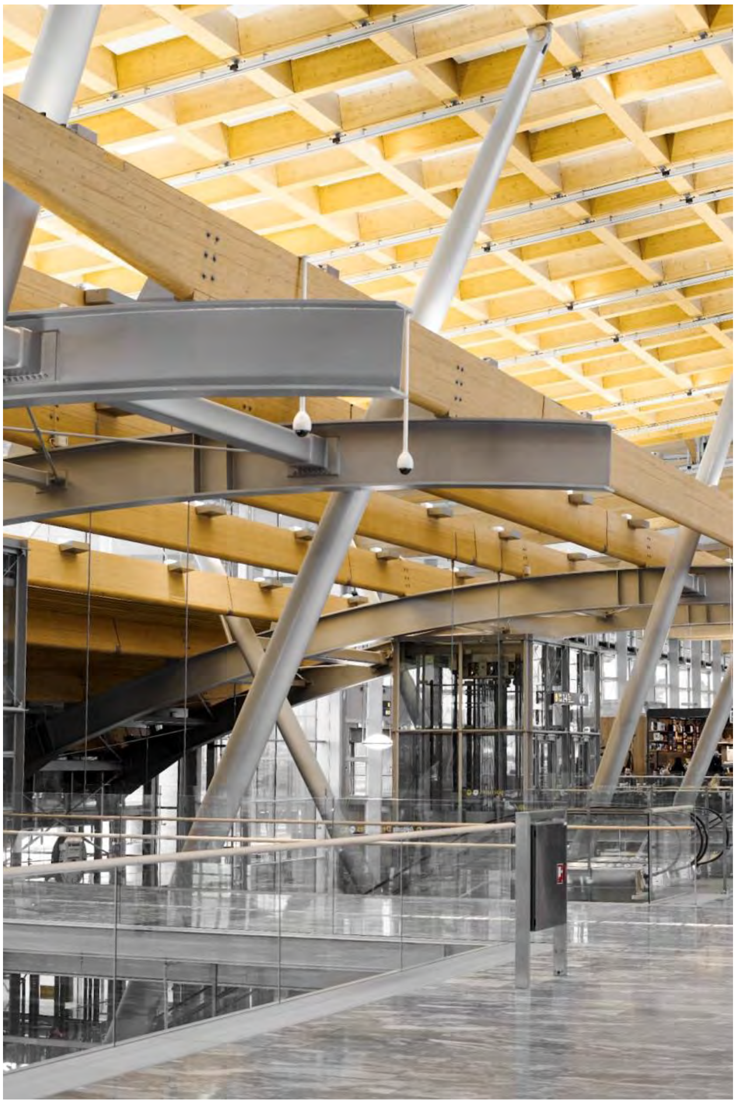
SAFETY AND TRANSPORT
SAFETY

Fire Safety Engineering for Innovative and Sustainable Building Solutions



Pierrick Mindykowski, Michael Strömgren

RISE Report 2017:42

Fire Safety Engineering for Innovative and Sustainable Building Solutions

Pierrick Mindykowski, Michael Strömgren

Abstract

Fire Safety Engineering for Innovative and Sustainable Building Solutions

Funktionsbaserade regler och standarder har länge visat sig vara ett effektivt sätt för att främja innovation. Men det är flera saker som behövs för att säkerställa kreativa och robusta miljöer. Kvaliteten måste säkerställas och det måste finnas tydliga förutsättningar för byggandet i kombination med ett regelverk som ger utrymme för nytänkande. Nordiska ministrar har också konstaterat att det finns det barriärer och handelsproblem på den nordiska byggmarknaden på grund av skillnader i regler och kontrollförfaranden. Av dessa skäl är det viktigt för byggsektorn i Norden att vidareutveckla funktionsbaserade standarder inom det nordiska samarbetet.

Brandsäkerhet är ett komplext kompetensområde som traditionellt har byggt på detaljerade regler. Detta beror bland annat på att brandsäkerhet är svårt att mäta och verifiera. Detta framgår av det faktum att de flesta nordiska länderna i många situationer fortfarande använder sig av de föreskrivande bestämmelserna som innehåller specifika lösningar, och som ofta skiljer mellan länderna. Detta tillvägagångssätt kan resultera i alltför konservativt och fördyrande brandskydd. Schablonregler riskerar att öka kostnaderna, hindra innovation och minska hållbarheten genom att begränsa användningen av vissa material.

Till skillnad från föreskrivande föreskrifter anger inte funktionsbaserade krav hur man ska uppnå brandsäkerhet. I stället formuleras prestandakrav i regelverket och en lösning tillåts som uppfyller dessa krav på prestanda, vilket möjliggör en mängd olika möjliga lösningar. Dessa lösningar kan optimeras för både kostnad och hållbarhet.

Norden är ledande i Europa inom funktionsbaserat brandskydd men saknar samtidigt en gemensam plattform. Detta medför att verifieringsprocedurer, resulterande lösningar och risknivåer varierar mellan länderna. Nya verifierings- och kontrollprocesser finns och den senaste forskningen kan ge en gemensam grund för att främja innovativt brandskydd. Nästa steg för de nordiska länderna är att utveckla gemensamma standarder som är funktionsbaserade för att underlätta innovation, handelsfrihet och hållbarhet.

Det nordiska brandsäkerhetsprojektet för innovativa och hållbara byggnadslösningar, finansierat av Nordic Innovation, SBUF (Svenska Byggbranschens Utvecklingsfond) och DIBK (Direktoratet for byggkvalitet), startade i juni 2014 och avslutades i augusti 2017.

Målet med detta projekt var att producera förslag på två praktiska specifikationer inom två områden inom brandteknik. Förslagen har lämnats över till det nordiska standardiseringssamarbetet, INSTA. Målet är att standarderna ska gå ut på remiss under 2017 och publiceras under 2018. Förslagen är:

- Standard för probabilistisk metod för att verifiera brandskydd i byggnader
- Standard för kontroll och granskning i byggprocessen

Publikationerna har skräddarsytts för den nordiska byggregelmiljön och har projektdeltagare från samtliga fem nordiska länder. Projektet stödjer nordisk harmonisering av brandsäkerhet som i slutändan kan underlätta innovation, hållbart byggande och ökad handel med tjänster och produkter.

Keywords: Fire Safety Engineering, Nordic countries, Standard, Building process, Design in building, Probabilistic method, Sustainability

RISE Research Institutes of Sweden AB

RISE Report 2017:42
ISBN: 978-91-88695-07-9
Borås 2017

Content

Abstract 4
Fire Safety Engineering for Innovative and Sustainable Building Solutions 4
Content 6
Acknowledgments 7
Background 8
Summary 9
Aim of the project 9
1 Description of the Work Packages 10
1.1 WORK PACKAGE WP 1 - Identification and Analysis of the Barriers to Innovation and Trade 10
1.2 WORK PACKAGE WP 2 – Development of Probabilistic Verification Method 10
1.3 WORK PACKAGE WP 3 – Development of Building Process Focusing on Review and Control of Fire Safety Engineering 12
1.4 WORK PACKAGE 4 – Application of WP2 and WP3 Methods on Practical Cases in the Nordic Countries 12
1.5 WORK PACKAGE 5 –Recommendations and Finalization 13
2 Future work after the project 15
3 Communication 16
4 List of the appendices 19
4.1 Appendix A 19
4.2 Appendix B 19
4.3 Appendix C 19
4.4 Appendix D 19
4.5 Appendix E 19
5 Appendix A: WP1 – Identification and analysis of the barriers to innovation and trade 20
6 Appendix B: WP4 – Application of WP2 and WP3 Methods on practical cases in the Nordic countries 46
7 Appendix C: Probabilistic method to verify fire safety design in buildings 97
8 Appendix D: Control in the building process 178

Acknowledgments

The project management would like to extend thanks to the associations providing funding for the project, namely the Nordic Innovation (in Norway), DiBK (Norwegian Building Authority) and SBUF (construction industry's organisation for research and development in Sweden). Thanks are also extended to acknowledge the work and own funding provided by the project partners,

- from Sweden: Briab, Boverket, Brandskyddslaget, Lund University, NCC and RISE Safety
- From Iceland: Iceland Construction Authority, Iceland Fire Research Institute
- From Denmark: DBI, Rambøll
- From Finland: KK Palokonsultti
- From Norway: DiBK, RISE Fire Research AS, COWI, Standards Norway

Background

The construction sector faces many significant challenges while trying to introduce innovative technology into a conservative industry that also faces increasing pressure to reduce costs while focusing on sustainability. These challenges include providing solutions and catering for an aging population, new energy requirements (which motivate the focus for sustainable construction), coping with changing climate loads, trade barriers due to national requirements, as well as ever more adventurous expressions of architectural creativity.

The newly implemented Construction Products Regulation (CPR) addresses some of the problems with barriers of trade but it is incomplete. While the CPR is a first step, it only addresses specific construction products, and additional efforts will be needed within the Nordic countries to remove barriers of trade for the construction sector in a wider context. The Nordic countries have strong cultural ties and other similarities, and are therefore in an ideal position to take the next step towards stronger cooperation.

All of the Nordic countries have introduced performance-based building codes. However, the implementation of performance-based codes has been delayed and has caused many conflicts because of the lack of standardized FSE-verification methods (Fire Safety Engineering). Designers rely on the pre-accepted solutions to avoid trouble, and local authorities are opposing performance-based codes because they question whether or not the design is meeting the regulations.

Differences in regulations and practices are causing problems for the trade of products and services. The problem for the trade barriers within the Nordic countries has been identified by the Nordic ministries and one goal is to create a unified Nordic construction market.

The challenge in this project is to create performance-based standards for fire safety engineering that will facilitate the design processes and technical innovations in a robust and sustainable way.

Summary

Performance-based regulations and standards have long been proven and effective way to facilitate innovation. However, several necessary elements are needed to ensure creative yet robust environments. Also, Nordic ministers concluded that there are trade problems in the Nordic construction market due to differences in building regulations and verification and control procedures. It is important for the construction industry in the Nordic countries that the further development of performance-based standards is performed via Nordic collaboration.

Fire safety is a complex field of expertise that is traditionally prone to detailed regulations. One important reason is that it is hard to measure and verify adequate fire safety. This is demonstrated by the fact that most Nordic countries in many situations still rely on the prescriptive regulations containing specific solutions. This approach may often result in overlap of fire safety features and overly conservative design. These regulations increase costs, hamper innovation and reduce sustainability by restricting usage of some materials while demanding the use of the others.

Unlike prescriptive regulations, performance based regulations do not specify how to achieve fire safety. Instead, performance-requirements are formulated in the regulations and any solution is permitted which meets these requirements on performance, thus allowing a variety of different possible solutions. These solutions may be optimized for both cost and sustainability.

Nordic countries are European leaders in the introduction and use of performance-based regulations but lack a common understanding, resulting in a variation in verification procedures and resulting solutions and risk levels. New verification methods exist and new research provides a common basis for the implementation of innovative methods. The next step for the Nordic countries is to develop common standards that are performance-based to facilitate innovation, freedom of trade, but also consistency.

Aim of the project

The aim of the project is creating new verification methods from a practical perspective to facilitate the implementation of performance-based regulations and thereby increase the use of innovative design and technology in the industry, such as green/sustainable buildings.

New innovative construction products may be used in the built environment, proven to be fire safe yet able to meet the changing requirements of society.

Therefore, INSTA standards/specifications are produced, providing the methods to facilitate innovative design by fire safety engineering methods and providing guidance on the process that lead to safe and innovative fire safety design.

1 Description of the Work Packages

Each Work Packages are described below. For each of them, a table shows the original milestone plan and the possible deviations meet during the project.

1.1 WORK PACKAGE WP 1 - Identification and Analysis of the Barriers to Innovation and Trade

Aim	To develop a specific technical method, for verification of innovative and sustainable solutions
Start	01.06.2014
End	28.02.2015
Responsible	Björn Karlsson, Iceland Construction Authority
Results	Problems and barriers to trade and innovation are addressed and a technical verification is proposed
Deliverable	A status report on the current situation, with prioritized areas for further progress (in WP 2 and WP 3)

The work package contains a screening of the building regulations in the Nordic countries to identify barriers.
WP1 was completed on schedule in February 2015 (as originally planned), under the leadership of the Icelandic Construction Authority, with the publication of a report entitled *Report on WP1 - Identification and Analysis of the Barriers to Innovation and Trade*.
More precisely, the report provides brief background on fire safety engineering methods in the Nordic and European countries. Also, it gives an overview of how such methods are used in combination with performance-based codes, presenting a discussion on how and why performance-based codes were developed, and how such codes contributed towards enhancing fire safety engineering practices.
An overview of the building codes in the Nordic countries with emphasis on fire safety engineering is given.
And finally, a discussion is conducted on the main problems and challenges related to fire safety engineering, based on questionnaires distributed to fire safety engineers and authorities and practical experience among fire safety engineers.
The report of the WP1 is provided in Annex A.

1.2 WORK PACKAGE WP 2 – Development of Probabilistic Verification Method

Aim	Identification of the problems and prioritization of necessary actions, for use in the later work packages
Start	01.01.2015
End	31.03.2016
Responsible	John Utstrand, COWI
Results	Problems and barriers to trade and innovation are addressed and a technical verification method is proposed
Deliverable	A preliminary technical verification method for use in fire safety engineering. Final version published in WP5.

WP2 started in January 2015 and completed in March 2016, under the leadership of COWI, with the production of a preliminary specification document that provides guidance on a basic probabilistic approach, supported by quantitative analysis, suggested acceptance criteria, and a collation of relevant fire statistics and reliability data. This document is entitled *Fire Safety Engineering – Probabilistic Methods For Verifying Fire Safety Design in Buildings*.

Description of the document:

In fire safety engineering, compliance with fire safety regulations can be demonstrated, either by the use of pre-accepted solutions that are defined by the building authorities, or by using fire safety engineering methods.

Fire safety engineering methods can be used to demonstrate fire safety in two ways:

1. The use of fire safety engineering methods in order to compare a design to pre-accepted solutions;

2. The use of fire safety engineering methods for the evaluation of a design against absolute criteria.

A lack of absolute criteria has been a hinder to extensive use of the second approach, and this Technical Specification aims to provide guidance also for analyses where pre-accepted solutions are invalid or where a comparative approach is not considered optimal. The execution of these methods requires input data which represent the frequency of events and an absolute criterion which correspond to an acceptable level of safety. In order to facilitate the implementation of performance-based regulations for non-pre-accepted solutions, this Technical Specification provides performance criteria, guidance on the use of fire safety engineering methods and guidance on the use of input parameters, such as reliability data and statistics.

This Technical Specification is supplementary to the INSTA/TS 950 Technical Specification, which describes comparative methods for assessments that use pre-accepted solutions as a basis. As INSTA/TS 950 has a primary focus on deterministic methods, this Technical Specification also provides guidance on a probabilistic approach to comparative analysis.

The result of this Work Package is not presented in this current document as it was only a work document being further developed in WP5.

1.3 WORK PACKAGE WP 3 – Development of Building Process Focusing on Review and Control of Fire Safety Engineering

Aim	To develop a process to facilitate development and verification of innovative and sustainable solutions
Start	01.01.2015
End	31.03.2016
Responsible	Johan Noren, Briab
Results	This work package will address process oriented problems identified in WP 1 and will result in the development of a preliminary specification
Deliverable	A preliminary specification for the process leading to verification of innovative and sustainable design. Final version published in WP5.

WP3 started concurrently with WP2 in January 2015 and completed in March 2016, under the leadership of Briab, with the production of a preliminary specification document that provides a harmonized process for the review and control of fire safety engineering designs, applicable for innovative and sustainable fire safety engineering solutions. This document is entitled *Fire Safety Engineering – Control in the Building Process*.

This Technical Report provides guidance about review and control of fire safety design in the building process. It is based on previous Nordic work (NKB, 1994), work conducted by ISO TC92/SC4 on fire safety engineering and SFPE Guidelines (SFPE, 2007 and 2009).

The result of this Work Package is not presented in this current document as it was only a work document being further developed in WP5.

1.4 WORK PACKAGE 4 – Application of WP2 and WP3 Methods on Practical Cases in the Nordic Countries

Aim	To use and test the products of WP 2 and WP 3 in practical application, i.e. real buildings projects
Start	01.01.2016

Aim	To use and test the products of WP 2 and WP 3 in practical application, i.e. real buildings projects
End	31.12.2016
Responsible	Thomas Järphag, NCC
Results	Experience from the use of the products of WP 2 and WP 3 and the application of the methods on actual cases for evaluation purposes
Deliverable	A report on the case study, using the products of WP 2 and WP 3

WP4 started in February 2016 and completed in December 2016, under the leadership of RISE (as explain in the Progress Report of 2016, a change from the previous nominated leader NCC).

The primary objective of WP4 is to use and test the outputs (preliminary specifications) from WP2 and WP3 in practical applications. Seven case studies have been performed in the case of the WP2, two case studies in the case of the WP3.

Also, both documents have been reviewed by an expert (Dr. Brian Meacham, Associate Professor at Worcester Polytechnic Institute, USA).

The WP4 report, namely *WP4 Report – Application of WP2 and WP3 Methods on Practical Cases in the Nordic Countries* is provided in Annex B.

1.5 WORK PACKAGE 5 –Recommendations and Finalization

Aim	To finalize and produce two specifications or standards that facilitate sustainable and innovative solutions by fire safety engineering
Start	01.08.2016
End	31.05.2017
Responsible	Michael Strömgren, RISE

Aim	To finalize and produce two specifications or standards that facilitate sustainable and innovative solutions by fire safety engineering
Results	Revision of the delivered reports of WP 2 and WP 3 based on conclusions of WP 4
Deliverable	Final version of the two reports from WP 2 and WP 3, to be published as technical specifications or standards

WP5 has started in August 2016 and completed in May 2017, under the leadership of RISE.

The first version of the specification document of the WP2 and WP3 has been modified according the outcomes of WP4. Both documents are now under the formatting process for a publication as standard/guidance. The National Standardization Bodies (SFS from Finland, SIS from Sweden, SN from Norway) have approved the proposals and their willingness to participate actively in the work.

In Annex C and Annex D, the final versions of the specifications *Fire Safety Engineering – Probabilistic Methods For Verifying Fire Safety Design in Buildings*, and *Control in the Building Process* are presented.

2 Future work after the project

The National Standardization Bodies (SFS from Finland, SIS from Sweden, SN from Norway) will process the specifications from WP 2 and WP 3 into INSTA documents. Indeed, those bodies have approved the proposals and their willingness to participate actively in the work. In addition, IST (Iceland) approves the establishment of an INSTA Technical Committee for Fire Safety Engineering (INSTA/TC FSE) but without direct participation. Standard Norway will hold the secretariat of this INSTA Technical Committee. In that sense, Vidar Stenstad (SN) has been nominated as chair of the INSTA/TC FSE and Lisbet Landfald (SN), will be secretary.

Therefore, SIS, SFS, SN, IST and DS (Danish Standard body) have been invited to nominate national delegates/experts to the new INSTA/TC, and the following are the nominated members of INSTA/TC FSE:

For Finland: Esko Mikkola.

For Norway: Anne Steen-Hansen, RISE.

For Sweden: Michael Strömgren, RISE (now, BRIAB) and Karin Ekström, SIS (as observer).

For Denmark: To be determined.

For Iceland: No active participation

A possible publications of the specifications from WP 2 and WP as standards will be in the first quarter of 2018.

3 Communication

Here the list of the communications activities during the project:

- In June 2015 a presentation entitled *Fire Safety Engineering for Innovative and Sustainable Building Solutions* was made at the 1st *SFPE Europe Conference on Fire Safety Engineering* in Copenhagen.
- In May 2016, two presentations were made during the *11th Conference on Performance-Based Codes and Fire Safety Design Methods*, which took place in Warsaw, Poland. The first relates to the work of WP2 and is entitled *Probabilistic Fire Risk Analysis in the Nordic Region*. The second, relating to WP3, is entitled *Fire Safety Engineering for Innovative and Sustainable Building Solutions – Development of Building Processes Focusing on Review and Control of Fire Safety Engineering*.
- A presentation entitled *Fire Safety Engineering for Innovative and Sustainable Building Solutions* was made at the Nordic Fire and Safety Days, the 16th and 17th June 2016 in Copenhagen, Denmark.
- An article entitled Next Generation Nordic Fire Safety Engineering has been published within the English version of Brandposten (number 55, 2017: http://www.mypaper.se/show/sp/show.asp?pid=3553551157066694).
- Seminars has been organized during May 2017, one in Malmö, Sweden and one in Oslo, Norway.
- A presentation entitled *Fire Safety Engineering for Innovative and Sustainable Building Solutions, Future Standard for control and review* was made at the Nordic Fire and Safety Days 2017, in Copenhagen, Denmark.

As requested by Nordic Innovation, the following paragraph consists on a press release

Press Release – Fire Safety Engineering For Innovative and Sustainable Building Solutions

The Nordic fire safety engineering project (funded by Nordic Innovation, SBUF, DIBK and own contributions by project participants) for innovative and sustainable building solutions is now finalized. We produced practical specifications on two areas within fire safety engineering:

- Standard on Probabilistic Method to Verify Fire Safety Design in Buildings
- Standard on Control in the Building Process

This project is important as it supports Nordic harmonization of fire safety which in the end may facilitate trade of services and products. We all share challenges in our societies as we introduce new technologies and aim for more sustainability, often challenging traditional fire safety concepts. For example, some cases where traditional fire safety regulations may hinder building design are:

- passive housing
- energy efficiency and use of combustible materials
- green facades or roofs
- tall buildings

So what is new in these standards? There are plenty of guidelines and standards on fire safety engineering by British standards, SFPE, ISO and others. What we have developed is however tailored for the Nordic context which is a region that has used fire safety engineering for quite some time now. In some areas, the Nordic region is doing pioneering work. Some things we are trying to achieve in this work are:

- turning good knowledge into practice
- take recommendations one more level
- bridge the gap between probabilistic criteria, such as FN-curves and acceptance criteria used in scenario based design
- quality control & review in the building process

We have come far enough to treat the new publications and review them for different type of cases in the Nordic countries. During the winter 2017-2018, the INSTA process will start in order to make specifications into INSTA documents.
The project is led by RISE and has the following partners:

<table>
<tr><th>Sweden</th><th>Iceland</th><th>Denmark</th><th>Finland</th><th>Norway</th></tr>
<tr><td>RISE Safety</td><td rowspan="3">Iceland Construction Authority</td><td rowspan="3">DBI</td><td rowspan="6">KK Palokonsultti</td><td>DiBK</td></tr>
<tr><td>Briab</td><td rowspan="2">RISE Fire Research AS</td></tr>
<tr><td>Boverket</td></tr>
<tr><td>Brandskyddslaget</td><td rowspan="3">Iceland Fire Research Institute</td><td rowspan="3">Rambøll</td><td rowspan="2">COWI</td></tr>
<tr><td>Lund University</td></tr>
<tr><td>NCC</td><td>Standards Norway</td></tr>
</table>

Photo 2: Meeting at DBI for the finalization of the WP 4.

From the right to left:

Esko Mikkola (KK Palokonsultti, Finland), Johan Noren and Fredrik Nystedt (BRIAB, Sweden), Annemarie Poulsen (formerly Rambøll, Denmark), Bengt Gåfvels (NN, Sweden), Anne Sønderskov Nielsen (If, Denmark), Pierrick Mindykowski (RISE, Sweden), Anders Dragsted (DBI, Denmark).

Not shown on the picture but present by skype: Anne Elise Steen-Hansen (RISE Fire Research AS), Björn Karlsson (Iceland Construction Authority, Iceland).

Picture taken by Michael Strömgren (formerly RISE, Sweden).

4 List of the appendices

4.1 Appendix A

Document name: WP1 – Identification and analysis of the barriers to innovation and trade

4.2 Appendix B

Document name: WP4 – Application of WP2 and WP3 Methods on practical cases in the Nordic countries

4.3 Appendix C

This document is part of the final outcome of the Work Package 5. It consists of the implementation of the modifications of the specification document (Work Package 2) found during the process of the Work Package 4.

Document name: Probabilistic method to verify fire safety design in buildings

4.4 Appendix D

This document is part of the final outcome of the Work Package 5. It consists of the implementation of the modifications of the specification document (Work Package 3) found during the process of the Work Package 4.

Document name: Control in the building process

4.5 Appendix E

Document name: Economic Report

5 Appendix A: WP1 – Identification and analysis of the barriers to innovation and trade

Nordic Innovation Project No.: P-13063

Fire Safety Engineering for Innovative and Sustainable Building Solutions

Report on WP1 – Identification and analysis of the barriers to innovation and trade

Fire Safety Engineering for Innovative and Sustainable Building Solutions

Report on WP1 - Identification and analysis of the barriers to innovation and trade

Project funded by Nordic Innovation, Project No. P-13063

Project owner: SP Technical Research Institute of Sweden

Contributing authors: Björn Karlsson, Michael Strömgren, Johan Noren, John Utstrand, David Winberg, Vidar Stenstad, Esko Mikkola, Anders Johansson, Thomas Järphag

February 2015

Table of Contents

1. Introduction 4
1.1 Summary of project main objectives 4
1.2 Recent Nordic efforts to harmonize building regulations 5
1.3 Comparison of European building regulations and fire safety 7
1.4 Overview of this report 8
2. Performance-based Codes and Fire Safety Engineering methods 9
2.1 Background on performance based codes and FSE 9
2.2 Recent work on performance based standards and guidelines in FSE 11
2.3 Discussion on performance based codes 11
3. Comparison of Nordic building codes 13
3.1 Denmark 13
3.1.1 Handling procedures 13
3.1.2 The control systems 14
3.1.3 Requirements for fire safety 14
3.2 Finland 14
3.2.1 Handling procedures 15
3.2.2 The control system 15
3.2.3 Requirements for fire safety 15
3.3 Iceland 16
3.3.1 Handling procedures 16
3.3.2 The control system 16
3.3.3 Requirements for fire safety 17
3.4 Norway 17
3.4.1 Handling procedures 17
3.4.2 The control system 17
3.4.3 Requirements for fire safety 18
3.5 Sweden 18
3.5.1 Handling procedures 19
3.5.2 The control system 19
3.5.3 Requirements for fire safety 19
4. Determination of focus areas for the current project 20
4.1 Fire Safety Engineering in the Building Process 20
4.2 WP2: Development of a verification method 21
4.3 WP3: Development of building process focusing on review & control of fire safety engineering 22
5. References 24

1. Introduction

This document reports on the work carried out in Work Package 1 within the project "Fire Safety Engineering for Innovative and Sustainable Building Solutions", financed by Nordic Innovation and coordinated by SP Technical Research Institute of Sweden. This chapter summarizes the project main objectives, discusses recent Nordic efforts to increase harmonization of building regulations, discusses the state of the art in Europe and gives an overview of this report.

1.1 Summary of project main objectives

Performance-based codes, i.e. regulations and standards, have long been proven an effective way to facilitate innovation, and all of the Nordic countries have introduced performance-based building codes. However, the implementation of performance-based codes for fire safety has not been overly successful due to the lack of standardized verification methods and acceptance criteria and instruments to ensure high quality fire safety design. As a result, fire safety design too often relies on prescriptive and detailed regulations due to uncertainties and lack of acceptance of performance-based design.

Differences in regulations and practices in the Nordic countries are causing problems for the trade of products and services. The problem of trade barriers within the Nordic countries has been identified by the Nordic ministries and one goal is to create a unified Nordic construction market. The Nordic countries have strong cultural ties and other similarities, and are therefore in an ideal position to take the next step towards stronger cooperation.

The challenge in this project is to create standards supporting fire safety engineering in a performance-based regulatory regime that will facilitate the design processes and technical innovations in a robust and sustainable way. The project will thereby continue the successful Nordic cooperation that resulted in the recently published Nordic specification on fire safety engineering – INSTA TS 950.

Aims of the project:

- Standardize verification methods and acceptance criteria based on a practical perspective to facilitate the implementation of performance-based codes and thereby increase the use of innovative design and technology in the industry, such as green buildings and sustainable technology.
- New innovative construction products may be used in the built environment, proven to be fire safe yet able to meet the changing requirements of society.
- Nordic standards (INSTA) will be produced, providing the methods to facilitate innovative design by fire safety engineering methods and providing guidance on the process that lead to safe and innovative fire safety design.

The project members in the consortium represent all Nordic countries and a broad range of stakeholders such as:

- Standardization organizations - Norwegian Standardization,
- Regulatory agencies - The Swedish National Board of Housing, Building and Planning (Boverket), Iceland Construction Authority, Norwegian Building Authority (DiBK)

- Research organizations - The Danish Institute of Fire and Security Technology (DBI), Iceland Fire Research Institute, Lund University, SP Technical Research Institute of Sweden and SP Fire Research AS
- Fire consultancy companies - Brandskyddslaget, Briab, COWI, KK-Palokonsultti, Ramböll
- Construction companies - NCC

1.2 Recent Nordic efforts to harmonize building regulations

The main objective of this section is to give a brief overview of efforts being made towards greater harmonization of building regulations and building standards in the Nordic countries and how this has links to some efforts being made on European level.

