Statutory Law in the EU". The COSHH limits for acrolein are very low (0.05ppm for a short term exposure << 15 minutes) compared to the LC50 values required to cause death (300ppm for 30 minutes), therefore, the method adopted by the authors of this paper gave much greater weight to irritancy rather than toxic dose.

In Chapter 2 of the Fire toxicity book (Stec and Hull 2010), equivalence ratio ϕ (< 1, = 1, > 1) defines fuel-lean (fuel-limited), stoichiometric and fuel-rich (ventilation controlled). Toxic yield is strongly influenced by the equivalence ratio ϕ.

In 70% of fatal dwelling fires in the UK, the fire is contained to the room of origin (Chapter 17, Stec and Hull 2010). In the UK, the fire statistics indicate that 55% of the deaths that occur in the fire room of origin, but in the USA, it is 21% in the room of fire origin and 67% on another floor. It is reported that the USA statistics imply 80% of their fire deaths could be saved if flashover is prevented since deaths that occur beyond the room of origin are primarily due to toxic smoke. The difference in the profiles of fire deaths seen between the UK and USA will probably be reproduced if similar data were available from Member States within the EU. The differences will depend on the regulatory framework and underpinning philosophy adopted within the different countries to satisfy their life safety objectives as well as the form of building construction and the extent of compliance with the building regulations.

There have been many studies on the production of chemical species from fires over several decades and it is not uncommon for CO/CO_2 ratios to be used as a key parameter. However, work by Stec and Hull (Stec and Hull 2011) concluded that these ratios can only be used to characterise fire stages for materials which do not contain chlorine or bromine since these elements significantly increase the CO yield in well ventilated fires. If studies of fire toxicity are only undertaken in well-ventilated conditions, it can make it difficult to extrapolate measured toxicity in small-scale tests to a meaningful fire condition.

The influence of fire ventilation conditions on toxic gas production is shown in Table 2 (taken from Stec and Hull 2011).

Table 2 - The main irritant and toxic components in fire gases and their toxic potencies (IC_{50}; LC_{50})

Yield independent of fire condition	**Yield increases with ventilation**	**Yield decreases with ventilation**
HF (500; 2900 ppm)	CO_2 (not specifically toxic, but replaces O_2 and increases respiration rate)	CO (5700ppm)
HCl (1000; 3800 ppm)	NO_2 (170; 250 ppm)	HCN (165 ppm)
HBr (1000; 3800 ppm)	SO_2 (150; 1400 ppm)	Acrolein (30; 50 ppm) Formaldehyde (250; 750 ppm) Aromatics, aldehydes, ketones, etc.

The work by Pitts (Pitts 1994) showed that under well-ventilated conditions ($\varphi < 0.5$), yields of CO are very low, typically less than 0.01. Above equivalence ratios of about 0.5, the yield of CO increases rapidly as the value of φ increases. Once φ reaches a value greater than about 1.5 (fuel-rich, i.e. ventilation controlled), the CO yield becomes rather constant at about 0.2 kg CO/kg fuel consumed, with the production rate principally dependent on the mass burning rate.

The ratio of the concentrations of CO_2 to CO, often used as a descriptive characteristic of a fire, depends more on the ventilation conditions of the fire than on the nature of the materials being burned (Babrauskas *et al* 1991). The ISO guideline for assessing life threat to people (International Organization for Standardization 2007) reports on the dependence of CO_2/CO ratios on the equivalence ratio and shows that for well-ventilated fires (i.e., $\varphi << 1$), essentially all the fuel carbon is oxidized to CO_2 and the ratio exceeds 20. Once the equivalence ratio has exceeded that associated with flashover, indicating a fuel-rich or ventilation controlled fire, the CO_2/CO ratio reaches a plateau at about 2 to 10 (Pitts 1994, International Organization for Standardization 2007). The basis for these ranges have not been established.

3.1.3 Assessment of toxic effects (FED/FIC)

As already highlighted, fire toxicity is a very complex matter. The meaningful measurement of toxic products from a fire is a challenging subject, however, the interpretation of their impact on the people in and around the fire is equally challenging. There has been much work around this specific aspect over the last 4 decades and this historical development is summarised by Purser (Purser 1989).

Toxicity assessment using fractional effective dose (FED) is summarised in Chapter 15 of Fire toxicity (Stec and Hull 2010) and in Purser's chapter of the SFPE Handbook for Fire Protection Engineering (Purser 2008). The ISO standard ISO 13344 (International Organization for Standardization 2004) defines a method for estimating the lethal toxic potency of fire effluents. Assessment of common polymers shows HCN or HCl (if present) can be more important for toxicity (FED) than CO.

Fire toxicity can also be expressed as an LC50, the loading per m^3 predicted to be lethal to 50% of the population. The smaller the LC50, the greater the fire toxicity (Stec and Hull 2011).

By the 1980s, the concept had begun to emerge that the toxic hazard from smoke is a function of both:

- the toxic potency of the smoke (often expressed as an EC50, the concentration needed to cause an effect on half (50%) of the exposed population), itself a function of the combustion environment, and
- the integrated exposure a person experiences to the (changing) smoke concentration over some time interval (IC(t) dt). Some of the effects of smoke increase with continued exposure, others occur almost instantaneously.

The additive effects of fire gases was advanced to include consideration of variable exposure time. This strategy is commonly referred to as the Fractional Effective Dose (FED) methodology (Hiemstra 2016, Guillaume and Blomqvist 2017). The FED is "the ratio of the Ct product (concentration × time) for a gaseous toxicant produced in a given test to that Ct product of the toxicant that has been statistically determined from independent experimental data to produce lethality in 50% of test animals within a specified exposure and post exposure time" (American Society of Testing and Materials 2002).

Although considerable attention was once directed toward incapacitation studies, testing for smoke toxicity ultimately made no such assessment. Incapacitation (defined as the inability to take action to accomplish an escape from a fire) is simply inferred from lethality data, with combustion toxicologists generally regarding incapacitating exposure doses to be about one-third to one-half of those required for lethality (Kaplan and Hartzell 1984). An important consideration within such analysis relates to the person that is exposed to the toxic species, for example, times to incapacitation for a child will be different from an adult and will also be impacted by their body mass and state of health.

3.1.4 Controlling toxicity by controlling ignition/heat release rate

There is a balance to be drawn between the benefits of flame retardancy on ignition of fabrics versus the toxicity of effluents once these materials became involved (Wesolek and Kozlowski 2002). The introduction of the Furniture and Furnishings Regulations in the UK in 1988 (The Furniture and Furnishings Regulations 1988) resulted in the possible use of flame retardants to increase the ignition times and slow the fire in its early stages of development with the potential to contribute to the toxicity of the products of combustion. All of the evidence does show that the benefits from the introduction of these regulations in the UK have been substantial in contributing to reductions in fire deaths The success in reducing the number of fires and/or slowing their early development giving building occupants longer times to respond to alarms and escape, outweigh the contribution to the fire toxicity from any additional flame retardants.

In the USA, it was considered (Gann 2001) that an important document in the early era of toxic hazard analysis resulted from a collaboration between the Fire Retardant Chemicals Association (FRCA) and NIST, USA (at the time the National Bureau of Standards) (Babrauskas *et al* 1987). The issue was whether fire retardant additives effect a trade-off between decreased burning rate and increased emission of toxic gases and whether there was a net safety benefit from the use of fire retardants. This project demonstrated the interaction between toxic potency and ultimate fire hazard, expressed as the time available for escape, and showed that reductions in burning rate far outweighed minor changes in toxic potency in providing this time. Subsequent work at NBS/NIST established the importance of rate of heat release as the controlling variable in fire hazard (Babrauskas and Peacock 1992).

Some of the additives used to reduce ignitability, flame spread and heat release rate can increase the amount of smoke and toxic gases (Molyneux et al 2014). This can be particularly true for flame retardants (fire retardants which operate in the gas phase) which work by interfering with the flaming reactions and can lead to high yields of products of incomplete combustion, including carbon monoxide (CO) and hydrogen cyanide (HCN). A bench-scale study into the correlation between CO and HCN production in a specific fire-retarded polymer (PA 6.6) noted that some additives increased the toxicity significantly, whereas others did not. Measurements were made using the ISO/DIS 19700 tube furnace. In the case of a brominated fire retardant, the toxicity increased by a factor of 10, and was worse at high temperature (typical of a fully-involved fire). A fire retardant containing aluminium phosphinate, on the other hand, only increased the toxicity by a factor of two, less at high temperature. The difference was explained in terms of details of the gas phase combustion chemistry and how the fire retardant inhibits it.

A paper on the fire protection of rail passenger coaches in 1994 (Peacock *et al* 1994) noted that Amtrak introduced toxicity measurement (in addition to the requirements of the Federal guidelines) and a full-scale test, rather than following the bench-scale approach of other countries such as France and Germany. The paper states that "several studies have indicated the nearly random ability of current flammability and smoke tests to predict actual fire behaviour" and recommends a hazard and risk assessment backed up by measurements on HRR. Even though fire deaths are most frequently due to toxic smoke, measuring HRR rather than toxicity was considered a better predictor of hazard.

Kerber (Kerber 2012) reported that the growth rates for USA domestic fires are much faster than in the past. This is attributed to the recent trends of larger houses, more open plan geometries, changes in contents and changes in construction products. It describes six full-scale room fires with variations in room size and contents (fire load). Pairs of tests compared "legacy" versus "modern" rooms. The modern rooms flashed over in less than 5 minutes; the legacy rooms flashed over in greater than 29 minutes (in the largest room, not at all). Clearly, in these experiments, the time to flashover is affected by the variations in contents and fire load distribution as well as the thermal properties at the boundaries of the fire room.

3.1.5 Long-term toxic effects

There have been a number of studies which have attempted to find a link between exposure to carcinogens during fire-fighting activities and cancer incidence in fire-fighters (Graveling and Crawford 2010, Demers *et al* 2011, Sadovska and Navratil 2012, Office of State Fire Marshall 2011, Modern firefighter article). Fire-fighters may be exposed to additional toxins/carcinogens, e.g. adsorbed on the surface of soot particles which may lead to contamination of clothing, or be inhaled or result in skin contact. These hazards may persist for some time, e.g. during "damping down" operations after the fire has been extinguished and the fire fighters will tend to be exposed to such hazards on a regular recurring basis unlike others involved in fire incidents. This topic is therefore very important within the context of occupational exposure to hazards and as such is the subject of a current European Commission funded research project and hence it is considered out of the scope of this project.

Environmental problems caused by fires and fire-fighting agents are the subject of a paper by Holemann (Holemann 1994). He concludes that in terms of environmental impact;

- Most pollution comes from forest/vegetation fires
- Large industrial fires/warehouse fires can also have a noticeable impact
- Kuwait oil fields during the first Gulf War were significant
- Fireground decontamination has some relevance.

Simonson, McNamee *et al* (Simonson, McNamee *et al* 2011) carried out a study on fires involving televisions with or without fire-retardant additives. It was found that dioxins and polyaromatic hydrocarbons have the greatest environmental impact.

3.2 Standard tests and measurement techniques

The standard tests which will be discussed in relation to both flammability and toxicity have been developed to provide reliable, repeatable and reproducible means of assessing the performance of materials. The specific design of each standard test is based upon a hazard scenario that is intended to be reproduced to allow an assessment of performance of different types of materials and/or products. However, the need for repeatability, reproducibility and performance criteria for use by designers, specifiers and regulators invariably means that the design of a standard test is an approximation that requires understanding in its application.

The appropriateness of a standard test rather than an ad hoc experiment or a reconstruction depends on the question being asked. If it is whether or not a material or design was compliant with legislation or a code, then the relevant standard test will be the appropriate tool to investigate performance. However, if it is to develop a fundamental understanding of the way in which a product or material behaved during a real fire incident, then the conditions of that real fire incident must be reproduced to the extent that the product or material is exposed to the same conditions as occurred during the fire incident.

3.2.1 Flammability and reaction to fire tests

A common series of tests and classifications (Euroclasses) has been developed within the EU to ensure that Member States of the EU who regulate for reaction to fire performance all use the same assessment methodology. The classification standard EN 13501-1 defines the reaction to fire performance classes and the test methods used to measure the performance of different materials and construction products. Of particular interest in relation to the production of smoke is EN 13823 often called the Single Burning Item (SBI) test. This is a test of the performance of the construction product in an arrangement representative of end use. That is, it is tested with joints, air gaps and/or fixings that are typical of its end use application. Measurements are made of heat release rate and smoke production rate (in terms of obscuration) as functions of time. From these, values of FIGRA (a FIre Growth RAte index) and SMOGRA (a SMoke Growth RAte index) are calculated. FIGRA is basically a measure of the rate at which a construction product will produce heat and SMOGRA is a measure of the rate at which a construction product produces smoke in the early initiation and growth phases of a fire in a building whilst it is fully ventilated.

3.2.2 Identification of toxic species

Throughout the early development of fire toxicity research, identification and quantification of toxic species produced in different test methods has been developed. The most common techniques were either, using reagents and solvents to extract toxic species so that they could be analysed by chromatographic techniques (gas, liquid or ion) or simply by colorimetric gas detector tubes (Draeger tubes). More recently, industry has been seeking to eliminate these techniques replacing them by Fourier Transform Infrared (FTIR) spectroscopy, due to its capability for continuous analysis of fire effluents during both standard and large-scale experiments (International Organization for Standardization 2006). It has been reported (Williams and Fleming 2008, Kinsella *et al* 1997) that both quantification and identification of chemical species is heavily reliant on either an operator or software being capable of separating out the overlapping of peaks from the various chemical species that might be present in the fire effluent.

3.2.3 Bench-scale tests for measuring fire toxicity

The steady state tube furnace, ISO TS 19700 (Stec and Hull 2011) also known as the Purser furnace creates steady state combustion conditions for fires including under-ventilated combustion (Figure 1). The apparatus may be set up to burn material either without flaming or, for flammable samples at a particular equivalence ratio, from well-ventilated through to forcing a steady state under the most toxic oxygen depleted conditions. It does so by feeding the sample and air into a tube furnace at fixed rates, so that the flame front is held stationary relative to the furnace. This enables it to provide reliable data on the product yields as a function of equivalence ratio. Unlike a “flammability test” where a material’s chemistry dictates the rate of burning, in the steady state tube furnace all flammable materials are burned at a fixed rate.

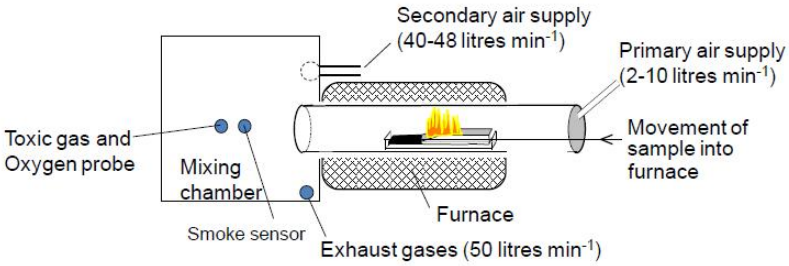


Figure 1: The steady state tube furnace (Purser furnace)

The steady state tube furnace has demonstrated that the burning conditions have a direct impact upon the formation of toxic combustion products and that although flammability and toxicity have been considered in relative isolation over a number of years, they actually need to be considered together when attempting any assessment of the overall hazard to life posed by fire (Purser 2008, International Organization for Standardization 2012).

Some other bench-scale tests for smoke toxicity are presented in the Fire Protection Handbook (Gann *et al* 2008).

In a study by NIST (Marsh and Gann 2013) yields of toxic gases generated by four bench-scale apparatus' were compared to previously conducted room-scale fires. The bench-scale apparatus' were the radiant apparatus in NFPA 269 and ASTM E 1678, the smoke density chamber in ISO 5659-2, a controlled-atmosphere version of the cone calorimeter ASTM E 1354 and the tube furnace in ISO TS 19700. In the bench-scale experiments, the test specimens were cut from finished products that were also burned in the room-scale tests: a stylised sofa made of upholstered cushions on a steel frame, particleboard bookcases with a laminated finish and household electricity cable.

The yields of CO_2 CO, HCl, and HCN were determined. The yields of other toxicants (NO, NO_2, formaldehyde, and acrolein) were below the detection limits, but volume fractions at the detection limits were shown to be of limited toxicological importance relative to the detected toxicants. The bench-scale and room-scale yields were compared, and the bench-scale apparatus' were assessed for the extent to which they accurately predicted room-scale yields. Fourier Transform Infrared (FTIR) spectroscopy was used to monitor CO_2, CO, HCN, HCl, NO, NO_2, H_2CO (formaldehyde) and C_3H_4O (CH_2=CH-CH=O, acrolein). A compilation of post-flashover CO yields showed that the yield of CO from post-flashover room fire tests of a variety of combustibles was 0.2 ± 0.09. This results from vitiation (and therefore truncation of the fuel oxidation process) in the upper layer of the burn room. None of the bench test methods consistently found post-flashover CO yields near 0.2.

Many devices have been used to generate data on the toxic potency of smoke from burning products and materials (Neviaser and Gann 2004).

The SEFS project (Gann 2001) provides guidance for calculating toxic hazard:

- The toxic potency of smoke from a given material or product, as measured in bench-scale apparatus, is not a strong function of the combustion conditions.
- For the large fires of most consequence, there is little change in the nature of the smoke as one moves further from the fire room: changes in respirability (from changes in aerosol dimension) and losses of toxicants from the breathable atmosphere are relatively modest.

3.2.4 Full-scale fire reconstructions

After a major fire event, a full-scale representation of the fire scenario is generally recognised by the sector as being the best possible method of obtaining the relevant fire parameters and consequent toxicity of the conditions to which any potential victims are exposed (British Standards Institution 1999). In particular, they allow investigators an opportunity to make use of knowledge around the development of a fire which has not been witnessed by anyone surviving the event. Fire reconstructions can aid investigators by providing information on one or all of the following (Shipp 2004):

- How did items involved in the fire burn?
- How or why did the fire spread?
- How quickly did it spread?
- Did a particular material contribute?
- How hot did it get?
- How large in area did it get?
- How large did the heat release rate get?

- How smoky was it?
- How toxic was it?
- How did the building react during the fire?

Once the fire dynamics have been characterised by the full-scale reconstruction, small and bench-scale studies can be used for parametric type analyses to answer specific questions and this might include further toxicity studies around very specific issues.

3.3 Toxic smoke from construction products

In a series of six demonstration domestic fires (Hazebroek *et al* 2015), rapid fire growth was observed in all cases. This rapid fire growth occurred in the interior fixtures and fittings: it was not until a later stage that the actual building structure was involved in the fire. This rapid fire growth in the fixtures and fittings was attributed to the use of 'fast' fuels in furniture such as foam rubber and other plastics. Closing a door was shown to be highly significant in terms of survivability. It was indicated that there was a survivable situation behind a closed door for at least another 10 minutes. Several closed doors would therefore provide better protection against heat and smoke rather than one door. In these tests, it was also observed that, besides CO, NOx also reaches high concentrations quickly after the start of the fire. This conclusion only applies to these demonstration fires as the species produced by the fires will be dependent on the fuels present and in this specific case, the fixtures and fittings.

An arson fire in a Swedish psychiatric detention clinic led to the death of two patients and injuries to many more (Hertzberg *et al* 2006). Rescue personnel had difficulties finding their way due to very heavy smoke-logging. A reconstruction indicated that a readily ignitable mattress provided sufficient heat and radiation to ignite a PVC flooring material that then became the main source for fire and smoke. (Note: the PVC released large amounts of chlorine - soot showed 7-10% Cl by weight - which acts as a combustion inhibitor, hence producing a smokier fire than normal). Irritants in the fire smoke were as dangerous as or even more dangerous than the common asphyxiate type of gases present, CO and HCN. The medical analysis of both victims in this arson fire showed that they died by CO intoxication. However, the report notes that irritant substances, such as HCl and isocyanates, cause other injuries, such as lung oedema and traces of such injuries are not normally looked for in Sweden and so would not normally be recorded as a cause of death.

A reconstruction of a fatal fire in an apartment building in Rinkeby, Sweden (Blomqvist 2011), provided toxicity measurements but did not indicate whether the construction products were in any way involved in the outcome of the fire. This work did suggest that automatic door closers might be appropriate on apartment doors in Sweden. Secondly, calculations indicated that automatic smoke ventilation of stairwells in apartment buildings would have also been effective in this case.

In a different Swedish study, three simulated room fires were conducted with a test room containing a typical Swedish domestic fuel load of furniture including a television (Blomqvist *et al* 2004). The measurement of the combustion gases included inorganic species and various organic species, among them polychlorinated and polybrominated dibenzodioxins and furans, and selected brominated flame retardant agents yielded from the domestic fuel load or the contents.

The work presented in Blomqvist's thesis (Blomqvist 2005) is largely based on the results of a number of unique series of large-scale fire experiments, where the composition of the fire effluents has been characterised in detail. The analyses have included many types of species, e.g. narcotic fire gases such as CO and HCN, irritants such as HF, HCl and isocyanates, carcinogenic compounds such as benzene, PAHs and dioxins. The particulate phase of the fire effluents has also been characterised in a number of tests.

An estimate of the total amounts of dioxin, PAH and VOC from fires in Sweden during a specific year was made, by combining the amounts of materials involved in fires with emission factors for these fires. It was concluded that the emissions of PAH, VOC and dioxins from fires are large. The fire related emissions of PAH and dioxins were further shown to be significant and comparable to those from many other sources. For dioxins, it is shown that large catastrophic fires can lead to major emissions.

Realistic full-scale fires of one bedroom apartments were conducted with a tenability assessment (Guillaume *et al* 2014). There were two scenarios: a) a bedroom fire (ignition of bed quilt by cigarette/small flame, door and window closed. This soon went out due to insufficient oxygen) and b) a waste bin fire (with door left open. This went to flashover). This work did not consider the construction products other than the PVC wall linings exposed to the fire.

Recently, there was an investigation into the relevance of the contribution to toxicity of different construction products with a fire starting in a furnished room (Weghorst 2017). Fire tests were carried out to examine the different stages of involvement of the contents of a room and the products from which the room was constructed during a fire. The results showed that untenable conditions in the room fires were reached before the construction products made a significant contribution

In another study, Smolka *et al* (Smolka *et al* 2015) carried out fire resistance tests to EN 1364-1 on composite panel walls with both combustible and non-combustible cores. The results revealed that the combustible-core panels started emitting smoke on the unexposed side at the joints between panels. In some cases, the smoke emission started early after the fire exposure. The start of the smoke production period appeared to depend on the method of fixing of the panels to the furnace frame, that is, three or four sides fixed as per EN 1364-1. FED calculations indicated that there could be a potential threat to the occupants on the unexposed side for a certain set of conditions.

The same authors (Mozer *et al* 2015, Smolka *et al* 2015) have carried out further studies looking at the potential for construction products to emit toxic species and/or smoke from the unexposed face and thereby potentially impact on building occupants during evacuation. The Fractional Effective Dose (FED) and Optical Density (OD) are modelled in a series of scenarios (Mozer et al.) to assess the effluents emitted from the compartment boundaries. The results indicate that some of the configurations represent a significant hazard based on the FED criterion and nearly all of the modelled situations exceeded the OD criterion. Although based on a very limited study, this could be taken to mean that OD is the worst case and a good measure of the life safety hazard from fire effluents. Measurements and analysis of gas and particle data (Smolka *et al* 2015) made it possible to carry out a simulation of tenability conditions in an adjacent fire compartment and the impact on evacuation taking opacity and toxicity of fire effluents into account. It was shown that the fire effluents released as a result of combustion of fire-separating elements can pose life safety risks. The data acquired and the initial analyses give a useful insight into the phenomenon of optical density and toxicity of smoke released solely from elements of a building structure. The tenability conditions in an adjacent space or compartment will depend on its dimensions and factors such as ventilation conditions.

Blomqvist and Johansson (Blomqvist and Johansson 2014) carried out a study on the small-scale characterisation of the fire effluent from burning sandwich panel products and the comparison of these results with the fire effluent composition measured during large-scale fire tests. Multiple fire resistance tests were conducted with sandwich panels according to EN 1364. In addition to standard measurements, the fire effluents on the cold side of the panels were collected and analysed in detail. Fire effluents were collected and analysed both before and after integrity failure. Material components from the same batch of sandwich panels were tested using ISO/TS 19700:2007, the steady-state tube furnace method. The sandwich panels investigated were of two common types, with a core of either mineral wool or PIR insulation material. Correlating the fire effluent composition between the large-scale tests and the small-scale characterisation was found to be challenging. Both the complexity of the tested products and the nature of the large-scale tests presented complications. However, the high level of complexity was useful to exemplify the considerations that have to be made when using small-scale fire effluent composition data.

The toxicity of six insulation materials (glass wool, stone wool, expanded polystyrene foam, phenolic foam, polyurethane foam and polyisocyanurate foam) was investigated under a range of fire conditions in the ISO/TS 19700 steady state tube furnace (Stec and Hull 2011). Stone wool and glass wool failed to ignite and gave consistently low yields of all of the toxic products within the test. For polyisocyanurate and polyurethane foam, FED calculations showed a significant contribution from HCN which resulted in a doubling of the overall toxicity, as the fire condition changed from well-ventilated to under-ventilated.

In a New Zealand study, sandwich panels were penetrated by a flue through which hot gases were passed (Baker 2002). This transferred heat to the EPS insulating core. However, it was noted that the core material shrank away from the heat source and did not sustain flaming. The authors concluded that this showed that a fire was unlikely to start in the core of this type of panel.

A Warrington Fire report (Warringtonfire 2017) describes two full-scale room fires with identical contents and different insulation types within the room walls (one had mineral wool insulation, the other PIR insulation). The test room was based on an ISO 9705 standard large-scale test. Insulation was between cellular concrete walls on the outside and gypsum board on the inside. There were vertical joints where the gypsum board was fixed to battens. The fire was ignited with a 30kW propane burner (equivalent to a waste bin) catching the curtains plus armchair. Both tests exceeded 1MW in 7 to 7.5 minutes from armchair ignition. In both tests, the fire decayed after 16 minutes 40 seconds from armchair ignition. The results show that after "flashover" which corresponds to a heat release rate of 1 MW, the PIR insulation contributed more heat to the fire. The combustion products were measured using FTIR spectroscopy (CO, HCN, formaldehyde, acrolein, SO_2, HCl, CO_2, NO_x). Thermocouples gave gas temperatures as a function of height. The FED/FEC calculations were dominated by the contribution from the furniture, particularly during phase 2 (peak HRR). After flashover, the PIR insulation produced HCN and NOx.

3.4 Current Regulations

This part of the literature review covers issues related to Section 1 (questions 1.1 to 1.5) on the questionnaire (Appendix F).

1. Protection of occupants from smoke in building fires
2. Protection of occupants from smoke toxicity from construction products in building fires
3. Protection of occupants from smoke in non-building fires (e.g. transportation)
4. Fire-resistant or non-combustible construction products
5. Combustible construction products

The European system for reaction to fire testing and classification, often called the Euroclass system, is essentially measuring how much a construction product will contribute to a fire in the early stages of a fire development (Fire Safe Europe 2014). The scenario being replicated is that of a small fire in a corner of a room with plenty of oxygen available for the combustion process. The system is focused on ignition and flame spread but does also measure the production of flaming droplets and rate of production of smoke. The Euroclass system does not consider the toxic gases that might be present in the smoke.

The main intent of building regulations in relation to reaction to fire and the early stages of initiation and growth of the fire is to slow down the growth rate of a fire and prevent large fires from developing.

A survey (Messerschmidt *et al* 2016) was conducted on what the requirements would be for three different buildings if built in eleven different European Member States[1]. The primary lessons learned from the survey are:

- The levels of safety implied by the regulatory examples are vastly different even if the building parameters and their purpose is identical.
- Most of the countries surveyed have reaction to fire requirements at product level and also for products built into assemblies. Only two countries appeared to consider only the performance of the complete assembly.

[1] The report on the survey does not mention toxicity of smoke from combustion products

- Fire compartmentation is the backbone of the fire safety strategy in all the surveyed countries, however, with significant differences to the size of the fire compartment allowed.

- Active fire protection is not widely required. Even in the two high rise buildings, only half of the countries surveyed required sprinklers. Whenever used, the sprinklers are apparently considered an add-on safety feature rather than a (partial) replacement of passive fire protection.

- The combustibility of the construction products used and, in particular, the insulation used in facades is considered in most of the countries surveyed.

Shigekura describes the fire rating procedure used in Japan in 1992 (Shigekura 1992). The JIS A1304 ((Japanese Standards Association 2011) standard included a toxicity test. Materials are Non Combustible (e.g. concrete, brick), Quasi Non Combustible (Cement board, gypsum board) or Fire Retardant (e.g. Fire Retardant plywood, Fire Retardant fibre board, Fire Retardant plastic board). Toxicity was compared to results using wood and eight mice were exposed in the determination of toxicity.

Chapter 16 of the Fire toxicity book (Stec and Hull 2010) covers Regulations in France, Germany, Poland, Russia, China, Japan that apply mainly to transportation due to restricted opportunities for escape. Focussing entirely on buildings in countries outside of the EU, in Russia, there is a GOST test with animal testing. This also includes an analytical determination of CO, CO_2, HCN. NOx, OI (but not HX). China tests fire retarded products, in particular thermal insulation foams and sub-assemblies for use in public places using a hybrid of DIN 53436 and animal cages from Japanese JIS A 1321. Japan is moving forward to performance oriented design. JIS A 1321: 1976 is still used to test the toxicity of building products. However, if the cone shows a low HRR, then this exempts the product from toxicity tests. The future trends were reported (Stec and Hull 2010) to be heading towards fire performance tests allowing development of fire scenarios and modelling and limiting the use of animals by replacing with analytical tests instead.

In 2005, six European countries had regulations regarding the installation of domestic smoke alarms: Norway, Denmark, Sweden, Finland, UK and the Netherlands (Schmidt, Pedersen and Steen-Hansen 2005). An overview is given of these:

Requirements regarding installation of domestic smoke alarms, 2005

- **Norway.** At least one approved smoke alarm has been required in both new and existing residential buildings since 1991. There are no specific requirements for which type of detector should be installed or the type of power supply.
- **Denmark.** Since December 2004, a smoke alarm system is required in single family houses with a maximum of two floors and a basement. The system shall be coupled to the mains and equipped with a backup battery system.
- **Sweden.** The Swedish Rescue Services Agency issued a general recommendation on installation of smoke alarms in all residential buildings in 2004.
- **Finland.** All new and existing residence, must be equipped with fire detectors since 1999. There must be at least one detector on each floor, and it must be kept in working order. Batteries are the required power source. If the detector is wire operated it must be provided with a battery backup.
- **UK.** According to the Building Regulations from 2000, dwellings shall be provided with devices for the early warning of fire. A general recommendation about placing smoke alarms in connection with bedrooms and installing at least one detector on each floor is given. Smoke alarms can be wired or battery operated.
- **The Netherlands.** Smoke detectors have been required in new dwellings since 2003. Detectors shall be of the non-ionic type, and shall be coupled to the electrical mains system.

3.4.1 Relevant standards

See Japanese Standard JIS A1304 ((Japanese Standards Association 2011).

EN ISO 13943:2010 contains the fire safety vocabulary/terms.[2]

ISO 19706:2011 contains the guidelines for estimating fire threat (International Organization for Standardization 2012).

ISO 13571 Life-threatening components of fire — Guidelines for the estimation of time available for escape using fire data (International Organization for Standardization) is the key standard for estimating the available safe time for escape.