The Nordic Council of Ministers is especially interested in further harmonization of the Nordic building regulations, in order to remove border barriers in the Nordic building market. Poul Schluter (the former Danish Prime Minister) wrote a report in 2005 for the Nordic Council of Ministers on Nordic border barriers (grænsehinder) and recommended that the Nordic countries should work actively towards further harmonisation of the building regulations and standards [1].

Here, we mainly concentrate on building regulations and standards, but it should be noted that the building sector does not only follow the building regulations and standards in each country, but also various advice and practices set forth by government agencies, research bodies and associations as well as being heavily influenced by trade traditions in each country.

Greater harmonization of the Nordic building regulations could be achieved in a number of areas, such as energy efficiency, structural stability, material use, sustainability, noise, stairways and ramps, daylight, accessibility and dimensions of habitable space and habitable room. However, in this project we shall focus on aspects that have to do with fire safety in buildings.

We shall in the following summarize some of the work which has been carried out towards further harmonization and finally give recommendations on how the work can be enhanced and followed up.

One of the aims of Nordic cooperation has been to make the Nordic countries a well-functioning market and an integrated region. In the building sector, various actors within the Nordic countries have been cooperating with the aim of increasing the harmonization of building regulations, thereby minimizing technical trade obstacles.

In 2009, the Nordic Council of Ministers asked the relevant building authorities of each Nordic country to designate one member each to a working group with the aim of recommending ways to further harmonize the demands made in the building regulations in the Nordic countries, as a result of the recommendations made in [1]. The working group delivered recommendations to the group EK-NE/Næring within the Nordic Council of Ministers [2].

Building laws and building regulations are very complex and comprehensive. The Nordic building regulations all have different foundations and it is not feasible to try to completely harmonize Nordic building regulations in the foreseeable future. Also, any serious changes within the building regulations of one country can have a considerable impact on that country's industry and/or import business.

However, it can be relatively easy to harmonize certain given technical demands that are made in the various Nordic building regulations. Several cooperation projects with this aim have been ongoing in the last few years, a good example is the publication of an INSTA standard on residential sprinkler systems [37]. Many of these have been conducted with financial assistance from the Nordic Innovation or NICe. Some of the projects have been concluded and final reports have been submitted, other projects are still ongoing, we shall discuss these efforts.

The Nordic Council of Ministers funded a program called 'Northern Dimension – Increased exchange in the Building and Construction Sector'. Within this program several very extensive studies have been carried out. Within the project the building legislation in the five Nordic countries were compared in [3] (report in Norwegian). This study was extended to include the Baltic States and Poland in [4] (report in English). These reports are very valuable when considering how best to increase harmonization in the building sector in the Nordic and Baltic region.

Further work was carried out [5], where suggestions were made to develop a cooperation programme, to select themes and to establish networks for stakeholders in the building sector from industry, governmental bodies and research for realization of R&D projects. Also, in [6], suggestions were made on how recognition of professional qualifications regarding the building process could possibly be carried out in the Nordic Region and the Baltic States.

Several projects on the building sector have been ongoing with financial assistance from NICe. The following two reports are an example of final reports, dealing with the Nordic building sector, that have recently been submitted to NICe:

[7] Pousette, A., Gustafsson, A., "Harmonisering av de nordiska ländernas träbyggregler – Trähusindustrins problem och byggreglernas krav, SP Rapport 2008:45, SP, Boras, Sweden, 2008.

[8] Thureson, P., Sundström, B., Mikkola, E., Bluhme, D., Hansen, A.S., Karlsson, B., "The use of Fire Classification in the Nordic Countries – Proposals for Harmonization", SP REPORT 2008:29, SP, Boras, Sweden, 2008.

The above reports describe in detail where technical demands in building regulations in the Nordic countries could be altered slightly, increasing harmonisation considerably.

A number of other projects backed by NICe are ongoing, for example:

Nordic Region Construction Technology Platform

Integrert energiplanlegging av bygg (IEP)

Room for humans: Innovativt Byggande II

Project on the use of natural stone in construction (natursten)

The outcome from the above projects can be used to harmonize technical demands in Nordic building regulations. Several other Nordic projects are ongoing, some without NICe backing, an example is the Nordic project on fire safety design and sprinkler systems resulting in the report "Verifying Fire Safety Design in Sprinklered Buildings" [38] financially backed nationally in each country. A further mapping of NICe projects, and other Nordic projects, that can lead to further harmonization within the Nordic building industry may be needed.

It is also important to mention the Nordic National Annexes to the Eurocodes. The 10 Eurocodes are enforced in the following 10 areas: General design, Actions/Loads, Concrete, Steel, Composite Concrete/Steel, Timber, Masonry, Geotechnical Design, Seismic design, Aluminium. All Eurocodes for materials (no 2, 3, 4, 5, 6 and 9) have one part on general building design and one part on fire safety design. Each Nordic country thus has National Annexes to the Eurocodes, used for designing buildings. For example, when designing a timber-framed building, a number of different factors influence the design very much. Some of these factors can be chosen in each of the countries and picked from the National document. It would be of great interest to harmonize the Nordic European Annexes. A Nordic working group on harmonization of building regulations initiated work on a report on how this could best be done [9].

Several other reports have been written recently on the need for harmonization of the Nordic building regulations and standards, we shall mention a few:

[10] Kristina Landfors, "RAPPORT 'Harmonisering av byggregler inom Norden", WSP, 5 Mars 2013

[11] Patrik Groth "Different Building Regulations in the Nordic Countries", SKANSKA, Skanska Sverige AB, 22 December 2010.

[12] Nikolaj Tolstoy, "Nordiska byggregler – gränshinder för handel av entreprenader, material och konstruktioner inom bygg och installation", Regeringskansliet, Socialdepartementet, 21 November 2011.

[13] NOTAT "Grensehindringer i Norden" Statens bygningstekniske etat, referens 11/6633, 18 November 2011.

1.3 Comparison of European building regulations and fire safety

We will conclude this section with a few words on European studies on building regulations comparisons. A number of studies have been conducted on the European level with the aim of comparing demands for a minimum quality for houses, regulated in national sets of technical building regulations. The most recent are the studies by Sheridan, Visscher and Mejer [14], [15]. Studies show that most West-European countries call their regulations 'performance based' and the goals and major subjects are quite similar. However, a more detailed look at the terminology and content of the sets of requirements, show quite fundamental differences. Research into the differences in terminology is a first and important step towards better mutual understanding of national sets of building regulations which is essential to start a discussion of the possibilities of further harmonization of the systems of the various countries. The reports by Sheridan, Visscher and Meijer [14], [15], present the results and conclusions of a comparative study of the building regulations in Belgium, Denmark, England, France, Germany, the Netherlands, Norway and Sweden. The systems and terminology of the requirements for houses have been compared in detail: stairways and ramps, fire safety, noise, daylight, accessibility and dimensions of habitable space and habitable room. They concluded that the broad spectrum of different systems forms a major barrier for further harmonization of building regulations in Europe and even so a barrier for the realization of an internal European market.

Also, the national fire regulations in Europe and some other countries in relation to the use of wood have been surveyed and results can be found in [39].

1.4 Overview of this report

Having given a brief background on fire safety engineering methods in the Nordic and European countries in Chapter 1, Chapter 2 gives an overview of how such methods are used in combination with performance based codes. The chapter presents a discussion on how and why performance based codes were developed, and how such codes contributed towards enhancing fire safety engineering practices.

Chapter 3 gives an overview of the building codes in the Nordic countries with emphasis on fire safety engineering. Chapter 4 discusses the focus areas for the current project and Chapter 5 gives a list of the main goals, the time frame and the leaders of Work Packages 2, 3 and 4.

2. Performance-based Codes and Fire Safety Engineering methods

For some decades, there has been a development towards replacing the traditional prescriptive approach to regulation, with performance based demands. This has had a very important effect on Fire Safety Engineering design practices, allowing a great variety of possible solutions to fire safety problems. This chapter gives an overview of this development and discusses the effect on FSE practice.

2.1 Background on performance based codes and FSE

It has been argued that the main purpose of building regulations is to serve as a legal tool to provide minimum social needs with regard to the built environment, without causing excessive costs to society [17]. This objective can be achieved by regulations composed of a mixture of prescriptive and performance requirements.

During the last two decades there has been an effort in many parts of the world to move from prescriptive demands in building regulations toward an increased use of performance-based demands. A very useful report on the transition from prescriptive to performance based building codes in 14 different countries around the globe was presented by the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) recently [18]. The Performance-based Building Thematic Network (Pebbu) was set up, funded under the European Commission's 5th framework, where over 70 organizations worldwide took part, resulting in several reports on the issue [19, 20]. The Society of Fire Protection Engineers has published guidelines on performance based codes [21] and international entities such as the Conseil International du Batiment (CIB), the International Standards Organization (ISO) and the International Code Council (ICC) have produced guidelines, standards and codes on this subject.

A number of decades ago, regulatory agencies of all types, and in many parts of the world, began to reconsider the traditional prescriptive approach to regulations, seeking ways to clarify the intent of regulation, reduce regulatory burden, and encourage innovation without compromising the level(s) of performance delivered. This gave rise to consideration of functional, objective-based or performance-based approaches to regulation. In the building regulatory environment, the hierarchy outlined by the Nordic Committee on Building Regulation (NKB) became a widely adopted model [22], [23], [36]. Figure 1 shows an outline of the NKB hierarchy of demands.

In the NKB model the regulatory provisions are based on a set of broad societal goals, at the top of the pyramid. Through increasing levels of detail, functional requirements (qualitative) and operational requirements (quantitative) for buildings are described. "Verification methods" are at the third level in the pyramid. Instead of prescribing a single set of design specifications for compliance, the approach outlines the need for instructions or guidelines for verification of compliance. This could include engineering analyses, test methods, etc, and would be used to demonstrate compliance with the operative requirements. Finally, at the bottom of the pyramid one finds "Examples of Acceptable Solutions". These are supplements to the regulations with examples of solutions deemed to satisfy the requirements, which may be prescriptive.

Figure 1. The NKB hierarchy of demands [22,23]

The NKB model is attractive because it places the focus on societal (policy-level) goals and allows for a variety of forms of regulatory provisions to provide the detail required to demonstrate compliance.

Any regulatory regime must find a balance between how tight controls should be in promoting consistency and accountability versus how much discretion should be granted in promoting flexibility and innovation. The prescriptive approach emphasizes control and accountability. The performance-based approach desires to promote flexibility with accountability for results [24].

Some of the potential benefits of moving toward a performance-based regulatory regime are that this may lead to greater effectiveness in reaching specific regulatory objectives, greater flexibility in means of adhering to the regulation and increased incentive for innovation, resulting in buildings that are to a greater extent designed for the intended use. Some of the potential drawbacks are uncertainties in how to interpret the regulation in practice, leading to inconsistencies in application of rules and decreased predictability in regulatory expectations. This may also lead to inconsistencies in the way that local building authorities enforce the regulation. Therefore, a move toward a performance-based regulatory regime calls for a considerable effort to produce supporting literature for designers, builders and inspectors, such as instructions, guidance documents, inspection manuals and examples of accepted solutions.

The very comprehensive report recently presented by the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) [18] gives a detailed description of how 14 different countries around the globe made the transition from prescriptive toward a performance-based building code. In many of these countries the shift was very gradual and careful. As an example, Canadian officials decided that rapid conversion of the model National Code Documents to a performance-based format would be extremely disruptive to the Canadian construction industry and regulatory community. A more evolutionary approach was sought and a decision made to retain the existing mixture of performance and prescriptive code provisions but to tie each provision to at least one explicitly stated Code objective [18].

Chapter 3 gives an overview of the building regulations in the Nordic countries and gives a summary of how they have embraced the performance based concept. Some countries, such a Sweden, made a decisive move toward a performance based building code in 1994, while

Icelandic authorities sought a gradual transition from a prescriptive to a performance-based building code. The reason for this might be that a small economy such as Iceland has very limited resources to produce guideline documents on technical demands regarding construction.

In some of the Nordic countries there is an overall lack of instructions, textbooks, courses and often expertize to provide engineering calculations as verification methods for code compliance.

Some of the Nordic countries have therefore made the choice to move gradually toward a more performance-based building code. This is typically done by inserting performance demands into all chapters and most sub-chapters of the code and simultaneously produce a decisive effort to enhance guidance documents related to the building regulation.

2.2 Recent work on performance based standards and guidelines in FSE

Alvares et al [25] wrote a comprehensive state-of-the-art review on how the performance-based fire protection design process has developed in the last two decades and identified several opportunities on how to enhance this process. CEN TC127/TG1 (now WG8) "Fire Safety Engineering" published the results of a questionnaire on the state of the art in fire safety engineering in Europe [35], showing how some European countries have implemented performance based requirements into their building regulations.

Several standards, codes and guidelines on the subject have been published in recent years, for example the SFPE Engineering guide to performance based fire protection [26]. Considerable work has been carried out in the Nordic countries. The very recent publication of the INSTA technical specification on fire safety engineering – comparative method to verify fire safety design in buildings is one of the hallmarks of this development [27]. This specification was prepared by a committee representing the Inter Nordic Standardization Cooperation, and the standard has been given the status of a national technical specification in Denmark, Finland, Iceland, Norway and Sweden.

Further, several guideline documents linked to performance based fire safety engineering design have been published in the Nordic countries in recent years. Some have to do with design procedures and recommendations. Examples are INSTA TS 950 [27], the BIV guideline on BR0 buildings [28] and the Norwegian Standard on requirements for risk assessment of fire in construction works [34]. Other guidelines have to do with advice on how to use specific computer simulation models like the BIV document on CFD calculations [29], or the Briab documents on smoke filling calculations [30] and evacuation calculations, [31] and the "Best Practice Gruppens" document on CFD calculations [32], a Danish contribution. Further, BIV published guidelines on how to control and inspect if the design and the building works fulfil regulations [33].

2.3 Discussion on performance based codes

In a performance-based code, compliance with the fire safety regulations can be demonstrated in two ways: either by constructing the building in accordance with pre-accepted solutions (defined by national building authorities), or by means of analyses and/or calculations which document that the fire safety is satisfactory. In some of the Nordic countries, the pre-accepted solutions are also referred to as 'deemed to satisfy' or 'acceptable' solutions, and are used to simplify the design process and construction of buildings by eliminating the need for analyses, so that analytical tools are hardly necessary for traditional buildings. The pre-accepted solutions are sometimes also published in separate approved documents, and the building is considered safe if these solutions are adopted. On the other hand, those who are in a position to perform analyses and calculations are given a real freedom of choice in establishing a particular fire safety design solution, without having to resort to exemptions or other departures from the requirements. A building is considered safe, irrespective of its design and construction, if it complies with the performance-based building code. As long as the performance requirements are met, the choice of design method - i.e. whether using pre-accepted solutions or analytical tools to result in buildings with satisfactory safety in case of fire - is immaterial.

Verification is a central element of a performance-based code. When pre-accepted solutions are adopted, the designer verifies that the building actually has been built according to the specifications of the pre-accepted solutions. The designer does not need to show that the design is safe, as accepted safety levels are assumed to be reached with the use of pre-accepted solutions. If analytical tools are used, verification becomes of utmost importance. The designer must use tools to show that the proposed design solution results in a safety level that is in line with what is accepted by the society, i.e. formulated in the performance requirements of the building code. This process of demonstrating sufficient safety is commonly referred to as verification, and can be performed with a number of different methods, ranging from qualitative screening techniques to extended quantitative analyses.

Although most buildings are designed using pre-accepted solutions, a deviation from some of these solutions may sometimes be in the interest of the builder. This process, when one pre-accepted solution is replaced by another, is generally considered as a design alternative. All design alternatives need to be verified in order to show that the achieved safety level complies with the regulatory requirements. This verification is performed by qualitative assessment, scenario analysis or quantitative risk analysis, and the result should be documented and thoroughly reviewed.

3. Comparison of Nordic building codes

In this section there will be a brief description of the building codes in the Nordic countries. The intention is to describe the principles which apply in the building procedures in each country, what are the handling procedures for building permits and who are responsible for the control and supervision. There will also be a brief discussion on what are the requirements for fire safety. This section is largely based on a report published by the Nordic Council of Ministers on Increased exchange in the Building Sector Comparison of Building Legislation in the Northern region [4]. Some updates have been introduced here, since changes have been made in some of the Nordic countries after [4] was published.

3.1 Denmark

Administratively, Denmark is divided into 5 regions and 98 local authorities (municipalities), in addition to the Faroe Islands and Greenland which have their own building codes based on previous versions of the Danish Building Code. There is a strong political will to delegate power to the local community.

There are separate laws for planning and building. The Planning Act is administered by the Nature Agency under the Ministry of the Environment, while the Building Act is administered by the Energy Agency under the Ministry of Climate, Energy and Building.

Regarding buildings with high hazard storage or production, there is an extra "layer" of fire safety legislation. This set of codes is administered by The Danish Emergency Management Agency (DEMA) which is an agency under The Ministry of Defense and is exclusively prescriptive. Building permits are handled by either the local fire authority or DEMA depending on the amount of hazardous stock.

In 2014 the Danish Government published "Vejen til et styrket byggeri i Danmark – regeringens byggepolitiske strategi" (a political strategy to strenghten the constructed environment). Initiative 2 in the strategy may be translated to "Simplified fire regulation". Among other things, it states that the system where two different governmental agencies are responsible for the fire regulation is too inefficient and often causes an unnecessary complicated process to achieve a building permit. Therefore, a reform of this system may be expected.

3.1.1 Handling procedures

The focus on the importance of local democracy leads to a different practice between the municipalities, regarding the administrative organization. Most often, the building applications are issued by the Planning Office to secure compliance with the local plan, but not always. And most often, the Planning Office and the Building Control Office are located in the same building to secure good communication and flexibility, but not always. The basis for the specific handling procedures are given in the Building Regulations, and the specification given there to divide the constructions into categories: a) where applications are needed, and b) smaller constructions where only notifications are needed.

The local authority Planning Office handles building permit applications. They primarily look for compliance with the approved local plan, but they also consider the architecture and the technical solutions (not in detail). They often issue the building permits in stages; first a principal accept for the concept, then for the foundations etc. Before issuing the building permit, there is a mandatory start meeting (early collaborating meeting) where the planning office, the applicant, the designers and some representatives from the Building Control Office participate, to be informed about the project.

After the building permit is issued, the Building Control Office organizes a start-up meeting with the applicant and his site manager (for all cases). Most often, the applicant requests the meeting, but this is a duty for the BC Office, and mandatory for them to take minutes from the meeting and these minutes are public property. At these meetings, they agree on which subjects the applicant must keep documentation on, or supervise. Here, they also agree on frequencies (and subjects) for inspections on the construction site. The costs for such meetings are covered by a fee.

3.1.2 The control systems

The applicant has complete responsibility towards the authorities, and he may fulfil his obligations the way he finds suitable. There are no qualification requirements on the applicant, or to his organization (except for safety reasons, construction calculations, gas etc.).

The main principle is that the general internal quality control is performed by the applicant, on his own terms and without public supervision of this. The public Building Control concentrates on the issues of public interest. The officers perform the control based on dialogue and construction site inspections including document control.

There are no formal requirements for internal control performed by the applicant or his organization. But they have some voluntary certification systems for companies, helping the applicants' quality checks.

3.1.3 Requirements for fire safety

The technical regulations are based on functional requirements of fire safety concerning load-bearing elements, generation and spread of fire and smoke and safety of occupants and rescue teams. There are two ways to design a building that satisfies the requirements.

Prescribed design - The building is designed and executed by applying the fire classes and numerical criteria provided by the regulations and guidelines.

Performance based design – The building is designed and executed based on design fire scenarios which cover conditions likely to occur in the relevant building.

3.2 Finland

Finland has two tiers of governance: State and Municipalities. There are 348 (2009) municipalities, but the number is diminishing. In addition, there are some intermediate levels. Municipalities co-operate in 74 sub regions and 20 regions, which are governed by the member municipalities, but have only limited powers.

Finland has a joint law; the Planning and Building Act (Land Use and Building Act), administrated by the Ministry of the Environment.

3.2.1 Handling procedures

A Building Permit is the legal basis for all building activity, the projects must be compliant with the local plan, and the Completion Certificates verify that the building is built according to the requirements.

The handling procedures for building permit applications aim on earlier dialogue between the applicant and the authorities. A (voluntary) early meeting has the possibility to send early applications to define the amount of needed documentation in the final application.

A Building Permit is the legal basis for all building activity, the projects must be compliant with the local plan, and the Completion Certificates verify that the building is built according to the requirements. In Finland, the significance of the Completion Certificate is focused and demanded as a basis for connection of the new construction to the local public water and sewage service.

The applicant has complete liability towards the authorities, and the building legislation does not mention any other mandatory roles with direct responsibility towards the authorities.

There are no formal requirements on the applicants. However, there are formal competence requirements on two other actors: the Principal Designer, other designers and the Site Manager (the requirements are personal, not on companies). The applicant must have hired those before the handling of the building permit application, and competence will be approved, related to each project.

There is no central public register for qualification on actors, but there is a voluntary private register, and the actors normally prefer to be listed.

3.2.2 The control system

Finland has formally placed the responsibility for sufficient control onto the applicant shared with public authorities. The reason is to allow the authorities to take over the task if they consider it necessary. In practice, normal procedure is 'delegation' to the applicant, while public control concentrates on the supervision process within the mandatory building inspection report.

The BC Office handles the issuing of building permits, but the office is divided into two sections – one for compliance with the local plan, and the other for all other requirements set by central or local authorities, such as competence by the construction companies and certificates on actors. This sector also performs the control tasks.

Approvals can be divided in stages in big or complicated projects, and the BC Office then define the stages. The control work is regarded to start with the up-start meeting after issuing of the building permit, and participants at this meeting are the BC Office, the site manager, and the main actors for design and construction. The site manager shall present a control plan, but this plan is not to be approved by the BC Office. This plan is used for defining milestones where new meeting and site inspections will be carried out.

3.2.3 Requirements for fire safety

Requirements of the technical regulations are compulsory. They cannot be challenged without an approval from the local building authority. The technical regulations are based on functional requirements of fire safety concerning load-bearing elements, generation and spread of fire and smoke, spread of fire to neighboring works and safety of occupants and rescue teams. There are two ways to design a building that satisfies the requirements prescribed and performance based design. Prescribed design; the building is designed and executed by applying the fire classes and numerical criteria provided by the regulations and guidelines. Performance based design; the building is designed and executed based on design fire scenarios which cover conditions likely to occur in the relevant building. Satisfaction of the requirements is checked in each case, by the local building authority, taking into consideration the use of the building and its properties.

3.3 Iceland

Iceland has two tiers of governance: State and 75 municipalities. Iceland has separate Planning and Building Acts since 2010. The Planning and Building Acts are administrated by the Ministry of Environment.

3.3.1 Handling procedures

The BC Office formally issues building permits, but the handling of the applications are divided between the planning office (controlling compliance with the local plan), and the BC Office for all other aspects – technical requirements and requirements on actors. The two sections have regularly meetings.

The procedures are the same for all kinds of projects. The control system has two main elements: the applicant's supervision, and the public control, and they do not distinguish between control and supervision.

A description of the case handling performed by the Building Control Office will comprise a first check of all documentation on both project and actors, then a meeting with all public authorities (regular meetings once a month are stated in the law), followed by a meeting in a political committee, and then the applicant must pay the fee to get the Building Permit. During the construction period, the BC Office follows the project closely, and normally performs approximately 10 construction site inspections.

The Completion Certificate will be issued after a final site inspection and document control, but the Certificate has little significance, even if it has become more important in recent years, especially for non-domestic buildings and for insurance purposes.

3.3.2 The control system

The applicant has the formal responsibility towards the authorities. But since there are traditionally high numbers of non-skilled one-time applicants and even self-builders, the system provides several tools to support the applicants.

First, there is a very strong public control, working on a more detailed level than building control offices in other countries where the intention is to support the applicant.

Secondly, the law requires a „Project Manager", having professional skills, to be assigned to the building project, responsible for the quality of the building works, both towards the authorities and to the applicant. The Project Manager must be insured against possible faults, but it is the applicants responsibility to correct faults discovered by the public control.

3.3.3 Requirements for fire safety

There are two ways to design a building that satisfies the requirements of the Icelandic building regulation; prescribed design or performance based design. In prescribed design, the building is designed and constructed by applying the fire classes and numerical criteria provided by the regulations and guidelines. In performance based design, the verification with the functional requirements is needed and a fire safety report must be submitted which will be reviewed by the local building authority.

3.4 Norway

Norway has three tiers of governance: State, county and municipality levels. The state also exerts its mandate on two levels; central authorities and county offices, which represent a 'regional state authority'.

Norway has a common Planning and Building Act that is administrated by the Ministry of Local Government and Modernization. The Norwegian Building Authority is the main agency for implementing building regulations and building policy.

3.4.1 Handling procedures

The normal procedure is in two steps; first a contextual approval, where the project is evaluated in relation to the valid local plan, and subsequent a building permit (Starting permit) is issued, approved on the basis of technical requirements and the competence of the actors responsible for different aspects of the design and construction. The two steps may be combined in a one-step procedure by choice of the applicant, and this is normal for simpler building projects.

In the normal procedures, the first step of approval comprises handling of neighbour complaints, classification of the project, requirements on actors and to control systems. The second step comprises approval of the design documentation according to the requirements, and approval of the competence of the actors. Normally, the handling procedures are initiated at the start of the design work, with a voluntary early meeting. The purpose of the meeting is to establish a dialogue, and define the frames, classifications and requirements for the project.

After receiving an application for a building permit, the Building Control Office has time limits for all further steps in the case handling, and if they exceed the time limits, the applicant may pay a lower fee. For small projects claiming to be according to plans and regulations, exceeding the time limit (3 weeks) means that the project can be started.

3.4.2 The control system

The applicant has the formal responsibility towards the authorities. But according to the legislation, all other actors in the building process have responsibility for the quality of their own work, not only to the applicant, but also directly towards the authorities.

Compulsory third party control was introduced as of 1.1.2013. Regarding fire safety this includes the control of the verification of fire safety (the fire safety strategy) in all larger building (project class 2 and 3).

There are competence requirements on all actors (except the Applicant), related to their role in the projects: designers, contractors, controllers of both design and construction works, and of site managers. The competence requirements are also related to the complexity of the projects.

The municipal building control was phased out in 1997, and was replaced by private control and a municipal building inspection. The municipal Building Control Office is dealing with approval of applications in terms of how the construction affects the adjacent buildings, the technical quality, the competence of all actors involved, and their plan for controlling themselves.

3.4.3 Requirements for fire safety

Technical regulations mainly state functional requirements. These regulations are compulsory. The guidelines to the technical requirements describe the pre-accepted solutions and the use of the guidelines is optional. The two ways to verify compliance with requirements of the technical regulations in Norway are prescribed design or performance based design. In prescribed design the guideline to the technical regulations describes acceptable solutions or pre-accepted design which meets the functional requirements for different building categories. In performance based design the designer is free to define specific solutions for the actual building but then he/she has to verify compliance with the functional requirements. The regulations refer to *NS3901.E:2012 Requirements for risk assessment of fire in construction works* [34] which describes the principles of risk analyses and comparative analyses.

3.5 Sweden

Sweden has two tiers of governance: State and municipality level. The state governs in two tiers: the central authorities and the level of regional state authority (Länsstyrelsen).

There is one common law, the Planning and Building Act. Implementation of the Act and guidance of the municipalities are delegated to the National Board of Housing, Building and Planning (Boverket).

3.5.1 Building permit and notification

An approved building permit is mandatory for most building activities. For some construction projects a notification to the building authority is sufficient.

The handling of applications for a building permit according to the Planning and Building Act is initially assessed in relation to approved local plans. However, an approved building permit is not sufficient to start construction works, you will also need a clearance (startbesked).

3.5.2 Clearance and ITP

A measure which requires a building permit, demolition permit, land permit or notification may not be commenced until the building committee has issued clearance. In order to obtain clearance, the developer must be able to show that the measure can be considered to fulfil the requirements laid down in the Planning and Building Act with associated regulations. If the building committee is to be able to decide whether the measure can be considered to fulfil the requirements or not, the developer must submit a proposal for an inspection and test plan (ITP) and the technical documentation. The building committee establishes the ITP in the clearance.

3.5.3 Inspectors (KA)

The main rule is that there must be one or more inspectors when measures requiring a building permit or notification are being carried out, though there are some exceptions to this. Inspectors must be certified by an accredited certification body.

3.5.4 Technical consultation and worksite inspection

In most cases, technical consultation will be held at the building committee. The consultation includes going through how the work should be planned and organized, the ITP proposal and general documentation. Technical consultation is not required if an inspector is not required.

In most cases, the building committee shall visit the site where the measures are being carried out at least once during the work. The need for the building committee to make a worksite inspection is decided during the technical consultation.

3.5.5 Final consultation

Once the construction measures covered in the technical consultation are complete, a final consultation is held, before a final approval is issued, unless this is clearly unnecessary. The final consultation is normally held at the site where the construction measures have been carried out.

3.5.6 Final approval

A final approval is required for all measures covered by the clearance. To obtain a final approval, the developer must show that all requirements that apply to the measure in accordance with the permit, the ITP, the clearance, or any decision concerning additional terms, are met, and the building committee doesn't find reasons to intervene with an inspection. If the requirements for final approval are not met, the building committee may under certain circumstances issue an interim approval pending a final approval. For construction measures, the developer is not normally permitted to put the structure to use before the building committee has issued a final approval. However, when issuing clearance, the building committee has the option to decide that a structure can be fully or partly put to use without a final approval or interim approval.

3.5.7 Requirements for fire safety

In the building regulations from Boverket (BBR) there is a focus on verification of fire design solutions with well-defined occupancy classes and building classes. The building- and occupancy classes are the basis for the need of different fire protection measurements. The building regulation is based on performance requirements which can be fulfilled either by deemed-to-satisfy solutions or by analytical design (FSE). Guidance on accepted fire safety design is included in the regulation.

General recommendations on how to verify your alternative solution with analytic design including acceptance criteria and design fires is available in a separate regulative document.

4. Determination of focus areas for the current project

This chapter will give a brief discussion on the main focus areas of the project. The main problems and challenges related fire safety engineering are shortly summarized. The information is partly based on earlier questionnaires distributed to fire safety engineers and authorities in 2008 and 2010 as well as on recent practical experience among fire safety engineers. The results from the questionnaires are further discussed in [40]. This included altogether about 60 detailed questions sent to 40 experts in 15 EU member state countries.

The recent publication of the INSTA standard TS 950, "Fire Safety Engineering – Comparative method to verify fire safety design in buildings" was a step forward in Nordic fire safety engineering practice and will serve as a partial background for the work carried out in this project.

Several other guidance documents have been published in some Nordic countries. For example, in Finland, the first guidance on fire safety design for engineers was published in 2003 [41]. Later, another guidance concentrating on fire safety underground was published [42]. In Finland, these documents are used as background information and they do not have any official status. The same can be said about published guidance material in the other Nordic countries, these documents have been discussed in previous chapters of this report and will be used as background information for the work carried out in the project.

4.1 Fire Safety Engineering in the Building Process

Based on a review of the comparison of Nordic countries' Building codes in chapter 3, and the questionnaires mentioned above, the following issues have been highlighted as barriers for innovative and sustainable solutions when it comes to fire safety engineering, control and quality assurance within the building process:

- There are differences to what extent the building process is formalized due to the different legal systems.
- There are both national and local building codes in some countries. To what extent depends on the country's will to delegate power to the local communities.
- The responsibility for the quality control varies between the countries. In some countries (Sweden, Denmark & Norway), the client has the full responsibility for the control of the construction. While, in Finland and Iceland, there is a shared responsibility between the client and the authorities.
- The qualification requirements vary within the countries. In some countries (Finland) there are no requirements on the client or it's organization while in the other Nordic countries there are specific qualification requirements. The requirements vary in magnitude and if they are on individual or company level.

From a more specific fire safety engineering perspective the following barriers have been identified:

- The level of performance based codes for fire safety varies between the countries.
- The role of the fire safety engineer within the building process is not always clearly defined.

- There is a lack of background information to the defined fire safety operative requirements in the countries' building codes
- There are little (or sometimes none) information about the purpose of some of operative requirements that shall be fulfilled.
- There is to some extent a lack of verification methods for qualitative assessment and for quantitative assessment with probabilistic analysis
- There are a lack of performance requirements within some areas of fire safety such as the development and spread of fire and smoke within the building and the safety of rescue personnel. Some issues that don't have clearly defined requirements are for example prevention of ignition, control of fire growth within the fire compartment and how to limit the fire spread within in a building.
- There are to some extent challenges in the assessment of the overall safety levels
- There are limitations in the use of scientific/engineering methods due to lack of design fire scenarios and input data. There is a need for applicable generic cases of common building types and uses and better statistically founded input data.
- The link between the control of the design process to the control and inspection on-site is not always clearly defined and the process varies between the Nordic countries.
- Due to lack of background information for the operative requirements in the building codes for all Nordic countries, it is difficult to ensure the right level of validation and control.
- There is lack of uniform practices in the design process and further guidance is needed to harmonize the fire safety engineering process. In some countries there are different acceptance criteria in different parts of the country and there is a need for assessment of eligibility and suitability (including limits of validity) when using fire safety engineering methods.
- Expertise about fire safety of local authorities is not always sufficient – guidance for third body inspection are needed within the field
- Management of the whole planning process - communication between designers of different planning sectors is essential
- Documentation and management of changes is partly inadequate - more attention needs be put to documentation of boundary conditions of fire safety to enable changes in the use of a building over time
- Maintenance of fire safety equipment/systems need to be emphasized

4.2 WP2: Development of a verification method

In 1994, NKB stated that standardization was yet not advanced to the point where one could verify compliance with every operational requirement. As WP2 has no mandate to alter national building regulations, the aim is to provide guidance on verification methods to ensure a more reliable and predictable verification.

Fire safety engineering can be said to be a way to cope for a considerable number of uncertain factors. In a prescriptive regime, the authority having jurisdiction dictates to what extent one should manage these uncertain factors – the pre-accepted solutions will form a benchmark for the level of fire safety required. When deviating from these pre-accepted solutions, or if these pre-accepted solutions are not applicable, the designer is required to prove an acceptable level of safety. Due to lack of verification methods and data, performance-based design tends to be based on over-conservative assumptions, leading to non-optimal cost-efficiency. When third party review is applied, the uncertainties tend to lead to even more conservativism. Unsafe designs may also be found acceptable when methods and criteria are unavailable or unsuitable.

Over time, this development may lead to a decreased will to apply performance-based design, both from authorities, clients and practitioners, and hence the intended room for innovation, flexibility and cost-effectiveness from performance-based building regulations will be lost.

One can argue, acknowledging the uncertainties in fire safety engineering, that the established deterministic study of scenarios is unsuitable in many cases. As a counterpart to deterministic analysis, there have been efforts made to implement probabilistic analysis. Even though some guidance is given, shortage of data and acceptance criteria has restricted the use of probabilistic analysis.

WP2 is to develop a preliminary specification that provides

- guidance on basic probabilistic approach, supported by qualitative analysis
- suggest acceptance criteria where possible
- collation of relevant fire statistics and reliability data

As part of this work, WP2 will attempt to initiate work on developing a cooperation in the collection and presentation of Nordic statistics regarding fire safety, to ensure an improvement in data quality over time.

The work package will proceed from January 2015 until March 2016, led by John Utstrand, COWI.

4.3 WP3: Development of building process focusing on review & control of fire safety engineering

Due to the identified barriers a separate work package will be carried out during the project, *WP 3 - Development of building process focusing on review & control of fire safety engineering.*

The aim for the work package is to develop a process to facilitate development and verification of innovative and sustainable solutions and to harmonize the process for review and control within the field of fire safety engineering.

Some of the major challenges are the differences in the legal systems, both national and local building codes in some countries and the different responsibility for the quality controls in the building process. Due to this, the work packages will focus on the development of a general process for review and control, independent of these matters, and primary focus on technical issues within fire safety engineering. But the work will also, to some extent, give guidance on how the fire safety engineering process can be a normal part of the overall control and review of the building process and define eligibility criteria for the one's doing the control.

The work will result in a preliminary specification based on the process oriented problems identified in in section 4.1 and clarify:

- when to perform review and control within the building process and within the specific fire safety engineering process
- how to do the review and control
- why the control should be done and the purpose of it
- Recommend eligibility criteria for the one performing the control

The work package will proceed from January 2015 until March 2016, led by Johan Norén, Briab.

5. References

[1] Schluter, Poul, Grænsehinder i Norden, Report of the Nordic Council of Ministers, 2005

[2] "Gränshinder på byggområdet, mandate till arbetsgrupp för nordisk standardisering av byggnormer", Nordiska ministerrådet 9 Juni 2009, samt rekommendationen "Arbetsgruppen om gränsehinder på byggområdet", 24 Februari 2011.

[3] Jerkø, Sidsel, Bygningslov for bedre bygg. Sammenligning av bygningslovgivningen i Norden, Tema Nord 2004:526. Copenhagen 2004.

[4] Jerkø, Sidsel, Increased exchange in the Building Sector - Comparison of Building Legislation in the Northern Dimension region, TemaNord 2009:506, Nordic Council of Ministers, Copenhagen 2008.

[5] Sørensen, Lone Møller, Storgaard, Kristian, Increased exchange in the Building Sector - Network for joint R&D - Nibcor Phase 1&2, TemaNord 2009:524, Nordic Council of Ministers, Copenhagen 2009.

[6] Matiss, Imants, Increased exchange in the Building Sector - Recognition of professional qualifications in the Building Process, TemaNord 2008:603, Nordic Council of Ministers, Copenhagen 2008.

[7] Pousette, A., Gustafsson, A., "Harmonisering av de nordiska ländernas träbyggregler – Trähusindustrins problem och byggreglernas krav, SP Rapport 2008:45, SP, Skellefteå, Sweden, 2008.

[8] Thureson, P., Sundström, B., Mikkola, E., Bluhme, D., Hansen, A.S., Karlsson, B., "The use of Fire Classification in the Nordic Countries – Proposals for Harmonisation", SP REPORT 2008:29, SP, Boras, Sweden, 2008.

[9] Tor-Ulf Wek et al. "Kartläggning av nordiska nationella bilagor till Eurokoder", Esbo, 15th November 2012.

[10] Kristina Landfors, "RAPPORT 'Harmonisering av byggregler inom Norden", WSP, 5 Mars 2013

[11] Patrik Groth "Different Building Regulations in the Nordic Countries", SKANSKA, Skanska Sverige AB, 22 December 2010.

[12] Nikolaj Tolstoy, "Nordiska byggregler – gränshinder för handel av entreprenader, material och konstruktioner inom bygg och installation", Regeringskansliet, Socialdepartementet, 21 November 2011.

[13] NOTAT "Grensehindringer i Norden" Statens bygningstekniske etat, referens 11/6633, 18 November 2011.

[14] Sheridan, L., Visscher, H.J., Meijer, F., Building regulations in Europe - Part I: A comparison of the systems of building control in eight European countries, Volume 23, Housing and Urban Policy Studies, Delft University Press

[15] Sheridan, L., Visscher, H.J., Meijer, F., Building regulations in Europe, Part II - A comparison of technical requirements in eight European countries, Volume 24 Housing and Urban Policy Studies, Delft University Press.

[16] Jönsson, R., Strömgren, M., Editors, "SFPE ECCG: White Paper for Professional Recognition for Fire Safety Engineering", SFPE, 3 May 2014.

[17] Oleszkiewicz, I., "The Concept and Practice of Performance-Based Building Regulations", IRC-IR-697, National Research Council Canada, November 1994.

[18] Meachham, B.J., editor, "Performance-Based Building Regulatory Systems – Principles and Experiences" Inter-jurisdictional Regulatory Collaboration Committee, 2010.

[19] Foliente G., Huevila, P., Ang G., Spekknik, D., Backens, W., "Performance Based Building R&D Roadmap", PeBBu Final Report, CIBdf, Rotterdam, 2005.

[20] Szigeti, F., Davies, G., "Performance Based Building: Conceptual Framework", PeBBu Final Report, CIBdf, Rotterdam, October 2005.

[21] "SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings", 2 ed, National Fire Protection Association, Quincy, Massachusetts, 2007.

[22] NKB, Nordic Committee on Building Regulations (NKB), Programme of Work for the NKB, Report No. 28, Stockholm, 1976.

[23] NKB, Nordic Committee on Building Regulations (NKB), Structure for Building Regulations, Report No. 34, Stockholm, 1978.

[24] May, Peter J., "Performance-Based Regulation and Regulatory Regimes", Center for American Politics and Public Policy, University of Washington, Presented at the Global Policy Summit, National Academy of Sciences, Washington DC, November 3-5, 2003

[25] Alvarez, A., Meacham, B.J., Dembsey, N.A., Thomas, J.R., Twenty years of performance-based fire protection design: challenges faced and look ahead, Journal of Fire Protection Engineering, July 2013.

[26] SFPE Engineering Guide to Performance-Based Fire Protection, Bethesda, MD, Society of Fire Protection Engineers, 2007

[27] INSTA TS 950, Fire Safety Engineering – Comparative method to verify fire safety design in buildings, 2014.

[28] Brandteknisk dimensionering av Br0-byggnader, Föreningen för brandteknisk ingenjörsvetenskap, http://www.sfpe-biv.se, BIV 2013.

[29] CFD-beräkningar med FDS, Föreningen för brandteknisk ingenjörsvetenskap, http://www.sfpe-biv.se, BIV 2013.

[30] Vägledning - brandgasfyllnad Extern version, Briab Brand & Riskingenjörerna AB 2012-12-01, 2012.

[31] Vägledning - utrymningsanalys Extern version, Briab Brand & Riskingenjörerna AB 2013-04-15, 2012.

[32] CFD Best Practice, Best Practice gruppen, Copenhagen, August 2009.

[33] Kontroll av brandskydd i byggprocessen, Föreningen för brandteknisk ingenjörsvetenskap, http://www.sfpe-biv.se, BIV 2013.

[34] NS3901.E:2012 *Requirements for risk assessment of fire in construction works,* Norsk Standard, 2012.

[35] CEN TC127/TG1 "Fire Safety Engineering", Questionnaire - State of the art in fire safety engineering in Europe.

[36] Nordic Committee on Building Regulations, NKB, Fire Safety Committee, "Performace Requirements for Fire Safety and Technical Guide for Verification by Calculation", NKB Committee and Work Reports 1994:07 E, Helsinki, 1994

[37] INSTA 900:1:2009 Residential sprinkler systems, 2009.

[38] Fredrik Nystedt, Verifying Fire Safety Design in Sprinklered Buildings, Report 3150, Department of Fire Safety Engineering and Systems Safety, Lund University, Sweden, 2011

[39] Östman, B., Rydholm, D. National fire regulations in relation to the use of wood in European and some other countries. Stockholm: Swedish Institute for Wood Technology Research (Trätek Report P 0212044.), 2002.

[40] Mikkola, E., Hakkarainen, T., "Fire safety in renovation – summary of regulations and practice in the EU", VTT Research Report VTT-R-03472-12, 2012.

[41] RIL 221-2003, Fire safety design, The Finnish Association of Civil Engineers, RIL, 2003.

[42] RIL 233-2007, Fire safety design for underground places, The Finnish Association of Civil Engineers, RIL, 2007.

6 Appendix B: WP4 – Application of WP2 and WP3 Methods on practical cases in the Nordic countries

Fire Safety Engineering for Innovative and Sustainable Building Solutions

WP4 Report – Application of WP2 and WP3 Methods on Practical Cases in the Nordic Countries

Pierrick Mindykowski
Michael Strömgren
Anders Dragsted
Vegard Olsen
Johan Norén
Fredrik Nystedt
Esko Mikkola
Axel Mossberg
Bödvar Tomasson

SP Technical Research Institute of Sweden, Fire Research

Fire Safety Engineering for Innovative and Sustainable Building Solutions

Report on WP4 – Application of WP2 and WP3 Methods on Practical Cases in the Nordic Countries

Pierrick Mindykowski, SP Fire Research, Sweden
Michael Strömgren, SP Fire Research, Sweden
Anders Dragsted, DBI, Denmark
Vegard Ervik Olsen, Ramboll, Norway
Johan Norén, Briab, Sweden
Esko Mikkola, KK Palokonsultti, Finland
Axel Mossberg, Brandskyddslaget, Sweden
Bödvar Tomasson, Iceland Fire Research Institute, Iceland

Abstract

Fire Safety Engineering for Innovative and Sustainable Building Solutions

This report is the result of the fourth work package (WP4) in the project "Fire Safety Engineering for Innovative and Sustainable Buildings Solutions". WP4 consisted of case studies where two draft specifications were evaluated in order to improve them. These specifications are entitled *WP2: Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings. Fire safety Engineering for Innovative and Sustainable Building Solutions Project.* and *WP3: Fire Safety Engineering: Control in the Building Process. Fire safety Engineering for Innovative and Sustainable Building Solutions Project.* The aim is to produce two technical specifications for the Nordic region to facilitate sustainable and innovative building solutions by novel fire safety engineering approaches. The case studies were conducted in all five Nordic countries. In addition has an external expert reviewed the specifications. The main conclusions from the case studies and the external review is that there is still a gap between acceptance levels used in scenario- and probabilistic approaches and there is a lack of data supporting probabilistic approaches. Roles and responsibilities also needs to be better defined in the control and review process.

Key words: case study, fire safety engineering, innovation, probabilistic method, review procedure, sustainability

SP Sveriges Tekniska Forskningsinstitut
SP Technical Research Institute of Sweden

SPRapport?:
2017:02

Contents

1.1	Project objectives	6
1.2	Scope	7
2	**WP2 Case Studies**	**8**
2.1	Large assembly hall	8
2.2	Timber buildings and high rise evacuation	16
2.3	Post flashover design fire	19
2.4	Fire section exceeding 10.000 m^2	27
2.5	Prolonged escape route	29
2.6	Sports arena used for concert	31
2.7	Combustible insulation in cavity wall in high rise buildings	32
3	**WP3 Case Studies**	**38**
3.1	National review of control process	38
3.2	Review of control in the building process	39
4	**Recommendations**	**43**
4.1	WP2 - Case studies	43
4.2	WP 2 - Expert elicitation	43
4.3	WP 3 - Case studies	44
4.4	WP 3- Expert elicitation	44
5	**Conclusions**	**46**
6	**References**	**47**
Appendix – Participant Descriptions		**49**

Preface

This report is the result of individual contributions from all Nordic countries and we are grateful for all who walked the extra mile to make this project possible. We would also like to thank Professor Brian Meacham of WPI who conducted an external review of the technical specifications which has been great support.

The individual contributors and project partners are described in the appendix. Their contributions are as follows:

- Brandskyddslaget – 2.1
- Briab – 2.2
- DBI – 2.7
- Iceland Fire Research Institute – 3.2
- KK-Palokonsultti – 2.3 and 3.1
- Ramboll - 2.4-2.6
- SP Technical Research Institute of Sweden - coordination.

The research project described in this technical note would not have been possible without the funding support from Nordic Innovation, the Norwegian Building Authority (DiBK) and the Swedish Construction Industry Development Fund (SBUF). The significant in-kind self-funded contributions from the project partners are also acknowledged.

Introduction

This report presents the work carried out in Work Package 4 (WP) within the project "Fire Safety Engineering for Innovative and Sustainable Building Solutions", financed by Nordic Innovation and coordinated by SP Technical Research Institute of Sweden.

1.1 Project objectives

Performance-based codes, i.e. regulations and standards, have long been proven an effective way to facilitate innovation [1], and all of the Nordic countries have introduced performance-based building codes. However, the implementation of performance-based codes for fire safety has not been overly successful due to the lack of standardized verification methods and acceptance criteria and instruments to ensure high quality fire safety design. As a result, fire safety design often relies on prescriptive and detailed regulations due to uncertainties and lack of acceptance of performance-based design.

Differences in regulations and practices in the Nordic countries are causing problems for the trade of products and services. The problem of trade barriers within the Nordic countries has been identified by the Nordic ministries and one goal is to create a unified Nordic construction market. The Nordic countries have strong cultural ties and other similarities, and are therefore in an ideal position to take the next step towards stronger cooperation.

The challenge in this project is to create standards supporting fire safety engineering in a performance-based regulatory regime that will facilitate the design processes and technical innovations in a robust and sustainable way. The project will thereby continue the successful Nordic cooperation that resulted in the Nordic specification on fire safety engineering using a comparative approach, INSTA TS 950 [2], that was published in 2014.

Aims of the project:

- Standardize verification methods and acceptance criteria based on a practical perspective to facilitate the implementation of performance-based codes and thereby increase the use of innovative design and technology in the industry, such as green buildings and sustainable technology.
- New innovative construction products may be used in the built environment, proven to be fire safe yet able to meet the changing requirements of society.
- Nordic standards (INSTA) will be produced, providing the methods to facilitate innovative design by fire safety engineering methods and providing guidance on the process that lead to safe and innovative fire safety design.

The project members in the consortium represent all Nordic countries and a broad range of stakeholders such as:

- Standardization organizations - Norwegian Standardization
- Regulatory agencies - The Swedish National Board of Housing, Building and Planning (Boverket), Iceland Construction Authority, Norwegian Building Authority (DiBK)
- Research organizations - The Danish Institute of Fire and Security Technology (DBI), Iceland Fire Research Institute, Lund University, SP Technical Research Institute of Sweden and SP Fire Research AS
- Fire consultancy companies - Brandskyddslaget, Briab Brand & Riskingenjörerna AB, COWI, KK-Palokonsultti, Ramboll
- Construction companies - NCC

1.2 Scope

The main objective of WP4 is to apply the methods of the WP2 [3] and the WP3 [4] specifications on practical cases in the Nordic countries.

The goal of WP2 [3] is to provide guidance for a probabilistic approach for fire safety engineering. Guidance is given for the use of fire safety engineering methods to evaluate compliance to an absolute criterion. This guidance may to some degree be used in combination with INSTA/TS 950 [2] in order to evaluate compliance with a comparative criterion. Acceptance criteria, relevant fire safety engineering methods and input data (reliability data and fire statistics) are within the scope of this report.

The aim of WP3 [4] is to facilitate verification of building solutions including innovative and sustainable solutions and to harmonize the process for control within the field of fire safety engineering within the Nordic countries.

The focus for WP3 is on a general level for review and control, independent of national legal matters in the Nordic countries, and primary focus on technical issues within fire safety engineering. But the process will also, to some extent, give guidance on how the fire safety engineering process can be a normal part of the overall control and review of the building process and define eligibility criteria for the ones doing the control.

2 WP2 Case Studies

The WP2 [3] technical specification draft called "Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings" has been applied in several case studies in order to evaluate the applicability of it. The case studies were selected in order to evaluate the draft specification for innovative and sustainable buildings solution. … Based on the cases studies, recommendations are made how to improve the quality of the specification contents.

2.1 Large assembly hall

This case study is based on a real building in Sweden where a number of deviations from the prescriptive regulation was requested. A comparative analysis was performed in accordance with INSTA/TS 950 [2]. A similar analysis was then performed with the WP2-draft specification [3] method and acceptance criteria, which is further described below.

The case study and this subchapter was performed and written by Brandskyddslaget, see Appendix.

2.1.1 Scope

The scope of the case study was to evaluate the methods and criteria described in the WP2 technical specification [3]. Primarily, the method outline presented (chapters 4 and 6 in the WP2 specification [3]) was tested together with the absolute acceptance criteria for loss of life (section 5.3.1 of [1]). However, an uncertainty/sensitivity analysis (chapter 7 of [3]) was also conducted and certain reliability data (annex C) used.

The selected building was a large, one-story market hall. The building had a very simple geometry and had no other uses.

The case study is summarized below. First a presentation of the building is made, and then the comparative approach and its results are described followed by the results using the WP2 specification [3]. As a final step the two approaches are compared.

2.1.2 Building description

The building studied has a very simple geometry and it is basically a box with the dimensions 33 m x 58 m x 9.5 m (L x W x H). It has emergency exits in every direction of the building and a total egress exit width of 9 meters. According to the prescriptive regulation this exit width gives a restriction in building occupants of 1350 persons. However, the building owner wanted the building to be able to hold a total number of 2150 persons.

Also, because of the size of the building, the egress travel distances are longer in the building than is accepted by the prescriptive code. The maximum egress travel distance in the building is 37 meters compared to 30 meters accepted in the prescriptive regulation.

In addition to this, the desired wall linings in the building does not fully comply with the prescriptive regulation as it was tested to B-s3,d0, instead of B-s1,d0. This translates to a similar fire development as the prescriptive material but with a worse smoke production.

As extra protective measures the building was installed with 6 m^2 (aerodynamic free area) automatic smoke ventilation (not a requirement), automatic fire and evacuation alarm (the system is manually activated) and also a large ceiling height (9.5 meters).

2.1.3 Comparative approach according to INSTA/TS 950

To accommodate for the deviances listed above, a comparative study was performed. The reference building chosen had the same occupancy and the same number of occupants but acceptable egress capacity (i.e. 14.3 meters egress width), acceptable egress travel distances (i.e. maximum 30 meters) and a "normal" ceiling height of 4 meters. Also the reference building had the protection required in the prescriptive code and was thus not equipped with any smoke ventilation and had only a manually activated evacuation alarm.

After establishing a reference building, an ASET/RSET[1] analysis was performed for both buildings. The ASET analysis was performed using the hand calculation methods in [5] and [6]. These calculations were also verified using the CFD model CFX.

The RSET analysis was performed using hand calculations as specified in the Boverkets general recommendations [7] on analytical design of a building's fire protection (BBRAD). This is a simple hand calculation expression where travel times are calculated. Pre-movement times were based on the same recommendations.

The calculated ASET times are shown in

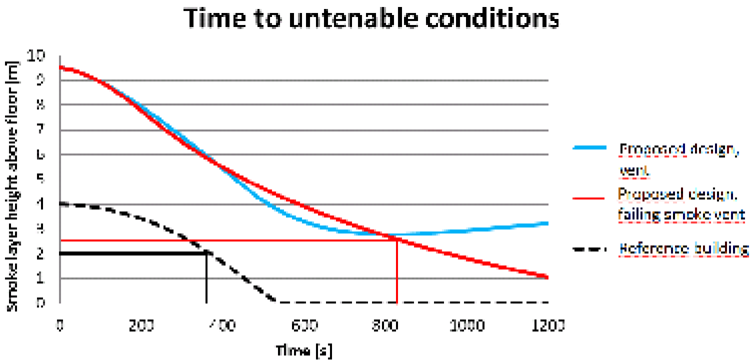


Figure 1. The untenable conditions in this case was regarded as when the smoke layer height reached 1.6 + 0.1 H, where H is the ceiling height, i.e. the proposed design and the reference building had different acceptance levels because of the difference in ceiling height, as shown below. This criterion is listed in BBRAD [7] but according to the recommendation, this should not be used in isolation as evacuation through smoke could be acceptable in some cases. However, as this is a comparative analysis, this criterion alone has been used to define untenable conditions.

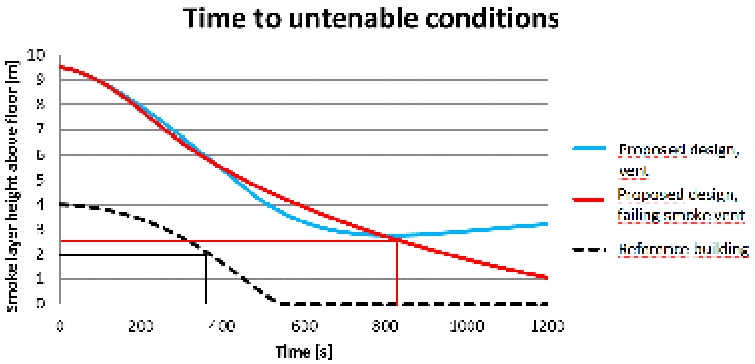


Figure 1. Calculated time to untenable conditions.

[1] ASET: Available Safe Egress Time / RSET: Required Safe Egress Time

As the calculations show, untenable conditions do not occur for the proposed design, if the smoke ventilation works properly. If the smoke ventilation fails, untenable conditions occur after approximately 14 minutes. For the reference building, this occurs after approximately 6 minutes.

The RSET calculations gave the results shown in Table 1.

Table 1. RSET times for the proposed design and the reference building.

Building	Recognition time (s)	Response time (s)	Travel time (s)	Total egress time (s)
Reference building	240	60	170	***470***
Proposed design	120	60	260	***440***

In the Swedish regulation the design is based on a design scenario, where the technical systems are working, and a robustness scenario, where the technical systems are assumed to fail one by one. In this case, untenable conditions do not occur for the proposed design unless the smoke ventilation fails. Hence, the case of failing emergency alarm is not relevant to study for the proposed design.

The ASET/RSET analysis is summarized in the Table 2.

Table 2. Results of the ASET/RSET analysis.

Building	RSET (s)	ASET (s)	Safety margin (s)
Reference building	***470***	***360***	***-110***
Proposed design	***440***	***840****	***400****

* Based on the robustness scenario with failing smoke ventilation.