Chapter 17 of the Fire toxicity book (Stec and Hull 2010) shows a hierarchy of various ISO standards:

- ISO 19706:2007 Guidelines for assessing the fire threat to people. This standard provides the introductory framework for assessment of the fire threat to people.
- ISO 16312-1 Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment (Selection of suitable effluent generation methods)
    - Part 1: Criteria ISO TR 16312-2 Guidance for assessing the validity of physical fire models for obtaining fire effluent toxicity data for fire hazard and risk assessment
    - Part 2: Evaluation of individual physical fire models
- ISO 13344:2004 Estimation of lethal toxic potency of fire effluents (Estimation of toxic effects)
- ISO 13571:2007 Life-threatening components of fire: Guidelines for the estimation of time available for escape using fire data (Estimation of toxic effects)
- ISO 19700:2007 Controlled equivalence ratio method for the determination of hazardous components of fire effluents ISO 19701:2005 Methods for sampling and analysis of fire effluents (Generation of fire effluents)
- ISO 19701:2005 Methods for sampling and analysis of fire effluents
- ISO 19702:2006 Toxicity testing of fire effluents: Guidance for analysis of gases and vapours in fire effluents using FTIR gas analysis
- ISO 19703:2005 Generation and analysis of toxic gases in fire: Calculation of species yields, equivalence ratios and combustion efficiency in experimental fires
- ISO 27368 Analysis of blood for asphyxiant toxicants: Carbon monoxide and hydrogen cyanide

[2] The cited standards and reports are just examples and cannot show the complete picture. The ways to test toxicity and to assess the impact of toxic combustion products especially for construction products are still under discussion in the worldwide community of researchers and experts in standardization.

3.5 Fire Statistics

This parts deals with issues related to Section 2 (questions 1 – 6) on the questionnaire in Appendix F.

1. Are there data on number of fires, deaths and injuries?
2. How are fire-related injuries (and deaths) defined?
3. What additional data on victims is available? For example, building or other, construction products (or just contents) involved in fire, nature of injury/cause of death.
4. What additional data on the building is available? For example purpose group, type of construction/products used, details on furnishings.
5. Is there any evidence that victims were exposed to toxic smoke specifically from construction products?
6. Which toxic gases are the ones mainly responsible for causing harm?

Most (if not all) EU countries have at least basic fire statistics on the number of fires, deaths and injuries. There is no consistent definition of "fire-related" injury/fatality; for example, if someone is injured in a fire, and dies some time later, is the fatality a consequence of their injuries or not?

Fire statistics may be considerably more detailed than the summaries which are publically available. This is known to be the case in England; the Incident Reporting System (IRS) database (Department of Communities and Local Government 2011) has approximately 100 fields per record, each field has several possible responses (some are >>10) and there are also some free text fields providing further data classified as "other".

Incident Reporting System Questions and Lists (Department of Communities and Local Government 2011) give details of the data that are collected in the UK fire statistics. Despite the level of detail available, the IRS data would generally not indicate if construction products contributed to the smoke generation, nor whether this affected the victim. The presence of certain construction products (e.g. sandwich panels) may be recorded, though even here, the nature of the panel's core material is usually not noted.

A paper on consumer fire safety - European statistics and potential fire safety measures (Kobes and Groenewegen 2009) concentrates on domestic fires, and gives a fairly generic approach since there is no uniformity in the collection of fire statistics across Europe. It includes data from USA and Australia. This paper attempts to estimate the effectiveness of different risk reduction approaches. It does not mention the control of toxicity of construction products.

A paper on fatal house fires in 2014 (Kobes 2014) does not mention the toxicity of construction products.

The Netherlands Institute for Safety (NIFV) collects the data in close collaboration with the National Fire Service Documentation Centre (NBDC) and the fire service officers and fire investigation teams involved in fatal domestic fires. The fatal domestic fires in 2011 were traced based on press releases, supplied by the National Fire Service Documentation Centre. In 2011, 26 fatal domestic fires took place, according to the press releases and information obtained from the fire service officers and fire investigation teams involved. In these fires, 28 people died. All of these fires were caused by accident: fires caused by intent (arson, murder or suicide) were excluded from this study (Fatal domestic fire 2011). The causes of death were not reported.

The fourth edition of "Injuries in the European Union" (Eurosafe 2013) presents an EU-level summary of the most recent injury statistics, mainly related to the years 2008 to 2010. In addition to data from EuroStat and WHO-Europe, this report also presents data derived from the European Injury Data Base (IDB). The IDB contains standardised cross-national data on the external causes and circumstances of injuries treated in emergency departments.

Injuries due to accidents and violence are a major public health problem, killing more than 230 000 people in the EU-27 each year (annual average 2008 to 2010). Fire accounts for about 2% of fatal injuries. According to these figures there were about 4,600 fire deaths in the EU each year. As an approximate check, most western nations experience between 5 – 15 fire deaths per million population per year (Runefors *et al* 2016); the EU currently has a population of 508 million (according to the Europa website) so this number of deaths seems plausible.

Kobes and Groenewegen highlight consumer fire safety as an area of concern (Kobes and Groenewegen 2009). In this paper they report that in Europe, there are 2.0 to 2.5 million fires are reported per year, resulting in 20,000 to 25,000 fire deaths and 250,000 to 500,000 fire injuries in Europe per year (CTIF 2006). About 80% of the fatalities occurring in private homes.

These reports highlight that the statistics related to the number of fire deaths are inconsistent.

Swedish Civil Contingencies Agency published the Swedish Rescue Services in Figures, 2008 (Swedish Civil Contingencies Agency 2008). Incident commanders record the number of people who were killed or injured at the incident. It is observed that incident commanders do not receive definitive information on this from the health authorities so incident statistics are based entirely on commanders' assessments of the likely consequences for the victims. Incident commanders only record someone as killed if they are sure that this was the case. This results in an underestimation of deaths and a corresponding overestimation of injuries.

80% to 90% Swedish fire fatalities are in residential premises (Runefors *et al* 2016). There are around 100 fire deaths per year in Sweden. Most fatal fires in Sweden occur in the home. In 2008, home fires accounted for 86 deaths. Thirteen deaths occurred in other buildings. Sixteen deaths occurred in non-building fires, most often in vehicles.

Investigations by the Fire and Rescue Services and police show that the most common known cause of fatal fires is carelessness when smoking. In 2008, 25 people died in such fires. In 2008, 47 people died in fires where the authorities were unable to identify a cause. It is substantially easier to identify the room of origin than the cause. Most fire victims died in fires which started in living rooms, bedrooms and kitchens.

Greenstreet Berman compared EU fire statistics (Department for Communities and Local Government 2011), typically collected by national Fire and Rescue Services. There were good data from Finland, Norway, Sweden, the Netherlands, Lithuania, Slovakia, Bulgaria, Italy and the UK. Injuries, systems, size of fire were recorded. Deaths in fire are treated differently and elapse time from the fire to the death of a victim varies too. Greenstreet Berman confirmed the difficulties in comparing current fire data between Member States and mapped out differences in reporting practices. They reported a willingness to support the development of comparable datasets and concluded that reconciling the existing data would be a significant task.

There are about 0.5 to 1.5 fire deaths per 10^5 population/year in most western countries (The Geneva Association 2015). Different types of people are at risk, such as elderly people, disabled people, and people with drugs/alcohol issues (Xiong *et al* 2015).

Runefors *et al* (Runefors *et al* 2016) analysed all 144 accidental fatal residential fires investigated by the Swedish police or fire department between 2011 and 2014. In each case, measures that could have prevented the fatality were considered. There was a total of 261 fatal fires in the period and of these, 20% of victims could have escaped but chose not to (fire-fighting). Table 3 shows the findings.

Table 3 – Potential effectiveness of different measures for smokers with homecare and the general public (taken from Runefors *et al* 2016)

Measure*	**All victims (%)**	**Smokers with homecare (%)**
Flame resistant bedclothes	24	50
Flame resistant clothing	11	31
Thermally activated suppression	68	31
Smoke detector activated suppression	59	88
Home smoke alarm	37	14
*Other measures were considered		

Chapter 1 of the Fire toxicity book (Stec and Hull 2010), states that fire deaths in the UK have fallen while the contribution from toxicity remains the same. The fire statistics show a rise in smoke injuries with a peak in 1990's in contrast to fire deaths which have been consistently falling since the 1980s.

Chapter 2 of the Fire toxicity book (Stec and Hull 2010) it is reported that in 70% of fatal dwelling fires in the UK, the fire is contained to the room of origin (TriData 2007). In the UK there are 55% of the deaths in fire room, but in the USA it is 21% room and 67% another floor. USA statistics imply 80% of their fire deaths could be saved if flashover is prevented. Deaths beyond the room of origin is due to toxic smoke.

Overall the literature shows, as expected, that there is a lack of common statistics relating to fire victims, and very limited published data on smoke toxicity from construction products. It also shows that evidence on successful safety measures are unfortunately not directly found in the current fire statistics (which focus on failures).

3.6 Potential options for reducing fire risks

This part deals with issues related to Section 3 (questions 1 -3) on the questionnaire (Appendix F).

1. Fire safety engineering
2. Regulation of construction products
3. Others

There are many options for reducing fire risks:

- Automatic fire detection in all (new) buildings (Linssen 2011, Kobes and Groenewegen 2009, Emsley *et al* 2005, US Fire Administration/National Fire Data Center 2012)
- Automatic sprinkler systems (Seo Economish Onderzoek 2014, Linssen 2011, Williams *et al* 2004, US Fire Administration/National Fire Data Center 2012)
- Heat-detection cut offs for cooking appliances (Letter to EU commissioner)
- Fire-safe cigarettes
- Community fire safety initiatives (educating people expected to be in a higher-risk group) (TriData 2007, TriData 2008, TriData 2009)

- Furniture and furnishings fire safety regulations (TriData 2007, Linssen 2011, Emsley *et al* 2005, US Fire Administration/National Fire Data Center 2012)
- Others (Linssen 2011, Emsley *et al* 2005).

Most building fires start by involving the building contents, rather than the building structure. A number of instrumented full-scale fire experiments have shown that, by the time construction products become involved in fire, the smoke exposure from the contents would already be unsurvivable.

Construction products may be involved in a fire if they are not correctly installed according to the manufacturer's instructions, or service penetrations are not properly fire-stopped or they are incorrectly specified, i.e. do not comply with the relevant building regulations or codes.

Some work on sandwich panels suggests that exposure to a (large) fire on one side may lead to the production of toxic species on the unexposed side. Standard fire resistance tests have a criterion for integrity, but this involves flames penetrating to the unexposed side, so would not detect this out-gassing.

There have been attempts to estimate the effectiveness of different risk reduction approaches (Kobes and Groenewegen 2009).

Norway has a standard for heat detectors in cooker hoods (Pers.Comm - Letter to EU commissioner) as a means to reduce fire risk.

Surveys of best practices in fire and rescue services were undertaken in England, Scotland, Sweden, Norway (TriData 2007) Australia, New Zealand, Japan (TriData 2008), Canada, Puerto Rico, Mexico and Dominican Republic (TriData 2009) to distil information. One recurring theme was the use of community fire safety initiatives.

The greatest fire risks are in a domestic environment, so it is here that measures are most likely to be effective. In a cost benefit analysis of residential sprinkler systems and furniture regulations using fire retardants in the Netherlands (Seo Economish Onderzoek 2014), residential sprinkler systems were found to not be cost-effective (blocks of flats may be an exception); furniture regulations were less clear-cut. A long list of possible measures were considered.

A study by the University of Surrey (Emsley *et al* 2005) gave a detailed analysis of changes in the numbers of deaths and injuries from fires in the UK related to the introduction of fire-safe domestic furniture (Furniture Fire Safety Regulations 1988) and also related to the increased installation of smoke alarms and reductions in the frequency of smoking in the population in the UK.

3.6.1 Fire Safety Engineering

If toxicity is being considered as part of a fire engineered solution, assumptions would be made about the fire scenario, for example, what was burning, where and how it was located, the ventilation conditions and the toxic yields. Smoke transport calculations would be performed using, for example, a Computational Fluid Dynamics (CFD) model or zone model to determine the length of time a person in any given enclosure would have before losing consciousness. Egress models would be used to determine the length of time people stay in different enclosures during evacuation and the time it would take to reach a place of safety. A number of countries provide guidance in terms of the tenability criteria that must be satisfied by a fire safety engineered design.

Linssen conducted a research project to investigate means of increasing survival times in residential fires. This research study (Linssen 2011) included escape ladders in a range of measures mainly aimed at facilitating means of escape from the fire.

3.7 Legal basis for EU-level regulation

This part deals with issues related to Section 4 (questions 1 and 2) on the questionnaire (Appendix F).

1. Is there a legal basis?
2. Would fire engineering or regulation at EU or national level be more effective/cost-effective? Can this be quantified?

Information from one of the stakeholders suggested that any regulation should respect the subsidiarity principle, i.e. be left to individual Member States. This though was more of a position statement than a formal legal opinion.

A number of documents from the stakeholders mentioned various risk reduction options, and in some cases attempted a cost-benefit analysis of the measure(s) in question. However, regulation of the smoke toxicity of construction products was not one of the measures considered in any of these analyses.

3.8 Effects on markets for construction products

This part deals with issues related to Section 5 (questions 1 and 2) on the questionnaire (Appendix F).

1. Which option (fire safety engineering or regulation) would be most beneficial to trade?
2. Would regulation lead to increased costs or disappearance from the market, for certain construction products?

A BRE report for UK Government on the production of smoke and burning droplets from products used to form wall and ceiling linings (BRE 2005) looked at adding a test for smoke and burning droplets to its wall lining classification requirements. However, as part of the costs benefit analysis of that study, the fire statistics showed virtually no deaths or injuries that could be directly attributed to wall lining materials. The analysis found the annual costs to be £260 million and the life safety benefits to be £175,000.

The cost benefit analysis part of this study must however be considered in context. In the UK, at the time of the project in 2005, the Europe test standard EN 13823:2002 was a voluntary alternative to BS 476 parts 6 and 7. Therefore, the introduction of the new test would have required the majority of construction products available in the UK market to have been re-tested with costs as reported. Since the introduction of the CPR in 2013 which made CE Marking mandatory throughout the EU the cost associated with such a measure will have changed.

3.9 Literature review on potential toxicity of smoke

3.9.1 Introduction

This part of the literature review develops section 3.1 and focuses on substances in smoke that can be related to construction products. Literature referred to can be found in Appendix C. Acute and chronic toxicity towards residents is considered; exposure (short- and long-term) of fire fighters to smoke is outside the scope of this review.

According to Fire Safe Europe more than half of all fire-related injuries and deaths are caused but by smoke for the reasons explained earlier rather than the fire directly. Smoke from a fire can obscure evacuation routes, impair the vision of evacuees, cause irritation to the respiratory tracts, and eventually bring about narcosis due to the inhalation of asphyxiate gases (Fire Safe Europe, 2014). The Construction Products Regulation (EU) No 305/2011 (CPR) requires that construction works are safe in case of fire. One of the most important aspects of fire safety is the reaction to fire, which is characterised by the performance parameters 'ignitability', 'smoke growth rate' and 'total smoke production'.

Through a literature study of documents that were provided by the steering committee and the project partners, substances that might be relevant for smoke toxicity were identified. These findings will be compared to the work undertaken by ISO TC92/SC3 which is most up to date knowledge on fire toxicity collected. The most important standards are ISO 13571, "*Life-threatening components of fire -- Guidelines for the estimation of time to compromised tenability in fires" (impact on human in an evacuation situation*) and ISO 13344:2004, "*Estimation of the lethal toxic potency of fire effluents" (for calculation of toxic potency of materials based on animal data*).

The substances that might be relevant for smoke toxicity identified in the study were classified for inhalation toxicity according the EU criteria, and a risk characterisation was performed.

3.9.2 Substances

The harmful components of fire effluent defined by the ISO 19706 2011 (International Organization for Standardization 2011) standard are the following:

a) asphyxiant gases: CO, HCN, oxygen-depleted air;
b) irritant gases: halogen acids (HCl, hydrogen fluoride (HF), hydrogen bromide (HBr)), partially oxidized organic molecules (e.g. acrolein, formaldehyde), nitrogen oxides, other fuel-specific gases;
c) aerosols and soot particles, particularly those of a size that are readily respirable and those that scatter light efficiently;
d) heat (radiative and convective) and elevated temperature.

The ISO 19706: 2011 standard includes a note stating that CO2 and some other gases also have an effect on the rate of uptake of toxicants.

Publications on concentrations of substances in smoke from real fires or from fire experiments are discussed below.

In Germany a producer of instruments (FTIR analysers) has made a library of reference infrared (IR) spectra of 200 components for calibration of equipment for gas measurements during fire (www.ansyco.de Link: IR-Spektren-Sammlung). For general fires measuring the following gases is considered of high interest by the German Authorities, some researchers and fire brigades:

acrolein, HCN, HCl, SO2, CO2, CO, ammonia and formaldehyde.

For all fires in buildings and in case of burning goods of unknown composition the following substances should be measured: acrolein (in case of cotton), ammonia (fertiliser), sulphur dioxide (wool, silk and nylon), NO2 (celluloid), hydrogen fluoride and its compounds (Teflon products) (Basmer and Zwick, 2004).

In a fire experiment smoke gases from burning simulated roofs with different fittings and insulation materials were analysed (Basmer and Zwick, 2004). Many measurements were below the detection limit of the gas analyser, which is not very surprising as the measurements were performed outside (Appendix D).

During another fire exercise, 20 tonnes of wooden pallets were set on fire in a tunnel (Basmer and Zwick, 2004). The measured concentrations at the tunnel portal are presented in Appendix D.

During a flashover at a room fire exercise, increase of the following gases was measured in the smoke: methanol, ethanol, acrolein, benzene, o-xylene, NO, NO2 and N2O, ammonia, SO2 and HCN. Before they were burnt, methane, acetylene, ethylene, ethane and hexane were detected (Appendix D). The walls and ceiling were covered with gypsum-cardboard sheets, the floor was covered with needle punched carpet (Basmer and Zwick, 2004).

In a series of large-scale fire experiments in Sweden, the composition of the smoke has been characterised in detail (Blomqvist, 2005). The fire experiments involved general fires, material for construction materials (particle board, polyvinyl chloride (PVC), rigid and flexible fire resistant PUR (polyurethane), polystyrene, chemicals, products, electronic consumer products (with PVC containing cables), and fuel.

The analyses included narcotic gases (CO2, CO and HCN), irritants (nitrogen monoxide (NO), NO2, ammonia (NH3), hydrogen fluoride (HF), hydrogen bromide (HBr), SO2 and HCl), volatile organic compounds (isocyanates, phenol and styrene) and carcinogenic compounds such as benzene, polycyclic aromatic hydrocarbons (PAHs) and dioxins. It was concluded that CO, NO, HCN and in particular HF are a major hazard for people in fires. Also the particulate phase of the smoke was characterised. The total amounts of dioxins, PAHs and volatile organic compounds (VOC) emitted during real fires in Sweden are large. For PAH and dioxins the fire related emissions are comparable to those from many other sources.

The combustion of PUR foams can form isocyanates and aromatic derivatives such as benzene and toluene. Very low oxygen concentrations can support generation of HCN from PUR. The combustion of polyacrylonitriles and nylon produces considerable amounts of NOx and ammonia. The gaseous products from pyrolysis of polyethylene with very low oxygen concentrations are methane, ethane and hydrogen. Combustion of PVC releases HCl and chlorine. One kg of PVC liberates 400 l of gaseous HCl. Some plastics can also release phosgene (COCl2), and small quantities of dioxins. Other halogenated plastics may generate HF and HBr (Svadovska and Navratil, 2012).

A series of 6 full-scale fire tests were performed in an existing building in the Netherlands. Rapid fire growth occurred in the interior fixtures and fittings: it was not until a later stage that the actual building structure was involved in the fire. In addition to CO, high levels of NOx were observed during the early phase of the fire; maximum values are presented in Appendix D. The authors recommend further research into other common combustion gases (HCN/HCl) should be carried out as part of future experiments (Hazebroek *et al.*, 2015).

Three simulated room fires were conducted with a test room containing a typical domestic fuel load of furniture including a TV-set. The lower half of the walls and the floor were covered with gypsum. The measurement of the combustion gases included inorganic species and various organic species among them polychlorinated and polybrominated dibenzodioxins and furans, and selected brominated flame retardant agents (Blomqvist *et al.* 2004). The results for inorganic substances and some aromatics in the smoke are presented in Appendix D. The major inorganic components were CO2 (428-465 kg) and CO (16-22 kg), followed by SO2 (2,8-3,2 kg). The total amount of VOCs was 410-1540 kg, of which 17-38% was for unidentified VOCs; the highest contribution to the identified VOCs was for benzene (21-38%) followed by naphthalene (16-18%). The total amount of PAHs was 333-867g, of which the highest contribution was for naphthalene (35,4-43,9 %) (Blomqvist *et al.* 2004).

Flame retardants are designed to slow down the combustion process and lower the resulting heat release and flame spread. Seven key elements are known to interfere or disrupt combustion: chlorine, bromine, phosphorous, aluminium, boron, antimony and nitrogen. They are incorporated in (but not restricted to) chemicals that act as flame retardants. Halogenated (chlorine and bromine) flame retardants are considered as the most effective and can be used at low concentrations (Hirschler, 2015). The presence of flame retardants in smoke was examined in experimental room fires by Blomqvist *et al.* (Blomqvist *et al* 2004). Three simulated room fires were conducted with a test room containing a typical domestic fuel load of furniture including a TV-set. Two types of TV-sets were studied in the experiments, i.e. those containing fire retarded and non-fire retarded enclosure material. The results indicated that a TV-set treated with brominated flame retardants included in the fire load of a room fire does not necessarily increase the emission of bromine containing organic combustion products. Of the two brominated flame retardants investigated, only trace amount were found, and no correlation could be made to the type of TV included in the room fire. Unexpectedly brominated species (tetrabromobisphenol A or TBBPA) were found in the combustion gases of the experiments with a non-flame retarded TV; the source must have been the furniture or the books (Blomqvist *et al.*, 2004).

The Dutch Institute for Physical Safety investigated 34 fatal domestic fires of 2009 and concluded that in more than half of the cases, serious smoke development was mainly caused by the presence of foams in furniture and mattresses. The construction materials used for the buildings hardly had any impact on the fire development (Kobes *a*nd Groenewegen, 2009).

3.9.3 Toxicity

Fire effluent consists of a complex mixture of solid particulates, liquid aerosols, and gases. Although fires may generate effluent of widely differing compositions, toxicity tests have shown that gases are a major factor in the causes of acute toxicity. The predominant acute toxic effects may be separated into two classes (IEC, 2010):

a. asphyxiant effects
b. sensory and/or upper respiratory irritation

Asphyxiation is a major cause of death in fires. An asphyxiant is a toxicant causing hypoxia (a decrease in oxygen supplied to or utilized by body tissue), resulting in central nervous system depression with loss of consciousness and, ultimately, death. Effects of these toxicants depend upon accumulated doses, i.e. a function of both concentration and the time or duration of exposure. The severity of the effects increases with increasing dose. Among the fire gas toxicants, CO and HCN have received the most study and are best understood with respect to their capacity to cause incapacitation and death of those exposed (EN, 2010). Sensory and/or upper respiratory irritation stimulates nerve receptors in the eyes, nose, throat and upper respiratory tract. Appearing to be related only to concentration, the effects lie on a continuum going from mild eye and upper respiratory discomfort all the way to severe pain. These acute effects can present a threat to safe escape. At sufficiently high concentrations, most sensory and/or upper respiratory irritants can penetrate deeply into the lungs, causing pulmonary irritation effects that are normally related both to concentration and to the duration of exposure (i.e. dose). Generally these effects are not acute and are therefore not regarded as presenting a threat to safe escape. However, pulmonary irritation may cause post-exposure respiratory distress and even death from a few hours up to several days after exposure due to pulmonary oedema. Some important irritants are acrolein, SO2, formaldehyde, NO2, HF, HBr and HCl (IEC, 2010). According to the general guidance on toxicity of fire effluent (EN 60695-7-1) products of unusually high toxicity (i.e. other than asphyxiation or irritancy) have not been reported to be important in fires. Extreme toxic potency suggests that the toxicity of the products is much greater on a mass basis than the toxicity of usual fire effluent. There is at present no recorded instance of a fire in which the hazard resulted from extreme toxic potency. Many technical studies show that most products and materials give fire atmospheres of generally similar toxic potency (IEC, 2010).

The composition of the fire effluent from a given material is not an inherent property of that material, but is critically dependent on the conditions under which that material is burnt. Therefore, toxic product yields and the toxic potency of fire effluent are dependent on burning conditions. The thermal exposure conditions, the chemical composition of the fuel, the decomposition temperature and the amount of ventilation are the main variables which affect the composition of fire effluent, and hence the toxic potency ((IEC, 2010).

In daily life, people may be exposed to chemical substances via three routes: oral, dermal and via inhalation. For residents exposed to substances in smoke, inhalation is the most relevant route. In the European Union (EU) substances are classified for intrinsic dangerous properties according to the criteria of the Classification, labelling and packaging (CLP) Regulation (EC, 2008). The classification of some substances (relevant for smoke toxicity) for harmful effects via inhalation is presented in Table 4.

Different conditions for thermal decomposition exist: oxidative pyrolysis (heated without flaming), well-ventilated flaming combustion, ventilation-limited combustion (flash-over fire or fire in airtight spaces), and smouldering. Neviaser and Gann (Neviaser and Gann 2004) generated toxicity data with rats and mice exposed to smoke from single component combustible polymeric materials and a limited number of products. The data on smoke toxicity towards the laboratory animals showed a wide range of toxic potency. The potency was compared for material and fire conditions. In the under ventilated area, the toxic potency was dominated by the large amount of CO produced during under-ventilated burning. It could not be shown that smoke from under-ventilated fires would be more lethal than from well-ventilated fires of the same materials. However, the incapacitating potency (IC50) in under ventilated conditions is about twice as high as for well-ventilated conditions (for rats: IC50 =15 mg/m³ ± 10 mg/m³ and 7 mg/m³ ± 2 mg/m³ respectively) (Neviaser *and* Gann, 2004).

Table 4: Classification of substances for inhalation toxicity

Substance	**Cas No.**	**Harmonised classification (CLP regulation (EC) No. 1272/2008)**
CO_2	124-38-9	Not classified
NH_3	7664-41-7	Acute tox 3* H 331: toxic if inhaled
SO_2	7446-09-5	Acute tox 3* H 331: toxic if inhaled
Phosgene	75-44-5	Acute tox 2* H 330: fatal if inhaled
HF	7664-39-3	Acute tox 2* H 330: fatal if inhaled
HCN	74-90-8	Acute tox 2* H 330: fatal if inhaled
NO_2	10102-44-0	Acute tox 2* H 330: fatal if inhaled
Acrolein		Acute tox 1 H 330: fatal if inhaled
HCl	7647-01-0	STOT SE[3] 3 H335 May cause respiratory irritation
Formaldehyde	50-00-0	Acute tox 3* H 331: toxic if inhaled Carc. 1B H350 may cause cancer
Benzene	71-43-2	Carc. 1A H350 may cause cancer

*minimum classification: classification criteria according to Directive 67/548/EEC do not directly match with criteria of CLP (CLP Annex VI, section 1.2.1)

The fire toxicity of six insulation materials (glass wool, stone wool, extruded and expanded polystyrene foam, phenolic foam, polyurethane foam and polyisocyanurate foam) was investigated under a range of fire conditions, using the Purser Furnace (a bench-scale test). Stone wool and glass wool failed to ignite and gave consistently low yields of all of the toxic products. For polyisocyanurate and polyurethane foam a significant contribution from HCN was seen resulting in doubling of the overall toxicity, as the fire condition changed from well-ventilated to under-ventilated. Overall these materials showed an order of increasing fire toxicity, from stone wool (least toxic), glass wool, polystyrene, phenolic, polyurethane to polyisocyanurate foam (most toxic). The yield of HF, HCl and HBr was independent of the fire condition. The concentrations of CO2, NO2 and SO2 increased with ventilation while the concentrations of CO, HCN, acrolein, formaldehyde, aromatics, aldehydes and ketones decreased with ventilation (Stec *and* Hull, 2011).

[3] Specific target organ toxicity- single exposure

According to Hirschler (Hirschler 2015), published data overwhelmingly shows that flame retardants do not contribute significantly to either acute or chronic fire toxicity in real fires. However by inhibiting an efficient combustion and hence contributing to more soot particles, flame retardants may contribute indirectly to smoke toxicity. The U.S. National Research Council (NRC) investigated toxic effects of 5 individual flame retardants and 2 groups, and concluded that the risk index (exposure from furniture compared to a safe level) was below 1; there was a recommendation from the NRC to also investigate other flame retardants. In the EU the use of octa- and pentabromodiphenyl ether (pentaBDE and octaBDE) as flame retardant has been banned since 2004 (EC 2006), mainly due to the bioaccumulative potential and harmful effects on fauna. Hirschler takes the view that death from smoke is overwhelmingly correlated with high CO levels and hence increased COHb concentration. Heat release leads to more CO therefore controlling heat is more beneficial than controlling toxicity of combustion products (Hirschler 2015).

The Phosphorus, Inorganic & Nitrogen Flame Retardants Association (PINFA) published the results of a literature review on the impact of inorganic phosphorus and nitrogen (PIN FR) based flame retardants on gas and soot toxicity in case of fire in a confidential report that was made available for this study (PINFA, 2017). The question addressed in the study was whether the emission of toxic gases during a fire can be badly impacted by the presence of flame retardants. Twenty-two scientific papers were investigated in which the smoke toxicity was assessed. In these papers the testing methods (defining the fire conditions and scenario) and the scale (bench test or real fire conditions) were well defined. For real life, full scale fires, the literature review showed that there is a lack of studies on the impact of PIN FR on smoke toxicity and especially on the soot generated. Most of the 22 papers dealt with bench scale tests thus ignoring a lot of interactions between materials and the fire environment. None of the papers pointed out an adverse effect of the addition of PIN FRs or a synergistic effect on the smoke toxicity of burning materials compared to the non-FR versions

It is known that the presence of few asphyxiants and irritant gases adds up to the acute toxicity of smoke; however the main toxic gas is CO which is present in larger quantities than other gases as it is produced from all burning organic materials. Regarding the use of PIN FR, those acting in the gas phase (low oxidation degree phosphinates) are inhibiting the flame and can therefore result in more incomplete combustion products but there is no evidence of a negative effect on the global toxicity of smoke. PIN FR acting in a condensed phase (e.g. metal hydroxides and many high oxidation degree phosphate derivatives) by generating a protective charred layer can help reduce the yields of airborne products since gases and soot given off are partly trapped (PINFA, 2017),

PlasticsEurope provided a short summary of a test they commissioned for comparing toxic gases emitted from construction products including PS foams and various non-plastic insulation products. Cone calorimeter tests were performed on material samples, analogous to tests for railway (EN 45545-2-2013) and maritime applications. The aim was to investigate the toxicity of smoke of PS foams. The materials tested were EPS and XPS foams, cellulose insulation, stone wool, flax insulation, sheep wool insulation, wood panel, cork and LD fibre board. Some of the EPS and XPS foams, contained no flame retardant, the others had a brominated flame retardant (HBCD) or polymeric flame retardant. The concentrations of the following toxic combustion gases were analysed after 240 s and 480 s: CO, CO_2, HCN, NO_x, SO_2, HCl, HF and HBr. As used for railway applications, the Conventional Index of Toxicity (CIT) was calculated from the measured concentrations of these gases. This is a value, which adds up the results of the comparison of each measured gas to a reference value. The reference values used in the calculation of CIT are IDLH-values (Immediately Dangerous to Life and Health) which are limiting values for personal exposure (30 min) from NIOSH (National Institute for Occupational Safety and Health, USA). Isocyanates were not included in the CIT calculation as there are only IDLH-values published for a very limited number of specific isocyanates. CIT values of EPS and XPS varied between 0 and 0.04. CIT values for mineral wool products varied between 0.01 and 0.13. PlasticsEurope referred to a report (Fire behaviour of EPS, APME September 2002) that suggested combustion gases from PS foams are no more toxic than those from natural products, like wood, cork etc. (Plastics Europe 2015). However, details on measured concentrations of the different toxic substances are missing and the report on the original study is not publicly available.

In a report for the Dutch Government (Efectis, 2010), the authors concluded that based on real fires, when looking at the whole building and for the fires they investigated, there was no reason to conclude that today's applications of combustible insulation (mainly for roofs and external walls) lead to a specific risk to building occupants or a relevant contribution to the fire spread. However, it is stressed that for other applications, such as the use for internal dividing walls or in buildings with a high number of less self-sufficient people, the validity of this conclusion has to be further investigated. The toxicity of smoke gases from combustible insulation materials is not significantly higher and in a limited number of cases probably lower than those of other building materials (for example wood) (Efectis 2010).