As the table above shows, the proposed design provides better conditions for egress than the reference building, which is designed according to the prescriptive regulations. Also, the proposed design can be assumed to be safely evacuated in the scenarios given by the Swedish guidelines on analytical design. Therefore, the proposed design is deemed acceptable.

2.1.4 Probabilistic approach using WP2

Using the approach proposed in WP2, the first step is to establish the probability of fire for the building. According to PD7974-7 [8], a probability of fire for public assembly areas could be estimated to 9.7 x $10^{-5}/m^2$ x year. This gives a probability of fire for the proposed building of approximately 0.19 / year. In addition to this, statistics from Swedish incident reports from 2004-2015 imply that 25 % of all fires in assembly halls occur at night. Since this is a daytime operation building, these fires are not included in these calculations, resulting in 0.14 fires / year for the building.

Since the building layout is basically one big assembly, the design fire process is quite straight forward. One design fire aspect is regarded, which is a fire within the large assembly that the building consists of. To calculate the ASET a number of scenarios are being studied.

First, a series of calculations were made to establish a minimum heat release rate needed in the building for untenable conditions to occur if the smoke ventilation failed. These calculations were made in the same way as in the INSTA [1] approach above. The result showed that at least a heat release rate of 750 kW was needed.

Following this, a series of calculations were made to establish what heat release rate was needed for untenable conditions to occur if the smoke ventilation worked. The result showed that a heat release rate of 25 MW or more would overtake the ventilation and fill the premises with smoke.

The probability of different fire sizes was calculated using the data in PD 7974-7 [8] and SS-EN 1991-1-2 annex E [9], as proposed in the WP2 report [3]. The maximum heat release rate possible during evacuation was set to 50 MW. The result of this is shown in the Table 3.

Table 3. Fire sizes and heat release rate probabilities.

m^2	Number of fires	kW	%	Acc. %
1 or less	4197	250	51.1%	51.1%
2-4	1987	750	24.2%	75.4%
5-9	619	1750	7.5%	82.9%
10-19	463	3750	5.6%	88.5%
20-49	430	8750	5.2%	93.8%
50-99	221	18750	2.7%	96.5%
100-199	127	37500	1.5%	98.0%
200-499	100	50000	1.2%	99.2%
500-999	29	50000	0.4%	99.6%
1000 or more	34	50000	0.4%	100.0%

The data above shows that the probability of a fire being below 750 kW is approximately 75 % and the probability of a fire being larger than 25 000 kW is approximately 3 %.

Also, the probability of the smoke ventilation working was then set to 90 % in accordance with PD 7974-7 [8]. This data can be combined in the event tree shown below. The purpose of this event tree was to establish the probability of scenarios where untenable conditions were possible, which is represented by outcome A2 and A4 that is highlighted below. In outcome A2 the smoke ventilation is working, but the fire size is larger than 25 MW, meaning that the smoke ventilation is not effective enough to handle all the smoke. In outcome A4 the smoke ventilation is not working and the fire size is larger than 750 kW.

Using the probabilities above, the probabilities of these different outcomes can be calculated. The probability of outcome A2 is calculated to 0.00345 fires per year and the probability of outcome A4 is calculated to 0.00375 fires per year. This gives a sum of 0.0072 fires per year where untenable conditions can occur. Together this represents approximately 5 % of the outcomes, meaning that in 95% of all fires in the building untenable conditions will not occur for the occupants.

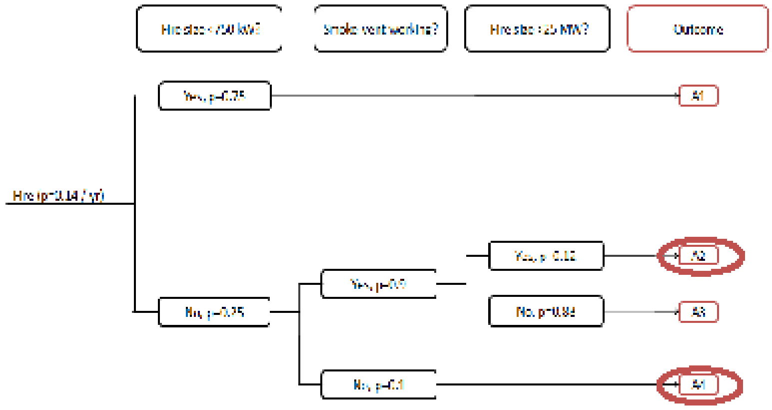


Figure 2. Event tree showing the events where untenable conditions could occur.

A separate ASET/RSET analysis was performed for the fires in the building where untenable conditions can occur (i.e. case A2 and A4 in Figure 2 representing 5% of the total number of fires), To be able to calculate the ASET and RSET as probability functions, expressions presented by Olsson & Frantzich [10] was used. These expressions are quite simple hand calculation expressions derived using regression analysis over a number of parameters. For example, the ASET (based on a smoke layer height of 1.6 + 0.1 H, radiation of a maximum 2.5 kW/m^2 and a smoke temperature of maximum 80°C) can be calculated using the following equation:

$$t_{krit,l} = 3.07\alpha^{-0.29}H^{0.27}A^{0.48}$$

In this equations, $t_{krit,l}$ is the ASET, α is the fire growth rate, H is the building height and A is the building area. Note that this ASET is calculated based on the assumption that the smoke ventilation is not working.

Using this equation and assessing α in accordance with the recommendations given in the WP2 draft specification [3] for Swedish assembly buildings (a lognormal distribution) a probability function for the ASET time can be derived. This was then simulated with a Monte Carlo analysis with 50 000 iterations using @Risk. The result of this calculation is shown in the Figure 3.

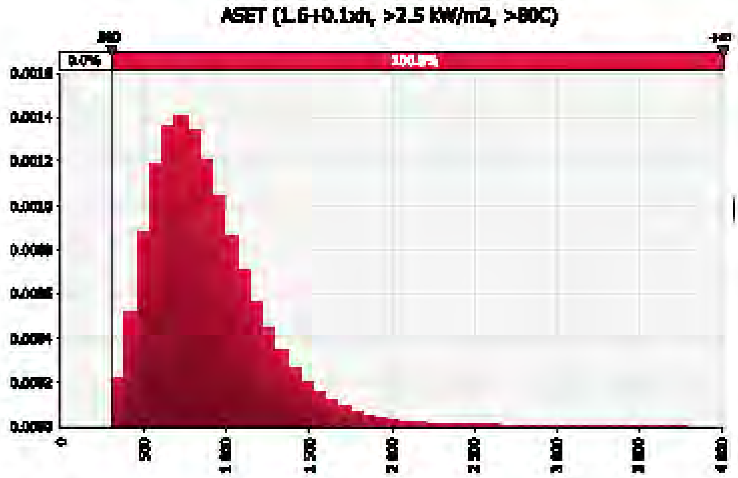


Figure 3. Calculated ASET probability distribution.

To calculate the RSET time, the same basic approach was used. To calculate the travel times, the hand calculation method presented in BBRAD [7], mentioned under the comparative approach headline above, was used but the input data was represented by probability functions over movement speed, number of persons and egress flows through openings. Mainly these parameters were based on work from Frantzich [11][12][13], Lund University. This was also the case of the recognition time and response time.

The results from these calculations are shown in the Figure 4.

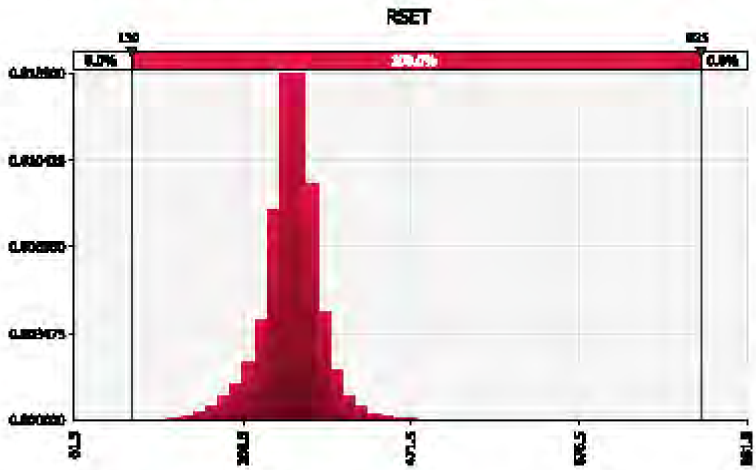


Figure 4. Calculated RSET probability function.

Combining these calculations to show the probability of the safety margin being below 0 is shown in the figure below. This shows a probability of RSET being greater than ASET is 0.1 %.

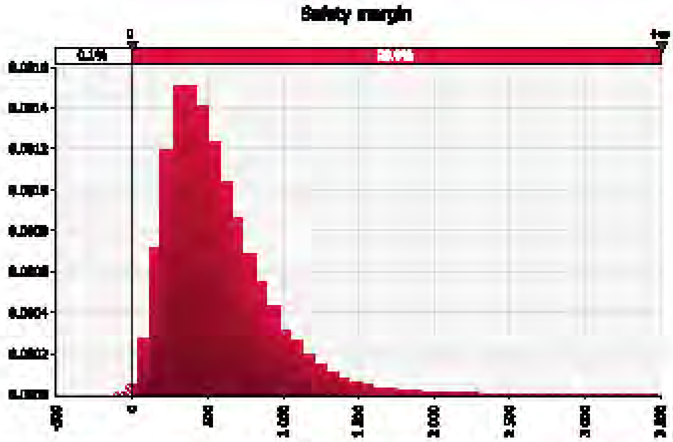


Figure 5. Calculated safety margin probability function.

This translates to a total risk of a person being subjected to untenable conditions of 6.96x10^{-6}. If compared to the risk criteria in WP2 [3], this could be deemed unacceptable, if based on the assumption that untenable conditions are being deadly. This is not the case and hence the comparison is not fully correct. This is illustrated as a F/N curve in the Figure 6.

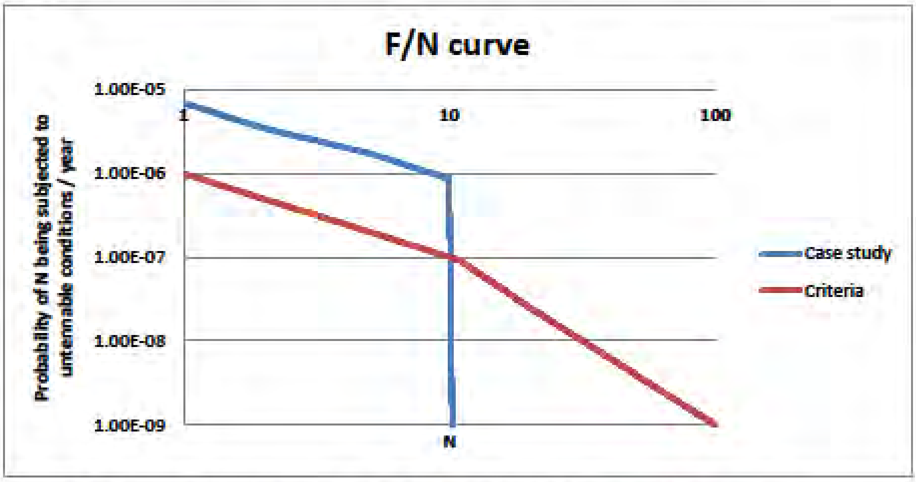


Figure 6. F/N curve showing probability of being subjected to untenable conditions in the building compared to the criteria in WP2.

As the F/N-curve shows, the number of persons being subjected to untenable conditions is at most 10 persons in the calculations. This is translated from the results of the safety margin by assuming that the negative margin consists of a queuing time for the evacuees.

One critical assumption here is that the number of occupants being subjected to untenable conditions are compared to a criteria based on fatalities. This, of course, is wrong. The maximum amount of time spent in untenable conditions, according to the calculations is approximately 120 seconds. As the occupants being exposed to untenable conditions are being so when they are queueing to an exit it is probable that they will still evacuate regardless of these conditions. The amount of time spent in untenable conditions would most probably not generate any fatalities amongst the persons exposed.

In the same study as the ASET calculation is retrieved from, another simple hand calculation gives the time to 100°C at 1.5 meter. If this is used as untenable conditions instead, the probability of being subjected to it is lowered to $2.78x10^{6}$, the risk profile is lowered and the maximum number of persons being exposed is lower than 8. However, the risk is still deemed intolerable compared to the set criteria.

It might be worth noting that according to the SFPE handbook [14], temperatures of >100°C can be tolerated in 10-15 minutes without causing injury or death. In the calculations, the longest exposure time for 100°C is calculated to approximately 80 seconds. Also, the evacuees exposed are most likely to be queuing to an exit. Hence, the conclusion that there is a low risk for evacuees getting caught inside the building and because of this, also the risk of fatality in the building because of a fire is low.

If incorporating the same calculations made for the reference building specified in the section on comparative analysis above, the calculated risk of persons being subjected to critical conditions is higher than in the proposed design and consequently higher than the acceptance criteria. This is illustrated in the Figure 7.

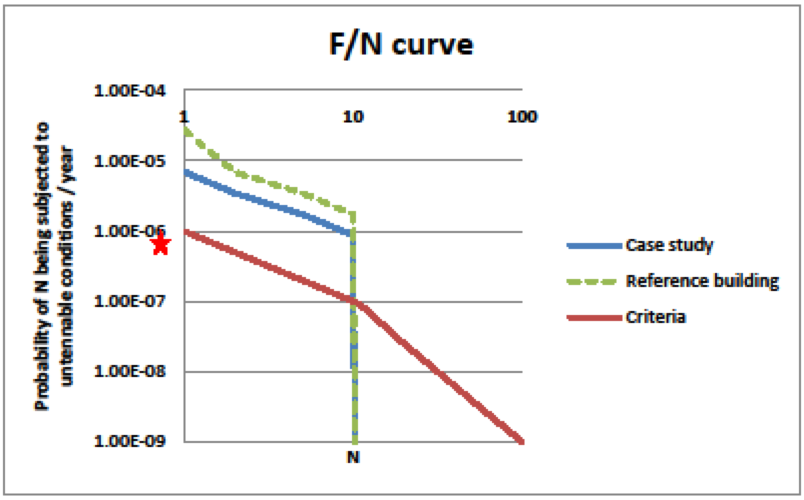


Figure 7. F/N curve showing probability of being subjected to untenable conditions in the building compared to the reference building and the criteria in WP2.

If comparing the calculated risks above, with Swedish statistics in the period 2004-2015 [15], it is obvious that the risk profiles presented gives an overestimation. The Swedish statistics [15] show that in these years three people have been killed in three different fires in assembly halls. This can be translated to a risk of $8.1x10^{-7}$, which is illustrated with a red star in the illustration above. The deviation between the calculated risk in the reference building, which represent the statistical risk for the given time period. However, it should be noted that there are large uncertainties regarding these statistics as rare events with a larger number of casualties are not reflected given the short time period. Such events may skew the statistics significantly. Still, one possible explanation to the difference may be the difference in measurements of fire fatalities and people exposed to critical conditions.

2.1.5 Discussion

In the case study above, the method in the WP2 draft specification [3] has been used and was deemed functional. However, there are a couple of observations made:

- Because of limited time, existing models have been used. These have shown good conformity with more complex models (i.e. hand calculations vs CFD in smoke filling) but the possibility of changing vital parameters has been limited. This is why untenable conditions have been studied and not lethal conditions. However, with the work in WP2 published, the incentive to create more and better models in the Nordic region might increase and this might solve the problem at hand.
- The guidance on design fires and fire parameters are quite useful but there is a lack of the same guidance in evacuation parameters. Here, a lot of assumptions are made which have great effects on the results.
- In comparing the results from the comparative approach with the PRA approach, both show that the proposed design gives lower risk of persons being subjected to untenable conditions. However, when comparing to the set acceptance criteria, both are deemed unacceptable. This is probably due to the translation of untenable conditions to fatalities, which gives an overestimation of the risk in the building.

2.1.6 Recommendations

Based on the work presented above, the recommendations for future work within the project are:

- Give more guidance on evacuation parameters.
- Even though quite intuitive, it might be good to specify that if untenable conditions are used, this gives an overestimation of the risk, compared to the fatality rate that the acceptance criteria is based on.

2.2 Timber buildings and high rise evacuation

The timber building case study is based on two buildings planned in Sweden.

The case study and this subchapter was performed and written by Briab Brand & Riskingenjörerna AB, see Appendix.

2.2.1 Scope

The case study is based on two buildings planned to be built in Sweden. The two buildings have two different areas of difficulties, i.e. a tall timber building with a focus on fire load, and a high rise building with focus on evacuation.

The method used for evaluating the two problems are the method defined in the WP2 specification [3].

The scope of the case study has been to evaluate if the method is usable for buildings taller than 16 floors due to the lack of prescriptive codes for these kinds of building in Sweden. The scope has thereby been to investigate if, and how the new method will add value to the future fire safety design process. Result from the analysis has been secondary due to business confidentiality. Furthermore, no comparison with other verification methods has been conducted due to the lack of verification methods and deemed to satisfy solutions for these kinds of buildings.

The object in scenario 1 – a tall timber building, is a multi-story building with 22 floors designed in wood. It is planned to be built in the urban area of a Swedish town and the main activities to be conducted in the building are apartments. Each floor is designed with 4-5 apartments formed in various sizes. The gross area of each floor is 350-450 square meters and the height of the building will be approximately 70 meter. The idea is to construct the building with exposed wood surfaces both inside and outside. The designed fire scenario consists in a fire that ignites in one of the apartments and turns into a fully developed fire but remains within the original fire compartment. Since the building is designed in timber, there are many uncertainties concerning the fire load, which has a major impact as a design criterion for the fire safety design process. The interest in this specific scenario is to evaluate the possibility to use the proposed method to calculate the fire load from a probabilistic risk approach.

To evaluate the fire load within the tall timber building, the used method was based upon the Swedish guidance about fire load [15]. Both permanent and variable fire loads were taken into consideration for the evaluation as well as protected and un-protected fire load. The design fire load was defined by a probabilistic approach where the variable and permanent fire load was defined as distributions. For the variable fire load a Gumbel distribution, defined with an average value of 780 MJ/m^2 and the 80 % - fractile of 948 MJ/m^2 [17]. The permanent fire load, i.e. the fire load from the building (construction elements, linings and finishing) was also defined as a distribution based upon different net calorific values for combustible material from construction elements. The used distribution was a triangular distribution with min: 18 MJ/m^2, average: 20 MJ/m^2 and max 30 MJ/m^2 [15].

In the evaluation, the probability for protected and unprotected fire load was also analyzed by defining an uniform distribution for the unprotected fire load with min value of 0 and a maximum value of 0,9.

To calculate the design fire load the following formula was used together with Monte Carlo simulations.

$$q_d = \sum_i q_{ki} \psi_{qi} \psi_{pi} \qquad [MJ/m^2]$$

Where:
q_d: design fire load
q_{ki}: variable fire load and permanent fire load (defined as distributions)
ψ_{qi}: optional factor for assessing variable and permanent fire loads (1,0 for both permanent and variable fire loads as statured in [15].
ψ_{pi}: optional factor for assessing protected fire loads (defined as a distribution).

Due to the probabilistic risk based approach the 80 % - percentile was used as a criterion to define the design fire load.

The object in scenario 2 – high rise building, is also a multi-story building with 78 floors. The main activities in this building are restaurants, offices and apartments. The floor to be investigated contains of 10 apartments with elevators and stairwells. One of the difficulties with fire safety design in a multi-story building is to verify that the building is designed with the possibility of satisfactory evacuation in case of fire. Therefore, an evaluation of this scenario is conducted with the aim to investigate the probability that a person that is located inside an apartment will not be able to evacuate the building through the defined escape routes.

The basis for the analysis is to calculate the safety margin which defines that evacuation can take place before critical conditions, defined by the National Board of Housing, Building and Planning in Sweden arise in the event of fire.

To analyze time to critical conditions, a simplified hand calculation model was used and different fire scenarios where analyzed. The estimated times are then compared with the time required to evacuate the building, which is studied using quantitative methods that includes human behavior in the event of evacuation. This is to determine whether the building's evacuation routes (number, width and location) are sufficient to generate an acceptable escape option in case of fire.

To calculate the safety margin, due to the numerous uncertainties surrounding the particular fire location, heat release rate, reliability for different technical fire safety systems, numbers of visitors and human behaviors, a probabilistic approach based on event tree methodology and common mathematical term for escape were used.

Due to the usage of a probabilistic approach and Monte Carlo simulations to calculate the safety margin, a so called β-index method as used for defining the acceptance criteria for the model. For the evaluation, a β-index similar to 2.33 was used.

2.2.2 Evaluation and recommendations

As result from the performed case study and evaluation of the usage of the developed method the following observations were made.

2.2.2.1 Scenario 1 – Tall timber building and fire load

The specification would be easier to use if it was structured so that the aims of a specific application could be more clearly defined in the specification. For example, one chapter on how to obtain the fire load, one chapter to obtain the evacuation and so on. It would be more user-friendly and less time consuming if it was divided into clearer chapters with a clear focus in the fire safety objectives. As in scenario 1 – analysis of fire load, it was difficult to get an understanding how to proceed and to get the overall picture on how to solve the problem using the proposed method.

To obtain the distribution of fire loads to be able to validate the calculated values, the specification refers to Eurocode EN 1991-1-2 [9] for the relevant type of occupancy. The part of EN 1991-1-2 that handles fire load in different types of occupancies is Annex E [9], which is not allowed to use in Sweden according to the Swedish regulation.

As a conclusion regarding fire load, the proposed method is difficult to use to evaluate the fire load of a tall timber building. The specification did not give much guidance or added value to the future design process. The calculated result was not based on probability but on efficient combustion heat (which in turn depends on material), floor area and amount of combustible material. The idea of this specification was to use a probabilistic method to get a result, which was not possible with existing background knowledge and given information.

2.2.2.2 Scenario 2 – Evacuation from a high rise building

In scenario 2, the specification and proposed method was of more use than in scenario 1 due to the scope of the task. Still, there are some difficulties in understanding how to get a holistic view over the process and how to use the information in an accurate way. Furthermore, definitions and terms are generally difficult to understand.
Chapter 5.3 of [3] with focus on acceptance criteria is helpful to be able to verify the possibility for evaluation of the evacuation. From previously experiences, it is uncommon to have such a specific number as acceptance criterion as is provided in this report, which is appreciated.

Four steps are described in the probabilistic risk analysis (PRA) process for fire safety engineering. The first step is described in chapter 6.1 of [3] and this is where the aims and different fire scenarios are identified. The chapter is good and gives some guidance about how to work with design fires. Though, the tables and equations in chapter 6.21 of [3] are quite hard to understand. More explanations and definitions of variables will simplify the usage. Some probabilities are presented in Annex C of [3], but they do not give the needed information to be able to analyse the evacuation situation in the case study.
As a conclusion regarding the possibility to analyse the evacuation situation from a high-rise building, the proposed method will add value, but due to the lack of input data and probabilities it may be difficult to use the method and process on an everyday basis. It may also be too time-consuming in compared to the added value the method and process will give us.

2.3 Post flashover design fire

This case study is based on a study in which a design fire exposure curve was generated for a situation where load bearing structures are made of massive timber. These structures may be protected totally or partly by gypsum board, or may be totally unprotected. This study was a general one (not for a specific building) aiming to find limiting conditions to ensure fire safe design.

The analysis reported here is concentrating on the effects of geometry and openings of the spaces of concern (which can be varying a lot) and ensuring the results by comparison with experimental data.

The WP2 specification [1] is not giving much guidance for this kind of topic. Thus general principles outlined in the WP2 specification were mainly used.

In the discussion section (§ 2.3.4) also some general comments on WP2 [3] procedures are given.

The case study and this subchapter was performed and written by KK-Palokonsultti, see Appendix.

2.3.1 Scope

The scope of this case study was to investigate if an analysis performed using the principles described in the WP2 draft specification [3] would generate useful results compared to experimental knowledge on post flashover fires with large visible surfaces of structural wood.

2.3.2 Probabilistic approach using parametric fire curves

The Parametric temperature-time curve is presented in Eurocode EN 1991-1-2 [17]. It can be applied e.g. for room fires where the fire loads are cellulose-based material (e.g. unprotected massive timber structures).

The parametric curves for the increasing temperature phase can be expressed as [17]:

$$\Theta_g = 20 + 1325(1 - 0.324e^{-0.2t^*} - 0.204e^{-1.7t^*} - 0.472e^{-19t^*})$$

Where $t^*$is scaled time factor (depending on geometry and thermal inertia of boundaries) and Θ_g [°C] is the gas temperature in the fire compartment.

Maximum temperature and decay phase are also defined in EN 1991-1-2 [17] taking into account the fire load density. The shape of parametric fire curves depend on openings and size of the room, fire load and thermal properties of internal surfaces (see examples in Figure 8).

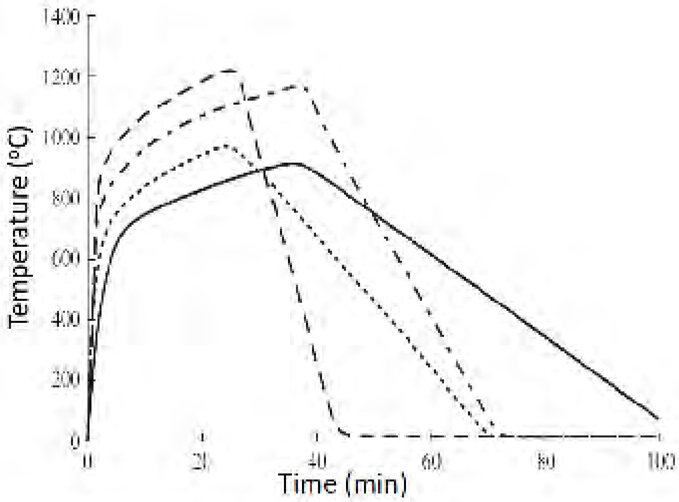


Figure 8. Examples of parametric fire curves [18].

Random sampling of the parametric fire curves were made by using Monte Carlo technique. The main principles of this method are:

1. Distributions are given for all parameters.
2. Random samples are taken from the parameter distributions and then the results are calculated using the model (parametric fire curve in this case).
3. Phase two is repeated as many times as needed in order to get enough results (10000 times in this case).

Examples of use of this Monte Carlo (MC) technique can be found e.g. in several publications ([19][20][21]).

Minimum and maximum limits for the distributions used in the calculations are tabled below (Table 4).

Table 4. Parameters and minimum/maximum values for their distributions

Parameter	Minimum	Maximum	Unit
Relative size of opening	0.1	0,3	-
Height of opening	1.5	2.4	m
Fire load density	400	800	MJ/m^2
Density of wood	400	640	Kg/m^3
Thermal conductivity	0,10	0,17	W/mK
Specific heat	2.4	2.8	kJ/kgK
Area	30	150	m^2
Height of room	2.4	3.0	m

2.3.2.1 Results

In Figure 9 an example of an individual calculated parametric temperature-time curve is presented together with a corresponding energy curve. The energy curve is describing the total energy (until certain time) which the structural surfaces receive per unit area. It is calculated based on heat flux produced by the temperature-time curve by integrating over time.

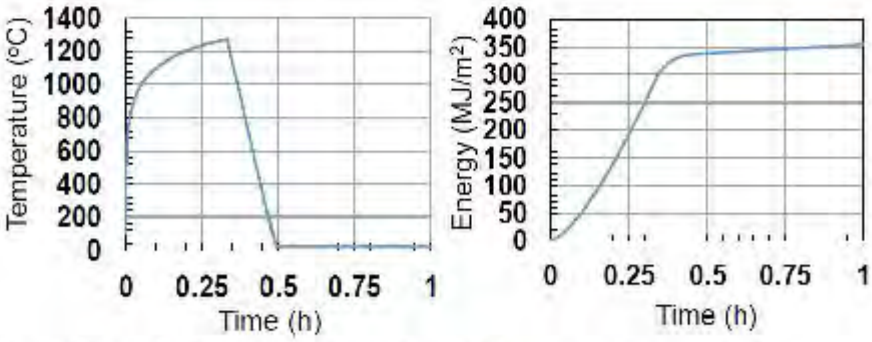


Figure 9. Example of individual parametric curve and corresponding energy curve.

Combining all the 10 000 iterations, the minimum, mean and maximum curves for temperature are obtained as indicated in Figure 10. The maximum temperatures are very high based on the low thermal inertia of the surfaces of the rooms of concern (these are later compared with experimental results from room fire experiments).

The mean temperature curve has a maximum of about 1250°C, before half an hour when the decay phase starts.

The individual parametric curves do have a linear decay slope which reached low (original) temperatures faster than in reality. The walls, ceiling and floor stay warm for a long period (in a non-collapsed room) and there may be some residue of the fire load glowing on the floor. The mean temperature curve in Figure 10 is thus more realistic.

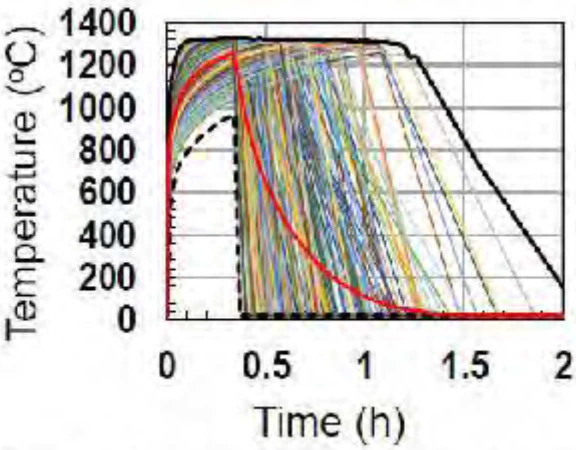


Figure 10. Temperature-time curves after Monte-Carlo iterations. The thick red curve indicated the mean value.

2.3.2.2 Fire exposures in energy terms

In Figure 11 the cumulative distribution of all the parametric curves in terms of total energy is presented. In Table 5 the total energies (MJ/m^2) are given for fractile levels between 0.5 and 0.999 in cases of small and large openings. There seems not to be much difference between these two openings when total energy inputs are compared.

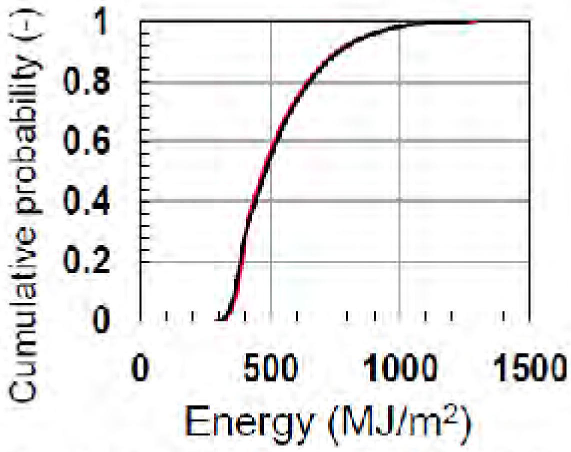


Figure 11. Cumulative distribution of total energies of parametric curves.

Table 5. Total energies of parametric fire curves at different fractile levels.

Fire exposure in total energy		Fractile
Opening factor		
Large	Small	
471	480	0.5
645	653	0.8
760	767	0.8
862	870	0.95
1048	1046	0.99
1198	1209	0.999

It is seen in Figure 12 that at very high fractile levels the parametric fire curves are quite close to the HC (Hydro Carbon) fire curve for the first half an hour. After that the parametric curves are higher until short after the decay phase has started.

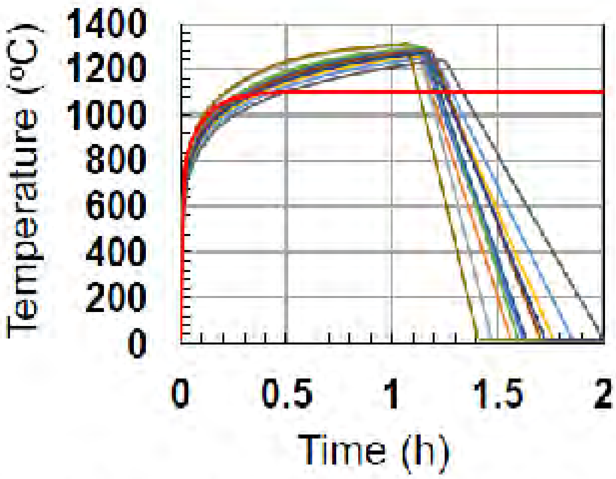


Figure 12. Parametric fire curves at large fractile levels (0.9985...0.9995) compared with HC fire curve (in red).

2.3.3 Comparison with room fire experiments

In the following a few experimental results are given for temperature developments and levels in room fire tests with massive timber structures which have been totally protected, or partly protected or there has been no gypsum board protection at all. Short descriptions of the experiments are given below (according to the figure numbers):

- Figure 13: Massive structure – no gypsum board protection. Room area about 16 m^2, window opening 2.3 m x 1.2 m, opening factor 0,042 $m^{1/2}$. Movable fire load 690 MJ/m^2.
- Figure 14: Massive structure – 12 mm + 15 mm (F) gypsum board protection on walls and ceiling. Room area about 16 m^2, window opening 2.3 m x 1.2 m, opening factor 0,042 $m^{1/2}$. Movable fire load 690 MJ/m^2.
- Figure 15: Massive structure – partly gypsum board protected. Room area about 13 m^2. Window 1.2 m x 1.6 m and door 0.9 m x 2.0 m), opening factor about 0.08 $m^{1/2}$. Movable fire load 660 MJ/m^2.
- Figure 16: Unprotected and protected (partly or totally) massive timber structures. Room area nearly 16 m^2 and door 1.1 m x 2.0 m). Movable fire load less than 350 MJ/m^2.

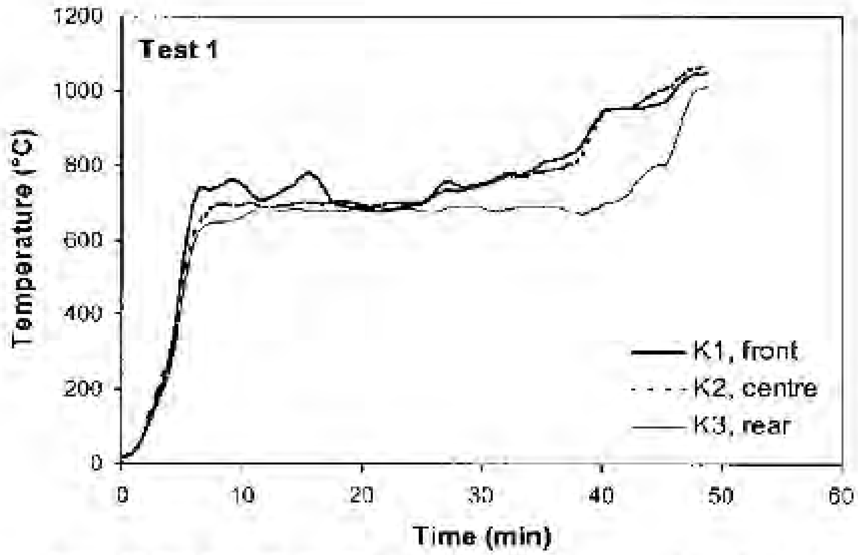


Figure 13. Fire test with massive timber structures; no gypsum board protection [22].

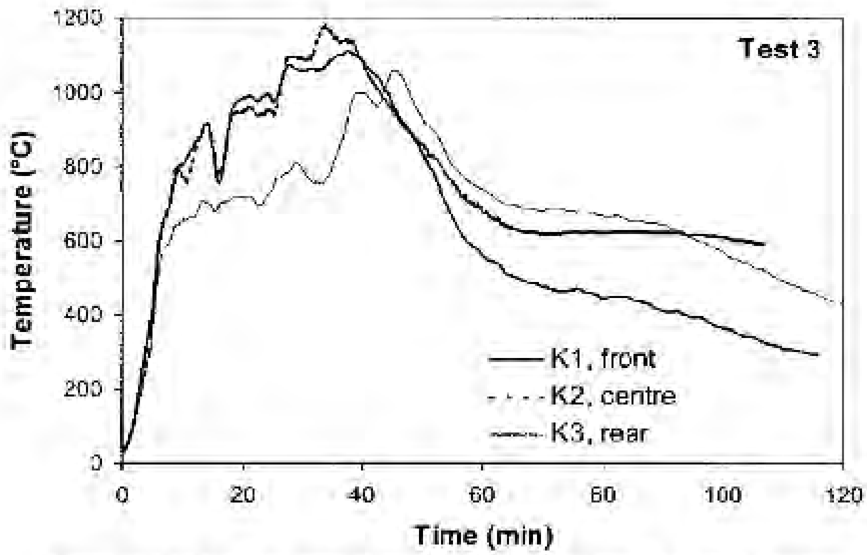


Figure 14. Fire test with massive timber structures; 12 mm + 15 mm (F) gypsum board protection [22].

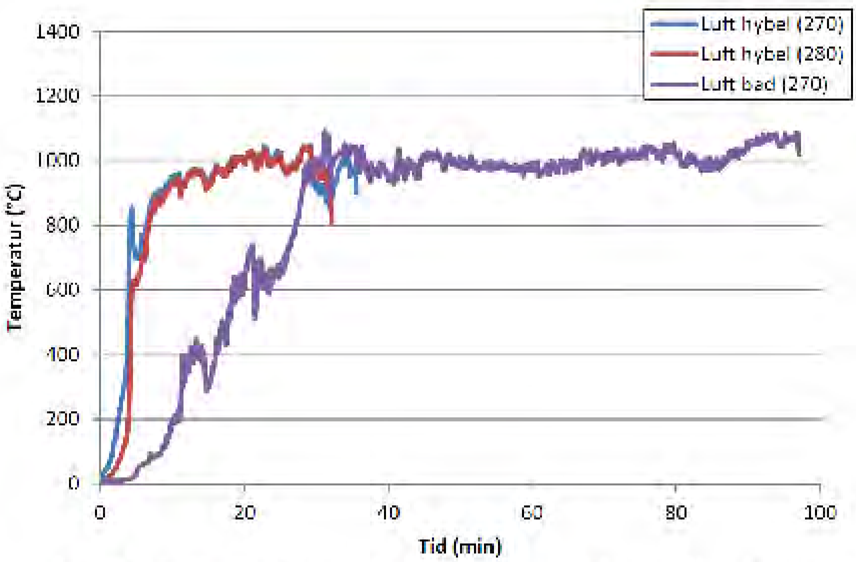


Figure 15. Fire test with massive timber structures; partly gypsum board protected [30].

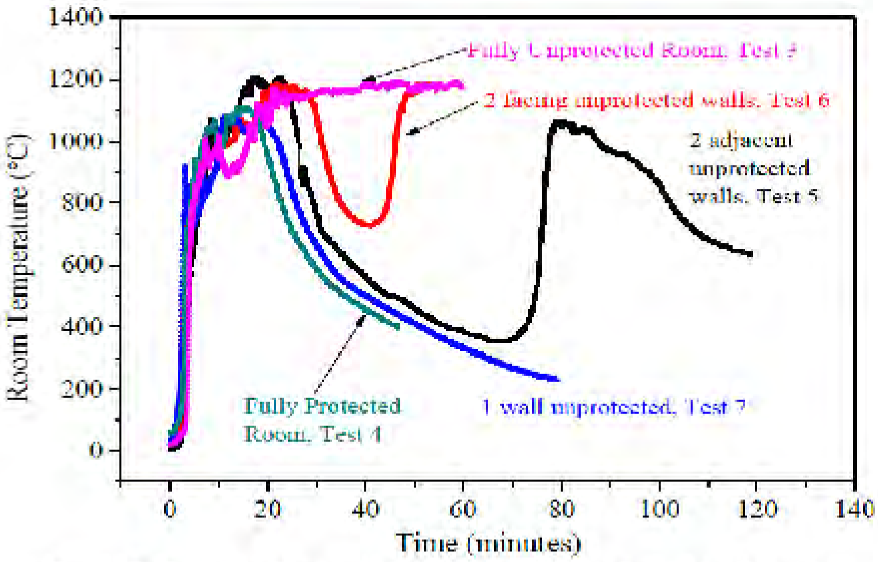


Figure 16. Fire test with unprotected and protected (partly or totally) massive timber structures [31].

The experimental results indicate that if there is a lot of visible wood material of the load bearing structures contributing to the fire, then the HC curve seem to be a quite relevant design curve for the purposes where the worst case situation (no extinguishing of fire assumed) is considered.

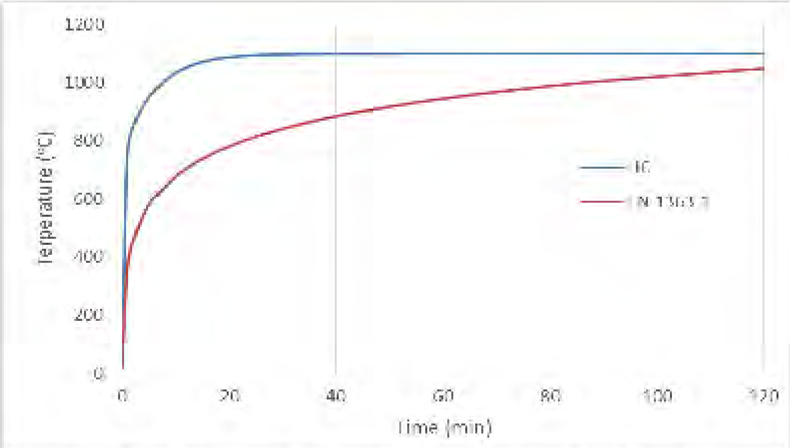


Figure 17. HC fire curve and the standard temperature-time curve for classification.

Figure 17 illustrates the difference between the HC fire curve and the standard temperature-time curve which is used in fire classification of structural members. The difference between total energy (fire exposure subject to the structures) of these two curves is given in Figure 18.

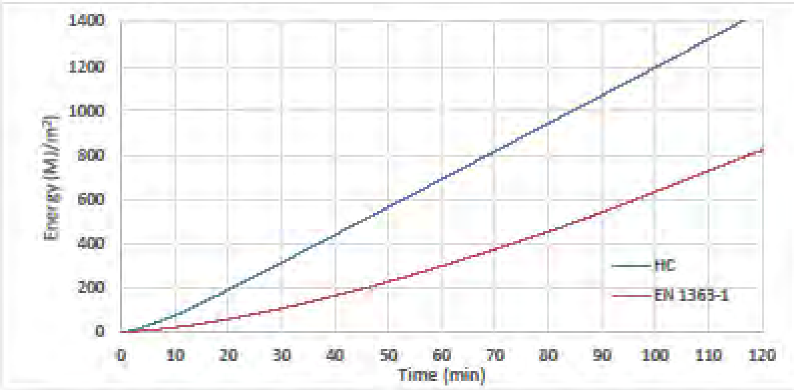


Figure 18. Total energy of HC fire curve and the standard temperature-time curve as a function of time.

Based on results of the probabilistic parametric fire curves and comparisons with real scale experimental results (which show the effects of structural timber contributing to fire) it was decided to use the HC curve as a fire exposure design curve for structural members. (Later results of this severe fire curve were transformed to the standard R requirements.)

2.3.4 Discussion

In the case study above, mainly some principles and process of the WP2 draft specification has been used because for the post flashover section there is no practical guidance available. However, there are some observations (and general comments) to be made:

The probabilistic method (with the background of earlier experience) worked well for the parametric fires. And it helped in finding out that in this case concerning the design fire, the opening factors were not much affecting the results. This could not have been proven from the experimental results (from literature) which were too few for this purpose. On the other hand, the experimental results were very necessary to confirm the fire exposure development when the structural elements are contributing to fire.

2.3.4.1 General comments (some valid also for this case):

It is reasonably easy to get detailed enough information on planned structures, geometries of the spaces of concern and number occupants.

Reliability of passive and active measures of fire safety: Reliability data given in WP2 [1] are on quite general level and some are based on 'expert opinions'. Also some guidance would be needed how to deal with different time dependences for passive and active system failures: Probability of the fire partition to achieve at least 75 % of the designed fire resistance can mean e.g. 45 minutes for partitions rated EI 60 which means that the failure occurs only after about 45 minutes. This is different from the case where sprinkler system reliability is 95 %, but in the 5 % of the cases the failure consequences are realised immediately.

Sensitivity analysis may often be used just to please reviewers/authorities. An experienced fire engineer learns to know quite many physical facts for which fire and fire development are not sensitive. And also which parameters are very important.

Use of FN curves in analysing safety of evacuation: This needs a lot of efforts compared to benefits in case by case studies. It is more useful in analysing e.g. concept solutions and relevance of specific regulations.

2.3.5 Recommendations

The following recommendations are made concerning WP2 - Section 6.2.1.4 Post-flashover fires:

- The statement "The design load is in this case characterized by a temperature-time curve assumed for the fully developed fire stage" would need some actual guidance, e.g.:
    - Parametric fire curves can be used for cases … (guidance/conditions from EN 1991-1-2 [17])
    - HC fire curve can used when no sprinklers are assumed and all or major parts of fire compartment walls and ceiling are made of massive wood without protection.
- Reliability data (Annex C [1]) would need to be reviewed in the sense of making a difference between statistical data and 'expert opinions'. Also some of the tables should be more specific when defining reliability values, e.g. for the sprinkler systems there are no references to European standards of the systems, neither performance levels of the systems.

2.4 Fire section exceeding 10.000 m^2

The case study is based on a real building in Norway, where the client wanted to expand his building from 10.000 m^2 to 20.000 m^2 without installing fire section walls.

The case study and this subchapter was performed and written by Ramboll, see Appendix.

2.4.1 Scope

The case study is based on a real building in Norway, where the client wanted to expand his building from 10.000 m^2 to 20.000 m^2 without installing fire section walls. In Norway there is a prescriptive demand to divide the building into compartments of maximum

10.000 m^2 with a REI-120 wall. A REI-120 wall is defined by a standard [23]. Briefly, such a wall is capable to maintain its ability to support the test load and its separating function (without causing the ignition of a cotton pad and without increasing its unexposed side temperature by more than 140 C) for 120 minutes.

The standard to verify functional requirements in code (TEK10 [24]), and its document deviations (VTEK10 [24]) are employed. Both the WP2 specification [1], and NS 3901 [25].

The following chapters from the WP2 have been used in detail in the analysis:

- Chapter 7.2 - Sensitivity analysis
- Annex D 1 – Event trees
- Annex C 2 – Fire partitions
- Annex C 3 – Fire suppression and extinguishing systems
- Annex C 4 – Fire detection, alarm and interactions
- Annex C 5 – Fire service intervention
- Annex C 6 – Other installations and systems
- Annex B - Validation of data for analysis.

The following chapters from the WP2 have been tested in other work or reviewed:

- Chapter 5.
- Chapter 6.3.2
- Chapter 6.3.3
- Chapter 6.3.4
- Chapter 6.4.2
- Annex D 4.1
- Annex D 4.2

The following relevant deviation from guidance to code was documented:

- Size of fire-section exceeding pre accepted solution of 10 000 m^2 in a sprinkled building.

2.4.2 Summary

At one of Norwegians biggest industrial factories the management wanted to expand the current production hall with 10 000 m^2, to a total of approximately 20 000 m^2. Twice what is described as a pre accepted solution in the code guidance for sprinkled buildings.

The WP2 report [3] was used to document that risk for loss of life could be minimized, and that a fire could not cause unreasonably large economic or material losses at the factory by division of the section in smaller fire cells. The latter being the focus of the probabilistic analysis.

The risk level was documented by using a comparative probabilistic approach using methods in both NS 3901 and the WP2. In the analysis, initial fire frequencies for both the analysis building and a comparative pre-accepted building was retrieved from Nordic statistical data and from the company as well.

Event trees for both buildings were then developed and compared, using a qualitative evaluation of the distribution functions and outcome ranges for all barriers. The result proved that risk for material losses in the whole fire-section could be reduced 2.55 %, compared to a prescriptive building.

2.4.3 Discussion

The WP2 report [3] appears to be a good compilation of methods and tools for carrying out quantitative analyses. Especially the description of univariate and bivariate approaches to fire risk will be useful in future work.

Defining the correct absolute acceptance criteria for individual and social risk is undoubtedly hard, but is also crucial for performing these kind of analyses. The acceptance criteria in the standard seems to correspond with other sources, and seems to give a reasonably risk level (based on some tests with event trees and Monte Carlo simulations for different building solutions). On the other hand demanding a 95 % percentile may be too high taking available statistical data into account.

The standard gives a better and a more thorough analysis than traditional qualitative methods, e.g. risk matrixes. The quantitative methods in the standard also make it possible to make a conclusion without use of more complex methods, e.g. FDS-simulations. One could therefore say that the probabilistic approach both fills the gap between the two mentioned methods, and also has the capability to be used in analyses where one want to combine the methods.

More focus on probabilistic fire risk will without a doubt increase the knowledge among the engineers working in the field, and community as a whole. The standard is very much welcomed.

2.4.4 Recommendations

The standard could contain more statistical data for barriers.

Demanding a 95 % percentile to draw conclusions from the analysis may in some cases be too high.

2.5 Prolonged escape route

The case study is based on a real building in Norway, where the client wanted a longer escape route than the prescriptive code allows.

The case study and this subchapter was performed and written by Ramboll, see Appendix.

2.5.1 Scope

The scope of the project was to investigate the possibility to increase the travel distance from 30 m (prescriptive demand) to 45 m. This was limited to one big 1 floor store.

2.5.2 Summary

The main purpose of setting requirements for distance of escape route is to make sure that it will go quickly to evacuate. The time available for escape is greater than the time necessary for escape. Exemption is thus related to the personal safety and this was the basis for analysis.

The store will be protected with sprinklers and fire alarms. The ceiling height inside the store is above 7 m.

There was conducted an ASET/RSET[2] analysis. Methods of acceptance criteria from WP2 were used. To verify the solution, we needed to show that:

"ASET" >"RSET" + "Safety Margin"

The method that was used to document the solution, was an ASET / RSET assessment. The β method (safety index) were used to address the probability of failure.

If "g" is the safety margin:

[2] ASET: Available Safe Egress Time / RSET: Required Safe Egress Time

g = ASET-RSET

g, ASET and RSET are random variables where g is assumed to be normal distributed.

β is defined as: $\beta=\mu_g/\sigma_g$

with: μ_g is the average value of g and σ_g is the standard deviation of g.

If the probability of failure is lower than 5%, as assessed solution satisfactory. For the safety margin should be positive in 95% of cases, be β be greater than 1.6449.

For the assessment, smoke-height is set as acceptance criteria. Several calculations with two-zone model C-FAST were made. Escape time are simulated using Pathfinder [26].

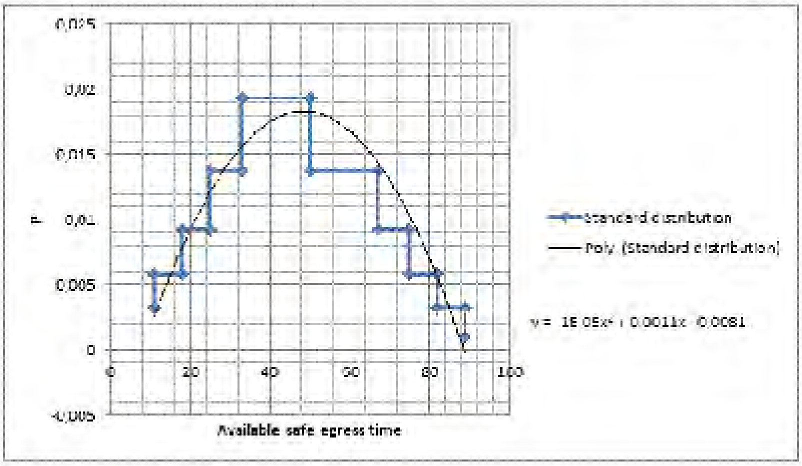


Figure 19. Normal distribution of the ASET

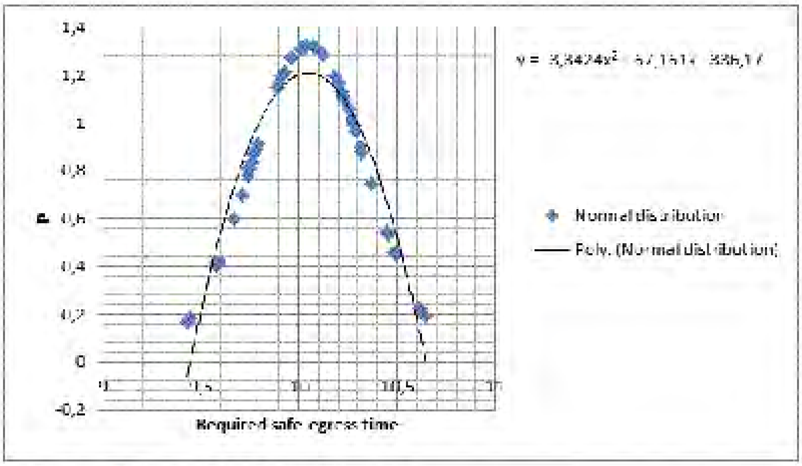


Figure 20. Normal distribution of the RSET

To calculate the mean and standard deviation of the safety margin, the following formulas is used:

$\mu_g = \mu_{ASET} - \mu_{RSET}$ and $\sigma_g^2 = \sigma_{ASET}^2 + \sigma_{ASET}^2$

This gives the following values of safety margins:

$$\mu_g = 60 - 10 = 50 \text{ min}$$

$$\sigma_g = \sqrt{23^2 + 0{,}3^2} = 23 \text{ min}$$

$$\beta = \frac{50}{23} = 2{,}17$$

A β-value of 2,17 is equivalent to a failure margin of 1- 2 %.

The results could show that safety margins were adequate and with 98% confidence.

2.5.3 Recommendations

The standard aims to set an absolute acceptance criterion, which is good. The criterion is only related to life safety. There should also be an absolute acceptance criterion for loss of assets.

2.6 Sports arena used for concert

The case study is based on a real building in Norway, where the client wanted to use the sports arena for a concert. The occupant load exceeded the accepted occupant load in the fire design for the building. In order investigate the possibility to use the sports arena for a concert an ASET/RSET analyses was conducted. Methods described in WP2 [1] has been used.

The case study and this subchapter was performed and written by Ramboll, see Appendix.

2.6.1 Scope

The scope of the project was to investigate the possibility of using a sports arena for a concert event. This was conducted by using a RSET/ASET method involving programs such as FDS and Pathfinder [26].

2.6.2 Summary

In the case of the concert, it will be allowed more people in the sports arena. It leads to free width of escape exits to be less than 1 cm for each person, which is the pre-accepted requirement in Norway. The sports arena also has escape routes more than 30 m length.

The method that was used to document the solution, an ASET / RSET assessment where β method (safety index) were assumed.

Both the ASET and the RSET results are treated as variables. The bivariate approach has been used. The two variables are indented, random and normal distributed. g is the function of a successful evacuation in case of fire: g= ASET-RSET

If "g" is normal distributed the safety index β can be expressed as:

$\beta = \mu_g$ (average)/σ_g (standard deviation)

Mean value: $\mu_{RSET} - \mu_{ASET} = \mu_g$

and standard deviation: $\sigma_{RSET}^2 + \sigma_{ASET}^2 = \sigma_g^2$

The probability of failure:

P(Failure)=1/2[1+erf (0- μ (ASET-RSET)/ σ (ASET-RSET) √ 2)]

If the probability of failure is lower than 5%, the assessed solution is deemed to be satisfactory. For the safety margin should be positive in 95% of cases, β should be greater than 1.6449.

For the assessment, the visibility of at least 10 m in the height of 2 m above floor was first set as the acceptance criteria to determine ASET. Several calculations with FDS [27] and Pyrosim [28] were made. Because of the large volume for smoke filling, the time to reach acceptance criteria was large. Several calculations with Pathfinder [26] showed that the people flow was stagnating when increasing the number of people, although the RSET time was much lower than the ASET time, even with 100 % of security margin. All calculations made in FDS and Pathfinder [26] (with different input values) was plotted with the use of the bivariate approach. This was used to derive the safety index, β =8.5488, which gave P(failure)=0.

The results could show that safety margins were adequate, with 100% confidence.

2.6.3 Discussion

In this case, the ASET/RSET analyses showed us that the case of fire was not the decisive scenario for determining the number of people that could be allowed in the sports arena in case of fire, but the risk of panic because of the poor people flow. The calculated probability of failure P(failure)=0 gives a good reflection of the results could be discussed.

2.6.4 Recommendations

The experience with the new standard is that the beta value could have been explained better. Calculating a value of β =8.5488 gives no understanding of the result. Table 6 of the technical specification [3] shows the relationship between probability and safety index. This table might require more explanations.

Also the formula showed in Figure 25 of the technical 24833specification [3] seems to not work in excel. This formula is used to find a normal distribution for the safety margin, based on the use of two normal distributions. This calculation might deserve also a better explanation.

2.7 Combustible insulation in cavity wall in high rise buildings

This report primarily provides comments on draft D of "Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings" [3]. However, some of the principles correlates with SIS-TS:2014/INSTA 950 [2] and are therefore included in this case study.

The case study and this subchapter was performed and written by DBI, see Appendix.

2.7.1 Scope

The case study is on use of combustible insulation in buildings taller than 22 m. The idea is to demonstrate whether the probabilistic approach is applicable to a current real life challenge within FSE.

Fire Safety Engineering methods can be used to demonstrate fire safety in two ways:

- Use of comparative fire safety engineering methods in order to compare a design to re-accepted solutions.
- The use of fire safety engineering methods for the evaluation of a design against an absolute criterion.