In a Swedish hospital fire, a mattress was set on fire deliberately and produced enough heat and radiation to ignite a PVC flooring material that became then the main source for fire and smoke. The smoke produced was very heavy (Hertzberg et al. 2007). The fire was reconstructed with room content similar to the original room content, including a TV screen. The following gas species in the smoke were quantified: CO, HCl, HBr, HF, HCN, NO, NO2, ammonia and SO2. The smoke contained a very high amount of chlorides (max. 9800 ppm HCl after 600 s and 2200 ppm as 5 min mean value). For CO, HCl, HCN and isocyanates, the authors weighted the smoke gas concentrations with limit values (Table 6). For IDLH and AEGL-3 the 30' limit values are used, while ISO TR 9122-2 provides only a 5' lethal exposure limit. The results in Table 2 show that HCl might cause a higher risk than CO and HCN. The authors concluded that the influence of irritants (HCl) on the smoke toxicity might be generally underestimated compared to the influence of toxicants such as HCN.

Table 5: Toxicity comparison based on maximum smoke gas concentrations and limit values after Hertzberg et al. (2007)

Substance	Conc/IDLH	Conc/AEGL-3	Conc/ISO TR 9122-2
CO	10,0	15	1,0
HCl	196	47	0,8
HCN	9,6	23	1,9

Note that there are also other important, non-toxic, threats to life. These include the effects of heat and radiant energy, the effects of depletion of oxygen, and the effects of smoke obscuration (IEC International Electrotechnical Commission (2010)) but these are out of the scope of the project.

3.9.4 Risk characterisation

In risk characterisation, exposure concentrations are compared with 'safe' concentrations. For occupational risk characterisation, the 'safe' values are called 'occupational exposure limits' or OELs. For the evaluation of the risk from exposure to substances in smoke, Basmer and Zwick (Basmer and Zwick 2004) compared the measured concentrations with German short-term OELs (Maximale Arbeitsplatzkonzentration, MAK). In the fire experiment simulating a roof fire. Concentrations that were substantially above the MAK-values were not found. However it has to be indicated that the fires were outside, which means that if the fire experiments would have been performed inside with the same materials and with less oxygen, higher concentrations could have been measured.

For concentrations listed in Appendix D, the risk characterisation ratio is presented in Table 6: Occupational exposure limit (OEL) and emergency response (AEGL-3) limit values, and risk characterisation concentrations are compared with the 8hr-OEL, short-term OEL and AEGL-3. When more than one OEL is available, the lowest OEL of a range of OELs from EU member States is presented unless there is an OEL defined at EU level. There are no short-term OELs defined at European level.

Emergency response limits make it easy to quickly assess whether a short-term exposure to a substance means a health risk. Lethal toxic potency values associated with 30-min exposures of rats are predicted by ISO 13344:2015 for CO, CO2, O2 (vitiation), and if present in the smoke, HCN, HCl, HBr, HF, SO2, NO2, acrolein and formaldehyde. The ISO standard is only applicable for the estimation of the lethal toxic potency of fire effluent atmospheres generated under controlled laboratory conditions (ISO, 2015). The toxic potency values of ISO 13344:2015 can be used for life-safety (emergency response) predictions for people for short time intervals. One well-known example of emergency response limits are the Acute-Exposure-Guideline-Levels (AEGL). The AEGL-3 is the airborne concentration of a substance above which it is estimated that the general public could experience life-threatening health effects or death.

For the risk characterisation of the substances in smoke, the OELs and AEGL-3 values are compared with the measured concentrations presented in Appendix D. The results of the risk characterisation are presented in Table 6 in terms of concentration and duration of exposure. .If the exposure is higher than the limit value, or duration, there may be a health risk for those exposed.

Table 6: Occupational exposure limit (OEL) and emergency response (AEGL-3) limit values, and risk characterisation for data collected in Appendix D

Substance	Cas No.	8h-OEL (ppm)[4]	OEL (short term or 15 minutes average) (ppm)	AEGL-3 at 30 minutes (ppm)	Risk characterisation
Acrolein	107-02-8	0,09	0,1	2,5	3 exposures < dl 0 exposures > AEGL-3 6 exposures > short term OEL
NO2	10102-44-0	0,2 (EU)	0,5	25	0 exposures > AEGL-3 1 exposures > short term OEL
SO2	7446-09-5	0,5	1	30	1 exposures < dl 0 exposures > AEGL-3 5 exposures > short term OEL 3 exposures ≥ 8h-OEL 1 exposures < 8h-OEL (one exposure value with other metric)
HCN	74-90-8	1,8	3,6	21	6 exposures < dl 0 exposures > AEGL-3

[4] http://www.dguv.de/ifa/gestis/gestis-internationale-grenzwerte-fuer-chemische-substanzen-limit-values-for-chemical-agents/index-2.jsp

					1 exposures > short term OEL 1 exposures ≥ 8h-OEL 1 exposures < 8h-OEL (one exposure value with other metric)
HCl	7647-01-0	2	4	620	Other metric used
NH3	7664-41-7	20 (EU)	20	1553,75[*]	3 exposures < dl All other exposures < 8h-OEL (one exposure value with other metric)
CO	630-08-0	25	50	600	4 exposures > AEGL-3 5 exposures > short term OEL 3 exposures ≥ 8h-OEL 4 exposures < 8h-OEL
CO2	124-38-9	5000 (EU)	10000	-	Other metrics used

[*] Life threatening value (the Netherlands)

Note: Besides exposure to toxic substances, other circumstances may be fatal to residents: choking by fumes, burns, physical injury, opacity of the smoke, lack of oxygen in the room in combination with decreased oxygen transport in the blood due to CO poisoning and decreased oxygen use in the body cells due to HCN poisoning.

3.10 Discussion

A lot of information is available on substances present in smoke that may be toxic to those trying to escape from a fire. The substances in smoke that are the most well studied are CO, CO2, HCN and HCl. The information on smoke composition is mostly generated during fire experiments, be it with specific construction materials or from a fuel load that is not restricted to construction materials. In the latter case it is difficult to assign the share of the measured concentrations to the construction materials and other elements of the fire load, such as furniture.

Fire experiments with specific construction materials give the opportunity to measure which toxic substances are present in smoke generated from construction products, and to perform toxicity weighted ranking. On the one hand, this ranking is interesting because it provides the possibility for prioritisation in case of product optimisation or regulatory actions for decreasing the contribution of specific substances to smoke toxicity. On the other hand, it is well reported that it is difficult to translate the results of such a specific fire scenario to a real fire.

One way to obtain some useful data on the substances and concentrations of gas species that are produced during real fires is to integrate sensors and sampling devices into the clothing of firefighters. Besides substances causing asphyxiant effects or respiratory irritation, carcinogenic substances (benzene, formaldehyde) are also produced in smoke. Formaldehyde as such may originate from construction products, and benzene may be a construction product impurity, a fire reaction product or an environmental contaminant.

Adverse health effects to fire-fighters resulting from long-term chronic exposure to carcinogenic substances in smoke or absorbed onto particulate is outside the scope of this project, and it is our understanding that it is the subject of a further project being carried out by the European Commission.

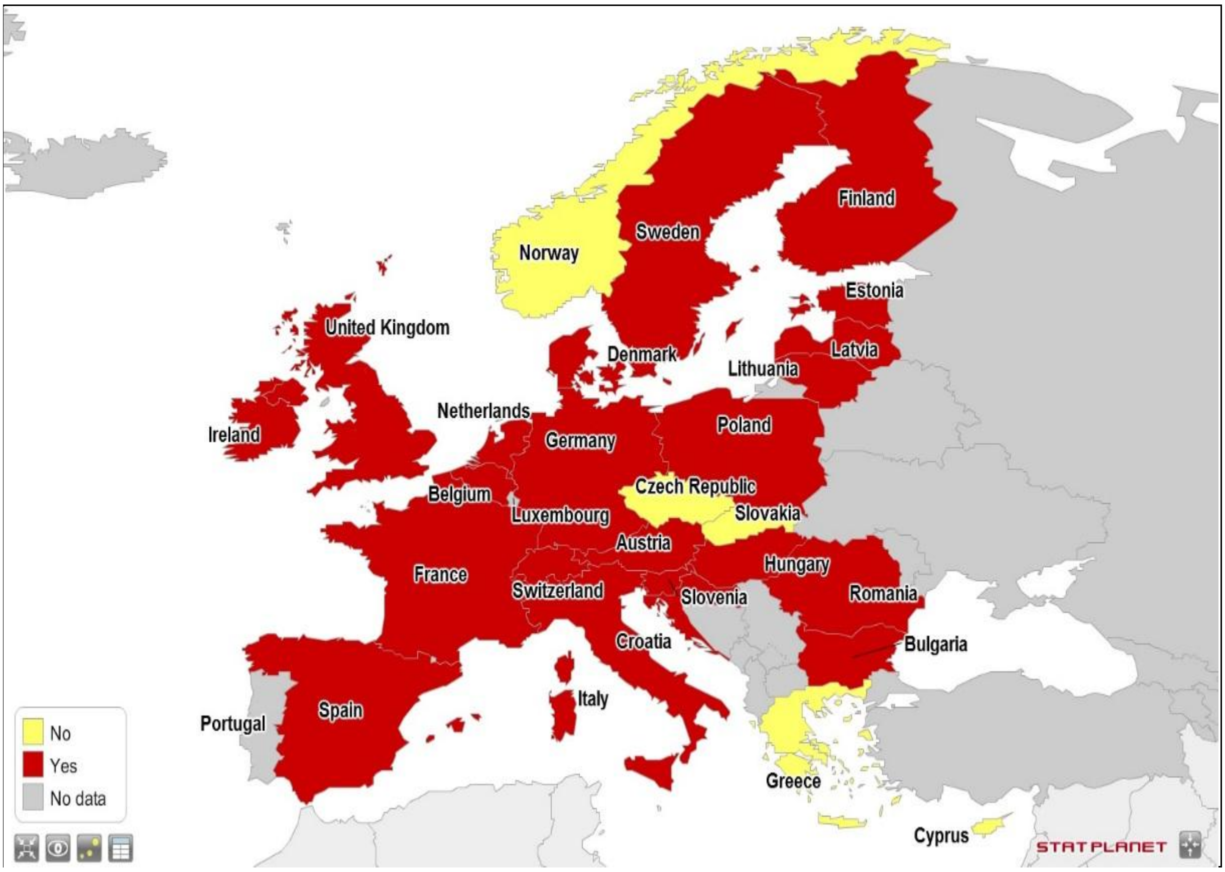
From this literature review it can be concluded that although a lot of research and standardization work has already been done on toxicity of combustion gases, the standards and reports cited in the study are examples of the current situation. The ways of testing toxicity and assessing the impact of toxic combustion products from construction products are still the subject of expert analysis and discussion between research and standardization experts, for example from ISO TC92/SC3. Therefore, even if one would decide to regulate at European level on smoke toxicity from construction products a lot of research and preparatory work to develop a robust and meaningful technical basis would be required.

4 Findings - Interviews

4.1 Current Regulations

As expected most Member States have some form of reguaiton related to the protection of building occupants from smoke (Figure 2)) but with the emphasis on compartmenation, ventilation, and evacuation.

Figure 2. Countries that have national regulations related to the protection of building occupants from smoke generated in building fires



Legend: YES/ NO/ NO DATA

In addition, many countries have regulations focussing of the safe use of the buildings e.g.:

- Keeping escape routes free and exits unlocked
- Fire safety organisation e.g. including regular fire drills
- Limitation of combustible content
- Mandatory active fire prevention means such as smoke detectors, alarms and sprinklers.

Many respondents agreed that smoke in itself is not specifically regulated in the sense of protection of people just from smoke, but that it is part of the larger framework of fire regulation which aimed at protecting people from smoke. Most national building regulations on fire strategies related to smoke concentrate on protecting buildings and inhabitants through:

A. **Passive fire protection**, which includes:
- Limiting fire development, and thus limiting generation of smoke (ignition, spread of fire);
- Limiting fire spread and smoke spread (e.g. fire doors, compartmentation);
- Providing safe escape.

B. **Active fire protection**, which includes:
- Providing early detection of fires (and in some cases automatic extinction) – smoke alarms;
- Smoke exhaust/ventilation systems.

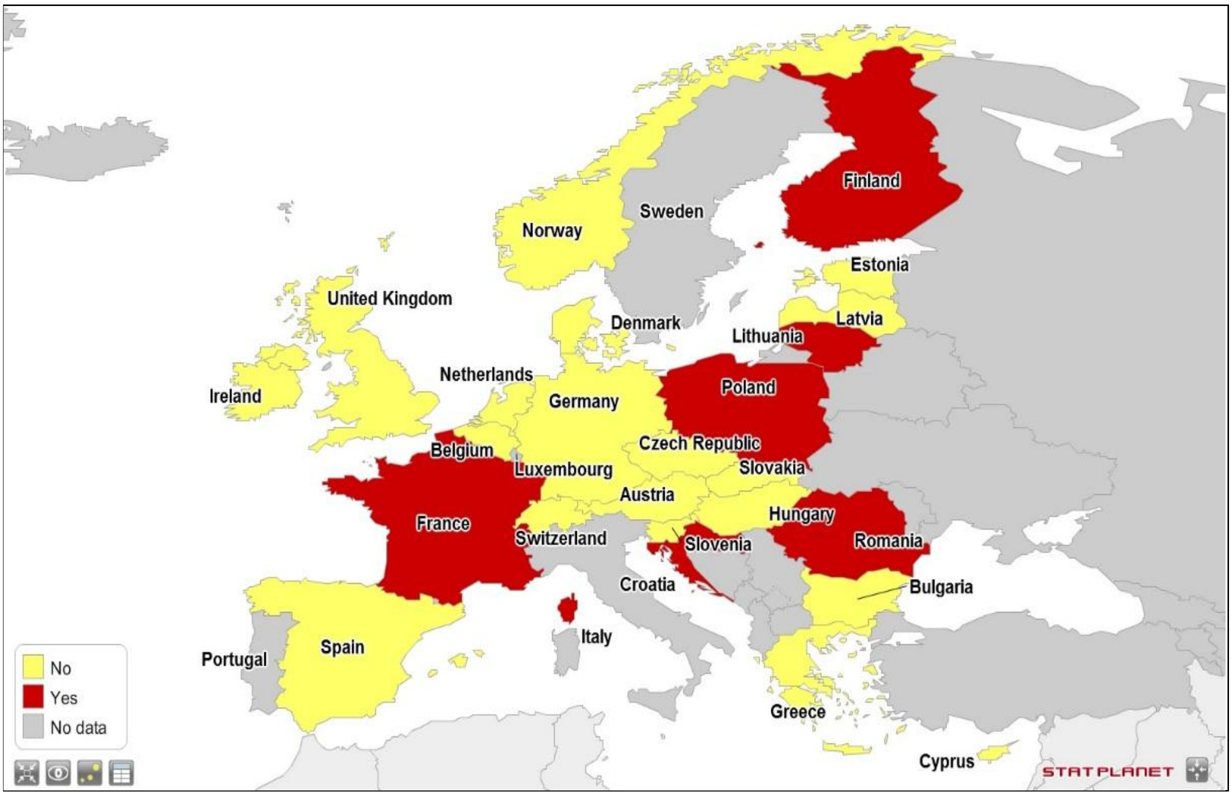
C. **Fire safety engineering methods** which tend to be applied to specific buildings.

Regulators commented that for construction products specifically, that a limited number of means to regulate smoke in building fires is included in the CPR.

Outside the scope of the CPR and building regulations, individual countries and the EU have regulation related to reduction of risk of and from fires. For example, reaction to fire requirements for furniture, specific requirements for cigarettes (self-extinguishing), lighters (children proof) or specific fire safety requirements for products in the sleeping environment of children.

Regarding national regulations or requirements related to the protection of building occupants from **toxicity of smoke** generated in building fires, the answers were limited (Figure 3). Member States regulations tend to cover toxicity of smoke in building fires and are not limited to construction products. The focus is to avoid the occurrence of fire, and the focus is not on toxicity.

Figure 3: Countries that have national regulations related to the protection of building occupants from toxicity of smoke generated in building fires



Legend: YES/ NO/ NO DATA

Countries that also regulate on the toxicity of smoke from construction products in fire	33%

Seven Member States[5] referenced regulations on the toxicity of smoke from construction products.

Belgium referred to requirements limited to certain electrical cables. These national requirements are in article 104 of the *Koninklijk besluit van 25 april 2013 tot wijziging van de artikelen 1, 3, 28, 100, 104, 151, 200 en 207 van het algemeen reglement op de elektrische installaties*[6] regarding the toxicity of electrical cables. The toxicity only relates to the corrosivity of the smoke from the cables which is mainly a property protection issue.

> "*Article 104 Fire precaution measures*
> *(…)*
> *f)* *Specific regulations*
> *f1)* *Formation of corrosive gases in case of fire*
>
> *In locations characterized by the external influencing factors BD2, BD3 and BD4 only cables with SA and SD characteristics may be installed."*

Where SA refers the acidity of the smoke and SD to the smoke production. The regulations prescribe the use of halogen-free cables.

This legislation has been notified to the EC under reference number 2010/87/B.

Croatia referred to a regulation on the fire resistance of the construction buildings, OG 29/13 and 87/15. S1, S2 and S3 classes for smoke production under the Ordinance on fire resistance and other requirements that buildings have to meet in case of fire (Croatian Official Gazette 29/13 and 87/17) are taken over from the EN13501-1[7] Standard and they are identical to S1, S2 and S3 classes listed in the additional classifications S1, S2 and S3 for smoke production in EN13501-1. For every category there is a prescribed construction material and system of permission of smoke production. However, this seems to be related to smoke production and not to smoke toxicity.

Finland - the regulation is for fire safety and not specifically for toxicity of smoke.

France referred to a regulation but added that it is rather limited scope. The regulation is "*the Order of 4 November 1975 regulating the use of certain materials and products in establishments open to the public*".[8]

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[5] Those identified are different from the Member States who responded in the interviews. Romania commented that "The regulations are implicit and don't cover all categories of buildings". No further information was provided or identified for the 'regulations' in Slovenia.

[6] Royal Decree amending Articles 1, 3, 28, 100, 104, 151, 200 and 207 of the General Regulations on Electrical Installations

[7] EN 13501-1:2007+A1:2009 Fire classification of construction products and building elements. Classification using test data from reaction to fire tests

[8] Source: https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000290159*and*fastPos=11*and*fastReqId=1436035552*and*categorieLien=cid*and*oldAction=rechTexte

The regulation refers to the use of synthetic materials and products such as synthetic plastics, fibres and textiles, elastomers, paints and varnishes, glues, the composition of which comprises nitrogen or chlorine which may be released in the form of hydrocyanic acid or hydrochloric acid, if the reaction to fire class is “worse” than B, s1[9]. The regulation refers to materials classified MO and M 1 which are part of an earlier French classification system which can be related to the European reaction to fire classes[10].

In addition, the requirement is strongly related to the end use of the product and the size of the room where it will be installed and applies to building receiving “outside visitors unfamiliar with the building”)

Compliance is verified by test reports and the “end user” is required to make the calculation for the specific installation (e.g. depending on the size of the room).

This regulation was notified to other member states under the TRIS 98/34 system but at a very early date.

Lithuania mentioned that the toxicity of smoke and evaluation of its ‘threat to life’ is partly regulated in Annex 6 of their national ‘*Main Fire Safety Requirements*’. Point 9 Annex 6 of the regulation is intended to regulate only if it is used method on the basis of calculations of fire engineering and risk assessment, it does not discriminate the source of the smoke - whether the smoke is caused by burning construction products or other materials. The calculations follow LST ISO/TR 13387 standards. The rules and the reference to Table 4 do not impose mandatory standards for the determination of toxicity of burning substances. This means that hazard data (maximum concentration) during a fire can be determined using selected generally accepted methodologies. Generally smoke toxicity is not regulated in cases where traditional design methods are applied.

This regulation was notified to other member states under the TRIS 98/34 system, reference IND-2010 0564 LT- EN- 2010 09 09 PROJET.

Poland. The main regulation is *'Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location (12 April 2002)'. Rules laid down in 'Regulation*...' which refers to 'PN-EN 13501 *Fire classification of construction products and building elements'* and 'PN-B-02855 *Fire protection of buildings - Test method for the secretion of toxic products of decomposition and combustion of materials'*. There are three levels of toxicity of construction products: moderately toxic, toxic, and very toxic. In general, the Polish legal acts divide smoke and toxic products generated in fire. They are treated separately. The smoke is considered mostly as an obstacle for firefighters during the rescue action. Toxic products are considered as harmful substances generated in fire.

[9] As defined in EN 13501-1:2007+A1:2009 Fire classification of construction products and building elements. Classification using test data from reaction to fire tests

[10] https://fr.wikipedia.org/wiki/Classement_de_r%C3%A9action_et_de_r%C3%A9sistance_au_feu

The requirements on toxicity of smoke for construction products concern only the group of public buildings occupied or visited by people. Private houses and apartments, storage and production halls and livestock buildings are not included in these regulations.

The measures refer to surface covering of walls (paints, wall paper, panels etc.. if visible) and toxicity of those, while others indicated that the requirement mainly concerns finishing materials and furniture. More specifically, they look at the surface of building elements, used in buildings (or part of buildings) characterised as high risk. These categories include buildings and/or compartments with a population of more than 50 persons (ZL I), for people with limited mobility: hospitals, retirement homes, nursery schools (ZL II), public houses (ZL III and ZL V). In such buildings and/or compartments, finishing materials should not have high fire toxicity as determined by 'PN-B-02855 *Fire protection of buildings - Test method for the secretion of toxic products of decomposition and combustion of materials*.

This regulation was notified to other member states under the TRIS 98/34 system at the time that Poland joined the EU. It has been amended twice in recent years and notified via TRIS on each occasion[11].

Sweden. "*Swedish National Board of Housing, Building and Planning's general recommendations BFS 2011:27 with amendments up to BFS 2013:12 on analytical design of fire protection for buildings(BBRAD)*" [12] describes 'alternative ways' – and in Table 6 (acceptable levels for the critical impact of fire for the verification of evacuation safety) sets limitations on CO, maximum level of CO_2, O_2 (shown below).

Design values for the fire scenarios should not be less than those specified in Table 6 for the early stages of the fire progression. These characteristics are applicable if well ventilated combustion can be expected.

Table 6 ***Design values for the production of soot and species for the early stages of the fire progression***

Occupancy	Soot production	CO-production	CO_2-production
Fire scenarios 1 and 2	0,10 g/g	0,10 g/g	2,5 g/g
Fire scenario 3	0,06 g/g	0,06 g/g	2,5 g/g

The values in Table 6 for required fire scenario 3 can also be used for required fire scenarios 1 and 2 if an automatic water sprinkler system is not provided within the space.

If the combustion takes place under ventilation-controlled conditions, this should be considered when selecting the values for production of soot, CO and CO_2.

[11] (OJ, No 75(690) of 2003, No 33(270) and of 2004, No 109(1156)

[12] http://www.boverket.se/en/start-in-english/publications/2013/the-swedish-national-board-of-housing-building-and-plannings-general-recommendations-on-the-analytical-design-of-a-buildings-fire-protection-bbrad/

The Swedish guideline is intended for analytical fire safety design, i.e. in cases where all prescriptive requirements are not met but where instead the safety of the building is showed to be equivalent or better by analytical design.

Compliance with the levels in the guideline is demonstrated by using numerical simulations (CFD) or alternatively by fire tests. Normally analytical design is used only for larger buildings with non-standard building solutions.

BBRAD are general recommendations if the builder choses to use fire safety engineering in order to deviate from prescriptive requirements. The CO and CO_2 levels are normally used as criteria and then CFD models are used for ASET/RSET (Acceptable / Required Safe Escape Time) analyses. Table 6 provides input values to use in the CFD model. This means that production of CO, and CO2 is linked to the design fire scenario, but not to a specific building product.

This regulation was notified to other member states under the TRIS 98/34 system

Another example provided was Germany which had regulations in the past specifically for testing of smoke toxicity for non-combustible products. Acidity of cables was tested, as the cables produce smoke with high level of toxicity, asphyxiating and debilitating. It was however decided that this was not needed in the current regulations as smoke obscuration is regulated and this was considered sufficient to control the exposure of the building occupants to smoke, whatever its composition is.

One comment that was made related to the fact that in reality there are so many scenarios in fires with multiple variables and rules on all aspects of fire safety, including toxicity of smoke, that have to be seen in context. As a result analysis should not be limited to the toxicity of a product, it needs to be related at the level of the entire fire. In this context two studies were mentioned as relevant:

"*Real-scale fire tests of one bedroom apartments with regard to tenability assessment"* (Guillaume *et al* 2014);

"*First Order Evaluation of Fire Hazard in a Room Due to the Burning of Poly(Vinyl Chloride) Products in a Plenum: Estimation of the Time Required to Establish an Untenable Atmosphere*" (Hirschler 1988).

.The solution for specific products and these parameters has been to identify well defined and relevant reference scenarios to characterise the fire hazard. Tests appropriate to these reference scenarios are then developed for products and provided that this information is available, designers, specifiers and /or fire engineers can utilise this relevant information within the building design.

The question on existing national regulations or requirements related to smoke generated in **non-building** (e.g. transport infrastructure) fires (Figure 4) provided some examples of this type. However, knowledge on this topic was rather inconsistently represented amongst respondents Regulators commented that different departments/regulators are responsible for fire safety in non-building applications. Where there were responses the comments were very similar to those for 'buildings' with the primary focus on the avoidance/extraction of smoke.

A number of test methods for characterising toxicity of smoke are currently being discussed in ISO (International Standardisation Organisation For regulatory purposes, standardised mandatory test methods for assessment of toxicity of combustion gases of materials and products have, so far, only been mandated in the area of transportation. This is because in vehicles and other means of transportation, escape of occupants from a fire may be delayed or not even possible at all.

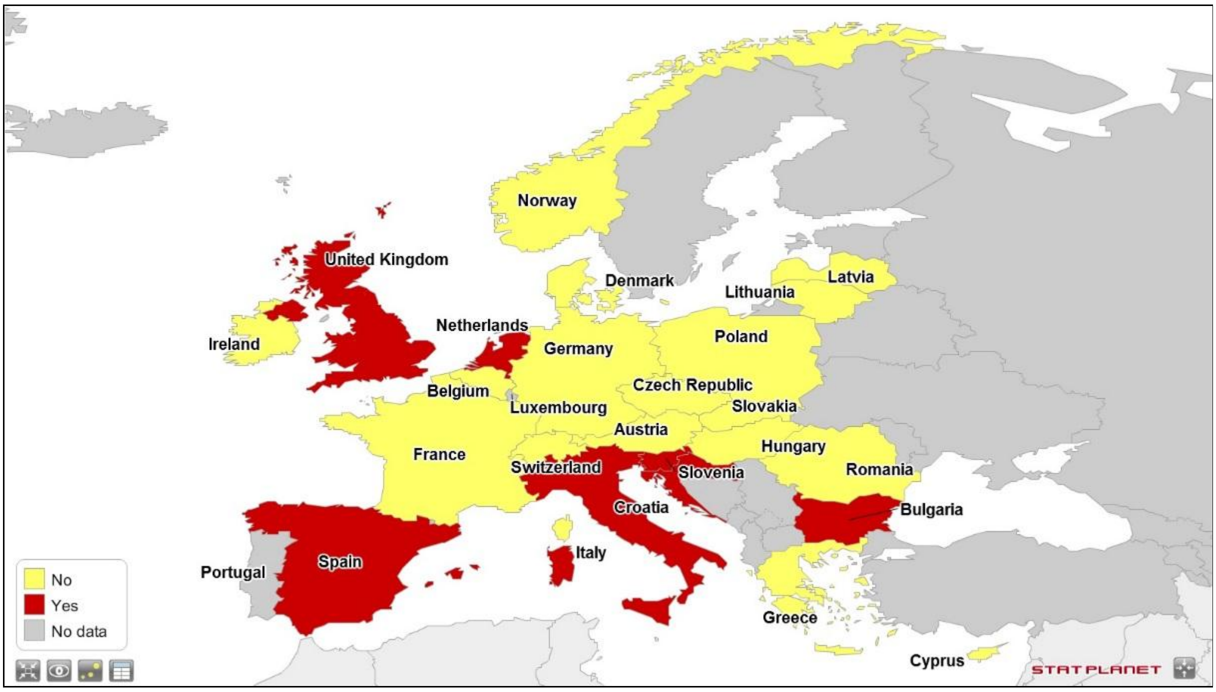
Organisations commonly mentioned regulations for ships; regulation for planes, and also for railways - trains. All acknowledged that this kind of provision is necessary for limiting the impact of fire because the escape is typically more difficult than in a . Materials used in ships, planes and trains typically have to be tested and classified for both quantity and toxicity of smoke in case of fire.

Of the Member States that stated they regulated for smoke in non-building locations only Spain referred to a regulation that specifically mentioned toxicity of smoke. The reference was to EN45545 EU Tunnel Safety Directive (2004/53/EC) Real Decreto 635/2006, however, this deals with smoke rather than toxicity (https://publications.europa.eu/en/publication-detail/-/publication/3681d17d-ec25-4d1a-b189-01af9633e04c/language-en).

In addition, several interviews referred to the requirements of London Underground Ltd "Fire safety performance of materials Number: 1-085" which makes reference to the toxic fume test B2 in Annex B of BS 6853.

http://www.prolitepartnership.eu/wp-content/uploads/2015/05/London-Underground-Subsurface-Fire-safety-Standards-1-085.pdf

Figure 4. Countries that have national regulations related to smoke generated in non-building (e.g. transport infrastructure) fires



Legend: **YES/ NO/ NO DATA**

Countries that regulate also on smoke generated by fires in structures which are not considered to be buildings (e.g. transport infrastructure)	14.3%

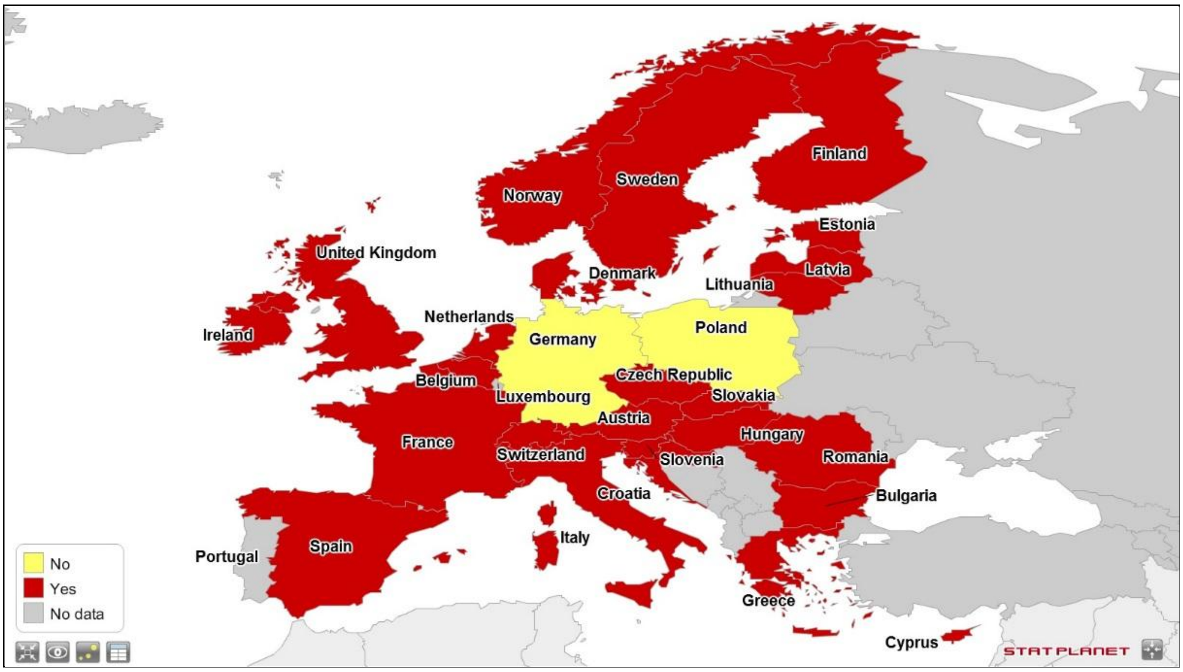
When asked about national regulations or requirements that prescribe or promote the use of **fire resistant construction products** in buildings, the aspect that was raised multiple times was which definition of "fire resistant" should be considered, as there are different definitions from different industries. Fire resistance is part of each European Member States' building regulations, but there are substantial differences between the application of classes to specific building types and locations within them. Reaction to fire was also mentioned as a specific type of characteristic that could be used to define 'fire resistance'. National fire regulations in most cases have a number of requirements for controlling ignition, fire growth and fire spread within a building and between buildings. Reaction to fire, resistance to fire, external fire performance, and characteristics of products provide some of the tools for satisfying these depending on factors that include building type, use, size and location. .

Most Member States have some requirement for the use of fire resistance products (Figure 5) in order to demonstrate compliance with national regulations. In most countries, these are part of the regulations regarding reaction and resistance to fire. In some Member states products classified A1 or A2 or low combustivity are required in some specific part of a building and this is used as a way to prescribe non-combustible products. These requirements are usual linked to the application domain, for example the function of the building or the height or the function of the location within the building.

As smoke is generally toxic, these regulations are aimed at limiting the production and spread of smoke limiting the risk of exposure to smoke of inhabitants whatever its composition. All countries have such requirements, but not explicitly related to toxicity.

Besides regulations on construction products, there are some regulations for products such as cables, which are of two separate categories (flame retardant and fire resistant).

Figure 5: Do you have regulations that prescribe or promote the use of fire resistant construction products in building?



Legend: **YES/ NO/ NO DATA**

Countries where these regulations stipulate application domain (for example type of buildings)	88%
Countries where toxicity of smoke explicitly or implicitly taken into account in the regulation	20%

Some regulators stated that the purpose of compartmentation is to contain fire and smoke. As a result all countries have such requirements, but not explicitly related to toxicity.

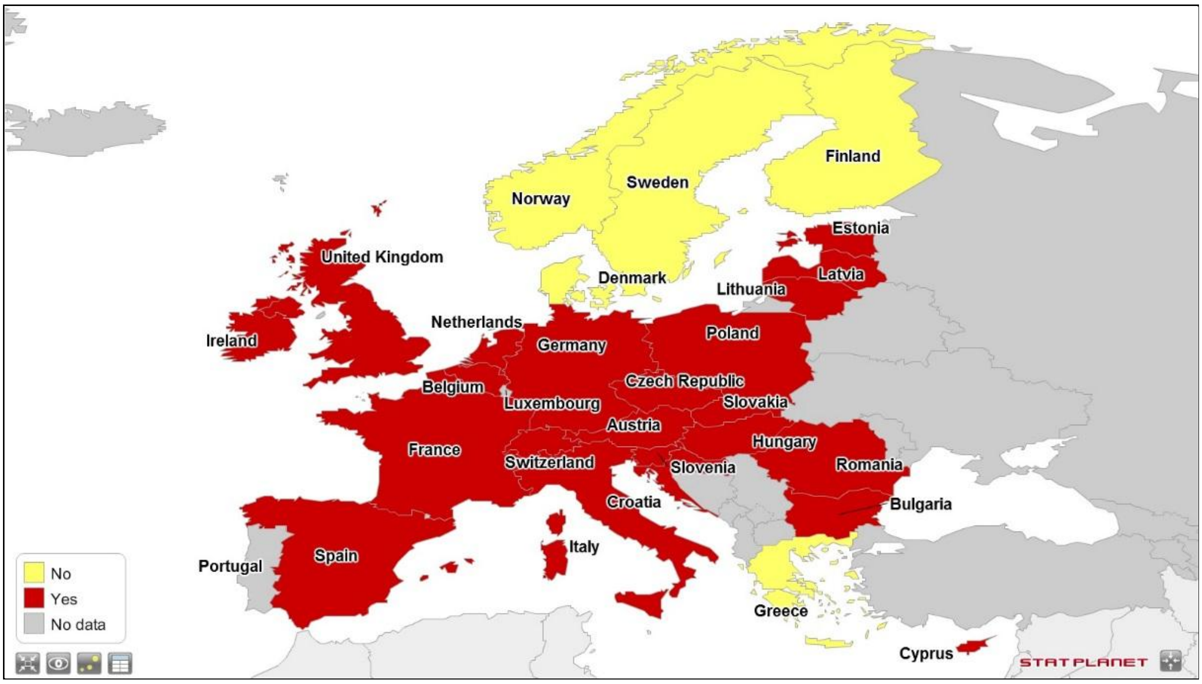
Five MSs mention having regulations that take account of smoke toxicity but analysis of the responses indicates that these are all implicit, for example by control of the amount of smoke. The only known exception is Poland (already detailed before).Outside the European Union, it was mentioned that China and in Russia are considering toxicity.

The last question of this section inquired on national regulations or requirements that prohibit, or restrict the use of combustible construction products in buildings, and if known, the application domain, as well as if toxicity of smoke explicitly or implicitly was taken into account.

Three participants commented directly that combustible and incombustible are not terms used in regulation, but that these concepts are captured through the European reaction to fire classifications (A1 to F). It could therefore be argued that prescribing the minimum acceptable class implies prohibition of others and in some cases, it was commented that this was a duplication or overlap with question 4.

There are national regulations (Figure 6) that restrict the use of combustible products in some buildings or parts of building. Reaction to fire is an important characteristic in every European Member State however, the specific classes of behaviour required differ based on building types and parts.

Figure 6: Countries having regulations that prohibit, or restrict the use of combustible construction in buildings



Legend: **YES/ NO/ NO DATA**

Countries where these regulations stipulate application domain (for example type of buildings)	95,5%
Countries where toxicity of smoke explicitly or implicitly taken into account in the regulation	31,8%

National regulations or requirements that restrict the use of flammable construction products in buildings is a standard approach to the mitigation of risk of fire growth and therefore implicitly also smoke generation. Examples can be found in any national regulation, especially for building parts/areas critical for means of escape. The underlying assumption being that low flammability leads to low contribution to fire development and hence low smoke development (in terms of volume) as well. Smoke toxicity in relation to flammability is not regulated in buildings or contents.

Occasionally the requirements are more explicit, for example in Denmark this is not regulated in the Building Regulations The guidance document produced by the Transport, Building and House Agency

may contain limitations (limited use in pre-accepted solutions). In Denmark there are rules in the emergency legislation, e.g. in the Executive Order on flammable and combustible liquids[13]. Other MSs (for example Norway) have a similar approach where combustible products need to the protected by other products.
A generally acknowledged side benefit of allowing only products with a certain combustibility rating is to limit heavy smoke generation in practice; although there is no general correlation between combustibility and smoke emissions as they depend on a broad range of variables as already discussed.

Almost all building regulations and regulations for construction products in Europe include requirements related to the reaction to fire behaviour of building elements, construction products or materials. Legally these shall refer to European classifications according to EN13501-1. The requirements vary from country to country depending on criteria such as:

- the type of building
- the size and height of the building
- ignition location within the building or building element
- whether this part of the building is an escape route
- other fire safety provisions (e.g. fire detection and alarms, sprinkler system).

It was observed that restrictions sometimes exist for specific situations such as escape routes or spaces occupied by many people or specific categories of population (hospitals, schools…). In all cases, the restrictions are based on the CPR classification of products that supplements other provisions applicable e.g. to the design of the building or the room, to active means, to furniture.

Eight MSs responded that toxicity is implicitly or explicitly taken into account. All appear to be implicit and/or general. For example, in Poland it is prohibited to use combustible construction products, which generate intensive smoke or very toxic substances.

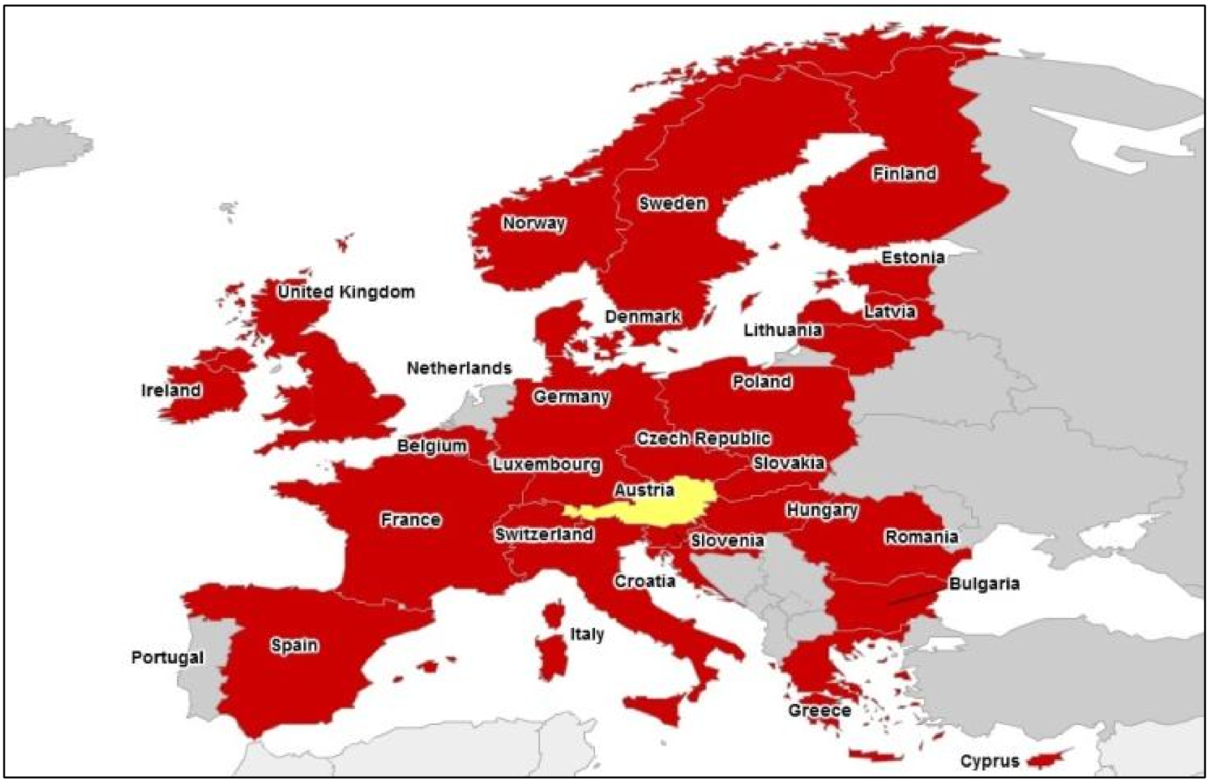
4.2 Fire Statistics

4.2.1 Member State Regulators

Member State regulators were asked about the statistics that were collected in their countries. Figure 7 shows those member states that collect fire statics.

[13] Executive Order no 1639 of December 2016 on flammable and combustible liquids: 3.7.4.7 Combustible insulating materials may only be used in walls whose insulating materials on all sides are covered with at least building class EI 60 A2-s1, d0 (BS-building part 60).

Figure 7: Countries that have fire statistics



Legend: **YES/** NO/ **NO DATA**

Countries recording numbers of fires	100%
Countries recording number of fire deaths	100%
Countries recording number of fire injuries	88%

Regulators were also asked if they had a definition of 'injury' and whether they have records related to fire victims. The responses are show in

Figure 8 and Figure 9.

Figure 8: Countries that have a definition of “injury”

Legend: **YES/ NO/ NO DATA**

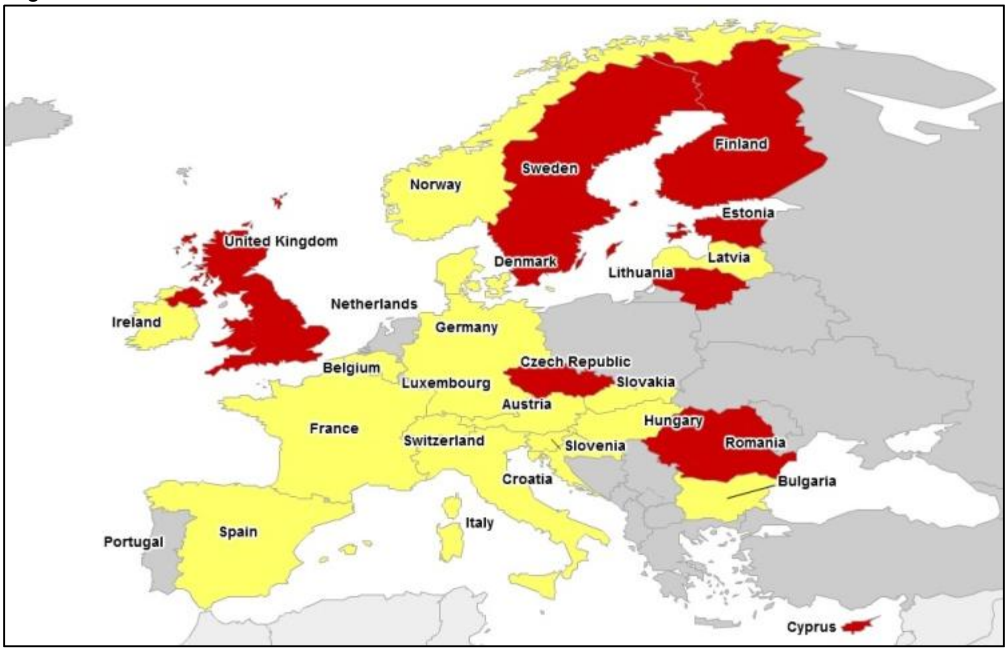
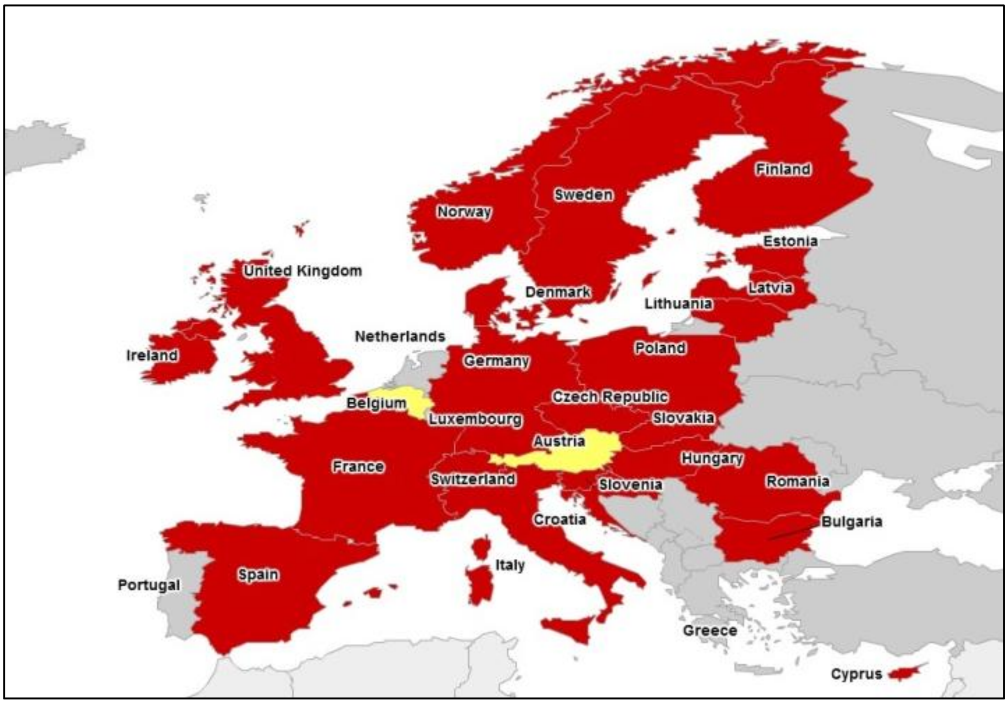


Figure 9: Countries that have records related to fire victims



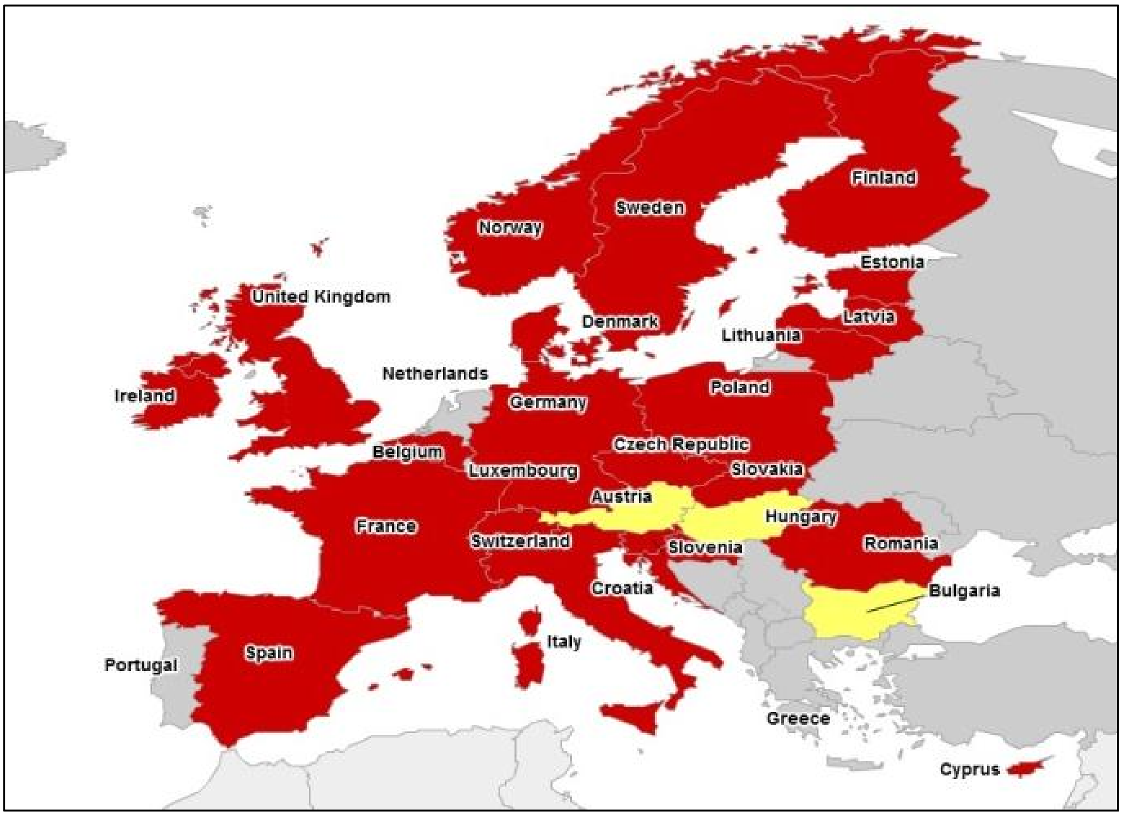
Legend: **YES/ NO/ NO DATA**

Countries recording number of deaths in building fires	100%

Countries recording number of deaths - other types of fire (e.g. vehicle fires)	87%
Countries recording number of deaths in fires that involve construction products	17,4%
Countries recording number of deaths in other types of building fire (e.g. those just involving contents such as furniture)	21,7%
Countries recording the nature of the injury / cause of death (e.g. smoke inhalation)	39%
Countries recording proportion of deaths from smoke inhalation.	39%

As expected as the level of detail increases the number of Member States recording that information decreases. Of those recording the number of deaths in fires that involve construction products and those recording the proportion of deaths from smoke inhalation the records are usually general and non-specific. For example, assuming that a fatality without physical injury is due to smoke inhalation.

Figure 10: Countries with information available on the building that was on fire



Legend: YES/ NO/ NO DATA

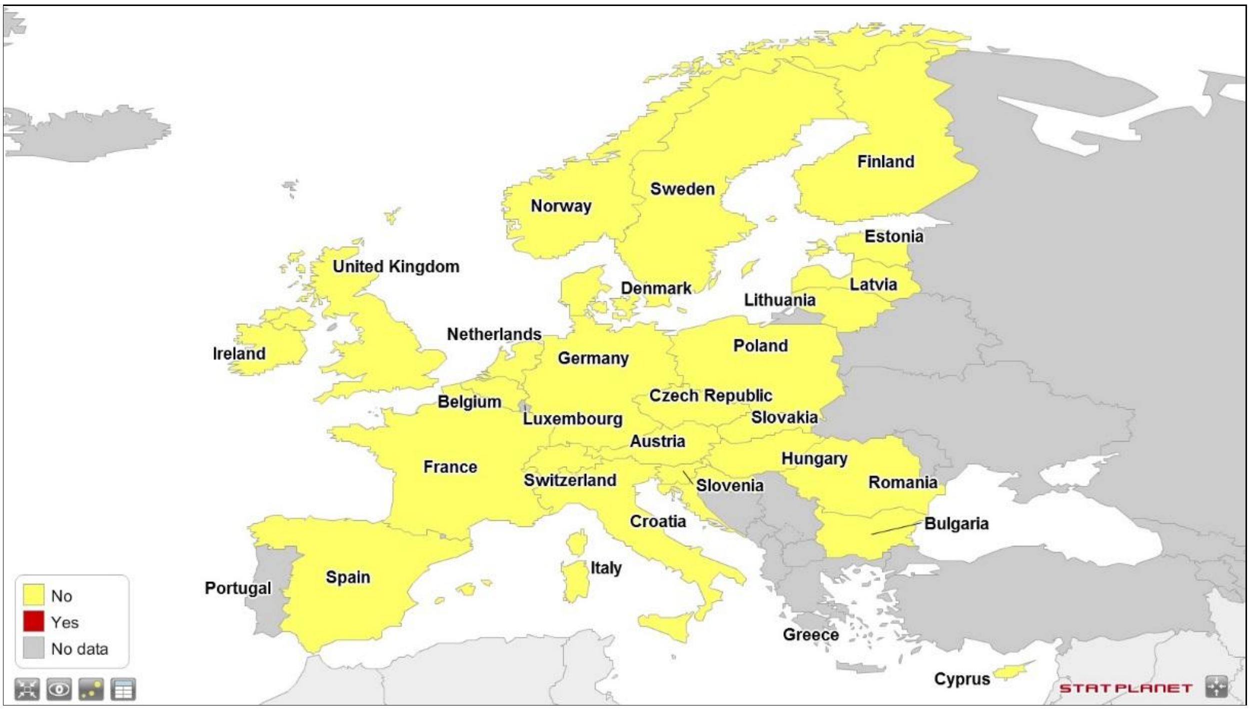
Countries with record on the type of building	81,8%
Countries with record on the main construction products used	40,9%
Countries with record on the presence fire resistant products indoors	31,8%
Countries with record on combustible furniture in the building	22,7%
Countries with record of other information	22,7%

Again the more specific the data, the less MSs collecting these details. Even where the data is collected there is no consistent approach. Most data that is collected is recorded in response to the requirements of individual fire investigations and the data may not be easily accessible.

There is no evidence from the statistics collected by Member States that victims in fires have died from inhalation of toxic gases specifically from construction products.

Figure 11). Some collect data on the presence of construction materials and their contribution to the fire; some collect data on fatalities linked to smoke inhalation; one (see below) has limited data on the toxic gases responsible (Figure 12); but no MS has data that identifies the inhalation of smoke from construction products as the cause of death.[14]

Figure 11: Countries with evidence that victims died from inhalation of toxic gases specifically from construction products



Legend: **YES/ NO/ NO DATA**

[14] There are specific case studies (for example the Bucharest fire) that identify certain materials as the source of the smoke but this type of data is exceptional. (See Section 3.3.2.2 below)

Figure 12: Countries collecting details on the gases, which are commonly responsible

Legend: **YES/ NO/ NO DATA**

4.2.2 European Organisations and Representatives

The first question of this section for Organisations and Representatives focused on examples of fires where victims died from inhalation of **toxic gases specifically from construction products**. However, due to the title of the section (on statistics) many respondents also specified that they do not have statistics, but just examples of fires. On these statistics it was mentioned that national fire statistics do not normally differentiate between death by inhalation of fire effluents from construction materials vs. the content of the building (e.g. furniture, decoration, clothes, textiles, consumer goods and papers/books), therefore it would be difficult to respond to this question.

While not having information from statistics, most participants agreed that it would be highly necessary to start to develop such statistics, preferably in a harmonised manner. Fire statistics could be used to identify and evaluate risk scenarios.

Looking in advance of such statistics being collected it was clear that proper definitions of terminology used would be necessary.

Regarding the gases which are commonly responsible for the death of fire victims following inhalation, the fact that smoke is considered always toxic was once again emphasised.

The source of the specific gases is not easy to determine, and the provided examples do not refer to gases specific to construction products in particular. Gases that are identified in any fire typically come from materials other than construction products. While there is some knowledge in this area, the opinion was shared that in most cases the exact mix of gases that contributed to death was not analysed to determine which gas was responsible and without statistics, this is difficult to determine.

In principle, both the lack of oxygen and well as high temperatures can be fatal. With reference to gases, carbon monoxide (CO) is considered to be the main cause of fatalities as it is the first gas that is emitted during a fire, and the most frequently identified, post mortem. Some interviewees thought that hydrogen cyanide (HCN) is more important than initially thought, particularly when there are materials containing nitrogen.

The tests used in transport (EN 45545) include a list of toxic gases that must be measured. It was suggested by a participant that during the development of those standards, valuable material may have been collected.

Specific case studies were cited by several interviewees with the Bucharest night club fire and the Rouen Restaurant and Dusseldorf Airport referred to most often. Apart from these there were no other clear examples where construction products[15] rather than fabric/fittings/contents contributed, and even in these examples, there seems to be general agreement that the problems come from non- compliance with existing national regulations – for example, in the choice or installation of materials. There are also references to the role of fabrics and furnishings in fires. One comment was that '*Enforcement of existing regulations is more important than new ones*'.

It was commented that it might be possible to use fire statistics could be used to identify and evaluate those cases and risk scenarios, where fire toxicity is a primary source of fire victims and injuries. For these, the relative importance of various sources of fire gases would need to be defined: items in the contents of the building, and building parts (surface and core products). Based on the relevant scenarios and risk evaluation, criteria and performance classes could be determined; and as the last step, a suitable test method should be developed to give information from tests representing the defined combustion conditions in an appropriate scenario.

In addition, it was acknowledged that the composition of toxic fire gases from a certain construction product does not only depend from the product burning, but also very much from the circumstances of the fire. This includes amount of oxygen available, temperatures in the room, location, size and orientation of the product.

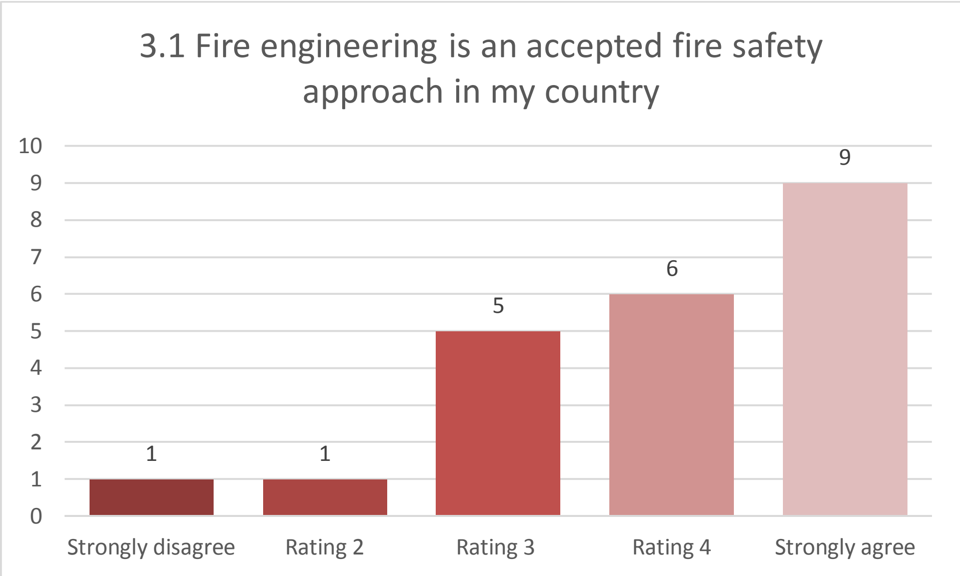
It was also stressed by many interviewees that some substances that are carcinogenic are more a problem for fire fighters as an occupational health hazard as such are regulated separately.

4.3 Fire engineering is an accepted fire safety approach

Interviews with the Member State regulators confirmed that fire safety engineering was an accepted approach (Figure 13) but generally as a method of demonstrating compliance with existing national regulations. There were also some concerns that the models and methods used in fire safety engineering were difficult to validate and so concerns were raised about the information and its application.

[15] Some of the 'construction materials' referred to are not within the scope of the CPR

Figure 13: Regulator responses – question 3.1



During the interviews with the European organisations and representatives, there were particular difficulties in rating the first statement, first of all due to the terminology "fire engineering" and secondly due to the possible interpretation of "acceptable". On fire engineering, the distinction was done on acceptability from the scientific point of view, and then the respondents that raised this aspect, all agreed that the rating would be 5, as opposed to acceptability from the regulatory perspective. In this situation, the realities as they are, now show differences between countries, therefore the level of acceptability of these rules decreases due to their inconsistent implementation and content.

Figure 14 and Figure 15 below show the difference in results in the two situations. Thus, most respondents agree with the fact that, if implemented systematically and following commonly agreed scientific principles, then fire safety engineering is "acceptable" to be used as a means to prevent risks. Regarding the current fire safety engineering implementation in regulation, in many countries there is no or little reference to fire safety engineering. Much more work needs to be done until it becomes acceptable, like developing it further, more validation to be done, as well as education in support of fire safety engineering.