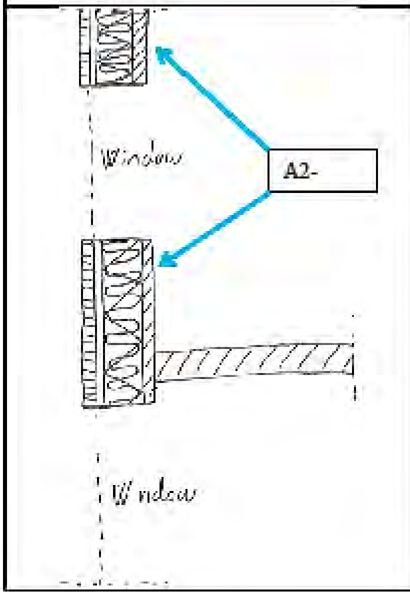
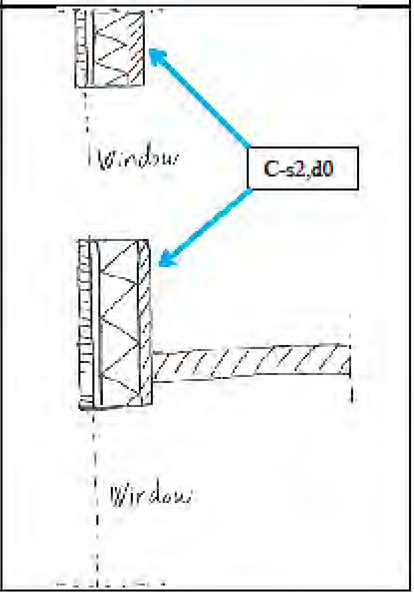
It should be noted that "Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings" [3] is focused around meeting an absolute criterion, whereas the INSTA 950 [2] focuses on comparative analysis.

The case study is based on an actual challenge in Danish building regulations. A prescriptive design – According to the Danish prescriptive guidelines [29]- would require the use of non-combustible insulation material (reaction to fire Class A2-s1,d0) in buildings taller than 22 m. However, Denmark has a performance based code like all other Nordic countries, thus a fire safety engineering approach is allowed in order to demonstrate an adequate fire safety level.

2.7.2 Summary

A reference building and new building design is given as in Table 6 below.

Table 6: Reference and new building design

Reference building design	New building design
Residential building taller than 22 m.	Residential building taller than 22 m.
Inner wall (concrete)	Inner wall (concrete)
Non-combustible insulation material (A2-s1,s0) + 25 mm cavity between insulation and outer brick wall	Combustible insulation material (C-s2,d0) + 25 mm cavity between insulation and outer brick wall
Outer wall(brick)	Outer wall (brick)
Slab (concrete)	Slab (concrete)
	

2.7.2.1 Risk

The fire risk in this case is the probability of fire spread from one fire compartment to another or to a part of the cavity within the façade which results in primarily one or two consequences.

<u>Probability</u>

Fire spread through insulation material in the façade;

- To compartment above → Untenable conditions in compartment
- To the façade (cavity of the wall)

<u>Potential consequences</u>

- People are exposed to critical conditions

- Fire brigade will not be able to extinguish the fire inside the façade structure

It is noted that the above mentioned probabilities and consequences only covers the risks directly related to the use of combustible materials. For example there is also a risk of external fire spread through openings resulting in the same or other consequences as mentioned above.
The above can also be expressed in an event tree as seen in Figure 21 and Figure 22 below.

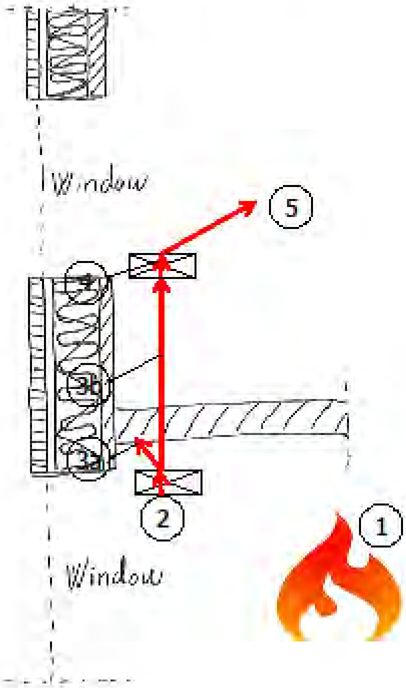


Figure 21: Risk scenario

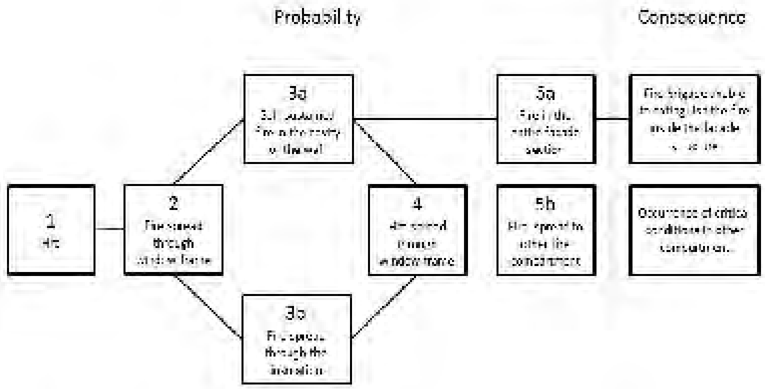


Figure 22: Risk event tree

2.7.2.2 Analysis

As mentioned above there are two possible approaches in order to show an adequate fire safety level using a performance based design – Either through comparative or probabilistic (absolute criterion) analysis.

Table 7: Different approaches for showing adequate fire safety level

Approach	Standard/Guidelines	Comments
Comparative	SIS-TS 24833:2014/INSTA 950 [1]	Existing specification
Probabilistic (absolute criterion)	Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings [3]	Proposed new specification (draft)
Prescriptive	Pre-accepted solutions (Not mandatory)	Guidelines based on earlier prescriptive Danish building regulation [29] (before introduction of performance based code in 2004)

In this case both the comparative approach and the analysis using an absolute criterion lead to the same challenge which is lack of necessary data. Thus, the WP2 standard cannot be applied to the scenario given in this report.

Table 8: Required data for comparative and probabilistic (absolute criterion) analysis. Green = existing data, Red = non-existing data, White = Not Needed (N/N)

#	Required data	Comparative	Probabilistic (absolute criterion)

1	Likelihood of fire in compartment	N/N (Same for reference and new design)	
2	Likelihood of fire spread to compartment above through separating slab of concrete (with variable opening geometry + room fuel load)	N/N (Same for reference and new design)	
3	Likelihood of external fire spread to compartment above (with variable opening geometry + room fuel load)	N/N (Same for reference and new design)	
4	Likelihood of external fire spread/fire spread through concrete slab leading to untenable condition for residents before evacuation	N/N (Same for reference and new design)	
5	Likelihood of self-sustained fire in the façade (resulting in fire spread inside the façade and leading to either untenable condition for residents before evacuation or danger to firefighting personnel)		

As seen in Table 8 not all data are available in order to conduct a thorough analysis using a comparative of probabilistic (absolute criterion) approach. Each element of the table is elaborated below.

1. There are a lot of existing data on the probability of a fire occurring in different building types. Hereunder also for residential buildings which would be needed in this case.
2. By knowing the design fire, the probability of fire spread through the slab as a function of time could be determined.
3. By knowing the design fire, the probability of external fire spread as a function of time could be determined.
4. There are currently not any data available on probabilities of occupants in the above compartment being exposed to untenable conditions. However, in this case it could be considered extremely unlikely that persons would be exposed to critical condition if they can use the escape stairwell. In order to perform the probabilistic analysis the following missing data would be required:
    a. Probability of the stairwell being compromised as a result of the compartment fire below before the fire spreads to a given other fire compartment.
    b. Probability of the fire service being able to extinguish/control the fire before it spreads to other fire compartments.

5. Some research of self-sustainable fires within façade systems has been carried out but the knowledge is limited. A lot of parameters have influence on the result. Some of them are e.g.:
    a. Size of cavity gap between insulation and the wall (typically outer wall).
    b. The size of contributing fire.
    c. Fire performance of used insulation material in a specific setup.
    d. Supply of oxygen through leaks in the façade structure.

Probabilistically, bullet point a. and b. could be reasonably determined with their respective standard deviations.

Bullet point c is much more complicated as the fire performance of a specific insulation material is dependent on a great number of sub-categories. E.g. heat of combustion, flashpoint, smoke potential etc. It should be noted that the reaction to fire classification is based on a reference scenario and does not say anything about the fire properties in the specific setup.

Bullet point d is also very complicated to estimate. It seems reasonable to assume that the supply of oxygen is unlimited (worst case scenario) but in reality a large standard deviation is expected since it is governed by façade design, material quality, workmanship etc.

2.7.3 Discussion

The case study has shown that there is a sum of unknown parameters which is needed in order to conduct a fully probabilistic analysis. The draft specification "Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings" [3] is considered applicable to this case study but only when the unknown parameters discussed above (as a minimum) have been identified. Thus the lack of knowledge is the reason why the draft specification cannot be used to demonstrate an adequate fire safety level.

It can be concluded that a probabilistic approach is not applicable without all parameters known. Estimating conservative values for the missing probabilities would lead to intolerable risks.

Nevertheless, the draft specification "Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings" [3] is deemed to be applicable for the type of FSE analysis aimed at in the current case study.

2.7.4 Recommendations

The main challenge for this case study is the lack of product specific data. The current European reaction to fire classification system serves its purpose in a prescriptive methodology but since the reaction to fire classifications are discrete levels without direct link to real fires, the classifications – or the test data behind – are not applicable to fire safety engineering calculations.

Therefore, it is recommended to establish a framework that supports the publication of "real" data for fire properties of building products. At best, the data are delivered by the building product manufacturers as a supplement to the reaction to fire classification.

3 WP3 Case Studies

The WP3 technical specification draft, called "Fire Safety Engineering – Control in the Building Process" [4] has been applied in several case studies, in order to judge the applicability of it. After having used the guidance, partners propose recommendations in order to improve quality of the specification contents.

3.1 National review of control process

This is a summary of a study which dealt with the use of performance-based fire safety design and fire safety engineering in Finland and proposed ways to develop the acceptance process.

The case study was carried out in Savonia University of Applied Sciences and it was part of a larger project coordinated by Aalto University School of Engineering where KK-Palokonsultti was one of the project participants. In the summary, discussion and recommendations parts also experience on the control process of the KK-Palokonsultti Oy employees are utilized.

This subchapter was written by KK-Palokonsultti, see Appendix.

3.1.1 Scope

This summary is based on study made at Savonia University of Applied Sciences (Kuopio) [32]. Research material for this project was collected by interviewing rescue departments in Finland and also some private sector companies (fire safety engineering).

3.1.2 Co-operation and stakeholders

Concerning fire safety issues, in Finland, the key stakeholders are the local authorities (building permit authority and rescue services), parties engaging in a construction project (owner, etc.), principle designer (often an architect) and fire safety engineer. In the planning process also other sectors of design (e.g. structural engineer, sprinkler designer, etc.) are involved. The building permit authority has the legal power. Rescue services and fire engineers give their opinions and statements.

The study shows that especially in small municipalities building permit authorities follow the opinion of rescue services. Concerning performance based fire safety design practically in all municipalities rescue services have an important role in accepting design fires, acceptance criteria and final results of the analysis.

3.1.3 Why performance based fire design

Most often the reason to use performance based fire safety design is because the building idea is going far beyond the limit of prescribed rules. This means large and complex buildings with very large fire compartments combined with large number of occupants. Examples are shopping malls, sports arenas, etc.

3.1.4 Third party review

The use of third party review is decided case by case. This is the principle. However, in any larger project third party review is a practice. Again building permit authority is the decision maker whether to use or not (often based on the recommendation by rescue service).

There are two ways of using the third party:

- Third party statement is required when the fire safety design documents have been prepared, or
- Third party reviewer has been involved in the process from the time when fire hazard, design fire and acceptance criteria proposals are available.

In the interviews the second option has been mentioned many times to be the desirable way of working in more demanding cases as it will reduce the number of mistakes and costs.

3.1.5 Objectives

The objectives are not always explicitly set. However, it is always clear for everyone that life safety is the dominating subject.

3.1.6 Fire hazards, design fires and acceptance criteria

Usually the fire design engineer provides the first proposal which is then reviewed by the rescue services and third party (if applicable). Building permit authority gives the final acceptance.

3.1.7 Problems reported

There are no standardized or commonly accepted sets of design fires which could be used in many 'normal' and usually quite similar cases. There are great differences e.g. in heat release rates of design fires and how sprinkler systems are taken into account. There is not enough published information on acceptance criteria for typical situations including their validity limits.

In the design phase, it is sometimes very important to investigate the end-use needs to avoid contradicting or unsuitable solutions. To get end-user commitment early in the project and at a detailed enough level may be challenging.

Local interpretation of building regulations and guidance seems to continue despite the existence of national guidance documents and co-operation between the authorities.

3.1.8 Conclusions of the interviews

The variations in the acceptance processes were not as significant as expected, but there were some differences between regional rescue department areas. The suggestions made in this project are to create a database for acceptance criteria and design fire scenarios, give examples on how the acceptance process should be performed, how to use a third party inspection in the acceptance process and to propose a model for education of those who work in the area of fire safety engineering.

3.1.9 Discussion

The extent of assigned and used resources for internal or in-house peer reviewing is in many cases underrated. This would be of added value as praxis early on, before problems arise.

Early involvement of the fire safety design and possible third-party reviewer in the project is always very important for quality and continuity of the design.

Communication with the approving body before actual approval negotiations and with the essential composition of stake holders, even with the end-user sometimes, is of great importance.

3.1.10 Recommendations

On a general level (not concerning the WP3 specification in particular) it is recommended to establish a data/knowledge bank for typical fire hazards, design fires and acceptance criteria. The information should include short descriptions of these measures together with their validity limits.

3.2 Review of control in the building process

This is a case study of the building control process in Iceland, for a design of a new school and gymnast building. The proposed review process in WP3 is used to analyze the design process.

The case study and this subchapter was performed and written by Iceland Fire Research Institute, see Appendix.

3.2.1 Scope

This case study is based on a design review case of a school building in Iceland. The process was reviewed using WP3 [4] methodology, in connection to Icelandic review process and requirements. The scope was also to review responsibilities and roles in the design process.

A special focus is on the external review and the role of different stakeholders.

3.2.2 Building process and review

The control process in Iceland involves both the designer and the local building committee. The local building committee usually consult the local fire brigade, which takes over the responsibility of the review.

The building regulation of Iceland [34] require fire engineering design of certain buildings. The building regulation is performance based, but with prescribed requirements as an alternative.

In some cases there is an external reviewer, but there is no general requirements dictating when an external reviewer needs to be a part of the project.

The building authorities in Iceland have issued an Inspection Manual with a checklist for construction design. Before issuing a building permit, an inspection of the design plans must be carried out, by an accredited inspection firm or building authority, in accordance with the manual. The Inspection Manual also describes the function of a possible external reviewer. This is applicable for more complex design, and involves checking if basic elements of design are adhered to and fully described in the design documents. The Inspection Manual for Design sets similar demands on external reviewing as is done in the EN 1990 EUROCODE – Basis of Structural Design [33].

The reasons for an external peer reviewer in Iceland are mainly the following:

- To ensure quality of design. The reviewer is hired by the client.
- Due to complexity and need for thorough review of design. The reviewer is requested by authorities but hired by the client.

3.2.3 Responsibilities in design process

The design process is to some extent influenced by the responsibilities as defined in the building regulation. The regulation does however, not define the review process in any detail.

In this study, a separate external reviewer was hired by the main client, to review the fire designer. The main contractor hired all designers and was responsible for the whole process.

The external reviewer role was twofold; 1. Review the design parameters for fire design that were put forward by the client (made by another external designer) and 2. Review the fire safety design documentation, before handed to the authorities.

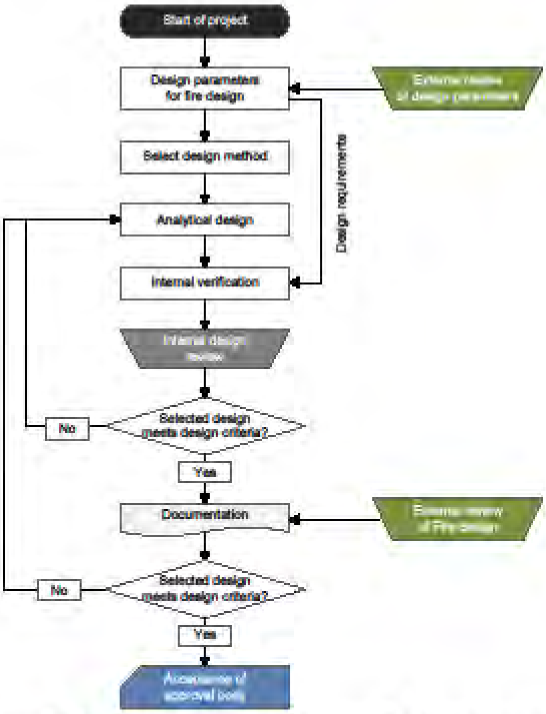


Figure 23: The role of external reviewer in the design process

The responsibilities of the fire designer are defined in a document specified in the building regulations as “A statement of the responsibilities of designers”. This definition, explaining the rand conditions of the designer and how it relates to other designers.

The designer is required to have a quality management system approved by the national building authority (Iceland Construction Authority).

3.2.4 Interviews and review of process

Simple interviews on the review process where conducted, with the following stakeholders:

- Fire brigade official, reviewer of fire technical design on the behalf of building authorities.
- Building authorities (MVS) in Iceland
- Fire designers

The stakeholders where led through the proposed design process as described in the WP3 [4] specification with an additional discussion on the design process in general.

The objective was to gain insight into issues faced by different stakeholders and with their view of the process.

3.2.5 Discussion

There were a number of challenges cited in the interviews and in the review process.

In the guidance document on “A statement of the responsibilities of designers” [35] there is a description on how the designer has checked the quality of the design. An option is given on performing an external quality check and reference is made to the methodology and requirements made in EN 1990 EUROCODE – Basis of Structural Design.

However, since the Inspection Manuals on construction design are relatively recently produced, there is still an uncertainty in the local building and fire authorities on when external review is relevant. There is a lack of knowledge by some local authorities on when there is a need for a more fire technical approach to the design and the quality level of related calculations.

The shift from when a prescribed solution is not sufficient to when performance based solution is required not always straight forward. This also affects the design and review process. If a complex problem is approached with a simple prescribed solution, the risk is that the problems are not seen in context. This could also result in a more simplistic review, than necessary for the actual problem.

The internal processes for review are often not clearly defined. The different complexity of the project sometime make it difficult to define, although there are many common elements.

There have been a tendency to simplify internal review and documentation of design checks. There is a need to follow up on requirements for internal review and for authorities to demand necessary documentation.

Without clearer requirements for review, there might be reluctance of the client to pay for external reviewer.

The designer might resist an attempt to call in an external reviewer, as it could mean criticism of his work and possible changes to the design. In most cases this leads to increased cost of (his) design.

3.2.6 Recommendations

The main conclusions and recommendations are the following:

- It is very important to clearly define the responsibilities in the review process.
- There is a need to inform designers and local authorities on the minimum requirements / criteria set in EN 1990 EUROCODE – Basis of Structural Design on when to add an external reviewer in the process.
- New standard on Control in the Building Process will be helpful guidance in the process.
- There should be clear responsibilities for all designers involved in the design process.
- There is a need to follow up on requirements for internal review and for authorities to demand necessary documentation.

The standard on review of the control process should address all of the above.

4 Recommendations

This chapter summarizes all recommendations done on the two technical specifications from WP2 and WP3.

4.1 WP2 - Case studies

For the WP2 - "Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings" [3], the following recommendations have been done.

One of the main recommendations concerns the evacuation parameters. More guidance and explanations should be done for these, in order to simplify their usage, particularly the table and equations in the § 6.4.2.1 of the specification. Also, it might be good to specify that if untenable conditions are used, it leads to an overestimation of the risk, compared to the fatality rate that the acceptance criteria is based on.

The second main recommendation is done about the specific fire parameters (§ 6.2.1 of the WP2 specification). More guidance is required for this paragraph. For instance, some cases could be given for the use of the parametric curves (guidance/conditions from EN 1991-1-2 [9]). Also, it seems difficult to evaluate the fire load in the case of a tall timber building due to the lack of input data and probabilities.

Another recommendation is the establishment of a framework that supports the publication of "real" data for fire properties of building products.

Finally, reliability data (Annex C [1]) would need to be reviewed in the sense of making a difference between statistical data and 'expert opinions'. Also some of the tables should be more specific when defining reliability values, e.g. for the sprinkler systems there are no references to European standards of the systems, neither performance levels of the systems.

4.2 WP 2 - Expert elicitation

Dr Brian Meacham, Associate Professor at Worcester Polytechnic Institute, has performed a review of the draft specification "Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings" [3].

A short summary follows.

Throughout the document, more precision with terms is asked for.

The scope and title of the document implies that a singular approach is provided, whereas chapter 4, 6 and the worked examples shows that this is not the case. Reference to other sources is given for framework of probabilistic risk assessment.

Dr Meacham comments thoroughly on acceptance criteria, stressing the need for being precise. The criterion for individual risk of 10^{-6} is questioned, and is considered by the reviewer as hard to achieve. A comment on how the criteria should be perceived across the population is also asked for – addressing vulnerable groups such as elderly and infants. To ensure a correct acceptance criteria for comparative analyses, more guidance on identifying and selecting the reference buildings should be provided.

More detailed guidance is considered useful for several sections of the document

4.2.1 WP2 - Student thesis

As part of this project a student thesis by David Ronstad *A Comparison between two different Methods to Verify Fire Safety Design in Buildings* was supervised by Greg Baker and Michael Strömgren in order to review the draft WP2 specification.

The following recommendations for further development were suggested in the thesis:

- Treatment of critical levels for evacuation scenarios
- Form a common Nordic statistical database
- Improved guidance of how to complete the validation analysis

4.3 WP 3 - Case studies

For the WP3 - "Fire Safety Engineering – Control in the Building Process, the following recommendations have been done.

The main conclusions and recommendations are the following:

- It is very important to clearly define the responsibilities in the review process.
- There is a need to inform designers and local authorities on the minimum requirements / criteria set in EN 1990 EUROCODE – Basis of Structural Design [33] on when to add an external reviewer in the process.
- New standard on Control in the Building Process will be helpful guidance in the process.
- There should be clear responsibilities for all designers involved in the design process.
- There is a need to follow up on requirements for internal review and for authorities to demand necessary documentation.

The standard on review of the control process should address all of the above.

On general level (not concerning exclusively WP3 report) it is recommended to establish a data/knowledge bank for typical fire hazards, design fires and acceptance criteria. The information should include short descriptions of these measures together with their validity limits.

4.4 WP 3- Expert elicitation

The draft standard "Fire Safety Engineering: Control in the Building Process" produced within WP3 has been subjected to review by Dr Brian Meacham, Associate Professor at Worcester Polytechnic Institute. Dr Meacham's comments are summarized below.

WP3 uses the "peer review" to describe both internal quality assurance work as well as review carried out by a third party and establishes the following levels of control:

1. The individual in charge of the fire safety design and verification controls his/her own work;
2. In-house peer review;
3. Third-party peer review

Dr Meacham points out a necessity to clarify the different roles related to the control process and suggests modifications to the definitions and terminology used in the draft standard. Dr Meacham proposes that "in-house peer review" is replaced by "internal quality control reviewer" in order to isolate peer review to a process kept only for external review. Dr Meacham also suggests that WP3 separates technical peer review from regulatory peer review. The first term focuses on analysis and engineering and the latter on regulatory compliance.

Details on the independence of the third-party reviewer ought to be clarified. Dr. Meacham states that an internal reviewer never can be assumed to be independent. It could also be questioned how independence could be granted regarding the third-party reviewer depending who assigns the reviewer and who pays for the service. An external reviewer could be assigned as a part of the internal quality control scheme and it is necessary to separate reviews that are carried out on an voluntary basis by the contractor and a review that is mandatory due to national regulations. Communication between the engineer and the reviewer must be regulated in order to ensure independence when such a review is required.

Finally, Dr. Meacham proposes a few references that could be investigated in order to produce additional explanatory figures and checklists.

5 Conclusions

This document reports on the work done for the Work Package 4 within the project named "Fire Safety Engineering for Innovative and Sustainable Building Solutions", financed by Nordic Innovation and coordinated by SP Technical Research Institute of Sweden.

The challenge in this project is to create two standards supporting fire safety engineering in a performance-based regulatory regime that will facilitate the design processes and technical innovations in a robust and sustainable way.

The first standard (i.e. the document from WP2 [3]) provides guidance for a probabilistic approach for fire safety engineering and the aim of the document from the WP3 [4] is to facilitate verification of building solutions including innovative and sustainable solutions and to harmonize the process for control within the field of fire safety engineering within the Nordic countries.

The results of the application of the WP2 and WP3 specification in several case studies as well as by external reviews has yielded the following main recommendations for further improvement:

- Application of the probabilistic method according to WP2 requires statistical data and recommendation on design parameters. A databank with such information is thus needed, not least concerning evacuation parameters, acceptance criteria and fire hazards.
- There is a gap between acceptance criteria used in comparative analysis, scenario analysis and the criteria used in probabilistic method that may lead to too tough requirements. Development of new methods and criteria for WP2 is encouraged to bridge this gap.
- Roles and responsibilities need to be more clearly defined in WP3 to ensure a more streamlined review and control process.

The input from case studies and external reviewers will lead to an improved end product as the final revision in WP5 commences. At the end of the project, two proposed specification will follow the INSTA procedure in order to establish a Nordic common approach to fire safety engineering to facilitate innovative and sustainable building solutions.

6 References

[1] B Meacham (2010) Accommodating innovation in building regulation: lessons and challenges. Build Res Inf 38:686–698. doi: 10.1080/09613218.2010.505380

[2] SIS, "Teknisk specification SIS-TS 24833:2014/INSTA 950, Fire Safety Engineering – Comparative method to verify fire safety design in buildings", Swedish Standards Institute, 2014

[3] WP2: Fire Safety Engineering – Probabilistic Method to Verify Fire Safety Design in Buildings. Fire safety Engineering for Innovative and Sustainable Building Solutions Project.

[4] WP3: Fire Safety Engineering: Control in the Building Process. Fire safety Engineering for Innovative and Sustainable Building Solutions Project.

[5] NFPA 92B "*Guide for smoke management in Malls, Atria, and Large Areas*" (1995 edition).

[6] CIBSE Technical Memoranda 19:1995 "Relationships for Smoke Control Calculations".

[7] BBRAD 1 Boverkets allmänna råd om analytisk dimensionering av byggnaders brandskydd – BFS 2011:27.

[8] Application of fire safety engineering principles to the design of buildings – Part 7: Probabilistic risk assessment. PD 7974-7: 2007; British Standards.

[9] Eurocode 1: Actions on structures – Part 1-2 : General actions – Actions on structures exposed to fire, Annex E : Fire load densities; SS-EN 1991-1-2.

[10] F. Olsson, H. Frantzich, Brandteknisk dimensionering med riskbaserade ekvationer (Fire Safety Design by Using Simple Risk-Based Equations), Lund University, Rapport 3107, 1999.

[11] H. Frantzich, Risk analysis and fire safety engineering, Fire Safety Journal, Volume 31, Issue 4, 1998, p313-329.

[12] K. Fridolf, E. Ronchi, D. Nilsson, H. Frantzich, Movement speed and exit choice in smoke-filled rail tunnels, Fire Safety Journal, Volume 59, p8-21, 2013,.

[13] S.E. Magnusson, H. Frantzich, K. Harada, Fire safety design based on calculations: Uncertainty analysis and safety verification, Fire Safety Journal, Volume 27, Issue 4, p305-334, 1996.

[14] SFPE Handbook of Fire Protection Engineering, ISBN: 978-1-4939-2565-0, 2016.

[15] Statistics from the Swedish Civil Contingencies Agency statistics database IDA. Retrieved from https://ida.msb.se/ida2#page=a0087 2016-10-01.

[16] BBRBE 1 Boverkets allmänna råd (2013:11) om brandbelastning - BFS 2013:11.

[17] EN 1991-1-2, Eurocode 1: Actions on structures - Part 1-2: General actions – Actions on structures exposed to fire, 2002.

[18] D. Drysdale, An Introduction to Fire Dynamics. 2011. 3rd edition.

[19] S. Hostikka, O. Keski-Rahkonen, T. Korhonen. Probabilistic Fire Simulator. Theory and User's Manual for Version 1.2. Espoo, VTT Building and Transport. 72 p. + app. 1 p. VTT Publications; 503. ISBN 951-38-62-35-6, 2003.