Figure 14: Responses from Organisations to fire engineering questions (1)

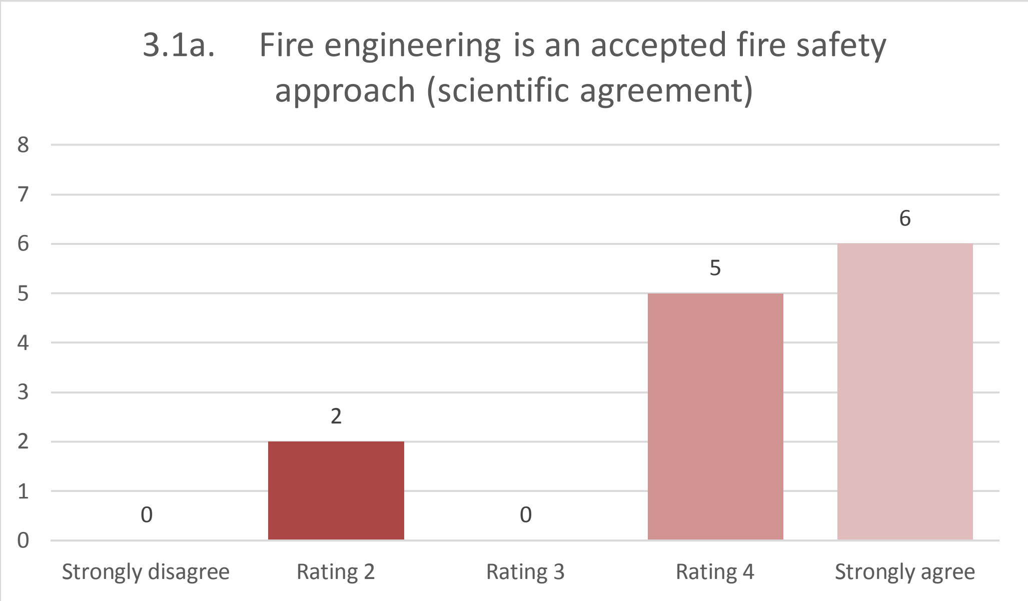


Figure 15: Responses from Organisations to fire engineering questions (2)

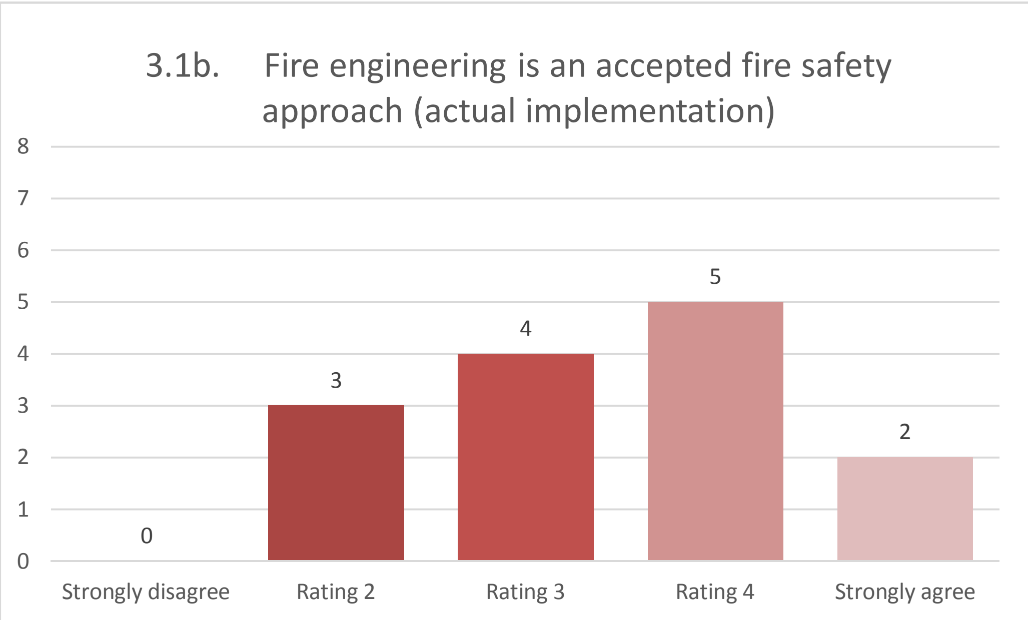
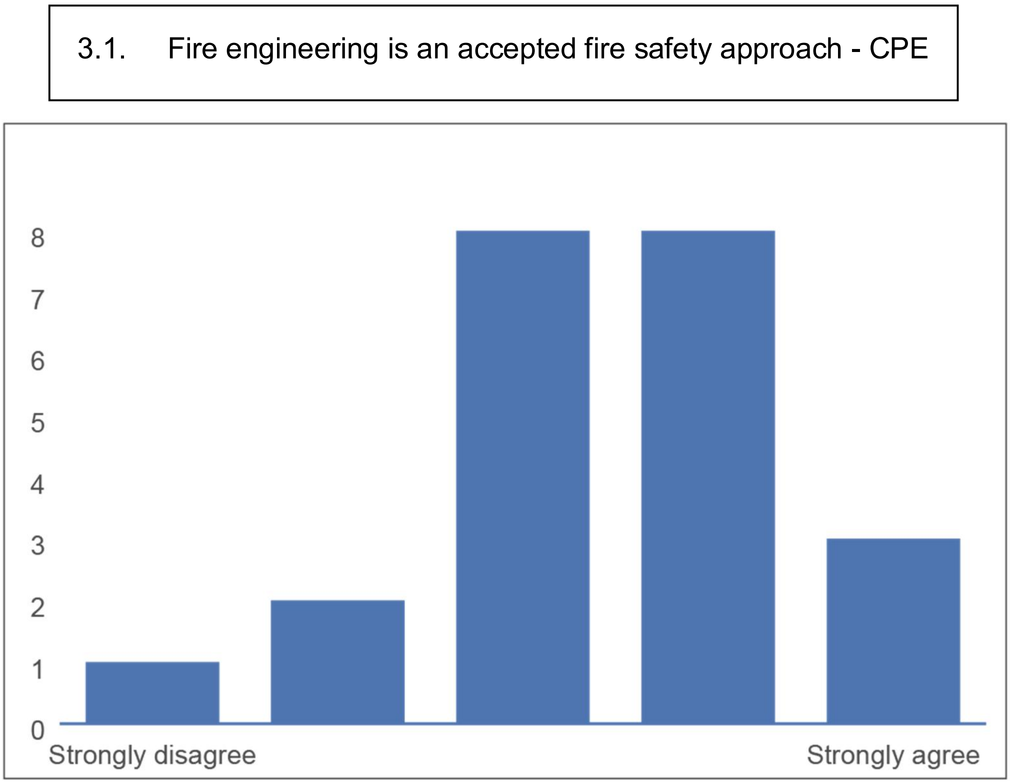


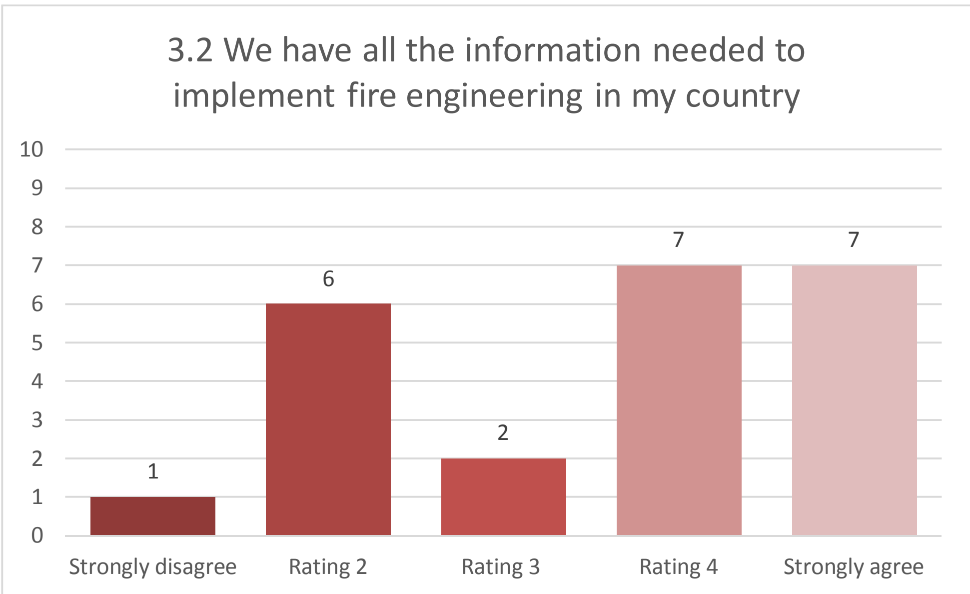
Figure 16: CPE responses - question 3.1



4.4 We have all the information needed to implement fire engineering

On the second question in this section there was a significant minority who believed that further information was required Figure 17.

Figure 17: Regulator responses – question 3.2



The European Organisations and Representatives were less positive about the availability of information (Figure 18) and commented that some aspects of fire safety engineering were seen as problematic. These were related to the uncertainty and robustness of FSE design, the need for a full set of input data including toxicity (smoke toxicity is missing from these rules) as well as the need for information on how some products interact. It was stated that the uncertainty of the design is impossible to determine, as different answers will be given in different contexts.

The respondents also expressed the view that more validation is necessary, especially validation in the case of more complex construction, for which the modelling of (multi-layer) products in their end use is still very difficult. The availability and publication of data in transparent databases, with a clear maintenance process of these databases is lacking.

On the other side, opinions were expressed that one can never have all the information needed, as the development of a deeper understanding of fire sciences, test methods and material properties is ongoing. The work carried out in the UK on BS 7974 is however considered as instrumental in understanding and forming an excellent basis for a common European approach.

As fire safety engineering gains traction, effort in training of Fire Engineers (and all other agencies involved with fire, such as the fire brigades) is essential to support improvements in safety through fire engineering. This approach is exactly the scope of the ISO TC 92, Sub-committee 4.

Figure 18: Responses from Organisations - question 3.2

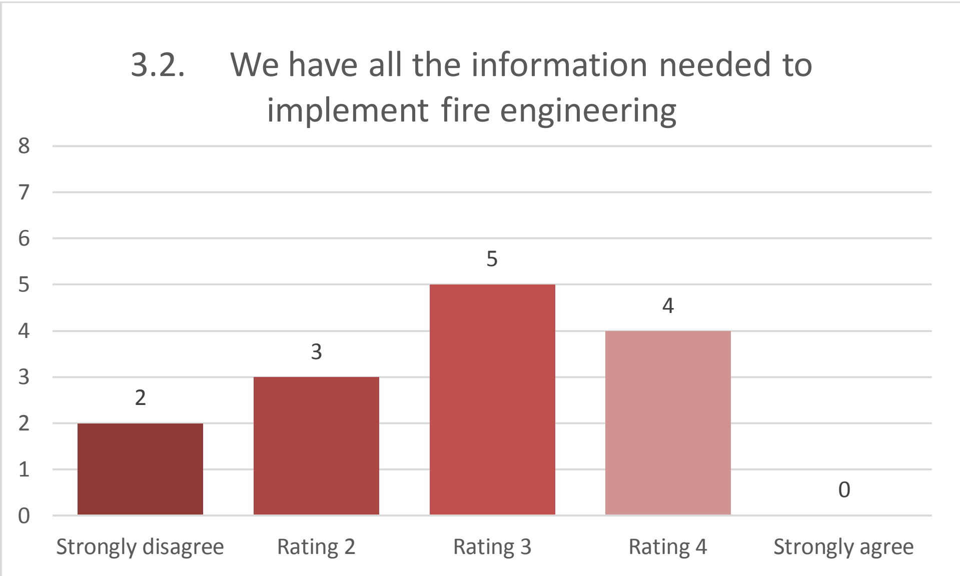
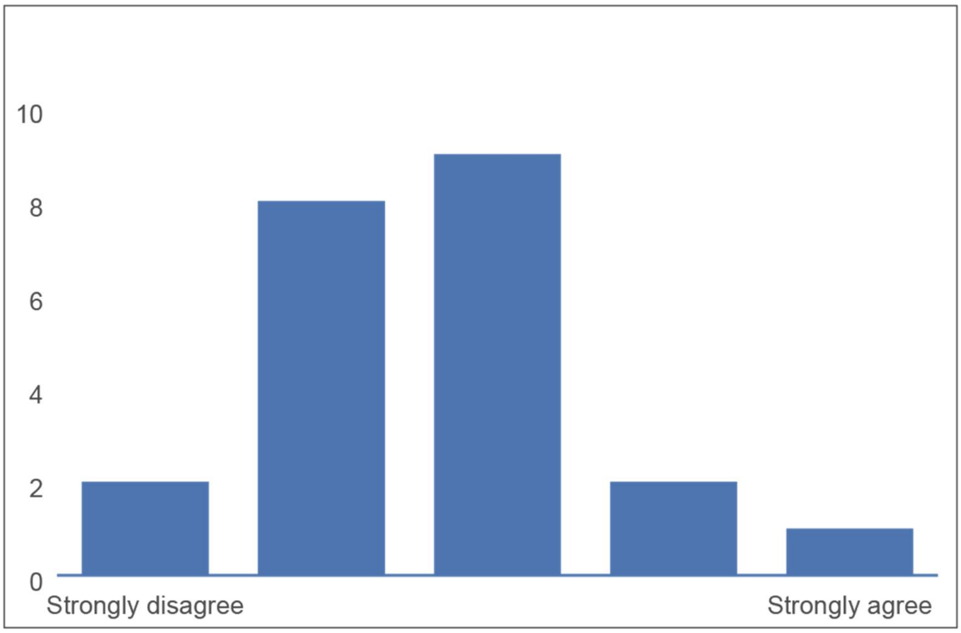


Figure 19: CPE responses – question 3.2

3.2. We have all the information needed to implement fire engineering



4.5 Fire engineering could deliver effective benefits in Europe

On the third statement of this section there is more consensus that fire safety engineering has the potential to deliver benefits to Europe (see Figure 20, Figure 21 and Figure 22) in order to achieve the targeted level of fire safety in the most cost effective way, as an alternative to prescriptive regulation.

However many interviewees believed it is not ready yet, and many more aspects need to be clarified, such as what kind of fire safety engineering and for what purpose: fire spread, smoke spread, risk evaluation, escape? Also opinion was expressed that fire safety engineering in the sense of toxicity modelling is in a very early development stage and it is far too early to consider modelling toxicity without any experience.

One Member State's Regulator commented that the benefits were likely to be greater for certain types of buildings but not for all. Another commented that, if used properly, fire safety engineering could deliver significant benefits, but if the use were distorted, uninformed and negligent, use of fire engineering could be counterproductive.

Figure 20: Regulator responses – question 3.3

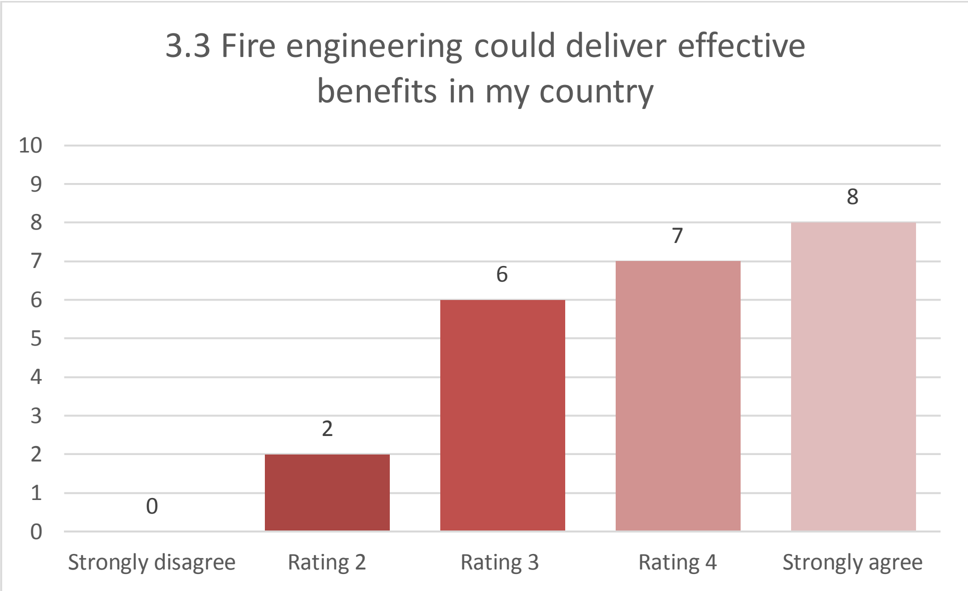


Figure 21: Organisation responses – question 3.3

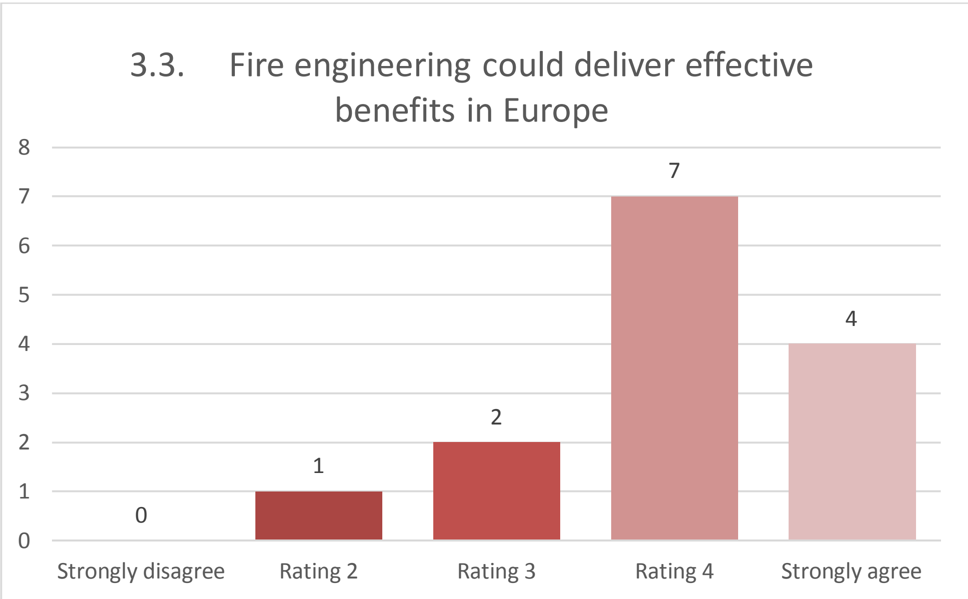
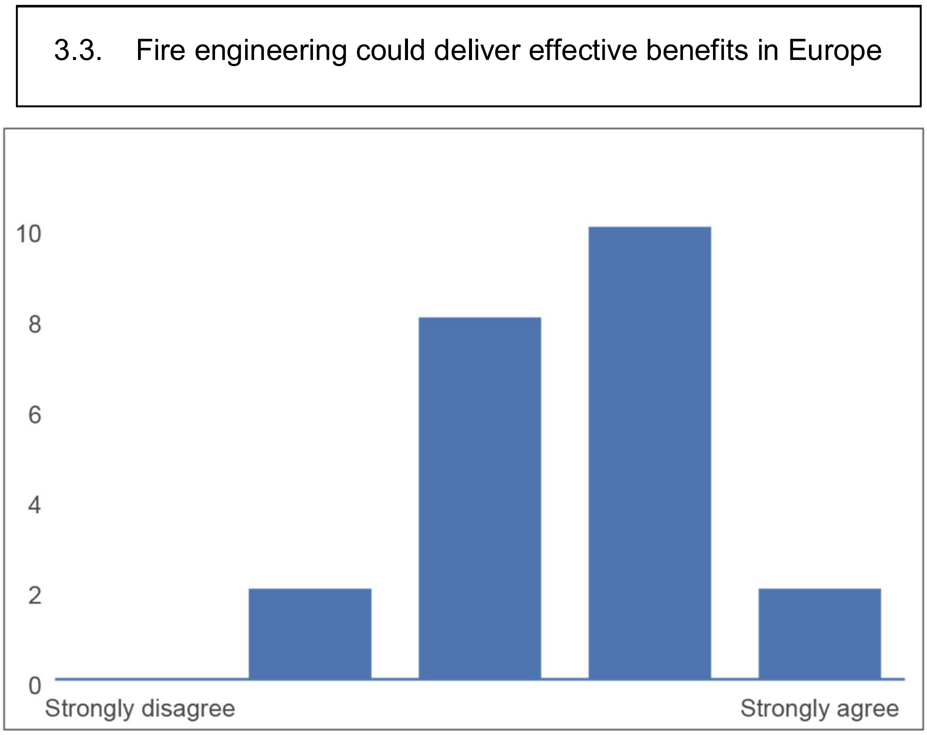
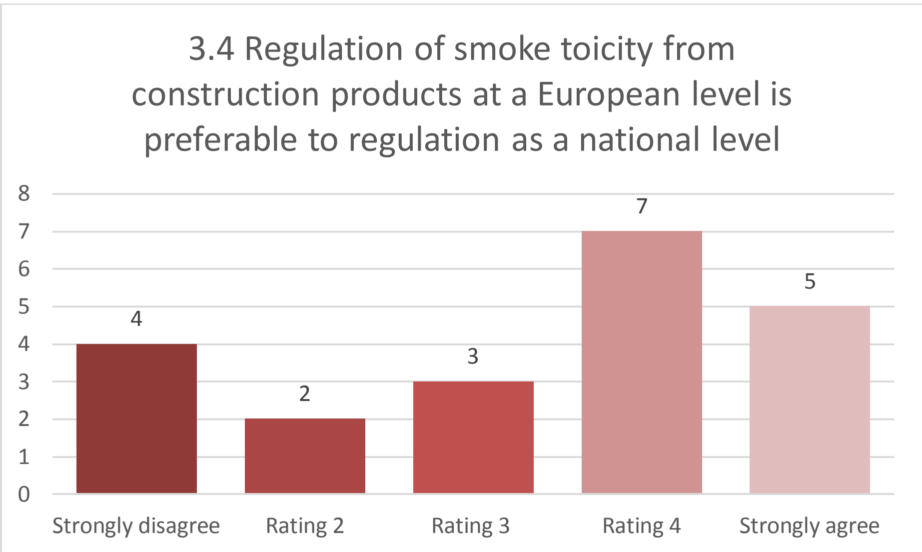


Figure 22: CPE responses – question 3.3



Regulators responses were consistent in agreeing that harmonized regulation at European level would be more efficient in comparison to regulation on a national level (Figure 23). There were also comments that regulation was not required at EU or member state level.

Figure 23: Regulator responses – question 3.4



In the interviews with organisations and representatives the statement on preference for legislation on European vs national level was met with reservations, with some participants choosing not to express an opinion, while others were of the opinion that neither is an option from their perspective, therefore didn't want to give a rating (Figure 24).

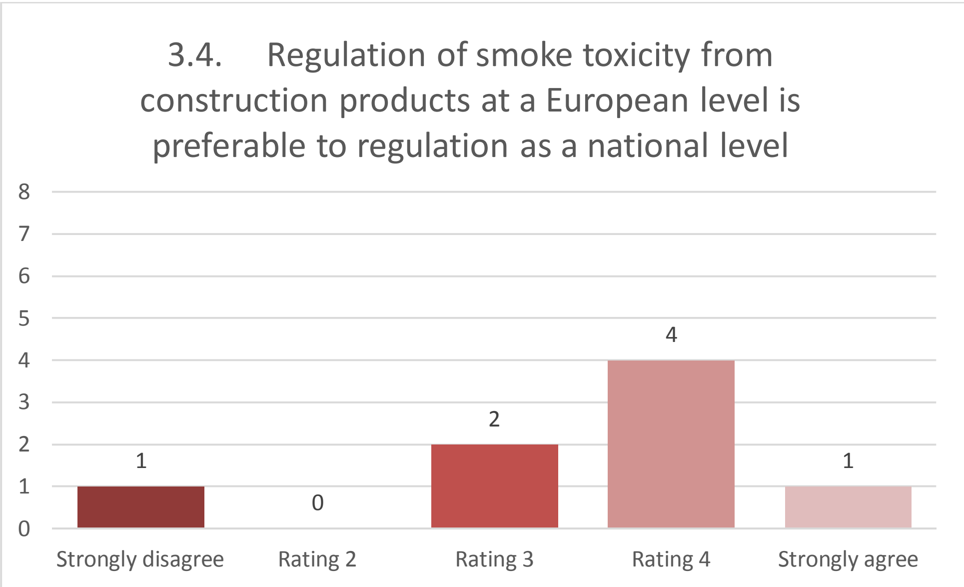
Preference for an EU wide approach was supported by several organisations who referred to available statistical information which indicates a steady decrease of fire deaths in the last decades[16]. In the words of EUPC

> "*it is not justified to regulate on toxicity of smoke resulting from construction products neither at European or national level, both because they are not primarily involved in the development of fire, and because the smoke cannot be differentiated between building and non-building products.*"

The principles of the EU "Better Regulation" initiative could cover this with clarification of the following elements:

- Evidence based regulation;
- Coherency of measures: does it make sense to introduce heavy measures towards construction products without measures in the field of the building content, which has the highest contribution to toxic smoke;
- Proportionality of the intervention related to the expected result;
- Evaluation of alternative policy options.

Figure 24: Organisation responses – question 3.4



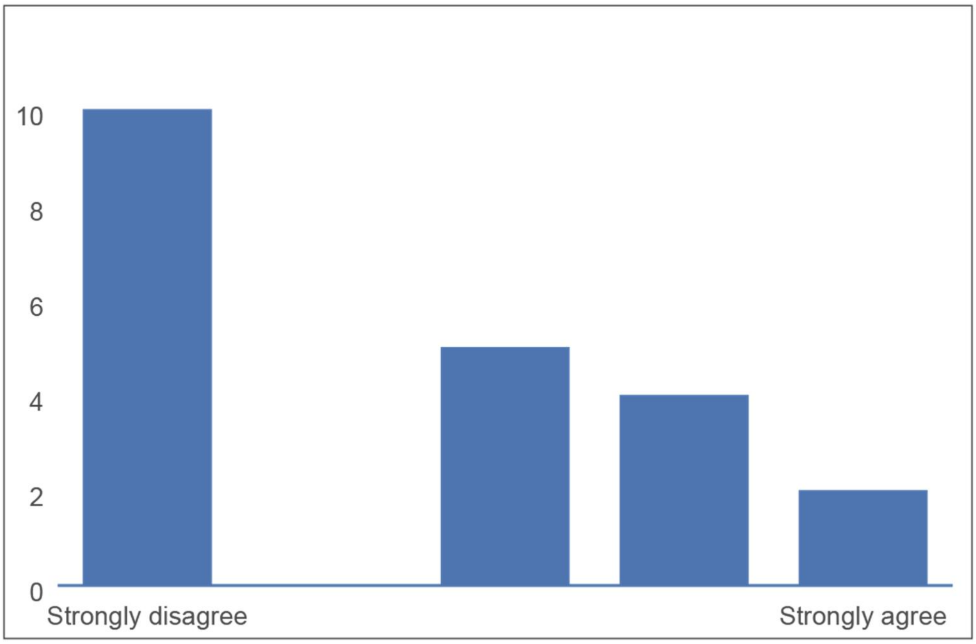
The responses from the CPE survey were less positive (Figure 25) about regulation at an EU level. This is thought to reflect a difference in understanding in that strong regulation at the EU level was seen as

[16] *According to ANSES study (2014 09) in countries where smoke detectors are implemented more than 80%, the death rate in building fires and also the number of fire requested fire brigades intervention have decreased by 50%.*
According to a French study (NIBRA 2009) Products firstly involved in fire are mostly non-building products: Bed sheets (23%) furniture (20%), clothing (16%) paper (6%) waste (5%)

potentially removing the ability to set performance requirements at the national level. In the face to face interviews undertaken with other European organisations, the study team's understanding of regulation was explained. Suggestions were provided that if regulation were considered necessary then it should follow the same principles as with the European Reaction to Fire (RtF) classifications, where the safety levels are set nationally but refer to common test standards.

Figure 25: CPE responses – question 3.4

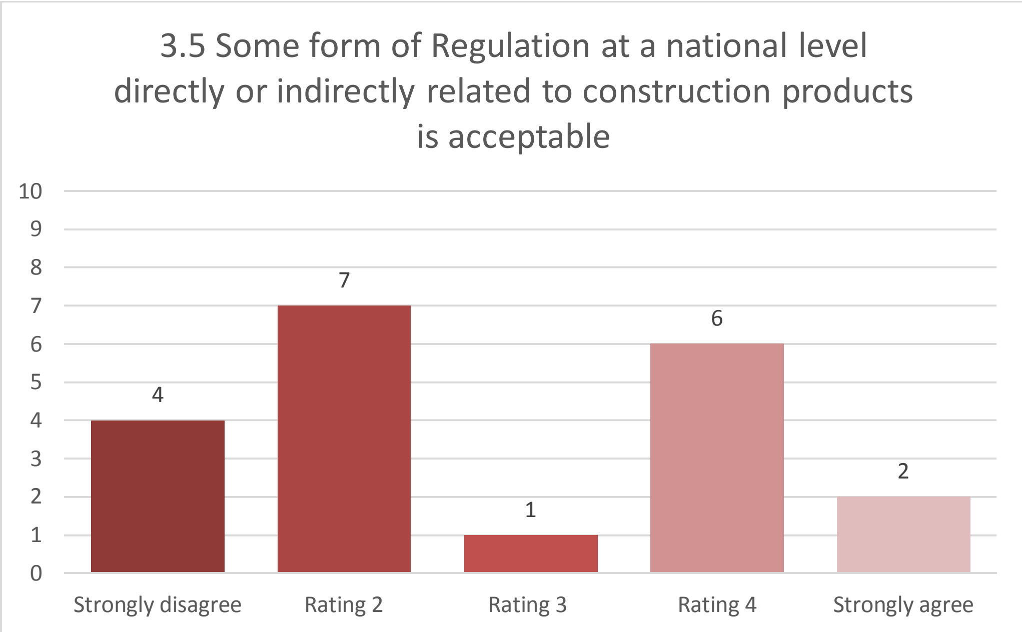
3.4. Regulation of smoke toxicity from construction products at a European level is preferable to regulation as a national level



4.6 Some form of Regulation at a national level directly or indirectly related to construction products is acceptable

The responses from the Regulators showed that if there were a robust case for regulation then they supported an EU wide approach but regulation at the member state level (Figure 26).

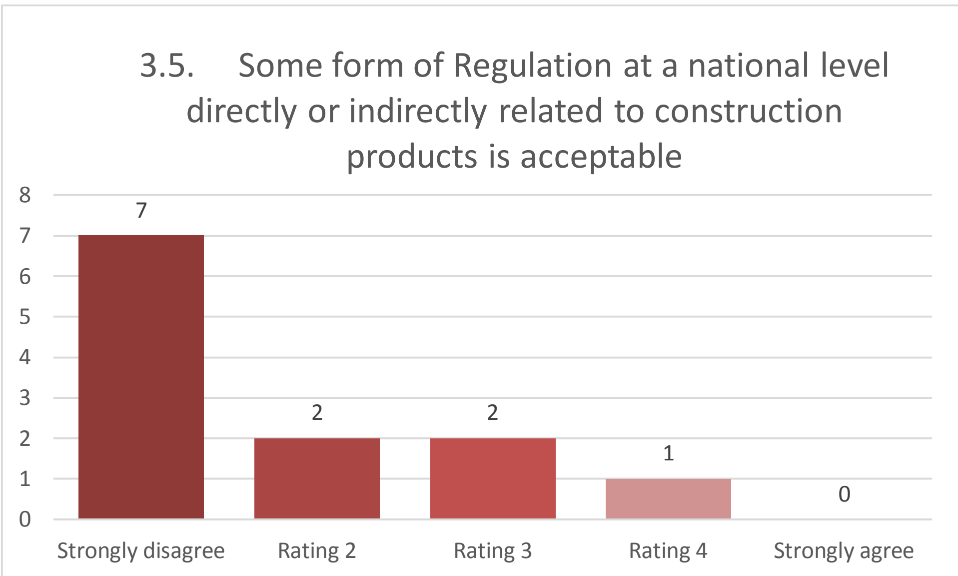
Figure 26: Regulator responses – question 3.5



With respect to the direct or indirect regulation at national level, the large majority of organisations and representatives were against this option (Figure 27), considering that it will create de facto barriers to trade close to a ban for affected products. Also regulation should not only apply to construction products but also for relevant items of building contents (e.g. furniture).

However the question is considered also not sufficiently clear and giving space to interpretations. The considered interpretation which was answered was of regulation which is “*additional regulation at national level for smoke toxicity of construction products*”.

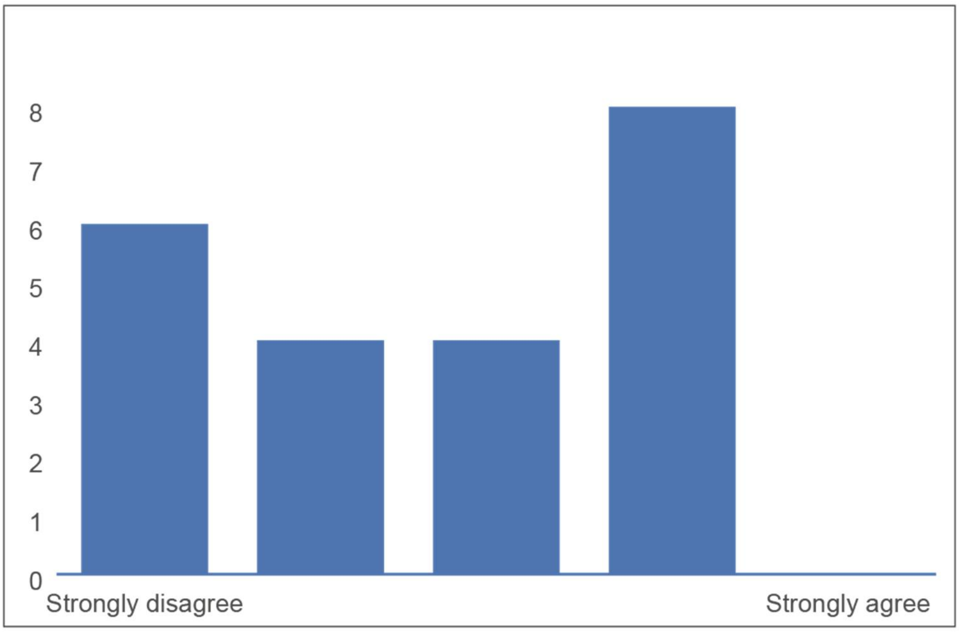
Figure 27: Organisation responses – question 3.5



The responses from the CPE survey showed a greater range of responses (Figure 28) - and as with the previous question this reflected the difference in understanding regarding regulation.

Figure 28: CPE responses – question 3.5

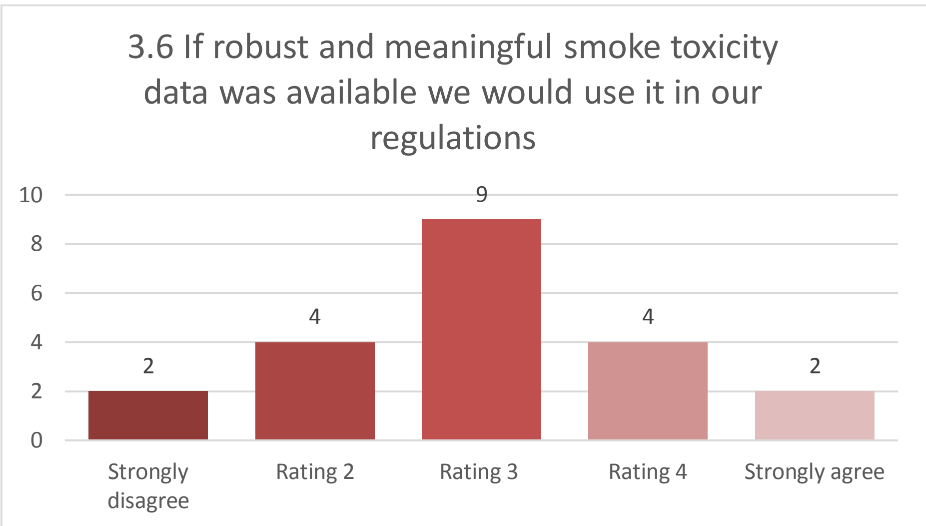
3.5. Some form of Regulation at a national level directly or indirectly related to construction products is acceptable



4.7 If robust and meaningful smoke toxicity data was available then it could be used to support regulations

The general impression from the interviews with the regulators was that they did not have a strong opinion for or against the need for regulation and so they were not sure that they would use it in national regulations (Figure 29).

Figure 29: Regulator responses – question 3.6



On the final statement of this section most European Organisations and Representatives strongly disagreed with the fact that meaningful smoke toxicity data could be used to support regulations if available (Figure 30). Only two organisations agreed, with one organisation strongly agreeing, as can be seen in graph below.

In the CPE responses there was a greater spread of responses with 10 respondents supporting the idea that data were available, it could be used to support regulation (Figure 31).

Figure 30: Organisation responses – question 3.6

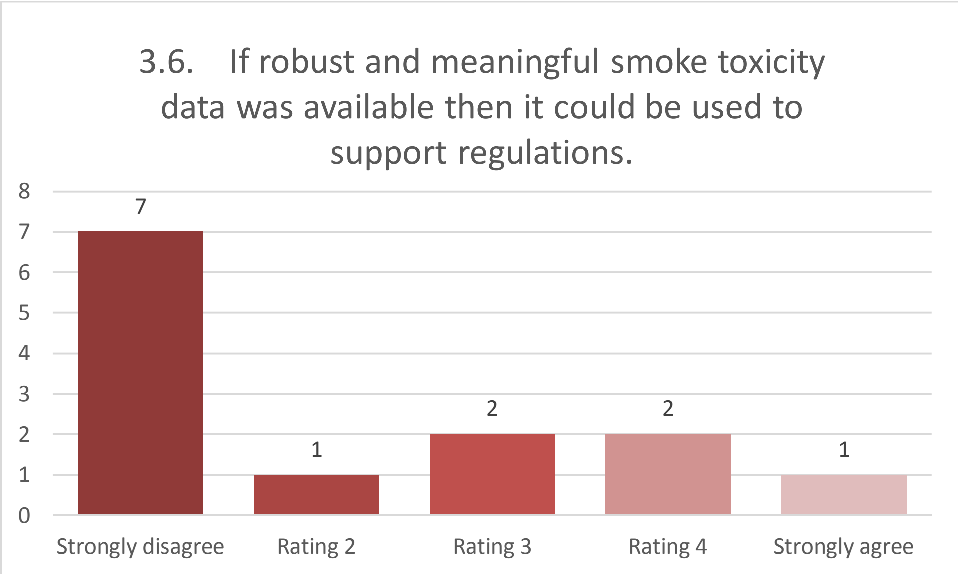
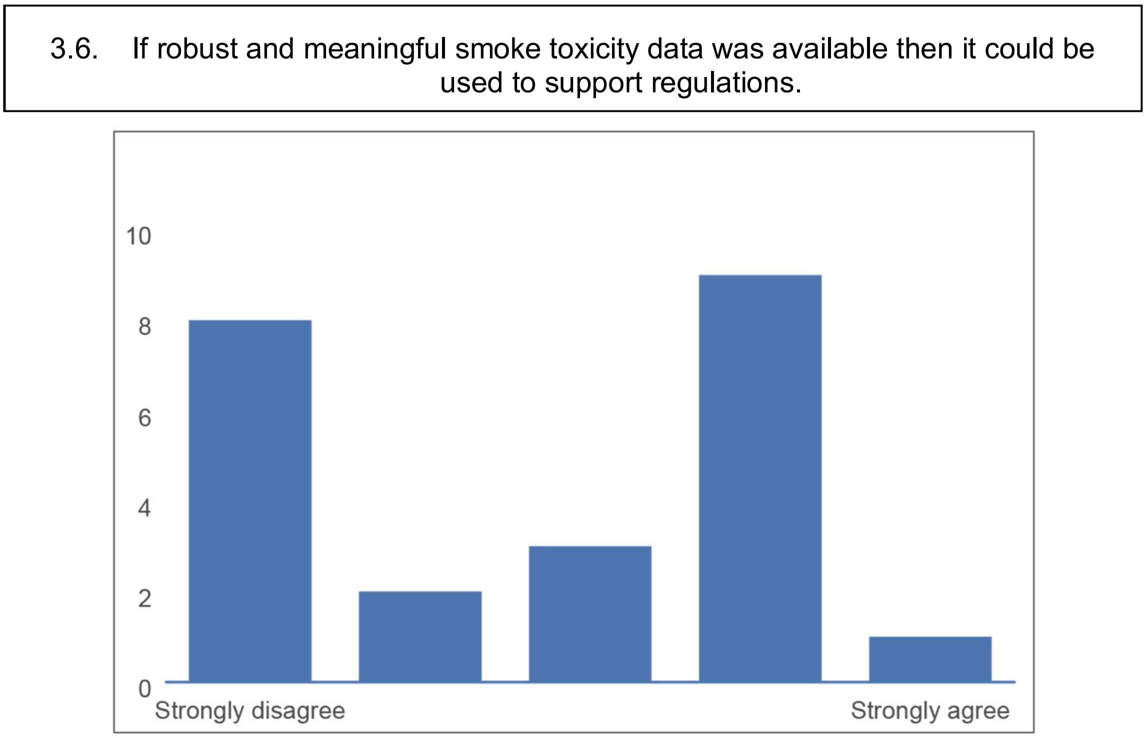


Figure 31: CPE responses – question 3.6



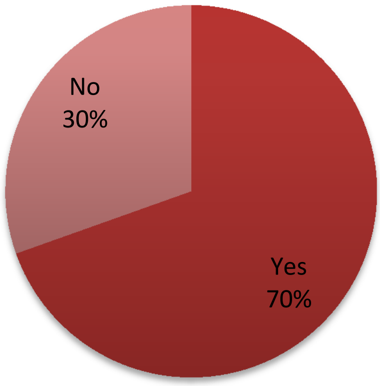
4.8 Legal basis for regulating at EU level

4.8.1 Legal basis for regulation

The participants in the survey were asked if they think that there is any possible legal basis for regulating at EU level on the toxicity of smoke from fires in building. Several respondents considered that the question is the competence of lawyers, not theirs.

There was general acceptance from the Regulators (Figure 32) that there is a legal basis for regulating at an EU level and that the CPR is the most appropriate legislation. However, MS regulators were clear that it was the assessment and classification that could be ‘regulated’ at EU level and that the ‘requirements’ were the responsibility of MSs. There were also several comments that using the CPR would limit the scope to regulated construction materials and that the use of separate legislation would allow the inclusion of all sources of smoke in buildings.

Figure 32: Regulator responses – question 4.1

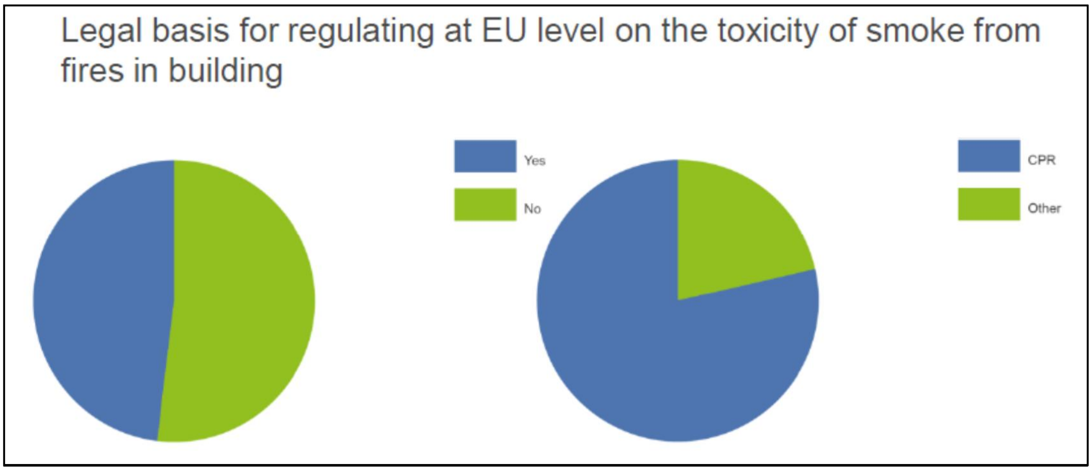


Organisations and representatives commented that if it could be demonstrated that there was a need or legislation at an EU level then it would be possible. However, most organisations believed that if regulation were considered necessary then common methods and classifications should be at an EU level (CPR) with MS allowed to set requirements/regulations.

Most organisations who expressed a view believed that the CPR was the correct legislation – the exception would be if the driver were the health of firefighters where DG Employment would be more appropriate.

Responses from the CPE survey showed that less than 50% of respondents believed that there was the basis for regulating and of those, the majority favoured regulation under the CPR.

Figure 33: CPE responses – question 4.1



An interesting comment that can be considered further was:

> *The CPR is product based and it is likely that any toxic smoke declarations could be taken out of context when life safety is being considered and therefore not deliver the benefits that one would seek. Introducing a risk based approach using fire safety guidance and similar to that used in the UK could be an option and that would require a legal approach (DG JUST.) A court of law would be duty bound to consider not only the construction product but the circumstances that it was used and all other contributory factors, such as building contents and fire suppression*

This comment reflected the views of most organisations that it is essential to include not only construction products (both those within the scope the CPR and construction products more generally) but to consider all contributory factors. [17]

Many respondents from European Organisations referred to alternative approaches as an alternative (or precursor) to regulations. Examples mentioned included:

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[17] It was said in one interview that 'smoke toxicity' was mentioned in CPD Interpretive Document 2 but then 'dropped'.

For information the wording in CPD Interpretive Document 2 Safety in case of fire is

> "4.3 Engineering approach in the field of Fire Safety
>
> Fire safety engineering is the approach by the application of engineering principles to evaluating the required level of fire safety and to designing and calculating the necessary safety measures.
>
> Regarding fire safety of construction works, the tools of fire safety engineering can be used in several ways:
>
> (c) for evaluating the performance of construction products when exposed to fire, e.g.
>
> - in developing fires, characteristics like ignitability, flame spread, rate of heat release, production of smoke and toxic gases
>
> - resistance of structures affected by fire in terms of load-bearing capacity and separating function

- Active systems - for example fire alarm systems would be a suggestion, also fire compartmentation;
- Passive protection using incombustible products and fire resistance systems;
- Fire suppression systems;

Organisations also referred to the need for special measures for handicapped persons in terms of safety until rescued, and that when designing haven areas it is essential to use materials that do not produce smoke.

In relation to the need to regulate at an EU level, FSEU commented "*We believe that the EU, through CPR, provides a harmonized method to test smoke toxicity so that member states can regulate as they see fit and fire engineers have the same type of data to regulate from. If not, we will have many different methods and barriers to trade. The only way to ensure we only do this once is to have a harmonized way of getting data. You have to do an EU version so you can do national and so you can do fire safety engineering!*

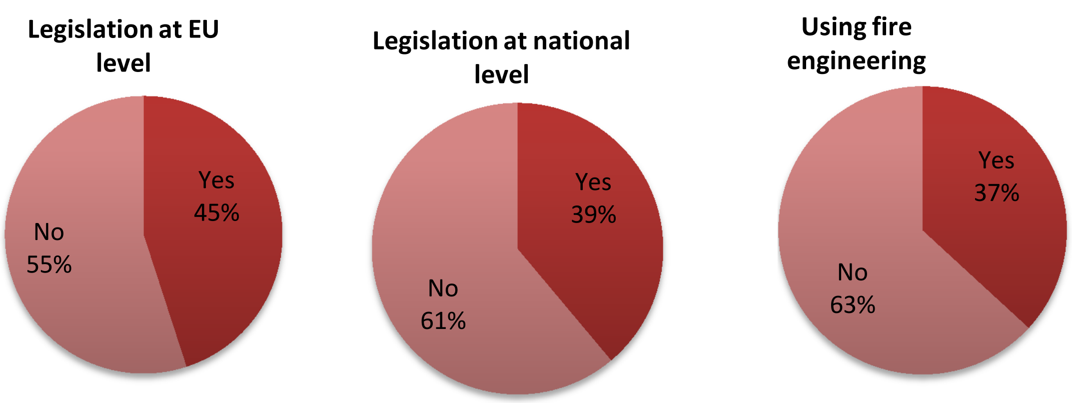
Several respondents referred to the EU "Better Regulation" initiative and that it would need to be taken into account to ensure:

- that if there is a regulation that it is evidence;
- that there is coherency of measures as does it make sense to introduce strict regulation of construction products without measures in the field of the building contents (which have a significant contribution to toxic smoke);
- the proportionality of any intervention is considered;
- that there needs to be evaluation of alternative policy options.

4.8.2 Costs and benefits of different approaches

The responses from the Regulators regarding whether the costs and benefits of EU legislation, national legislation and greater use of fire engineering are quantifiable are shown in Figure 34.

Figure 34: Regulator responses – question 4.2



In general only 1/3 of the regulators believed that the costs and benefits could be quantified for any of the three suggested approaches.

In the interviews with organisations and representatives, it was suggested that before any additional measures related to toxicity of construction products are implemented, their potential effectiveness should be evaluated compared to other measures. Scientific publications indicate more cost effective measures are available and therefore preferable, such as:

- Public fire prevention awareness campaigns
- Product safety measures
- Active fire prevention measures such as (connected, smart) smoke detectors, home sprinklers.
- Wider implementation of existing measures.

In general it was agreed that it is much easier to quantify costs than to quantify benefits which are largely health and social. However, even the costs are difficult to quantify without knowing the form legislation might take. Interviewees provided some comments on both costs and benefits and these are summarised in Table 7. The initial review identified a non-exhaustive list of expected potential impacts. The list was based on those expected from regulations and the associated European standards and test methods and this is used to identify the potential impacts in Table 7. The impacts are benchmarked against the current situation in all EU countries and, whilst acknowledging the impacts may differ and the magnitude of the costs and benefits vary between Member States, the potential impacts are aggregated for the EU. The final column has been included in response to the comments from organisations and representatives that impact of existing approaches which could have wider application should be evaluated. Existing approaches referred to in the interviews include some or all of: Public fire prevention awareness campaigns; Product safety measures; Active fire prevention measures such as (connected, smart) smoke detectors, home sprinklers.

Table 7 also includes an indication of who will meet the costs and who will benefit. As is common in cost benefit studies the costs are carried by different stakeholders from those who will benefit. The key to the entries with some observations is shown below.

(1) Costs are to the European Commission or a European Organisation (for example CEN). However, ultimately all of these costs are likely to be carried by tax payers within Member States.

(2) Costs are to the Member State or a national organisation (for example a national standards body). As in (1) ultimately all of these costs are likely to be carried by tax payers within Member States. However, there are also potential benefits at the Member State level and these could benefit individuals.

(3) Costs and benefits attributed to the economic operator. Potentially the economic operator will transfer the costs to the end user/purchaser by increasing the price; it is also possible that benefits are also transferred to the end user.

(4) Costs and benefits attributed to the end user.

(5) Benefits attributed to the firefighters

Table 7. Potential costs and benefits impacts of the three options and some suggested alternative approaches.

Impact	Legislation at EU level	Legislation at National Level	Fire Engineering	Alternative approaches
Costs				
Administrative cost of developing a potential EU-wide standard	✓ (1)			
Costs of developing an EU-wide standard/test method to reach consensus	✓ (1)			
Costs of adapting the test method		✓ (2)		✓(2/3/4)
Costs of independent studies			✓(3)	✓(3)
Cost of testing materials and products	✓(3)		✓(3)	
Cost of testing materials and products - multiple tests for different countries	✓(3)	✓(3)		
Additional costs of testing on a larger scale		✓(3)	✓(3)	
Changes in costs due to adaptation of composition of construction products.				✓(3)
Changes in processing conditions/technologies and their costs				
Impacts on licenses, certification requirements, product approvals, etc.	✓(3)	✓(3)		✓(3)
Difference in availability, functionality, performance or quality standards of certain products				
Price effects of end-products		✓(4)	✓(4)	
Reduced competition / reduced choice of products	✓(3/4)	✓(3/4)	✓(3/4)	
Potential impact on recyclability by potentially substituting compounds	✓(2/3)	✓(2/3)		

Impact	Legislation at EU level	Legislation at National Level	Fire Engineering	Alternative approaches
Benefits				
Health benefits e.g. reduced number of victims, reduced treatment costs	✓(2/4)	✓(2/4)	✓(2/4)	✓(2/4)
Long-term health benefits to fire-fighters	✓(2/5)			✓(2/5)
Potential environmental benefits due to substitution in construction products	✓(3/4)	✓(3/4)		
Reduced insurance costs				✓(4)
Avoided costs of using varying test methods in different countries	✓(3)			✓(3)
Scale economy for testing	✓(3)			
Potential new markets linked to a change in the range of goods and services produced (new products or substitutes)	✓(3/4)			✓(3/4)
Potential for improve products/improved quality	✓(2/4)	✓(2/4)	✓(2/4)	✓(2/4)
Data for other uses – e.g. fire safety engineering	✓(3)			

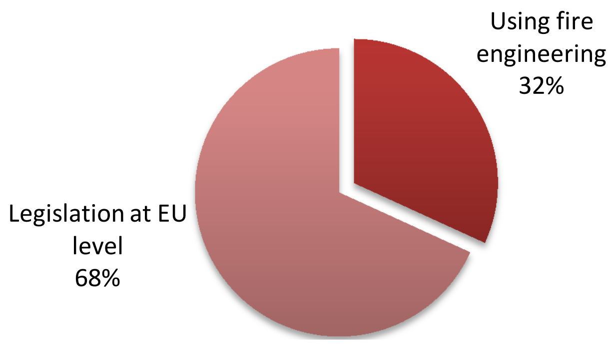
The responses reviewed in other sections of the study show that the magnitude of the costs and the benefits will be strongly influenced by the form and extent of any legislation, particularly the inclusion or exclusion of furnishings and other products currently outside the scope of the CPR.

The potential differences in any of the four identified options makes any estimate of costs (in monetary terms) very difficult and potentially misleading. For example, if there were to be a classification for smoke toxicity then the costs to the producer would depend on the testing chosen, the frequency of testing, the products included, use of CWFT, etc. The benefits would also have to be clearly defined by each Member State in terms of the number of lives saved, the reduction in injuries (including the number, duration of hospital stays/types of treatment/long terms health effects) directly attributable to controlling the toxicity of construction products and then the costs associated with these benefits quantified. From the surveys that we have carried out as part of this project, the responses highlighted that many Member States do not even have reliable statistical information associated with fire deaths and injuries in general and so will not have the information associated with the specific issue of toxicity from construction products fire deaths and injuries.

4.8.3 Which option is the most effective?

The MS regulators favoured an EU wide approach although a significant number believed that using fire engineering was the most beneficial approach (Figure 35). Those favouring fire engineering commented that this approach allowed a greater degree of flexibility and a more performance based approach. However, those who commented against a fire engineering approach believe it could lead to inconsistency and variations in the quality of the 'products' (partly as a result of limited understanding and information on fire engineering).

Figure 35: Regulator responses – question 4.3



In the responses from Organisations there were comments that none of the three options was ideal and that other options and alternative approaches should be used (see 3.3.4.1 above.). However, where asked for a preference most agreed that the EU level had the best potential to be beneficial. Thus, some considered that if it was proven to bring significant benefits, then EU level regulation is preferred to national level regulation, provided that the subsidiarity principle applies. However it was emphasised that the regulation should cover all products, not only construction products, and must also consider end use of the product and its potential for contributing to the perceived hazard, otherwise the regulation becomes meaningless when applied to real situations.

The CPE survey provide similar results with the majority responding the legislation at EU level would be the most beneficial (Figure 36).

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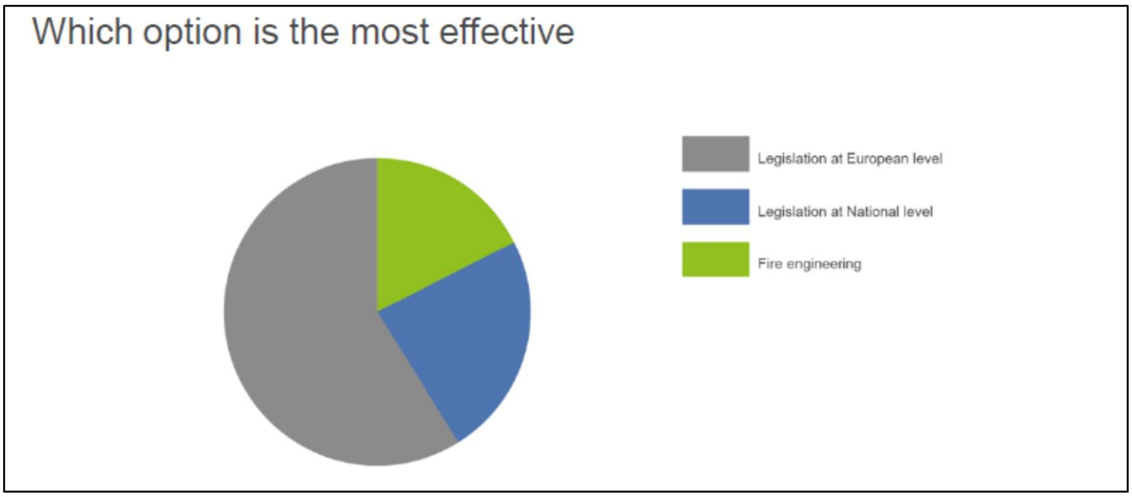
Figure 36: CPE response – question 4.3



The respondents to the CPE survey commented that legislation at European level:

- Provides a uniform market for product manufacturers;
- Rationalises product marketing across member states;
- Fire risk to protect people and goods are not country dependent.;
- Risk management and technical solution can be standardised with a maximum of efficiency

- The same approach as the other fire performance classes could be used: European classes + national safety levels
- Safety levels are set nationally but must refer to harmonized methods.
- Fire engineering is not mature enough.

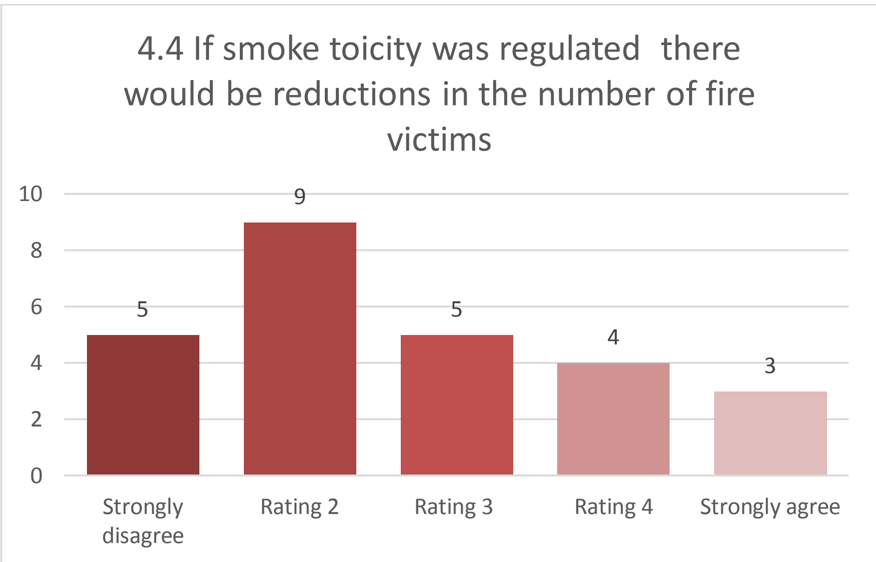
4.9 Possible effects on the reduction of fire victims

4.9.1 Regulation and potential reduction on deaths

Member State regulators were divided almost 50:50 when asked if regulation of smoke toxicity from construction products would reduce the number of deaths (Figure 37). There was a much stronger response disagreeing that deaths from smoke toxicity could be eliminated because of existing buildings, and the extensive use of combustible materials in buildings but not necessarily construction products (Figure 43).

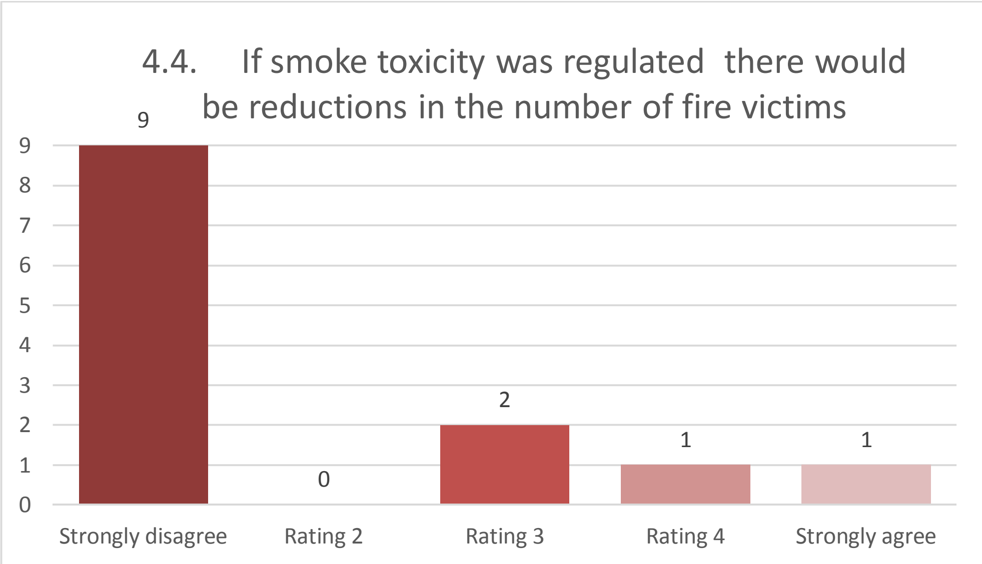
The regulator respondents that strongly agreed argued that currently without any supporting sufficiently detailed statistics, it is impossible to say how many injuries or fatalities would be avoided, and there are also doubts on the evidence of casualties due specifically to the smoke toxicity of construction products. Additionally it was stated that, smoke toxicity regulation for construction products "*without additional regulation for the building content would not be an example of coherent regulation*". A further reduction of victims would probably be possible by improving regulation further using the existing measures of enforcement rather than regulation of the toxicity fire effluents.

Figure 37: Regulator responses – question 4.4



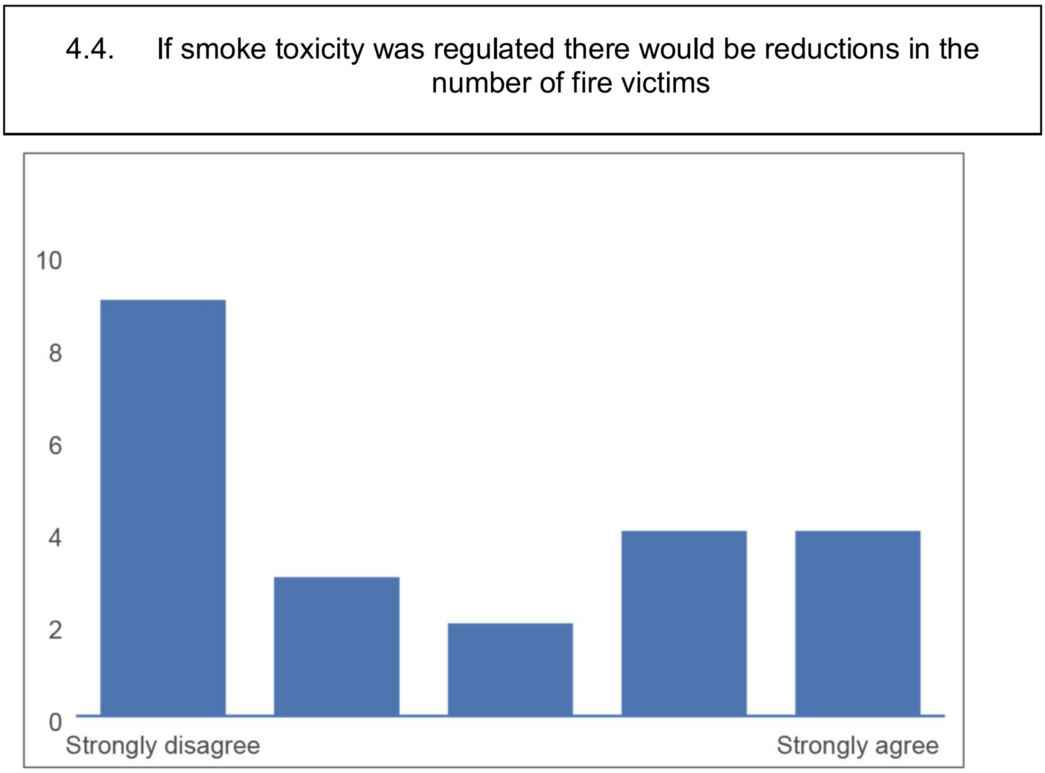
The responses from the European Organisations and Representatives show an even greater level of disagreement that the regulation of smoke toxicity would reduce the number of fire victims (Figure 38). Amongst the responses from these organisations there were several comments that it is very difficult to predict the decrease in fire deaths/injuries if smoke toxicity associated with construction products were controlled/regulated, and that if it were possible to quantify this aspect then it would also be necessary to quantify all alternative approaches. The respondents also said that the number of victims has been decreasing since the last 30 years without such regulation and that the control of smoke in general is a key factor in this decrease – along with the correct use of materials in buildings.

Figure 38: Organisation responses – question 4.4



The responses in the CPE survey were consistent though there were more respondents agreed/strongly agreed (Figure 39).