[20] S. Hostikka. Development of fire simulation models for radiative heat transfer and probabilistic risk assessment. Espoo, VTT. 103 p. + app. 82 p. VTT Publications; 683. ISBN 978-951-38-7099-7, 2008.

[21] S. Hostikka, T. Kling, J. Mangs, A. Matala,. Implementation of Quantitative Fire Risk Assessment in PSA (FIRAS). FIRAS summary report. SAFIR2010. The Finnish Research Programme on Safety 2007-2010. Final Report. 2010.

[22] T. Hakkarainen. Post-Flashover Fires in Light and Heavy Timber Construction. Journal of Fire Sciences, Vol. 20. p133-175. 2002.

[23] EN 1363-1:2012. Fire resistance tests

[24] TEK10: Building regulations, Directorate for Building Quality (DiBK)

[25] NS 3901:2012, Krav til risikovurdering av brann I byggverk, Requirements for risk assessments of fire in construction work.

[26] www.thunderheadeng.com/pathfinder

[27] https://pages.nist.gov/fds-smv/

[28] www.thunderheadeng.com/pyrosim

[29] Eksempelsamling om brandsikring af byggeri 2012", 2nd ed., The Danish Transport, Construction and Housing Agency, 2016

[30] K. Hox, Branntest av massivtre, SP Fire Research AS. SPFR-rapport SPFR A15101, 2015.

[31] X. Li, C. McGregor, A. Medina, X. Sun, D. Barber, G. Hadjisophocleous, Real-scale fire tests on timber constructions. WCTE 2016, Vienna, Austria.

[32] A. Heininen. Developing Fire Safety Design in Finland. Thesis for degree of Fire Officer (Engineer). Savonia University of Applied Sciences, 2016.

[33] CEN. EN1990 – Eurocode: Basis of structural Design – April, 2001, CEN.

[34] Skoðunarhandbækur, ("Inspection Manuals"), Mannvirkjastofnun, Iceland Construction Authority, Reykjavik, Iceland, 2016.

[35] Greinargerð hönnmarstjóra um ábyrgðarsvið hönnuða, ("A statement of the responsibilities of designers"), article 4.1.3 in the Icelandic Building Regulation, Mannvirkjastofnun, Iceland Construction Authority, Reykjavik, Iceland, 2016

[36] D. Ronstad (2017) A Comparison between two different Methods to Verify Fire Safety Design in Buildings. Luleå University of Technology

Appendix – Participant Descriptions

Brandskyddslaget

Brandskyddslaget is an independent Swedish consulting company offering services in fire safety design, risk management and design of sprinkler systems. Brandskyddslaget was founded in 1989 and has about 60 employees at offices in Stockholm, Karlstad, Falun, Örebro, Gävle and Malmö. The company has been employee-owned since 2003.

Brandskyddslaget has broad experience and expertise in all aspects of fire safety and has been involved in many of the largest building projects in Sweden. Examples of major projects where Brandskyddslaget has been responsible for the fire protection are: Friends Arena, Mall of Scandinavia and Victoria Tower.

Briab Brand & Riskingenjörerna AB

Briab brand & Riskingenjörerna AB has approximately 90 employees. Briab was founded 2012 and has offices in Stockholm, Uppsala, Gävle, Falun, Norrköping and in the Öresund region with basis in Malmö.

Briab is working within all fields of fire safety and have experts within management services, operational support, and expert analysis such as fire safety design and inspections.

On an everyday basis Briab is working in a broad spectrum of projects, ranging from apartment buildings to high-rises as well as complex infrastructure.

DBI

DBI is Denmark's leading knowledge centre in the field of security and fire safety. DBI maintain their knowledge through relevant participation in research and development activities and services that are offered to private and public enterprises, institutions and authorities. DBI also participate in efforts to set norms and standards at national and international levels within their key fields of activity.

DBI has worked within safety for almost 100 years and is an independent, private, non-profit enterprise. DBI is part of a national network called GTS – Advanced Technology Group.

DBI services include fire safety engineering, testing, certification, consultancy, research and development, fire inspections, fire investigations, investigations related to corporate fraud, publications and training

Iceland Fire Research Institute

Iceland fire research institute is an umbrella for fire research in Iceland.

The following study was conducted by Iceland Fire Research Institute. EFLA Consulting Engineers also contributed with actual case on which the study is build.

KK-Palokonsultti Oy

KK-Palokonsultti Oy is a private Finnish consulting company offering services in fire safety design, fire risk analysis and research projects for industry and national authorities. KK-Palokonsultti Oy was founded in 2006 and has 14 employees at offices in Espoo, Seinäjoki and Kolari.

In addition to fire safety consultation many of the employees have earlier experience on fire research (especially from VTT Technical Research Centre of Finland) or from rescue services. The company has experience in planning new facilities and in renovation projects, as well as in underground construction, ships and other means of transport. Also research projects providing background for revision of fire regulations and guidance are important topics.

Ramböll

Ramböll is a leading engineering, design and consultancy company founded in Denmark in 1945. We employ 13,000 experts and have a strong presence in the Nordics, North America, the UK, Continental Europe, Middle East and India, supplemented by a significant representation in Asia, Australia, South America and Sub-Saharan Africa.

Ramböll has about 100 fire engineers. Ramböll Norway has about 1500 employees, where 40-45 are fire engineers. The company has been involved in many of the largest projects in Norway. An example is the new National museum of art, architecture and design in Norway.

Research Institutes of Sweden (RISE)

SP is a leading international research institute belonging to the RISE group (Research Institutes of Sweden), which is owned by the Swedish government. SP Safety - Fire Research, a technical unit within SP, conducts research, testing and certification related to fire safety. It has extensive experience of experimental and computational R&D into different aspects of fire safety through nationally and internationally financed projects in the fields of fire resistance, reaction to fire and fire suppression. It has large testing facilities in all three areas and is accredited for numerous international and European standards. It participates in and coordinates several projects for the European Commission and is heavily involved in European and international standardization. SP Fire Research also carries out bespoke training for consultants and other parties in Sweden and the other Nordic countries. The expertise covers several application areas such as buildings, materials, infrastructure, transportation and offshore.

SP Sveriges Tekniska Forskningsinstitut

SP-koncernens vision är att vara en internationellt ledande innovationspartner. Våra 1 400 medarbetare, varav över hälften akademiker och cirka 380 med forskarutbildning, utgör en betydande kunskapsresurs. Vi utför årligen uppdrag åt fler än 10 000 kunder för att öka deras konkurrenskraft och bidra till hållbar utveckling. Uppdragen omfattar såväl tvärtekniska forsknings- och innovationsprojekt som marknadsnära insatser inom provning och certifiering. Våra sex affärsområden (IKT, Risk och Säkerhet, Energi, Transport, Samhällsbyggnad och Life Science) svarar mot samhällets och näringslivets behov och knyter samman koncernens tekniska enheter och dotterbolag. SP-koncernen omsätter ca 1,5 miljarder kronor och ägs av svenska staten via RISE Research Institutes of Sweden AB.

SP Technical Research Institute of Sweden

Our work is concentrated on innovation and the development of value-adding technology. Using Sweden's most extensive and advanced resources for technical evaluation, measurement technology, research and development, we make an important contribution to the competitiveness and sustainable development of industry. Research is carried out in close conjunction with universities and institutes of technology, to the benefit of a customer base of about 10000 organisations, ranging from start-up companies developing new technologies or new ideas to international groups.

Företagsnamn?
Adress?
Telefon?
Epost?
www.sp.se

Publ? www.sp.se/publ

Enhetsnamn?
SPRapport?
Årtal?:RapportNr?
ISBN ISBN?
ISSN 0284-5172

PART OF RI.SE

7 Appendix C: Probabilistic method to verify fire safety design in buildings

Date: 2017-05-26

Fire Safety Engineering –

Probabilistic Methods for Verifying Fire Safety Design in Buildings

i

Contents

Page

Introduction ... iv

1 Scope ... 1

2 Normative references ... 2

3 Terms and definitions ... 3

4 Procedure ... 7
4.1 General ... 7
4.2 Problem definition and scope ... 8
4.3 Identify fire safety objectives and functional requirements ... 8
4.4 Initial design review: fire safety concept and trial fire safety designs ... 10
4.5 Choice of verification approach ... 11
4.6 Choice of performance criteria (acceptance criteria) ... 11
4.7 Verification of each defined safety objective ... 11
4.8 Uncertainty management ... 11
4.9 Documentation ... 11

5 Performance criteria (acceptance criteria) ... 12
5.1 General guidance ... 12
5.2 Relative criteria ... 12
5.3 Absolute criteria ... 13
5.4 Property Protection and Business Continuity ... 18
5.5 Probability of failure ... 18

6 Probabilistic Tools and Methods ... 21
6.1 Selection of Design Fire Scenarios ... 22
6.2 Defining Design Fires ... 23
6.3 Estimating Distributions ... 27
6.4 Analysis methods ... 28

7 Uncertainty and sensitivity management ... 38
7.1 General ... 38
7.2 Sensitivity analysis ... 38
7.3 Uncertainty analysis ... 39
7.4 Robustness analysis ... 40

8 Documentation ... 41

Annex A (Informative) Nationally determined parameters ... 43

Annex B (Informative) Validation of fire statistics ... 44
B1 General ... 44
B2 Frequencies of ignition for different types of occupancy ... 45
B3 Fire losses ... 45
B4 Probability of a fire spreading beyond the room of fire origin ... 46
B5 Distributions of fire loads for different types of occupancy ... 46
B6 Relevant databases ... 46

Annex C (Informative) Reliability data ... 48
C1 Intended use ... 49
C2 Fire partitions ... 49
C3 Fire suppression and extinguishing systems ... 49
C4 Fire detection, alarm and interactions ... 50

C5 Fire service intervention 50
C6 Other installations and systems....53
C7 Human response 53
C8 Introduction to reliability analysis 53

Annex D (Informative) Worked examples 56
D1 Event tree method 56
D2 Fault tree method 58
D3 Bayesian network model 59
D4 Safety index (β) method 62
D5 Probability of Incapacitation, based on FED....65

Annex E (Informative) Basic Concepts of Statistics 68
E1 Probability Density Function and Probability Mass Function 68
E2 Estimating Non-Parametric Distributions 70
E3 Estimating Parametric Distributions....73

Bibliography 75

Further reading 77

Introduction

In fire safety engineering, compliance with fire safety regulations can be demonstrated, either by the use of pre-accepted solutions that are defined by the building authorities, or by using fire safety engineering methods.

Fire safety engineering methods can be used to demonstrate fire safety in two ways:

1. The use of fire safety engineering methods in order to compare a design to pre-accepted solutions;

2. The use of fire safety engineering methods for the evaluation of a design against absolute criteria.

A lack of absolute criteria has been a hinder to extensive use of the second approach, and this Technical Specification aims to provide guidance also for analyses where pre-accepted solutions are invalid or where a comparative approach is not considered optimal. The execution of these methods requires input data which represent the frequency of events and an absolute criterion which correspond to an acceptable level of safety. In order to facilitate the implementation of performance-based regulations for non-pre-accepted solutions, this Technical Specification provides performance criteria, guidance on the use of fire safety engineering methods and guidance on the use of input parameters, such as reliability data and statistics.

This Technical Specification is supplementary to the INSTA/TS 950 Technical Specification, which describes comparative methods for assessments that use pre-accepted solutions as a basis. As INSTA/TS 950 has a primary focus on deterministic methods, this Technical Specification also provides guidance on a probabilistic approach to comparative analysis.

1 Scope

This Technical Specification provides guidance for a probabilistic approach for fire safety engineering. Guidance is given for the use of fire safety engineering methods to evaluate compliance with an absolute criterion. This guidance can also be used in combination with INSTA/TS 950 in order to evaluate compliance with a comparative criterion. Performance criteria (acceptance criteria), relevant fire safety engineering methods and input data (reliability data and fire statistics) are within the scope of this report.

This document is intended to be used as a reference for building authorities and for use in verifying compliance with regulations by fire safety designers, local authorities and others in the building industry.

The information given within this Technical Specification should not be seen as requirements, but guidance on verifying compliance with functional requirements in a performance-based regime – e.g. performance criteria on property loss do not apply in regions or nations where only life safety is governed by the authority having jurisdiction. In these cases, a voulentary performance criteria for property safety must be set in in a process involving the relevant stakeholders.

(1) NOTE: Limitations regarding the use of this specification may be set in the National Annex.

The user of this Technical Specification must verify that applied models are valid for the relevant design situation and that national requirements are met.

2 Normative references

The following references are required for the application of the methods described in this report. For dated references, only the cited edition applies. For undated references, the latest edition of the reference document, including any amendments, applies.

EN 1990, Eurocode – Basis of structural design

EN 1991-1-2, Eurocode 1: Actions on structures – Part 1–2: General actions – Actions on structures exposed to fire

EN-ISO 13943, Fire safety – Vocabulary

INSTA/TS 950, Fire Safety Engineering – Comparative method to verify fire safety design in buildings

ISO/TR 13387-2, Fire safety engineering – Part 2: Design fire scenarios and design fires

ISO 13571, Life-threatening components of fire – Guidelines for the estimation of time to compromised tenability in fires

ISO 16730, Fire safety engineering – Assessment, verification and validation of calculation methods

ISO 16732-1, Fire safety engineering – Fire risk assessment – Part 1: General

ISO/TS 16733, Fire safety engineering – Selection of design fire scenarios and design fires

ISO/TR 16738, Fire safety engineering – Technical information on methods for evaluating behaviour and movement of people

ISO 22301, Societal security – Business continuity management systems – Requirements

PD7974-1, Application of fire safety engineering principles to the design of buildings – Part 1: Initiation and development of fire within the enclosure of origin

PD7974-7, Application of fire safety engineering principles to the design of buildings – Part 7: Probabilistic risk assessment

3 Terms and definitions

3.1 Acceptance criteria
criteria that form the basis for assessing the acceptability of the safety of a design of a built environment

(1) NOTE: May be qualitative or quantitative – absolute or relative.

[SOURCE: EN-ISO 13943]

3.2 As Low As Reasonably Practicable – ALARP
an upper limit of acceptable risks, corresponding to reasonable costs and effort

3.3 Available Safe Escape Time – ASET
time available for escape for an individual occupant, the calculated time interval between the time of ignition and the time at which conditions become such that the occupant is estimated to be incapacitated, i.e. unable to take effective action to escape to a safe refuge or place of safety

[SOURCE: EN-ISO 13943]

3.4 Comparative analysis
a comparison between the fire safety level within a trial fire safety design and a reference building that is designed in accordance with pre-accepted solution(s)

3.5 Design fire scenario
specific fire scenario that is analysed with fire safety engineering methods

3.6 Design prerequisites
set of conditions and properties assumed and required for the building

3.7 Design fire
quantitative description of assumed fire characteristics within the design fire scenario

(1) NOTE: This is, typically, an idealised description of the variation with time of important fire variables such as: heat release rate, flame spread rate, smoke production rate, toxic gas yields and temperature.

3.8 Deterministic model
fire model that uses science-based mathematical expressions to produce the same result each time the method is used with the same set of input data values

[SOURCE: EN-ISO 13945]

3.9 Deterministic approach
use of deterministic models to assess the concequences of fire, where uncertainties are addressed by utilizing safety factors/ safety margins and concervative input parameters.

3.10 Fire safety engineering
application of engineering methods based on scientific principles for the development or assessment of designs in the built environment through the analysis of specific fire scenarios, or through the quantification of risk for a group of fire scenarios

[SOURCE: EN-ISO 13943]

3.11 Fire scenario
qualitative description of the course of a fire with time, identifying key events that characterise the fire and differentiate it from other possible fires

(1) NOTE: This typically defines the ignition and fire growth process, the fully developed fire stage, the fire decay stage, and the environment and systems that will impact on the course of the fire.

[SOURCE: EN-ISO 13943]

3.12 FN-curve
a representation of a relationship between the frequency and number of casualties

3.13 Hazard
Situation with a potential for human injury

[SOURCE: PD 7974-7]

3.14 Hazard identification
the process of determining the level of impact the identified risks and hazards have on the fire safety level and to define what objectives in the pre-accepted solutions that the analysis shall focus on

[SOURCE: INSTA/TS 950]

3.15 Initial design review
a qualitative process to identify possible ways in which a fire hazard might occur in relation to the fire safety objectives which are not fulfilled by pre-accepted solutions, and establish one or more trial fire safety designs to maintain the risk at an acceptable level

[SOURCE: modified from INSTA/TS 950]

3.16 Performance criteria
quantitative criteria which form an acceptable basis for assessing the safety of a design for a built environment

[SOURCE: EN-ISO 13943]

3.17 Performance-based design
application of engineering methods in order to design the fire safety (or other objectives) of a built environment. Performance-based design may include simple qualitative verification methods or more complex methods such as deterministic or probabilistic verification methods. Performance-based design of fire safety is referred to as fire safety engineering

[SOURCE: modified from INSTA/TS 950]

3.18 Performance-based regulation (Code)
a document that expresses requirements for a building or building system, in terms of societal goals, functional objectives and performance requirements, without specifying a single means for complying with the requirements.

[SOURCE: IRCC – Inter-Jurisdictional Regulatory Collaboration Committee]

3.19 Pre-accepted solution(s)
a solution that has been determined by the authority having jurisdiction (AHJ) to comply with the objectives set in the fire safety requirements

(1) NOTE: The definition may vary between different countries. Other terms include, for example deemed-to-satisfy solutions, acceptable solutions, prescriptive solutions

[SOURCE: INSTA/TS 950]

3.20 Probabilistic model
methodology to determine statistically the probability and outcome of events

[SOURCE: PD 7974-7]

3.21 Probabilistic approach
use of probabilistic or deterministic models to assess the concequences of fire, where uncertainties are addressed by treating all or some parameters as random.

3.22 Quantitative risk analysis
the analysis of specific scenarios where probabilities and consequences are quantified for each scenario. Advanced probabilistic analysis may include probability distributions of variables

3.23 Reference building
building designed by pre-accepted solutions, i.e. fulfilling the national requirements. The reference building may then be used in a comparative analysis where the risk level or performance of a trial fire safety design is compared to the reference building

3.24 [Fire] Risk
Combination of the probability of a fire and a quantified measure of its consequence

[SOURCE: EN-ISO 13943]

(1) NOTE: The quantification of risk will, as described in this document, also include a quantification of uncertainty.

3.25 Robustness
the ability of a design to cope with the stress of failing fire safety systems or changes in prerequisites due to events that may occur in the building

3.26 Required Safe Escape Time – RSET
time required for escape, calculated time period required for an individual occupant to travel from their location at the time of ignition (to a safe refuge or place of safety)

[SOURCE: EN-ISO 13943]

3.27 Safety margin
additive adjustment applied to calculated values to compensate for uncertainty in methods, calculations, input data and assumptions

(1) NOTE: Also used as the difference between calculated available safe egress time (ASET) and calculated required safe iegress time (RSET)

3.28 Sensitivity
sensitivity is the measure of how much a variable affects the final output or results of a model

(1) NOTE: variables that may be sensitive in an analysis include: fire growth rate, location of a fire when calculating fire and smoke spread, the wind direction when simulating smoke ventilation or occupants' travelling patterns when calculating egress times.

3.29 Sensitivity analysis

an analysis performed to determine the degree to which a predicted output will vary given a specified change in an input parameter, usually in relation to models

[SOURCE: NFPA 101]

3.30 Trial fire safety design

design chosen for the purpose of making a fire safety engineering analysis and evaluation

[SOURCE: ISO 23932 (DIS)]

3.31 Uncertainty

quantification of the systematic and random error in data, variables, parameters or mathematical relationships, or of a failure to include a relevant element.

(1) NOTE: Uncertainties may be related to the reliability and validity of a model, accuracy in estimating the effect of exposure, randomness in the attributes of a population or randomness in the possible events that may occur.

[SOURCE: ISO 23932 (DIS)]

3.32 Verification methods

different methods that prescribe one way to comply with the building requirements.

(1) NOTE: Verification methods may include: calculation methods, using recognized analytical methods and mathematical models; laboratory tests, using tests (sometimes to destruction) on prototype components and systems; tests-in-situ, which may involve examination of plans and verification by test, where compliance with specified numbers, dimensions or locations is required (non-destructive tests, such as pipe pressure tests, are also included)

[SOURCE: IRCC – Inter-Jurisdictional Regulatory Collaboration Committee].

4 Procedure

4.1 General

Verifying fire safety in buildings may be performed using a variety of different methods. While this Technical Specification focuses on a probabilistic approach, this chapter will address matters that may be used for the process of fire safety verification in general.

Initially, one shall decide what main verification method(s) shall be used, see Figure 1, according to the defined problem and scope. For most buildings, it will be possible to use pre-accepted solution(s). Fire safety engineering methods will not be needed in that case. If deviations are made from the pre-accepted solution(s), verification by fire safety engineering methods is normally needed as stated in national building regulations.

One way to do this, if pre-accepted solutions are valid, is using comparative analysis, which is described further in INSTA/TS 950. In the following sections, other approaches such as using performance criteria (or acceptance criteria) determined by absolute values are further elaborated. Where the pre-accepted solutions are valid for the building in question, these two documents can also, to some degree, be used in combination when a probabilistic, comparative approach is used.

The general fire safety engineering process adopted when using a probabilistic approach is described in Figure 2. The process is intended to be used as guidance from the problem definition, through the fire safety engineering process to the final step of verifying that the fire safety design is acceptable. Each step in the process will be described in detail in the ensuing chapters. While the process is described as a step-by-step procedure, the process may in reality be iterative.

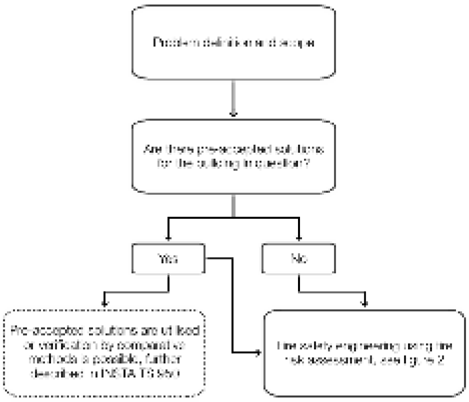


Figure 1 - Flowchart describing how the choice of verification method may be decided. Where pre-accepted solutions are applicable for the building, the user may choose freely between different approaches.

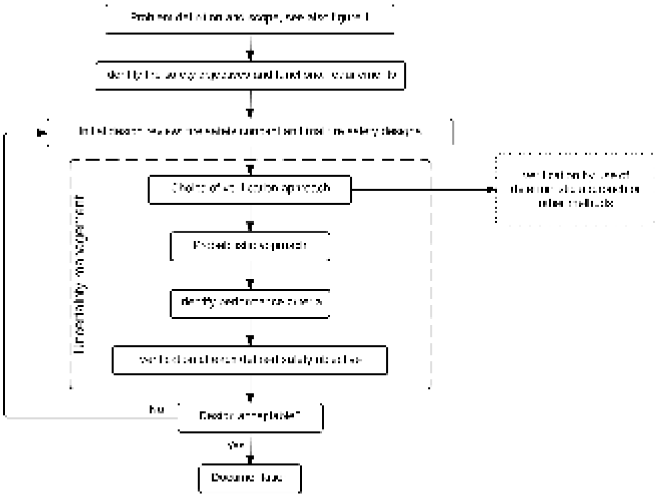


Figure 2 - The fire safety engineering process with a focus on a probabilistic approach.

The above procedure is meant as a general guidance and the bullets are explained further below. However, depending on the approach chosen, more detailed guidance on the procedure can be found in other documents and standards, e.g. ISO 23932.

4.2 Problem definition and scope

This is the initial step in the fire safety engineering process where the problem is defined and addressed. By briefly identifying any deviations from the pre-accepted solution(s) the scope of the process will be defined.

Typically, preliminary architectural drawings or design concepts may be analysed. Possible verification methods may then be considered, see Figure 2 above and Figure 1. It is also important to limit the scope of the fire safety analysis as part of the building design.

Changes made to the scope of the problem during the process, may necessitate a restart of the fire safety engineering process.

4.3 Identify fire safety objectives and functional requirements

This step is closely linked to the previous step and is based on the defined problem. The relevant fire safety objectives affected by deviations from pre-accepted solutions (if applicable) shall be determined, and relevant functional requirements identified. Often, building regulations will play a significant part here as they may set functional requirements and/or fire safety objectives that shall be met.

This chapter gives guidance on how to determine which fire safety objectives are affected by defined deviations from pre-accepted solution(s). In this sense, verifying fire safety ensures that certain objectives are fulfilled, thus giving a reasonable level of safety. Verification may be done on different levels, i.e., as individual objectives, a set of objectives or even for all fire safety objectives.

(1) NOTE: Specification of fire safety objectives and verification thereof may be set in the National Annex. It is recommended that method 1 is used if pre-accepted solution(s) are linked directly to fire safety objectives in the regulations. Otherwise, method 2 is recommended.

4.3.1 Method 1 – Objectives linked to pre-accepted solutions

This method is applicable if the pre-accepted solutions are clearly connected to specific fire safety objectives. This may be the case when a performance-based regulatory system specifically points out the fire safety objectives with pre-accepted solution(s) connected to each of these objectives. Deviations from pre-accepted solution(s) may then be clearly linked to these objectives, revealing which objectives need to be verified - see Table 1. Note that this is an example and that the objectives may vary depending on the scope of the project or structure of the building code in the country in question.

Table 1 - Example of a tool to identify added and removed fire safety measures for different fire safety objectives

Fire safety objective (this table may have to be divided into sub-objectives)	Deviations from pre-accepted solutions							
	Added measure				Removed measure			
Means of egress								
Stability and load-bearing capacity in case of fire								
Protection against the spread of fire and smoke within the building								
Protection against the spread of fire between buildings								
Services and safety for rescue operations								

Table 1 is not in itself enough to verify deviations. Verification must be performed in accordance with the relevant verification method.

4.3.2 Method 2 Deriving objectives

If national requirements do not specify the fire safety objectives that pre-accepted solution(s) are deemed to satisfy, the affected objectives must be derived. Deviations from one pre-accepted solution may affect other fire safety objectives. This verification shall be emphasized in cases where multiple deviations occur.

Table 2 gives an example of interaction between different aspects of fire safety. When applying deviations from pre-accepted solution(s), one must identify whether one or more fire safety objective(s) are affected. When deviating from pre-accepted solutions with respect to means of egress, verification against the means of egress objective is obvious, while verification against the stability and load-bearing objectives is less critical (assuming pre-accepted solution(s) for fire resistance). If the design allows for narrow stairs or greater distances to exits, the verification shall include an assessment of how the proposed design may affect the fire service operations. Each of the affected fire safety objectives needs to be addressed.

Table 2 - Interaction between deviations from pre-accepted solutions and affected fire safety objectives

Deviation from / Check against →	Stability and load-bearing structures	Fire spread between buildings	Fire compartments (cells)	Fire compartments (sections)	Linings/ finishes	Technical installations	Means of egress	Facilitating fire service operations	Comments
Stability and load-bearing structures	Primary	Tertiary		Tertiary			Secundary	Secundary	
Fire spread between buildings	Tertiary	Primary		Tertiary			Tertiary	Tertiary	
Fire compartments (cells)			Primary	Tertiary			Secundary	Secundary	
Fire compartments (sections)			Tertiary	Primary				Tertiary	Societal risks
Linings/ finishes			Tertiary		Primary		Secundary	Tertiary	
Technical installations			Tertiary	Tertiary		Primary	Tertiary	Tertiary	
Means of egress							Primary	Tertiary	
Facilitating fire service operations	Tertiary	Tertiary	Tertiary	Tertiary			Tertiary	Primary	

Primary focus of verification
Secundary focus of verification
Tertiary focus of verification

(1) NOTE: Examples of how these tools may be used can be found in (Nystedt, 2012) and (Nystedt and Östman, 2012).

4.4 Initial design review: fire safety concept and trial fire safety designs

The initial design review is a qualitative process to identify the need for verification (e.g. deviations from the pre-accepted solutions) and possible ways in which a fire hazard might arise connected to the fire safety objectives that are not fulfilled by pre-accepted solutions. To enable further studies to be carried out, one or more trial fire safety designs (fire protection strategies) shall be defined. Key information is also gathered to enable evaluation of the design solutions in the further analysis.

The trial fire safety design may then be evaluated against relevant functional requirements and be evaluated in a systematic way to ensure that no objectives or functional requirements identified in earlier steps are omitted.

4.5 Choice of verification approach

The evaluation of the trial fire safety designs can be made using either an absolute or comparative approach. Verification using the absolute approach is only possible if there are quantifiable performance criteria. In other cases a comparative approach may be the only alternative.

Guidance on verification approaches using probabilistic methods is given in chapter 6.

Guidance on verification approaches with comparative methods is given in INSTA/TS 950.