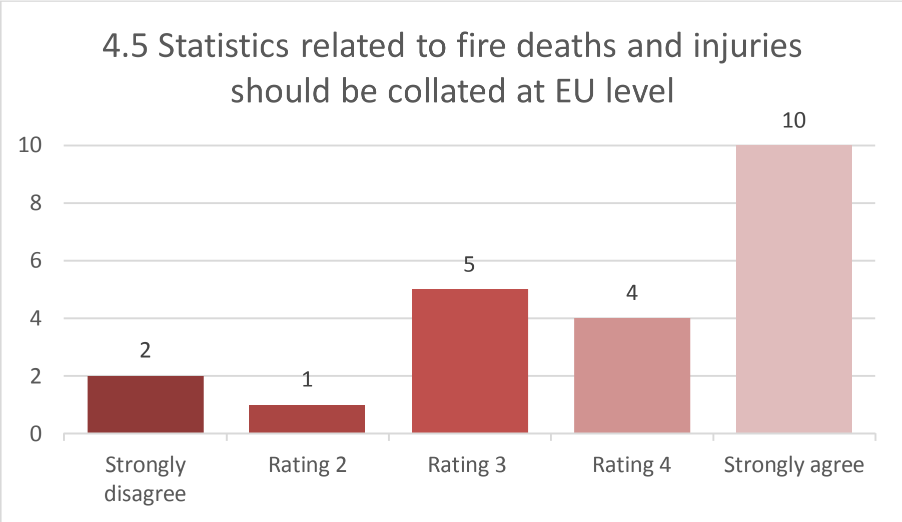
Figure 39: CPE response – question 4.4



4.9.2 Collection of fire statistics

There is a belief among regulators that if statistics on fire deaths and injuries are required then they should be collected at an EU level. There was limited acceptance that Member States would use the data to support regulation of smoke toxicity from construction products.

Figure 40: Regulator response – question 4.5



Amongst the Organisations and Representatives there is a belief that if statistics on fire deaths and injuries are required then they should be collected at an EU level (Figure 41, Figure 42) but there was limited acceptance that the Member States would use the data to support regulation of smoke toxicity from construction products. If this were to be done, then first of all, it would be important to standardize the use of terms used across member states, e.g. the definition of fire victims differs in different countries. However, the data would still need to provide detail at the national level.

Figure 41: Organisation responses – question 4.5

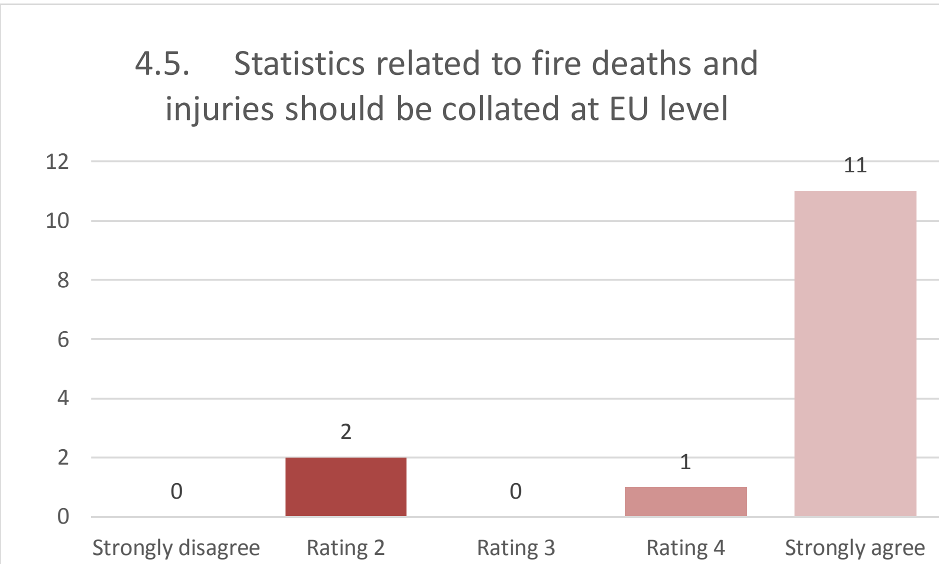
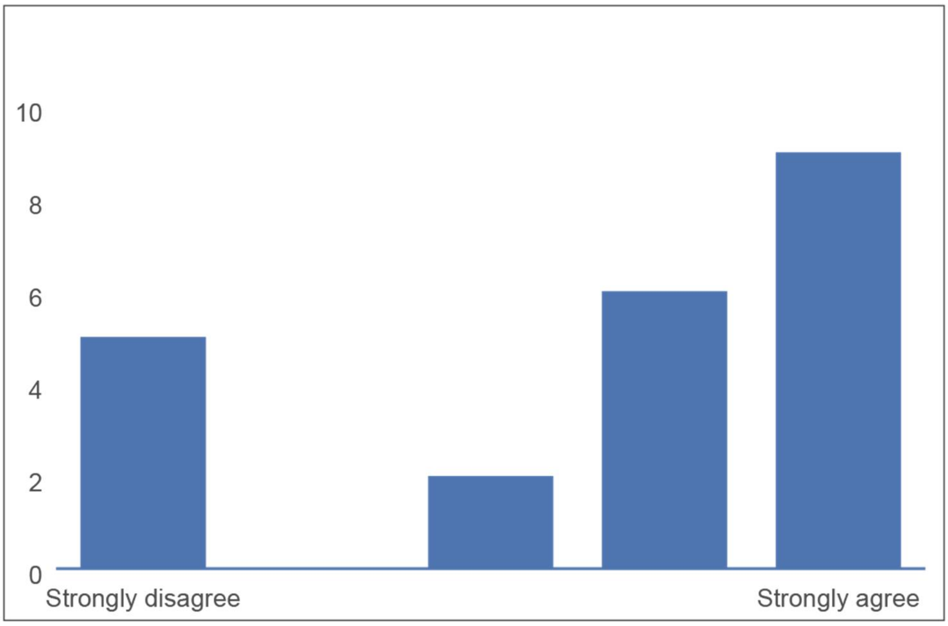


Figure 42: CPE responses – question 4.5

4.5.	Statistics related to fire deaths and injuries should be collated at EU level



4.9.3 Elimination of deaths from inhalation of toxic smoke

Comments from the regulators on the possibility of eliminating deaths from the inhalation of toxic smoke were that it seems unlikely that deaths caused by inhalation of toxic smoke can be completely eliminated (Figure 43). One member state commented that it is worth checking that the number of deaths due to inhalation of toxic smoke can be reduced if there is an effective way to regulate toxicity. There were also comments related to the existing building stock where the potential for toxic smoke is difficult to address.

The responses from the Organisations (Figure 44) and CPE (Figure 45) were very consistent with those of the regulators.

Figure 43: Regulator responses – question 4.6

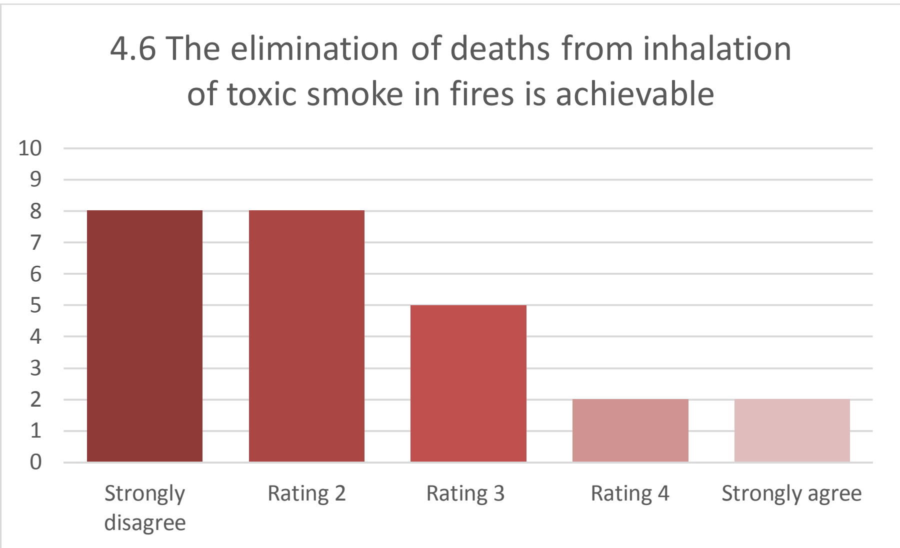
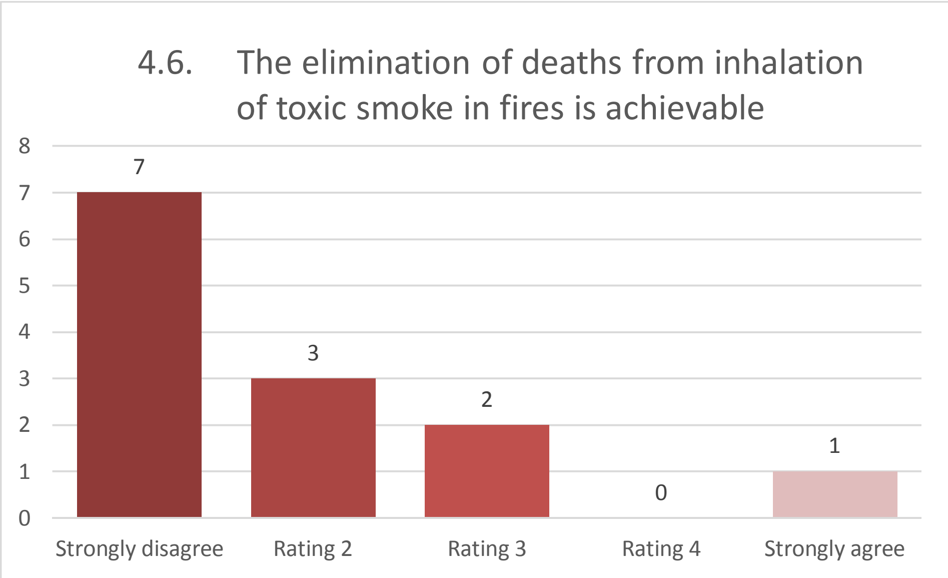


Figure 44: Organisation responses – question 4.6



Three comments from European Organisations and Representatives seemed to be particular insightful:

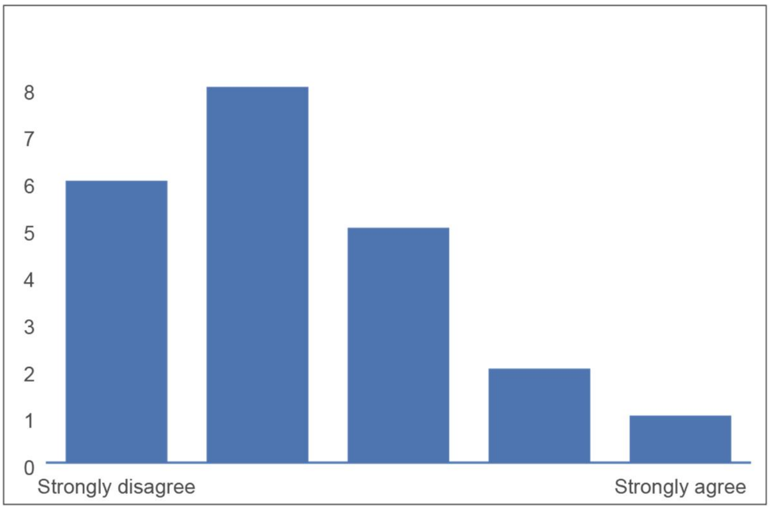
> "*As long as there are fires, people will always die from toxic smoke. What can be achieved is limitation of fire spread (by early detection and compartmentation) early alerting and safe evacuation measures, slow burning material …. Anyway in most cases the risk from smoke is originating from building contents (not only furniture but also other contents) and there are limitations what can be regulated.*"

> *"Reduction 'yes' – elimination 'no'"*

> *"With a low flammability and toxicity in used products combined with effective alarm systems, mobile sprinklers, education of all citizens and a highly effective, trained and dimensioned fire department close by, the numbers of fire death could be reduced significantly, maybe even 50%.*

Figure 45: CPE responses – question 4.6

4.6. The elimination of deaths from inhalation of toxic smoke in fires is achievable



4.10 Possible effects on the marketing of construction products

On the first question of this section, regarding the option that would be the most beneficial to trade out of legislation at EU level; legislation at national level; using fire engineering, both the first and last alternatives were supported for different reasons. Opinions on this topic covered almost the entire spectrum, from the ones that considered that none of the mentioned options were appropriate, to the opinion that all levels would need to be combined for a proper efficiency, where, for example, if implemented correctly, EU and national level are more complementary than excluding each other.

There is a risk that legislation at EU or at national level would introduce some sort of restrictions or imperative standards directly applicable to construction products leading to some of which will be excluded from markets where they have (or could have) been used before.. The view was expressed that fire engineering, on the other hand, would not affect the market, because every construction structure would be individually evaluated by these fire engineering requirements, without directly influencing the construction products market.

The other questions in this section considered the potential impact on products, in terms of barriers to trade, cost, and availability.

Responses from the Regulators included comments that the impact depends on the regulation, but it makes sense to think that a regulation would affect the market. Some of the products would be withdrawn from the market, some of them would be improved. At the beginning, the regulations are likely to force some changes in the technology of producing certain construction products. At the beginning, the supply of products that meet new standards will be lower than the demand. Later, as a result of a natural process of market adapting, the situation will stabilize (see Figure 46, Figure 49, Figure 52).

The responses from Organisations and Representatives covered a wide range of responses but it was noted that direct answers are also difficult to be given due to the question, where it is not clear what is meant by beneficial to trade, as all of them can create a barrier to trade, depending on how they are combined and implemented.

The statement assessing the increase of barriers to trade due to the introduction of regulations related to toxicity of smoke for construction products produced shared opinions, with most organisations agreeing or strongly agreeing with it (Figure 47, Figure 48). In general the expected barriers to trade relate to high costs of tests for toxicity of smoke for the construction products. In particular SMEs would be affected, with a technical rather than legal barrier to trade.

Most organisations believed that the introduction of regulations related to toxicity of smoke for construction products would lead to the loss of some products (Figure 50, Figure 52)and an increase in the cost of products (Figure 53, Figure 54).

There were concerns expressed that depending on the way regulation would be implemented per product, a number of tests would be necessary (exposed, various composite products, multi-layer, orientation, fixing, etc.). Something that would add to the number of tests per product is the lack of experience of toxicity testing which would increase costs further until accepted “extended application” (EXAP) rules were developed[18].

[18] EuPC emphasized that the discussions on the costs and benefits of a potential regulation on the EU level do not entirely reflect the implications for small and medium sized companies (SMEs). EuPC said it believes it cannot be

Figure 46: Regulator responses – question 5.2

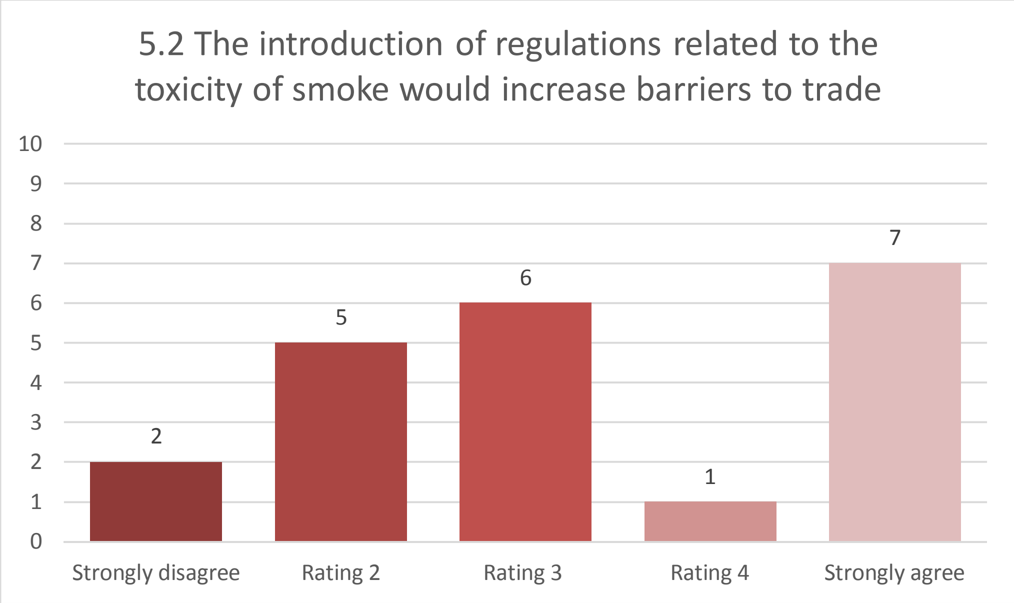
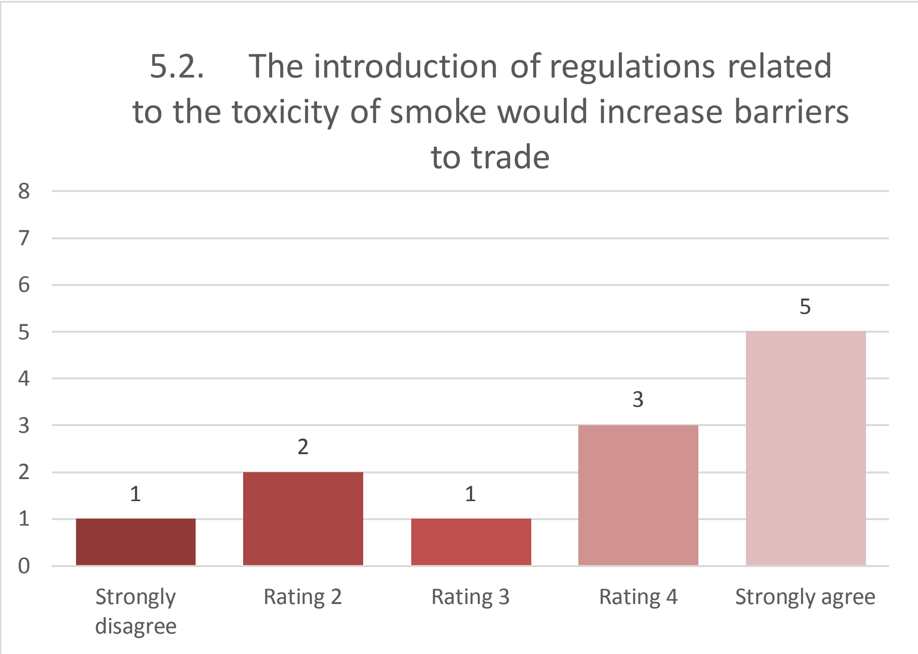


Figure 47: Organisation responses – question 5.2



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assumed that SMEs are acting mainly on local markets and therefore would not be subjected to additional testing of their construction products.

Figure 48: CPE responses – question 5.2

5.2. The introduction of regulations related to the toxicity of smoke would increase barriers to trade

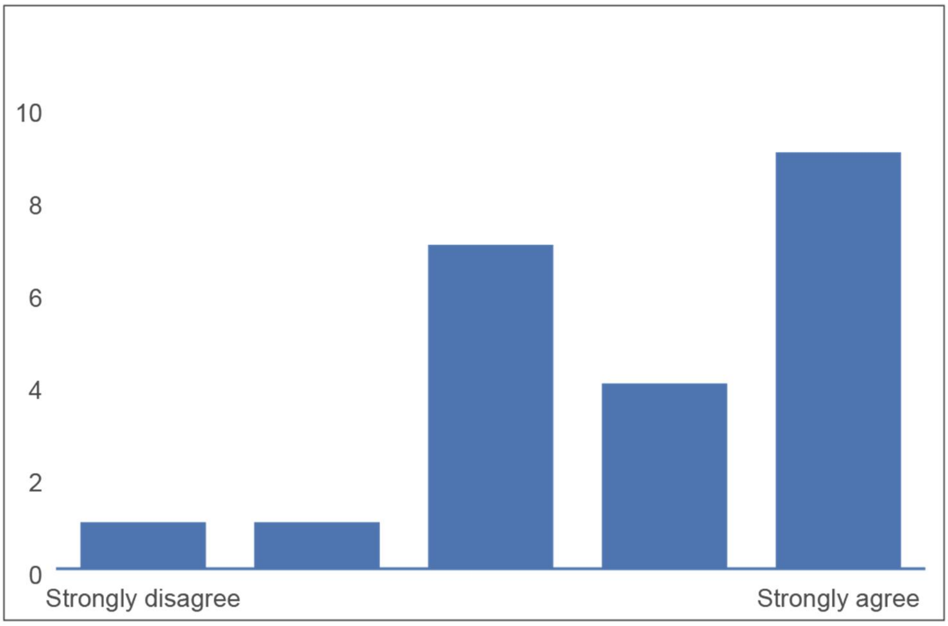


Figure 49: Regulator response – question 5.3

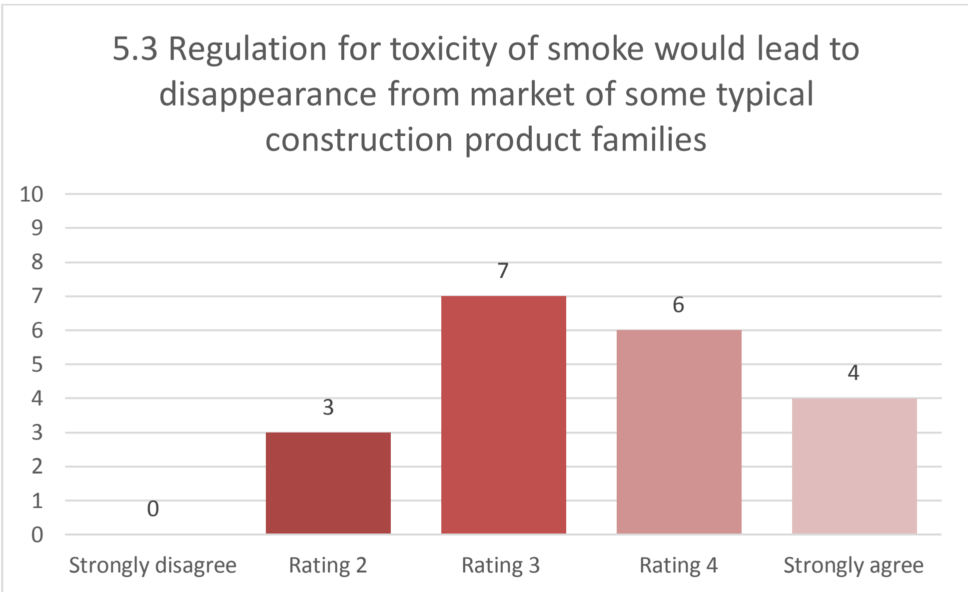


Figure 50: Organisation responses – question 5.3

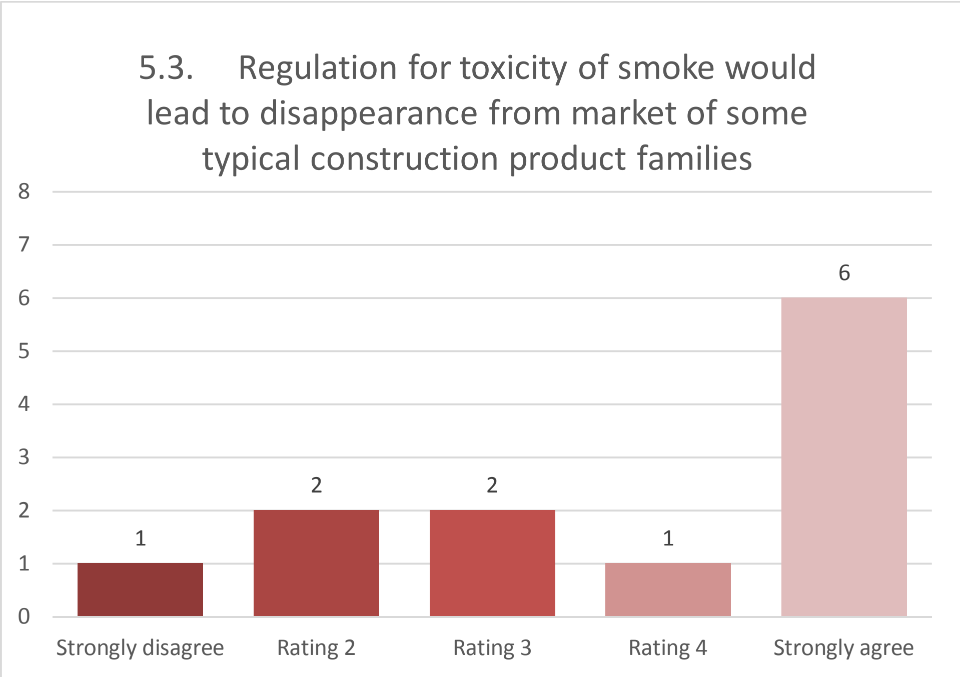


Figure 51: CPE responses – question 5.3

5.3. Regulation for toxicity of smoke would lead to disappearance from market of some typical construction product families

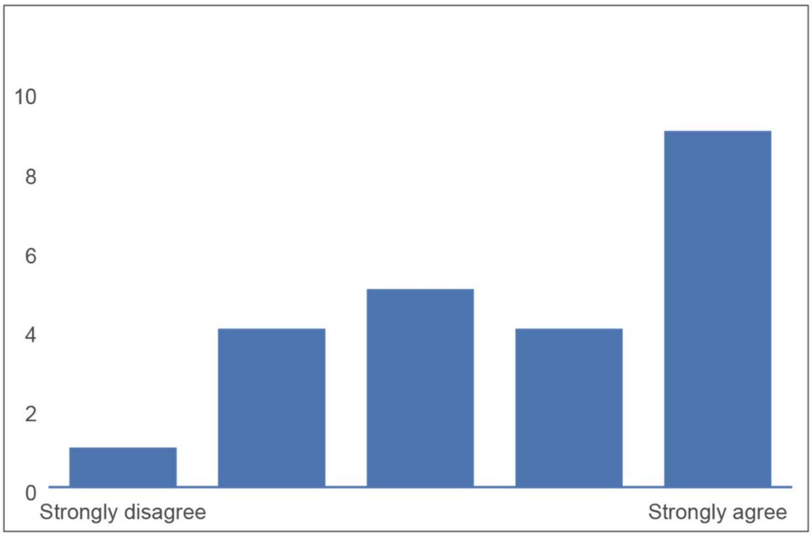


Figure 52: Regulator responses – question 5.4

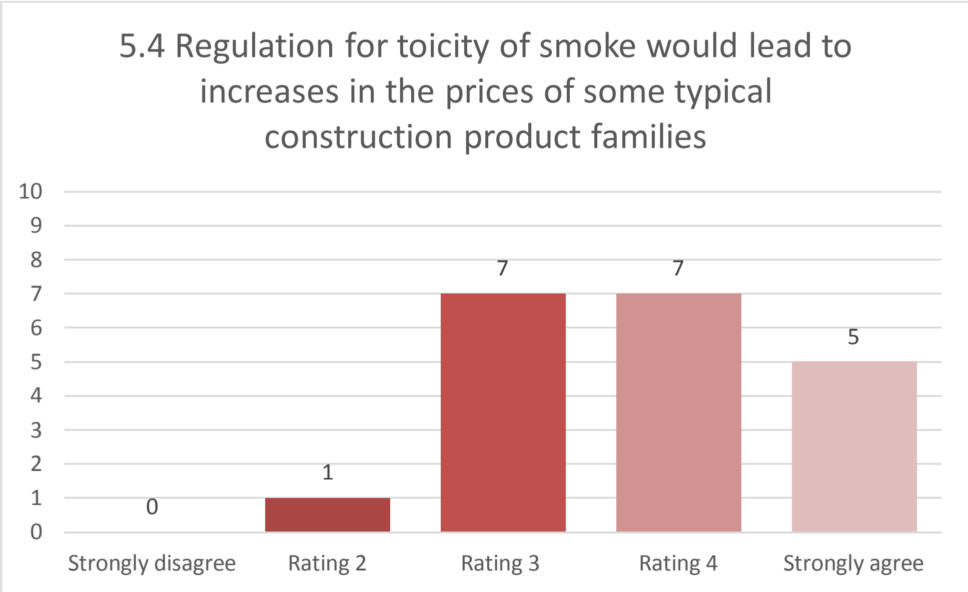


Figure 53: Organisation responses – question 5.4

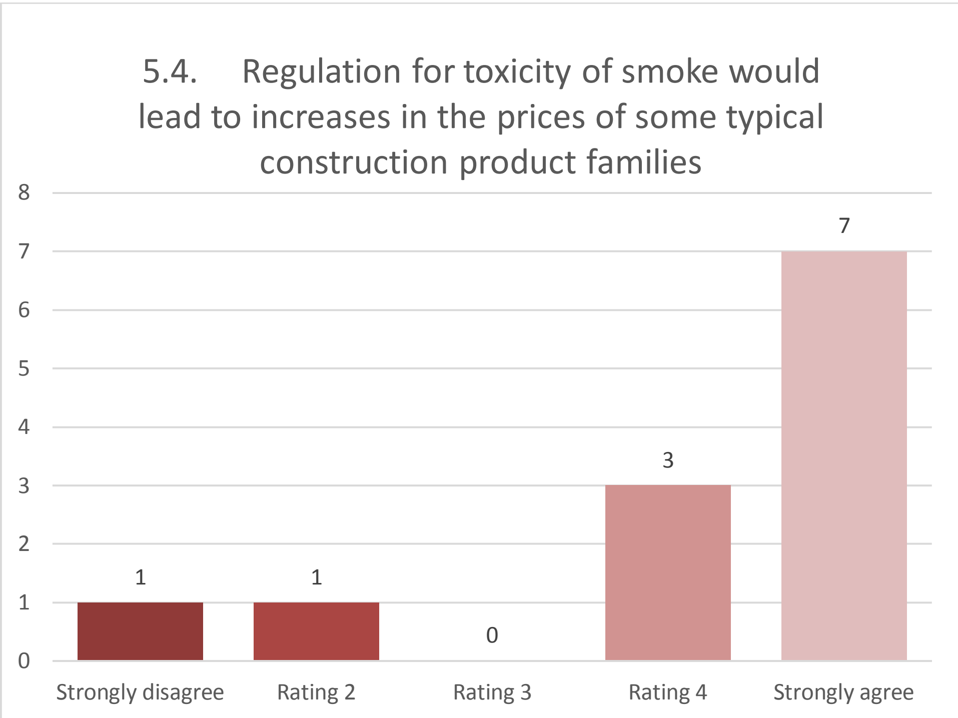
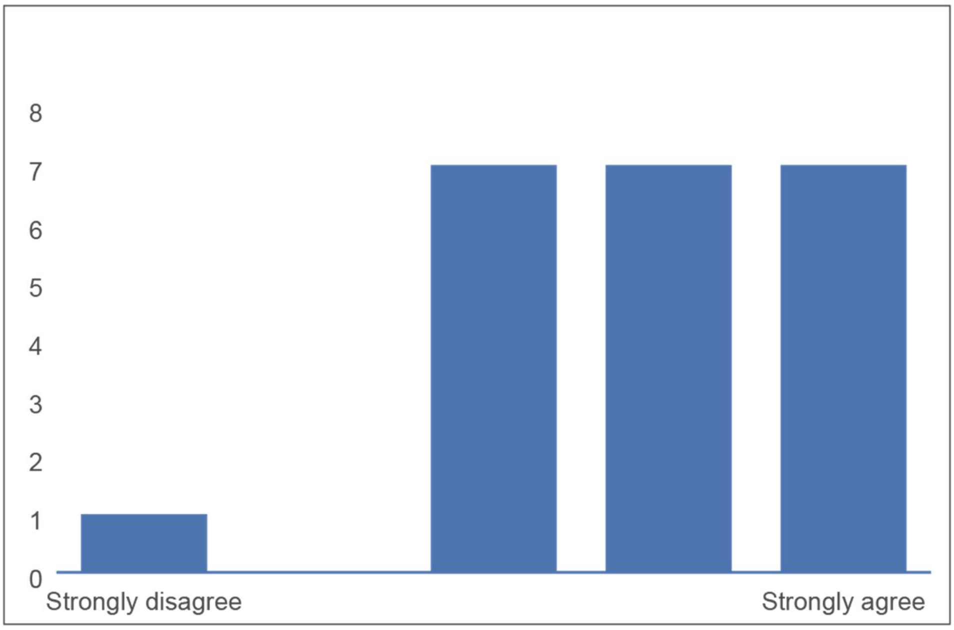


Figure 54: CPE responses – question 5.4

5.4. Regulation for toxicity of smoke would lead to increases in the prices of some typical construction product families



5 Replies to the research questions

5.1 Current Regulations

Do Member States currently have regulations on the toxicity of smoke generated in building fires?

As expected most Member States have some form of reguaiton related to the protection of building occupants from smoke. The main intent of these regulations is to slow down the growth rate of a fire and prevent large fires from developing whilst allowing occupants to escape safely from the building with the emphasis on compartmenation, ventilation, and evacuation. In addition, many countries have regulations focussing of the safe use of buildings.

The current system of European standards focuses on ignition and flame spread but does also measure the production of flaming droplets or the rate of production of smoke. At present the system does not consider the toxic gases that might be present in the smoke.

The study identified seven countries who stated that they had a regulation related to the toxicity of smoke. The five which have been notified to the EC as regulations are:

> **Belgium**. Article 104 of the *Koninklijk besluit van 25 april 2013 tot wijziging van de artikelen 1, 3, 28, 100, 104, 151, 200 en 207 van het algemeen reglement op de elektrische installaties* regarding the toxicity of electrical cables;
>
> **France** referred to a regulation but added that it is rather limited scope. The regulation is "*the Order of 4 November 1975 regulating the use of certain materials and products in establishments open to the public"* ;
>
> **Lithuania** referred Annex 6 of their national '*Main Fire Safety Requirements*'. This regulation was notified to other member states under the TRIS 98/34 system, reference IND-2010 0564 LT- EN-2010 09 09 PROJET.
>
> **Poland.** The main regulation is *'Regulation of the Minister of Infrastructure on technical conditions to be met by buildings and their location (12 April 2002)'. Rules laid down in 'Regulation...'* which refers to 'PN-EN 13501 *Fire classification of construction products and building elements'* and 'PN-B-02855 *Fire protection of buildings - Test method for the secretion of toxic products of decomposition and combustion of materials'*;
>
> **Sweden.** "*Swedish National Board of Housing, Building and Planning's general recommendations BFS 2011:27 with amendments up to BFS 2013:12 on analytical design of fire protection for buildings* which set limitations on CO, maximum level of CO_2, O_2.

All of these have limited fields of application but refer to limits on levels of toxic gases in the context of construction products and building elements.

5.2 Fire Statistics

Are there adequate fire statistics in the EU or other evidence (e.g. studies, or medical records) which reliably show that victims of building fires are due to the inhalation of toxic gases from construction products? Which are the responsible toxic gases?

As expected there is no common basis for the collection and analysis of fire statistics across the EU. There was general, but not universal, support for the collection of statistics on a European basis – but only if it were demonstrated to be required and to be beneficial. If statistics were to be collected then a common terminology would need to be agreed.

At present there is very little evidence from fire statistics or other evidence to reliably show that victims of building fires are due to the inhalation of toxic gases from construction products. No Member State has data that identifies the inhalation of smoke from construction products as the cause of death.

Specific case studies were cited by several interviewees with the Bucharest night club fire and the Rouen Restaurant and Dusseldorf Airport fires referred to most often. Apart from these no other clear examples were cited where construction products[19] rather than fabric/fittings, contributed, and even in the examples there seems to be general agreement that the problems came from non- compliance with existing national regulations – for example in the choice or installation of materials.

In cases where fatalities can be attributed to toxic gases, the gases involved are primarily CO, CO_2 and HCN but the origin of the gases cannot be linked to construction products rather than furnishing and fittings.

It was noted in the study the ISO/TC 92/WG 13 Fire safety – Statistical data collection is active in this area.

5.3 Potential options for reducing risk

If the victims in building fires are mainly due to the inhalation of toxic gases from construction products, which are the available options for effectively reducing the risk (e.g. to regulate on the smoke toxicity, from constructions products at EU level, to leave Member States to regulate at national level by application of the subsidiarity principle, or to support other fire engineering measures e.g. appropriate building design, installation of alarm systems, etc.)? Which are the advantages and the disadvantages of each available option?

The study has not identified any evidence which unequivocally links victims in building fires to the inhalation of toxic gases from construction products. However, if it were found to be necessary to control the toxic gases from construction products then the clear preference from the survey was that this should be done at European rather than national level. This would ensure that the approach was consistent and would not introduce national barriers to trade. It was suggested that such an approach should be based on a range of classifications derived from test results similar to the reaction to fire classification approach. The toxicity classes could be additional voluntary classes. In this way, the regulatory requirements related to the different classes and their application within buildings would be the responsibility of the regulators and the building regulations within each Member State. The advantage of this approach is that it is based on principles that are already well known throughout Europe. The primary disadvantage is that it could lead to the introduction of new regulatory requirements and associated increased costs for industry.

Other possible approaches to saving lives in the event of a fire are dependent on the early detection of the fire and the ability of the person(s) to escape to a place of safety while remaining separated from the combustion products/smoke. These objectives can be achieved in many ways by the application of fire engineering principles and/or the introduction of means to detect fires at an early stage and/or control, suppression and/or containment of the fire. Some of these options are in widespread use in some Member States and have been subject to detailed cost benefit analyses, whereas in some countries the concepts

[19] Some of the ‘construction materials’ referred to are not within the scope of the CPR

of performance-based design to satisfy the objectives is not well developed or understood and would require training and education leading to adoption of these options.

5.4 Legal basis for regulating at EU level

Which would be the possible legal basis for regulating at EU level on the toxicity of smoke from fires in building? Which are the advantages and the disadvantages of each available legislative option?

There was general acceptance from the Regulators that there is a legal basis for regulating at an EU level and that the CPR is the most appropriate legislation. However, most regulators were clear that it was the assessment and classification that could be 'regulated' at EU level and that the 'requirements' were the responsibility of Member States.

In the responses from Organisations there were comments that none of the three options was ideal and that other options and alternative approaches should be used. Where asked for a preference most agreed that the EU level had the best potential to be beneficial. However it was emphasised that the regulation should cover all products, not only construction products, and must also consider end use of the product and its potential for contributing to the perceived hazard, otherwise the regulation becomes meaningless when applied to real situations.

Most organisations who expressed a view believed that the CPR was the correct legislation – the exception would be if the driver were the health of firefighters where DG Employment would be more appropriate.

Organisations and representatives commented that if it could be demonstrated that there was a need or legislation at an EU level then it would be possible but the effectiveness of a regulation relative to alternative methods would need to be demonstrated. However, most organisations agreed with the regulators that if regulation were considered necessary then common methods and classifications should be at an EU level (CPR) with Member States allowed to set requirements/regulations.

Interviews with the Member State regulators confirmed that fire safety engineering was an accepted approach but generally as a method of demonstrating compliance with existing national regulations.

Most respondents agreed that, if implemented systematically and following commonly agreed scientific principles, then fire safety engineering was "acceptable" to be used as a means to prevent risks and has the potential to deliver benefits. However, in many countries there is no or little reference to fire safety engineering and so much more work needs to be done until it becomes acceptable and able to deliver wider benefits.

5.5 Possible effect of regulation on fatalities

What could be the possible effects of the above measures on the reduction of fire victims?

Member State regulators were divided almost 50:50 when asked if regulation of smoke toxicity from construction products would reduce the number of deaths. However, because of existing buildings, and the extensive use of combustible materials in buildings but not as construction products, there was a strong disagreement that deaths from smoke toxicity could be eliminated.

The regulator respondents that strongly agreed argued that currently without any supporting sufficiently detailed statistics, it is impossible to say how many injuries or fatalities would be avoided, and there are also doubts on the evidence of casualties due specifically to the smoke toxicity of construction products. Besides, smoke toxicity regulation for construction products "*without additional regulation for the building content would not be an example of coherent regulation*". A further reduction of victims would probably be possible by improving regulation further using the existing measures of enforcement rather than regulation of the toxicity fire effluents. However, as a number of Member States do not apply the fire engineering approach in their regulations one could reasonably assume that a further reduction of fire deaths could be achieved by applying the existing fire engineering knowledge (even without fire toxicity data) in these Member States. During this period the collection of fire statistics could be harmonised and better focused to investigate the relationship between smoke toxicity from construction products and fire injuries in order to provide, if necessary, a solid basis for a future regulatory approach.

The responses from the European Organisations and Representatives show an even greater level of disagreement that the regulation of smoke toxicity would reduce the number of fire victims. The respondents also said that the number of victims has been decreasing in many countries for the last 30 years without such regulation and that the control of smoke in general is a key factor in this decrease – along with the correct use of materials in buildings.

Responses from the regulators, representatives and organisations were consistent in their view that it seems unlikely that deaths caused by inhalation of toxic smoke can be completely eliminated. There were also comments related to the existing stock where the potential for toxic smoke is difficult to address.

5.6 Possible effects on the marketing of construction products

What could be the possible effects on the marketing of construction products if regulated as above?

Regulators and organizations agreed that any form of regulation for the toxicity of smoke from construction products has the potential to increase costs and remove products from the market.

The regulators observed that a regulation should impact on products and if working well should result in the improvements to existing products and the development of new products. If 'dangerous products' are present on the market then the regulation should lead to withdrawal of these products. There seemed to be agreement that if some products were no longer marketed that these would be from a range of product families and not focused on a single product family. However, it was also noted that there are already "reduced fire hazard" or "low smoke zero halogen" alternative materials on the market.

There were general concerns raised that a poor regulation had the potential to increase barriers to trade and that SMEs and microenterprise might find their costs increasing disproportionately.

5.7 Possible impacts of regulation

The study has identified areas where stakeholders believed there would be costs and also benefits but these were more difficult to quantify.

Overall the responses confirmed that if there were to be legislation based on assessment and classification, that it should be undertaken at EU level. The provision of data using an agreed approach and presented in a consistent format would allow compliance with national requirements to be demonstrated and a performance based fire engineering approach to be adopted in MSs. However, the study seemed to confirm that the majority of MSs believe that there is sufficient information on fire engineering to deliver benefits at a MS level.

The responses to the questions on costs and benefits also show that legislation at a European level (in the form of agreed testing, classification, and verification) is seen as having a more positive impact than legislation at Member State level. The benefits are largely seen as related to health and to reductions in injuries and fatalities, but the magnitude of these benefits is seen as being closely linked to the extension of any legislation or requirements (at EU or national level) to a range of materials or products that is wider than currently within the scope of the CPR.

However, the wider implementation of existing and/or alternative methods (for example public fire prevention awareness campaigns; product safety measures; active fire prevention measures such as smoke detectors, home sprinklers), and wider enforcement of existing measures were seen as beneficial for limited cost impacts.

6 Conclusions

1. The interviews have shown a clear definition of terminology is lacking e.g fire safety engineering, injury and death. This would be needed for any future European initiative to collect data and produce coherent fire statistics at EU level.

2. Fire regulations: Member States recognise that all smoke is toxic and have a raft of regulations for the protection of occupants. Seven Member States referenced regulations on the toxicity of smoke from construction products; five of these have been notified to the EC as regulations These regulations are from Belgium, France, Lithuania, Poland and Sweden. In each case their application is defined and limited in scope.

3. Fire statistics: The type and format of data collected varies across Member States, and, at present, statistics on smoke toxicity are not collected and therefore the effectiveness of potential measures cannot be assessed. Data shows the number of deaths per million people reducing over the last 30 years without regulations specific to smoke toxicity. The rate of reduction varies between Member States. There is general agreement that if statistics are required then collecting them at a European level in a coordinated and harmonised system based on standardised terms and definitions would be critical

4. Although there is a lack of agreement as to what constitutes fire engineering and also that there isn't sufficient data for a fuller implementation fire engineering is seen as already delivering benefits when used as a tool for demonstrating compliance with national requirements.

5. Legislation: The responses received do not agree that regulation of toxicity of smoke from construction products is required. However, if the case for regulation were proven, then an agreed European system for testing and classification, with regulations and requirements at national level is favoured.

6. The responses to the questionnaire showed that legislation at EU level was seen as having a more positive impact than the other two options. However, greater use of existing legislation and alternative safety approaches were also seen as important in the potential impact of any additional legislation. If legislation were considered appropriate then detailed cost – benefit and impact analyses would be required and the costs and benefits of existing regulations and alternative active and passive methods, would need to be considered.

7. There were many comments questioning the usefulness of singling out construction products and emphasising that if legislation related to the toxicity of smoke from construction products were considered appropriate that it would need to be part of an holistic approach to fire and effectiveness of measures and would need to address the issues associated with the toxicity of smoke produced by building contents.

8. Legal basis: The responses indicate that interviewees believe there would be limited benefits from regulating specifically for the toxicity of smoke from construction products. Some interviewees believed that there could be greater benefits if the flammability (and hence smoke toxicity) of furnishings and fittings was addressed across all Member States.

9. The potential dangers of smoke in general, including toxic smoke, leaking into or being generated in areas that are considered to be safe zones and / or escape routes need to be considered in new or amended existing regulations.

10. Effect on the marketing of construction products: There is general agreement that regulation of toxicity of smoke of construction products could increase product costs, and potentially remove

some products from the market. Additionally, it was agreed a regulation would be expected to impact products by driving improvement and developments of new products.

Appendix A List of organisations participating in the Project Steering Group

Association of Plastics Manufacturers in Europe (Plastics Europe)

Construction Products Europe (CPE)

Danish Firefighter Cancer Association

Danish Transport and Construction Agency

Deutsches Institut für Bautechnik

Efectis France

European Association for Passive Fire Protection (EAPFP)

European Chemical Industry Council (CEFIC)

European Concrete Platform (ECP)

European Confederation of Woodworking Industries (CEI-BOIS)

European Extruded Polystyrene Insulation Board Association (EXIBA)

European Insulation Manufacturers Association (Mineral Wool) (EURIMA)

European Manufacturers of Expanded Polystyrene – Construction (EUMEPS)

European Phenolic Foam Association (EPFA)

European Plastic Convertors (EUPC)

Federation of European Rigid Polyurethane Foam Associations (PU Europe)

Federation of the European Union Fire Officer Associations (FEU)

Fire Safe Europe

Fire Safety Platform

Flame Retardant Olefinic Cable Compounds (FROCC)

Ministero dell'Interno, Italy

Netherlands Standards Organisation (NEN)

Phosphorus, Inorganic and Nitrogen Flame Retardants Association (PINFA)

Portuguese Agency for Competitiveness and Innovation Portugal

Promat Research and Technology Belgium

Research Institutes of Sweden (RISE)

University of Central Lancashire, UK

Appendix B Literature review - list of sources reviewed

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- Chapter 3 - Hazards from smoke and irritants (Purser, D A)
- Chapter 4 - Asphyxiant components of fire effluents (Purser, D A)

- Chapter 5 - Effects of fire effluents on fire victims (Shepherd, R)
- Chapter 15 - Estimation of toxicity during burning of common materials (Stec, A A)
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Appendix D Concentrations of smoke components

Substance	Smoke concentration	Circumstances	Reference
CO_2	5,1 % vol	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
CO_2	0,06 % vol	Roof experiment – combustible paste	Basmer and Zwick (2004)
CO_2	0,50 % vol	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)
CO_2	0,64 % vol	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
CO_2	0,49 % vol	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
CO_2	0,19 % vol	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
CO_2	0,12 % vol	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
CO_2	0,37 % vol	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
CO_2	0,60 % vol	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
CO_2	0,20 % vol	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
CO_2	428-465 kg	3 simulated room experiments	Blomqvist *et al.* (2004)
CO	4004 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
CO	5 ppm	Roof experiment – combustible paste	Basmer and Zwick (2004)
CO	254 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)

CO	187 ppm	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
CO	3 ppm	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
CO	19 ppm	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
CO	12 ppm	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
CO	44 ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
CO	29 ppm	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
CO	373 pm	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
CO	±5000 ppm	Bedroom fire experiment – closed doors	Hazebroek *et al.* (2015)
CO	±12000 ppm	Kitchen fire experiment – closed doors	Hazebroek *et al.* (2015)
CO	±3500 ppm	Living room fire experiment – hallway door open	Hazebroek *et al.* (2015)
CO	±5000 ppm (peak of 39000 (4%vol) after 1h2')	Living room fire experiment – hallway door closed	Hazebroek *et al.* (2015)
CO	±25 ppm	Living room fire experiment – front door open	Hazebroek *et al.* (2015)
CO	Peaks of ±15000 and ±36000 ppm	Bedroom fire experiment – door open	Hazebroek *et al.* (2015)
CO	16-22 kg	3 simulated room experiments	Blomqvist *et al.* (2004)
NO	26 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
NO	< dl*	Roof experiment – combustible paste	Basmer and Zwick (2004)

NO	21 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)
NO	< dl*	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
NO	< dl*	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
NO	< dl*	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
NO	< dl*	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
NO	2,5 ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
NO	< dl*	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
NO	11 pm	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
NO2	5 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
NOx	±80 ppm	Bedroom fire experiment – closed doors	Hazebroek *et al.* (2015)
NOx	±140 ppm	Kitchen fire experiment – closed doors	Hazebroek *et al.* (2015)
NOx	±130 ppm	Living room fire experiment – hallway door open	Hazebroek *et al.* (2015)
NOx	Very low	Living room fire experiment – front door open	Hazebroek *et al.* (2015)
NOx	±50 ppm	Bedroom fire experiment – door open	Hazebroek *et al.* (2015)
NH3	< dl*	Roof experiment – combustible paste	Basmer and Zwick (2004)
NH3	0,2 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)

NH3	0,5 ppm	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
NH3	0,4 ppm	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
NH3	< dl*	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
NH3	0,4 ppm	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
NH3	0,2 ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
NH3	< dl*	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
NH3	0,5 pm	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
NH3	< dl – 0,69 kg	3 simulated room experiments	Blomqvist *et al.* (2004)
HCN	< dl*	Roof experiment – combustible paste	Basmer and Zwick (2004)
HCN	6,3 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)
HCN	< dl*	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
HCN	< dl*	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
HCN	< dl*	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
HCN	< dl*	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
HCN	2,4 ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
HCN	< dl*	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
HCN	1 ppm	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)

HCN	0,44-1,1 kg	3 simulated room experiments	Blomqvist *et al.* (2004)
HBr	<0,03-0,20 kg	3 simulated room experiments	Blomqvist *et al.* (2004)
HCl	0,10-0,65 kg	3 simulated room experiments	Blomqvist *et al.* (2004)
SO2	< dl*	Roof experiment – combustible paste	Basmer and Zwick (2004)
SO2	1,5 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)
SO2	2,3 ppm	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
SO2	0,6 ppm	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
SO2	1,1 ppm	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
SO2	4,2 ppm	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
SO2	0,6 ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
SO2	0,7 ppm	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
SO2	0,4 pm	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
SO2	< dl – 3,2 kg	3 simulated room experiments	Blomqvist *et al.* (2004)
Methane	442 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
Acetylene	151 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
Benzene	32 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
Benzene	21-38% of the VOCs	3 simulated room experiments	Blomqvist *et al.* (2004)
Toluene	4-6% of the VOCs	3 simulated room experiments	Blomqvist *et al.* (2004)

Formaldehyde	23 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
Formaldehyde	< dl	Roof experiment – combustible paste	Basmer and Zwick (2004)
Formaldehyde	2 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)
Formaldehyde	1,2 ppm	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
Formaldehyde	0,3 ppm	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
Formaldehyde	< dl	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
Formaldehyde	1 ppm	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
Formaldehyde	0,3 ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
Formaldehyde	< dl	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
Formaldehyde	2,1 pm	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
Acrolein	0,6 ppm	Roof experiment – combustible paste	Basmer and Zwick (2004)
Acrolein	1,9 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)
Acrolein	< dl	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
Acrolein	0,4 ppm	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
Acrolein	0,6 ppm	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
Acrolein	1 ppm	Roof experiment – bitumen + burner	Basmer and Zwick (2004)

Acrolein	0,3ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
Acrolein	< dl	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
Acrolein	< dl	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
Ethanol	60 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
Acetone	7 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
n-Hexane	< dl	Roof experiment – combustible paste	Basmer and Zwick (2004)
n-Hexane	21 ppm	Roof experiment – PIR[1] + combustible	Basmer and Zwick (2004)
n-Hexane	0,8 ppm	Roof experiment – foam glass + combustible paste	Basmer and Zwick (2004)
n-Hexane	0,2 ppm	Roof experiment – bitumen + combustible paste	Basmer and Zwick (2004)
n-Hexane	9,4 ppm	Roof experiment – bitumen + heptane	Basmer and Zwick (2004)
n-Hexane	1,4 ppm	Roof experiment – bitumen + burner	Basmer and Zwick (2004)
n-Hexane	1,2 ppm	Roof experiment – PUR[2]/PIR + burner	Basmer and Zwick (2004)
n-Hexane	1 ppm	Roof experiment – PUR/PIR + heptane	Basmer and Zwick (2004)
n-Hexane	14,1 pm	Roof experiment – PUR/PIR + wood	Basmer and Zwick (2004)
Ethylene	323 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)
Acetic acid	13 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)

Acetaldehyde	13 ppm	Tunnel experiment - wooden pallets	Basmer and Zwick (2004)

[*] detection limit; [1] polyisocyanurate heat insulation sheet; [2] polyurethane heat insulation sheet

Appendix E List of Interviewees

Fire regulators contacted /interviewed

Austria	Latvia
Belgium	Lithuania
Bulgaria	Luxembourg[1]
Croatia	Malta[1]
Cyprus	Norway
Czech Republic	Poland
Denmark	Portugal[1]
Estonia	Romania
Finland	Slovakia
France	Slovenia
Germany	Spain
Greece	Sweden
Hungary	Switzerland
Iceland[1]	The Netherlands
Ireland	United Kingdom
Italy	

(1) these Member States did not respond.

European Organisations interviewed

European Commission (EC)	
Construction Products Europe (CPE)	
Fire Safe Europe (FSE)	
Fire Safety Platform	
European Association for Passive Fire Protection	
Plastics Europe	
PU Europe	
European Association of EPS (EUMEPS)	
European Plastic Convertors (EUPC)	
European Phenolic Foam Association (EPFA)	
CEI-Bois (The European Confederation of Woodworking Industries)	
European Mineral Wool Manufacturers Association	
Eurogypsum aisbl	
Federation of the European Union Fire Officer Associations (FEU)	
Society of Fire Protection Engineers (SFPE) – European Chapters Coordination Group	
European Flame Retardants Association (EFRA) and Phosphorus, Inorganic and Nitrogen Flame Retardants Association (PINFA)	
European Fire Sprinkler Network - EFSN	
European Cellulose Insulation Association (ECIA)	
CPE Contact Group – the response from CPE was collated from 15 products sectors, these are listed below.	
Chemicals Ventilation Fire protection Cold rooms Mortars Insulated panels and profiles EPS insulation Mineral wool insulation	PU insulation Metallic structures Roof lights Glass Steel Plastics Wood

Appendix F Questionnaire – Member State Fire Regulators

Section 1 – Current regulations

The first section is about the current national regulations on smoke generated in building fires in (add country name at interview)

1. Do you have national regulations related to the **protection of building occupants from smoke** generated in building fires?

2. Do you have national regulations related to the protection of building occupants from **toxicity of smoke** generated in building fires?

   → If yes, do you regulate on the toxicity of smoke from construction products in fire?

3. Do you have national regulations related to smoke generated in **non-building** (e.g. transport infrastructure) fires?

   → If yes, do you regulate on the **toxicity** of smoke generated by fires in structures which are **not considered to be buildings** (e.g. transport infrastructure)?

4. Do you have regulations that prescribe or promote the use of **fire resistant construction products** in building?

   → If yes, do these regulation stipulate application domain (for example type of buildings)?

   → If yes, is toxicity of smoke explicitly or implicitly taken into account in the regulation?

5. Do you have regulations that prohibit, or restrict the use of **combustible construction products** in buildings?

   → If yes, do these regulation stipulate application domain (for example type of buildings)?

   → If yes, is toxicity of smoke explicitly or implicitly taken into account in the regulation?

Section 2 – Fire Statistics

The second section is about fire statistics or other evidence (e.g. studies, or medical records) which reliably show that victims of building fires are due to the inhalation of toxic gases from construction products.

1. Do you have **<u>fire statistics</u>**?

   → If 'yes' do you record -

   i. Numbers of fires

   ii. Number of fire deaths.

   iii. Number of fire injuries

2. Do you have a definition of "**<u>injury</u>**"?

   → If 'yes' what is it?

3. Do you have records related to **<u>fire victims</u>**?

   i. Number of deaths in building fires

   ii. Number of deaths - other types of fire (e.g. vehicle fires)

   iii. Number of deaths in fires that involve construction products

   iv. Number of deaths in other types of building fire (e.g. those just involving contents such as furniture)

   v. The nature of the injury / cause of death (e.g. smoke inhalation, burns, physical injury, etc.)

   vi. The proportion of deaths from smoke inhalation.

4. Is there information available on the **<u>building that was on fire</u>**? For example type of building; (dwelling, public building, office, old or new building); main construction products used for the building (bricks, concrete, wood, etc.); were fire resistant products used indoors.
   Is the presence of combustible furniture in the building recorded?

5. Do you have evidence that victims died from inhalation of **<u>toxic gases specifically from construction products</u>**?

   → If 'yes' what form does the evidence take it?
   → If 'yes' are gases routinely monitored in deceased fire victims?
   → If 'yes' which toxicants are considered in the treatment of smoke inhalation victims?

6. If there is evidence, are there details of **<u>the gases which are commonly responsible</u>**?
   For example asphyxiant gases (carbon monoxide, hydrogen cyanide, etc.), incapacitating or irritant gases (including acidic gases such as hydrochloric acid) and also various organic compounds.

Section 3 – Potential options for reducing risk

*In this third section we ask you to consider - if it is shown that the victims in building fires are due to the inhalation of toxic gases from construction products - which are the available options for effectively reducing the risk (e.g. to regulate on the smoke toxicity from construction products at EU level. Do you think that Member States should be allowed to regulate at national level by application of the subsidiarity principle, or support **fire engineering measures** at a European or national level (e.g. appropriate building design, installation of alarm systems, etc.).*

We ask you to consider the advantages and the disadvantages of each available option and indicate on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree) your opinion of the following options

1. Fire engineering is an accepted fire safety approach in my country
2. We have all the information needed to implement fire engineering in my country
3. Fire engineering could deliver effective benefits in my country
4. Regulation of smoke toxicity from construction products at a European level is preferable to regulation as a national level
5. Some form of Regulation at a national level directly or indirectly related to construction products is acceptable
6. If robust and meaningful smoke toxicity data was available we would us it in our regulations.

Section 4 – Legal basis for regulating at EU level

The section is about the possible legal basis for regulating at EU level on the toxicity of smoke from fires in building. We ask you to consider the advantages and the disadvantages of each available legislative option.

1. Do you think that there is any possible **legal basis for regulating at EU level** on the toxicity of smoke from fires in building?

   If yes, would that be the CPR or another piece of EU legislation (e.g. DG EMPL (Employment), DG JUST) (Justice)?

2. What are the **costs and benefits for each option**? Are they quantifiable?

   i. Legislation at EU level

   ii. Legislation at national level (subsidiarity)

   iii. Using fire engineering

3. Which option is the most effective? Why?

We ask you to consider the advantages and the disadvantages of each available option and indicate on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree) your opinion of the following statements

4. If smoke toxicity was regulated there would be reductions in the number of fire victims

5. Statistics related to fire deaths and injuries should be collated at EU level

6. The elimination of deaths from inhalation of toxic smoke in fires is achievable

Section 5 – Possible effects on the marketing of construction products

The final section is the possible effects on the marketing of construction products if regulated as above.

1. Which option (Legislation at EU level; Legislation at national level; Using fire engineering) do you think would be **more beneficial to trade**?

   Why do you consider the other two less beneficial?

We ask you to indicate on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree) your opinion of the following statements

2. The introduction of regulations related to the toxicity of smoke would increase barriers to trade

3. Regulation for toxicity of smoke would lead to disappearance from market of some typical construction product families (e.g. thermal insulation, wood, PVC)

4. Regulation for toxicity of smoke would lead to increases in the prices of some typical construction product families (e.g. thermal insulation, wood, PVC)

Section 1 – Current regulations

The first section is about the current national regulations on smoke generated in building fires

6. Do you know of any national regulations or requirements related to the **protection of building occupants from smoke** generated in building fires?

7. Do you know of national regulations or requirements related to the protection of building occupants from **toxicity of smoke** generated in building fires?

   → If yes, do you know if they relate to the toxicity of smoke from construction products in fire?

8. Do you know of national regulations or requirements related to smoke generated in **non-building** (e.g. transport infrastructure) fires?

   → If yes, do you know if they relate to the **toxicity** of smoke generated by fires in structures which are **not considered to be buildings** (e.g. transport infrastructure)?

9. Do you know of national regulations or requirements that prescribe or promote the use of **fire resistant construction products** in building?

   → If yes, do these stipulate application domain (for example type of buildings)?

   → If yes, is toxicity of smoke explicitly or implicitly taken into account in them?

10. Do you know of national regulations or requirements that prohibit, or restrict the use of **combustible construction products** in buildings?

    → If yes, do these stipulate application domain (for example type of buildings)?

    → If yes, is toxicity of smoke explicitly or implicitly taken into account in them?

Section 2 – Fire Statistics

The second section is about fire statistics or other evidence (e.g. studies, or medical records) which reliably show that victims of building fires are due to the inhalation of toxic gases from construction products.

7. Do you have any examples of fires where that victims died from inhalation of **toxic gases specifically from construction products**?

   → If 'yes' what form does the evidence take it?

8. If there are example, are there details of **the gases which are commonly responsible**? For example asphyxiant gases (carbon monoxide, hydrogen cyanide, etc.), incapacitating or irritant gases (including acidic gases such as hydrochloric acid) and also various organic compounds.

Section 3 – Potential options for reducing risk

In this third section we ask you to consider - if it is shown that the victims in building fires are due to the inhalation of toxic gases from construction products - which are the available options for effectively reducing the risk (e.g. to regulate on the smoke toxicity from construction products at EU level. Do you think the Member States should be allowed to regulate at national level by application of the subsidiarity principle, or support fire engineering measures at a European or national level (e.g. appropriate building design, installation of alarm systems, etc.).

We ask you to consider the advantages and the disadvantages of each available option and indicate on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree) your opinion of the following options

7. Fire engineering is an accepted fire safety approach
8. We have all the information needed to implement fire engineering
9. Fire engineering could deliver effective benefits in Europe
10. Regulation of smoke toxicity from construction products at a European level is preferable to regulation as a national level
11. Some form of Regulation at a national level directly or indirectly related to construction products is acceptable
12. If robust and meaningful smoke toxicity data was available then it could be used to support regulations.

Section 4 – Legal basis for regulating at EU level

The section is about the possible legal basis for regulating at EU level on the toxicity of smoke from fires in building. We ask you to consider the advantages and the disadvantages of each available legislative option.

7. Do you think that there is any possible **legal basis for regulating at EU level** on the toxicity of smoke from fires in building?

   If yes, would that be the CPR or another piece of EU legislation (e.g. DG EMPL (Employment), DG JUST) (Justice)?

8. What are the **costs and benefits for each option**? Are they quantifiable?

iv. Legislation at EU level

v. Legislation at national level (subsidiarity)

vi. Using fire engineering

9. Which option is the most effective? Why?

We ask you to consider the advantages and the disadvantages of each available option and indicate on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree) your opinion of the following statements

10. If smoke toxicity was regulated there would be reductions in the number of fire victims

11. Statistics related to fire deaths and injuries should be collated at EU level

12. The elimination of deaths from inhalation of toxic smoke in fires is achievable

Section 5 – Possible effects on the marketing of construction products

The final section is the possible effects on the marketing of construction products if regulated as above.

5. Which option (Legislation at EU level; Legislation at national level; Using fire engineering) do you think would be **more beneficial to trade**?

   Why do you consider the other two less beneficial?

We ask you to indicate on a scale of 1 to 5 (where 1 is strongly disagree and 5 is strongly agree) your opinion of the following statements

6. The introduction of regulations related to the toxicity of smoke would increase barriers to trade

7. Regulation for toxicity of smoke would lead to disappearance from market of some typical construction product families (e.g. thermal insulation, wood, PVC)

8. Regulation for toxicity of smoke would lead to increases in the prices of some typical construction product families (e.g. thermal insulation, wood, PVC)

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