There may be situations in the building codes where neither one of the approaches seems applicable. The user must ensure applicability in each individual case.

4.6 Choice of performance criteria (acceptance criteria)

As mentioned above, one or several performance criterias need to be established. These will vary depending on the verification approach, but will in most cases be a quantification of a qualitative functional requirement.

Recommendations on performance criteria for different applications are given in chapter 5.

4.7 Verification of each defined safety objective

The verification must ensure that each affected fire safety objective is met. However, different verification approaches may be used for different fire safety objectives.

4.8 Uncertainty management

Uncertainties in methods, input data, criteria and other variables that are relevant to the fire safety design must be taken into account during the entire analysis process.

Strategies to manage uncertainties in the fire safety design may include using conservative input data or criteria. In addition, the robustness of the design, i.e., making the fire safety level less dependent on individual system malfunctions, may be used strategically.

Guidance on uncertainty and sensitivity management is given in chapter 7.

4.9 Documentation

The final analysis shall be documented to ensure transparency and to permit the performance of review and control procedures - this is described further in chapter 8.

5 Performance criteria (acceptance criteria)

5.1 General guidance

General statistical principles also apply to probabilistic methods in fire safety engineering. However, the uncertainty and the number of unknown parameters may result in "wide" distributions. Furthermore, relevant and reliable statistical data can be difficult to obtain.

The objective of this chapter is to provide guidance on performance criteria, so the use and acceptance of probabilistic methods in fire safety engineering can progress in a transparent and controlled manner.

Performance criteria can be either absolute or relative.

Absolute (also known as explicit) criteria consist of some form of pass/fail fire safety target, e.g., a certain number of fire fatalities per unit of time. Relative (also known as implicit) criteria describe a relative fire safety level relative to some reference, e.g., an equivalent reference building that complies with pre-accepted solutions.

Generally, the guidance of this chapter applies to analyses where there is reasonable certainty concerning the validation/verification of models/sub-models, statistical data and other input parameters. The user is responsible for considerations of uncertainty according to chapter 7.

5.1.1 Statistical data

Due to lack of stated performance criteria, statistical data of loss of lives and property damage have historically been used as performance criteria. These statistical data may be based on fires in buildings or sites not complying with relevant regulations, and most countries would have ambitions to reduce the loss for future buildings – hence the statistical data do not necessarily represent the accepted risk.

If the recorded losses are consistent over an extended period of time, and where one can see regulators or stakeholders not taking action to reduce the losses, one could argue, after a study of the material, that the risk is tolerable. Most nations have however increased their expectations with respect to the level of fire safety over the years. Statistical data should not be used as performance criteria unless there is a statement from the relevant regulators that these levels of risk are acceptable, or if the analyst can show a considerable improvement from the level of risk indicated by the relevant statistical data.

5.2 Relative criteria

5.2.1 Pre-accepted solutions

Comparative analysis is covered in INSTA/TS 950, which also provides some guidance on probabilistic methods.

The methodology is based on describing a reference building which fully complies with pre-accepted solutions, and thus creating a comparative criterion by quantifying the pre-accepted risk. The reference building should be as similar to the trial design as possible, whilst still being within pre-accepted solutions.

(1) NOTE: Not all buildings are covered by pre-accepted solutions. For the reference building to be a representation of acceptable level of risk, the analyst must justify that the pre-accepted solutions are applicable.

(2) NOTE: Pre-accepted solutions are intended to cover a wide range of buildings and occupancies, so the identified level of safety is deemed to vary, and may not meet the suggested risk criteria of this chapter.

5.3 Absolute criteria

5.3.1 Loss of lives

Absolute risk criteria are a controversial topic, as it involves the acceptance of the loss of human lives. The probability of loss of lives will not be zero, whether one defines a criterion or not. Furthermore, prescriptive requirements are deemed to set levels of safety less than 100 %. Hence the use of risk criteria should not be seen as more controversial than the use of pre-accepted solutions.

In this chapter, loss of lives is assumed to be the number of occupants exposed to fatal conditions. Tenability criteria as given in INSTA/TS 950 may be used as conservative approximation of fatal conditions, where other quantifications of fatal conditions are unavailable.

If reliable estimates for FED are available, one can assume a relation between FED and probability of incapacitation described as a log-normal distribution with a standard deviation of 1.0 and an mean of 0.0. E.g. 90 % of the population are assumed to be incapacited when exposed to FED of 3.6. Calculated FED exposure and probability of incapacitation can be addressed with the bivariate approach described in Annex D.

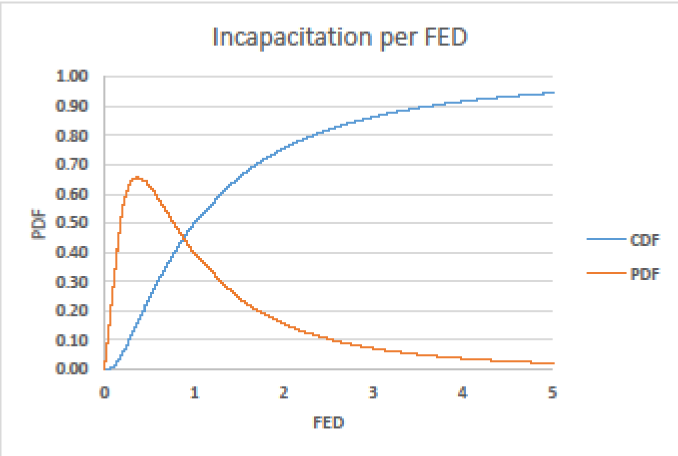


Figure 3 Probability of incapacitation as a function of FED

The intent of providing absolute criteria in this document is to increase the use of probabilistic methods. Restiction of use or development of alternative criteria is not intended. The criteria may be adjusted through national annexes.

5.3.1.1 Individual risk

Generally, an individual risk criterion of 10^{-6} per year is recommended, meaning an individual may be subject to fatal conditions due to fire every 1 000 000 years. The individual risk criterion represents approximately a tenth of the recorded loss of lives (all occupancies) in the Nordic countries.

The acceptable or tolerable risk can be influenced by several factors, e.g. to what degree the person is benefiting from the activity, if the activity is voluntary, if the risk is known, etc. Alternative criteria can also be assessed through ALARP analyses – refer to chapter 5.3.3.

5.3.1.2 Societal risk

One generally assumes a lower acceptance for a low number of incidents with high number of casualties, than a high number of incidents with lower consequences per incident. The suggested societal risk criteria contain two curves to address this (risk aversion);

N, Fatalities	F, Frequency
1-10	$F(N) = 10^{-6}\frac{1}{N}$
10-100	$F(N) = 10^{-5}\frac{1}{N^2}$

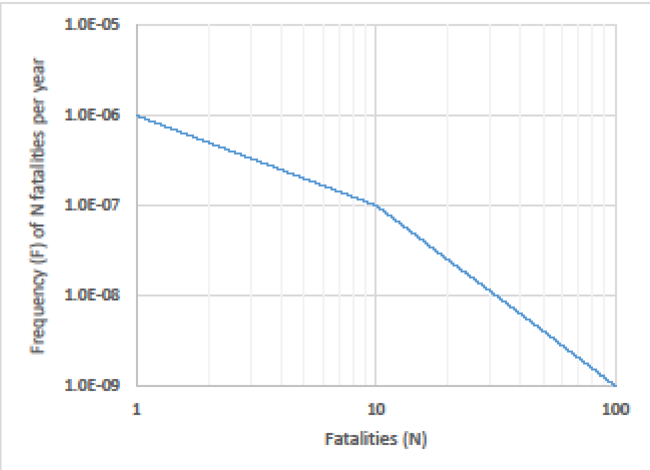


Figure 4 - Suggested FN-curve, as criteria for societal risk

Buildings with high numbers of occupants (e.g., stadia, concert halls) may have the potential for more than 100 casualties – meaning the probability of more than 100 casualties is greater than 0. The intention of Figure 4 is not to state that such venues are unacceptable, but that the societal risk criterion (including risk aversion) should be set by the analyst. Furthermore, one would expect an ALARP-approach, mitigating risks with very high consequences.

5.3.2 Absolute criteria for other objectives

Absolute criteria for objectives other than life safety have not been identified. Objectives like spread of fire and smoke within and between fire compartments, are however covered indirectly by the criteria for loss of lives.

When analysing other objectives, refer to section **Error! Reference source not found.** Relative criteria or section 5.5 for guidance on acceptable uncertainty, i.e., how to draw conclusions when applying a deterministic methodology approach with probability distributions as input parameters.

5.3.3 Factors supporting alternatives to the absolute criteria

5.3.3.1 ALARP analysis

This clause gives an overview of a methodology within risk assessment, where risk levels between negligible and intolerable risk are being mitigated to the point where further risk reduction is not possible or proportionate to the disadvantages.

The methodology was introduced in the UK Health and Safety Act of 1974, which required safety "So Far as is Reasonably Practicable", SFAIRP. This has since been adapted in several sectors (e.g., offshore) under the acronym ALARP – As Low As Reasonably Practicable.

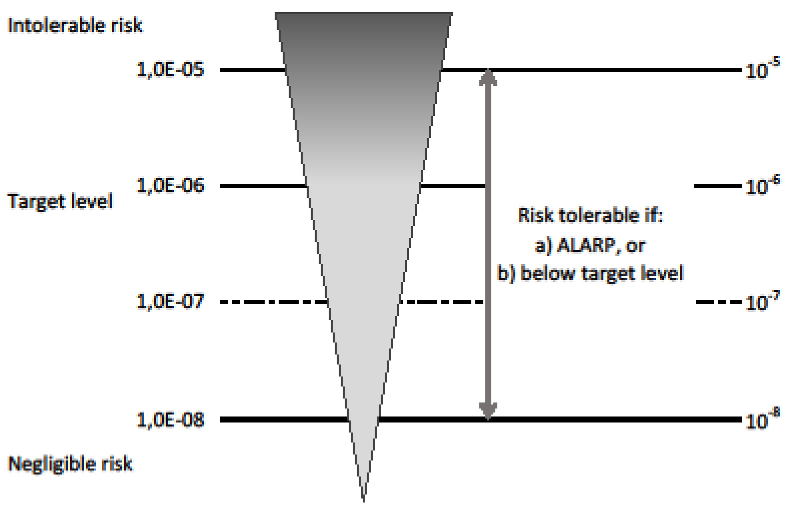


Figure 5 - Visualization of the ALARP principle for individual risk (Trbojevic, 2005). Risk is deemed tolerable if it is below target level of 10^{-6} or ALARP – still not more than 10^{-5}.

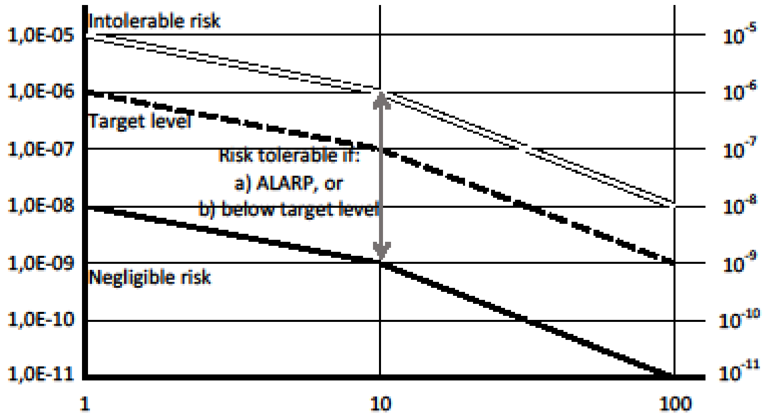


Figure 6 - Visualization of the ALARP principle for societal risk

Figure 5 and Figure 6 are examples of how the methodology can apply to life safety: Certain levels of risk are simply deemed intolerable, no matter the efforts made to mitigate. Other levels are deemed negligible, without stringent requirements to introduce risk mitigating measures. Between these extremes, there is a region called the ALARP-zone.

For risk levels in the ALARP-zone, one shall mitigate the risk to the point where further risk reduction is impossible or will lead to cost or other disadvantages becoming disproportionate to the risk reduction. This process shall be documented.

Further guidance can be found in ISO 16732-1.

5.3.3.2 Self-control, volition and benefit versus risk of loss of lives

Several sources point out that tolerable risk will vary depending on a set of conditions:

- To what degree is the individual at risk aware of the risk and in control of the risk?
- To what degree is the risk voluntary?
- To what degree is the individual at risk benefitting from the activity?

When justified and documented, the analyst can deviate from absolute criteria in subsection 5.3.1, based on the above mentioned factors. The justification may be based on statistical data, literature, expert judgement or criteria given for comparable industries.

Wolski (2000) describes the mechanisms of risk perception, and provides methods of quantifying it.

Table 3 Risk concersion factors

Risk factors	Scale	Risk conver-sion factors (RCF)	Comment
Volition	Voluntary - involuntary	**100**	
Severity	Ordinary - catastrophic	**30**	NFPA has suggested that a catastrophic fire is one that causes - 5 or more deaths in residential proper-ties or - 3 or more deaths in non-residential properties.
Effect mani-festation	Immediate - delayed	**30**	
Familiarity	Common (old) - dread (new)	**10**	
Controllability	Controllable – uncontrollable	**5-10**	
Benefit	Clear - un-clear	**Note**	Risk is roughly proportional to the third power of its benefit
Necessity	Necessary - luxury	**1**	
Exposure pat-tern	Continuous - occasional	**1**	
Origin	Natural - man-made	**20**	

For example risk factors for an assumed risk to life from fire in an office building can be described as: uncontrollable, catastrophic, immediate, man-made, voluntary and familiar. From the table, the mean-acceptable-risk-level for this type of risk is 10^{-6}. When assessing the acceptability of fire risk that is not easily identifiable for the occupants (unfamiliar), one should concidere a criterion 10 times more stringent, 10^{-7}. If the subject of the risk is in direct control of the risk, one could argue that a 5-10 times higher crierion could be used.

Table 4 The mean-acceptable-risk-of-death per person per year

			Controllable risk				Uncontrollable risk			
			Ordinary		Catastrophic		Ordinary		Catastrophic	
Hazzard source	Voluntary risk	Familiar risk	Immediate risk	Delayed risk	Immediate risk	Delayed risk	Immediate risk	Delayed risk	Immediate risk	Delayed risk
Man-made	No	Yes	1,3E-06	4,0E-05	5,0E-08	1,5E-06	3,0E-07	1,0E-05	1,0E-08	1,0E-07
Man-made	No	No	1,3E-07	4,0E-06	5,0E-09	1,5E-07	3,0E-08	1,0E-06	1,0E-09	3,0E-08
Man-made	Yes	Yes	1,3E-04	4,0E-03	5,0E-06	1,5E-04	3,0E-05	1,0E-03	1,0E-06	3,0E-05
Man-made	Yes	No	1,3E-05	4,0E-04	5,0E-07	1,5E-05	3,0E-06	1,0E-04	1,0E-07	3,0E-06
Natural	No	Yes	1,3E-05	1,0E-03	1,0E-03	N/A	6,0E-06	2,0E-04	2,0E-07	N/A

5.3.3.3 Criteria from comparable industries

After consideration from the analyst, criteria from other industries may be utilized. The analyst shall justify and document the use of alternative criteria. This justification may include risk conversion factors, as described in 5.3.3.2.

5.4 Property Protection and Business Continuity

The ambitions for protection of property and business continuity should be determined in close dialogue with the client. Depending on the property/business at hand (e.g., cultural heritage, critical infrastructure, and the environment) the involvement of authorities having jurisdiction may be required to define the acceptance criteria.

The expected loss of inventory, production time, etc., may form the basis for cost-benefit analyses or dialogue with the insurer. Comparative analysis may be applicable where national regulations require protection against loss of property.

For buildings and functions identified as European Critical Infrastructure, refer to EU Council Directive 2008/114/EC of 8 December 2008 (The European Parliament and Council, 2008).

Guidance on continuity management can be found in ISO 22301.

An ALARP-approach may be beneficial for buildings or sites containing cultural heritage artefacts, as some fire safety measures may themselves reduce the conservation value.

5.5 Probability of failure

5.5.1 General

The required confidence level (or acceptable uncertainty) is strongly linked to how the input parameters are defined, the consequences of failure, etc (described further in chapter 7). Assuming well-defined input parameters, and verified and validated verification models, one can generally draw conclusions based on 95 % confidence intervals/levels. The principles of chapter 5.5 should not be seen as criteria for risk acceptance, but guidance on drawing conclusions under uncertainty.

For events with high consequences, focus on probability alone will not be sufficient. Although "high consequences" cannot be defined and quantified on a general basis, the analyst shall assess the consequences of failure. Estimates should be made to compare the results with relevant criteria in relevant sections 5.1 through 5.4.

The probability of failure, P(ASET<RSET) is deemed acceptable when demonstrating compliance with absolute criteria for individual and societal risk, clauses 5.3.1.1 and 5.3.1.2. FN curves can be produced with the basis of the number of casualties in the scenarios yielding a negative safety margin, and their respective probability.

5.5.2 Safety index (beta)

The safety index (beta) method is described in clause 6.4.2.1. The following criteria may be used when assessing the probability of failure, given a fire.

Table 5 - Criteria for probability of failure and β value

	Probability of failure	β (normal distribution)
General	0,05	1,6449
High consequence scenarios	Risk assessment, including uncertainty management	

(1) NOTE: The analyst is to include uncertainty management in the calculation of probability of failure

(2) NOTE: High consequence scenarios should be assessed with an ALARP-approach

(3) NOTE: The above is not meant as criteria for risk acceptability. When the fire risk (including the fire frequency) is analyzed, criteria given in section 5.3 should be used.

Guidance on estimating distributions is given in 6.3. Guidance on defining design fires is given in section 6.2.

5.5.3 Proving compliance with deterministic statements

When conducting a probabilistic analysis, one may have to relate to requirements or expectations stated in deterministic manner. When applying probabilistic principles to a comparative analysis, one will have to determine on what confidence level the trial fire safety design is considered to surpases the pre-accepted level of safety. The applicable building code may also contain requirements that are stated with a deterministic wording, for example:

- Main load bearing systems shall be designed to maintain adequate load bearing capacity and stability for the complete duration of a fire, as this can be modelled.
- Structures shall be a minimum distance of 8.0 m from other structures, unless the structure is constructed to ensure fire will be prevented from spreading for the full duration of a fire.
- During the time a fire cell or escape route shall be used by people escaping, no temperatures, concentrations of smoke gases or other circumstances shall occur that hinder escape.

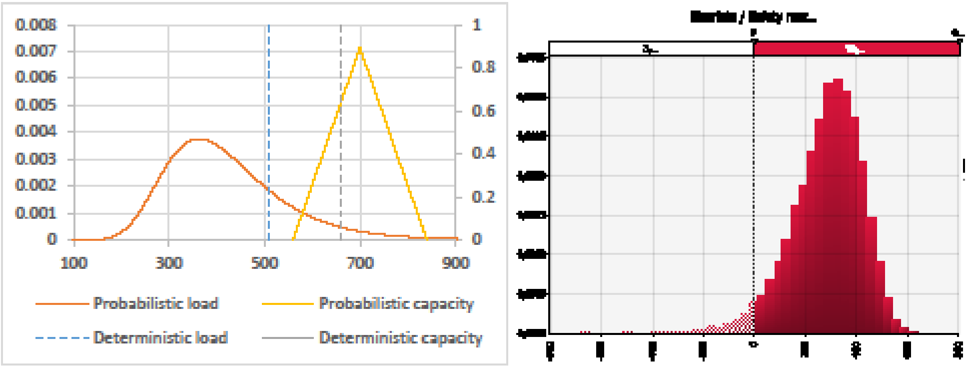


Figure 7 - Visualization of deterministic and probabilistic approach to load v.s. capacity (left), and the safety margin for a bivariate probabilistic approach (right)

Figure 7 is a comparison between a probabilistic and a deterministic approach – indicating the degree to which the current deterministic practice is concervative.

Note that fire frequency is not taken into account. The probability of failure is linked to deterministically formulated requirements, and not the absolute criteria of section 5.3.

There may be several sources of uncertainty, and these will have to be addressed through, safety margin, safety factors, concervative assumtions, a combination of these or as introducing random parameters in the calculation.

When uncertainty management is an integral part of the analysis, a confidence level of 95 % is generally assumed sufficient.

6 Probabilistic Tools and Methods

This chapter provides details on a probabilistic approach to verifying fire safety design in buildings (refer to fire safety engineering process Figure 2). The term 'probabilistic approach' is intended to include all methodologies that involve some form of probabilistic quantification of the uncertainty involved in fire safety engineering.

In fire safety engineering, risk is treated as being a function of both probability and consequence.

As a component of the risk assessment process, risk analysis quantifies both the probability of an event occurring, and the consequence of the event. This gives rise to the term *probabilistic risk analysis* (PRA) which is also known as *quantitative risk analysis*.

The term *frequency* is often used in relation to *probability*, but the two concepts are not identical. While *probability* is the likelihood of an event occurring, *frequency* is the *probability* of the event <u>over a period of time</u>.

One feature to note with generic PRA is that an event of high frequency and low consequence is treated as being of similar importance to an event of low frequency but high consequence.

Design fire scenarios are at the core of fire safety engineering. Design fire scenarios are analysed and the adequacy of the fire safety systems in a building evaluated to determine if the specified performance criteria have been met and hence if the fire safety performance objectives achieved.

A design fire scenario is characterised by various factors, including:

- The type of fire, its initiation, and development
- Species production
- Ventilation conditions
- Performance (including reliability) of fire safety systems
- Fuel type, distribution and fire load density

In this chapter, four steps are described in the PRA process for fire safety engineering

Step 1	Selection of Design Fire Scenarios (section 6.1)
Step 2	Defining Design Fires (section 6.2)
Step 3	Estimate Distributions (section 6.3 and Annex E)
Step 4	Verification (section 6.4)

6.1 Selection of Design Fire Scenarios

The number of possible fire scenarios in a building is nearly infinite. To achieve a successful PRA a systematic and comprehensive approach should be taken in the identification of design fire scenarios. The design fire scenarios shall be representative for the possible fire outcomes in the building. To achieve a manageable number of scenarios the fires in a building can be treated as fire scenario clusters. A fire scenario cluster is a group of fire scenarios having similar characteristics. For each fire scenario cluster one fire scenario is identified to represent all the fires within the cluster.

When using the probabilistic approach both the probability and the consequence of all the fire clusters identified in the building are to be quantified. When estimating probabilities, it is important to ensure that the sum of all the related probabilities equals one. Rather than using the worst credible case, a probabilistic approach is to describe the uncertainty connected to the different input variables in the design fire scenarios. In this way a more risk-informed design procedure can be achieved.

In both cases above, the methodology described in ISO/TS 16733 and ISO/TS 16732 may be used. This methodology for defining design fire scenarios is outlined in Figure 8.

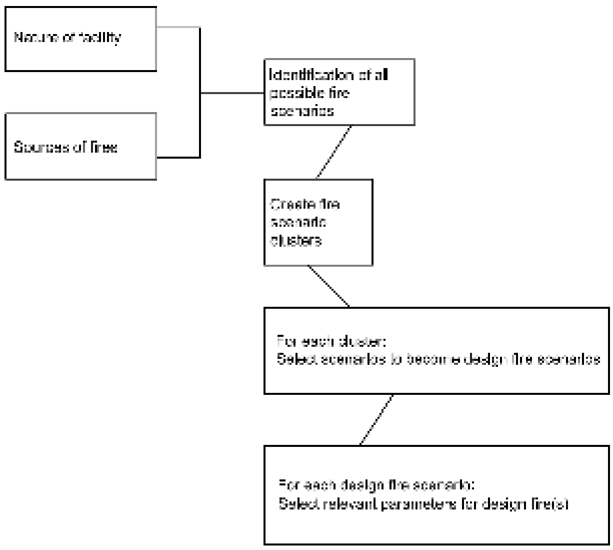


Figure 8 - Description of the methodology for selecting design fires (Fig. 1, p. 4 in ISO/TS 16733)

Each design fire scenario shall be linked to one or several of the fire safety objects studied. The fire scenarios are to be representative for the possible fires in the building and the probabilities for different scenarios to occur is to be based on relevant statistical data. It is important that the chosen design fire scenarios also represent the scenarios not chosen to study. Justification for the selection and definition of the design fire scenarios, as well as those not selected for further investigation, shall be formally documented, along with relevant references where appropriate. Note that both high consequence and high probability events can produce a significant risk contribution. Also note that even if a fire scenario cluster is concluded to have nearly insignificant risk contribution in itself, this might not be the case when studying combination of scenarios.

The number of design fire scenarios will be a function of both the building complexity and the amount of deviation from the relevant prescribed solution(s).

Note that each design fire scenario will be linked to one or several evacuation scenarios. The probability for different factors regarding the evacuation scenarios, e.g., behaviour, availability of escape routes, people types, etc., can be linked to the probabilities given by the design fire scenarios. Hence, the possible evacuation scenarios depend on the design fire scenarios. Further guidance on evacuation scenarios is given in ISO 16738 and ISO/TS 16733.

6.2 Defining Design Fires

For each design fire scenario, one or more design fires shall be defined, so as to be able to evaluate the effects of the design fire scenario. Preferably each design fire scenario is described by a range of design fires, for which the important parameters are represented by distributions describing the possible range of values each of the parameters can assume. More information on how to estimate distributions can be found in section 6.3.

The specific details of each design fire will vary depending on the nature of the design fire scenario and the linked fire safety objective. For example, for a life safety objective, the design fire will generally include a HRR curve that covers all potential stages of the fire development and in particular the pre-flashover stage, whereas for a structural stability objective, the design fire will generally include post-flashover time-temperature information.

The probability for a specific location for a design fire can be hard to predict. Hence, the location of the design fire(s) shall be selected to give a reprecentative picture of the fire risk. Multiple locations for the design fire within the design fire scenario shall be investigated. Where locations are excluded from the analysis, the reasoning shall be formally documented. Concervative simplifications may be needed in order to limit complexity and computation time i.e. clusters and descrete distributions can be treated concervatively by assuming the entire cluster/ group shares the most onerous properties.

ISO/TS 16733 and ISO/TR 13387-2 may be used to identify relevant design fires. If national statistics do not have relevant information on potential sources of ignition, the data in PD 7974-1 can be applied. The most relevant sources are always to be used. Difference in building tradition, culture and many other things can affect the probability of different ignition sources and fires, hence national statistic shall be prioritized when possible.

6.2.1 Specific fire parameters

When assuming specific fire parameters relevant distributions are to be selected. These should be based on statistical data and fire tests, or well-based engineering judgement. All relevant parameters and their distributions should be described and, where possible, referenced.

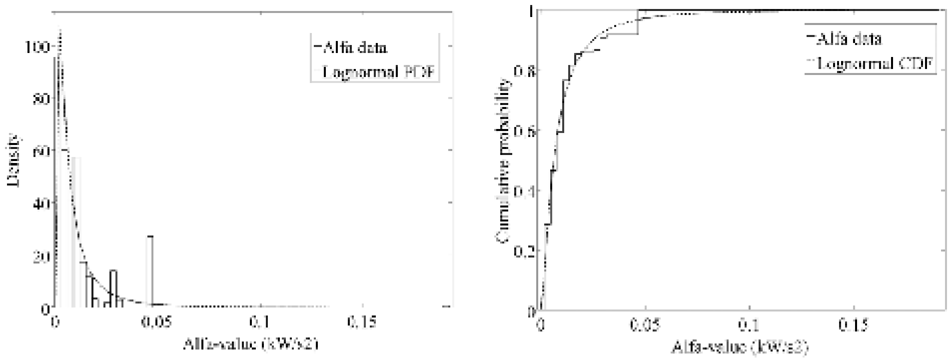
6.2.1.1 Fire growth rate

To calculate the fire growth rate in a building an approach like the one given by Nilsson et al. (Nilsson, Johansson & Van Hees 2014), may be used. This approach is based on statistical data and fire tests. If large data sets are available approximation using distributions of these data sets are to be preferred. An example for Swedish commercial buildings is shown in Table 6. Here the distribution of fire growth rate follows a lognormal distribution. If not accounting for arson fires the fast fire growth rate (0,047 kW/s^2) represents the 97th percentile of growth rates. When arson fires are accounted for the fast fire growth rate represents the 91th percentile.

Table 6 - Parameters for lognormal distributions and percentile values of fire growth rate, commercial buildings

	μ_α (Std.Err.)	σ_α (Std.Err.)	E(α) (kW/ s²)	α_{95} (kW/ s²)	$\alpha_{99.5}$ (kW/ s²)	Percentile for α = 0.047 kW/ s²
Accidental fires (arson excl.)	-5,091 (0,023130)	1,100 (0,0163611)	0,011	0,038	0,105	97 %
All fires (arson incl.)	-4,727 (0,024032)	1,246 (0,0169978)	0,019	0,069	0,219	91 %

The probability density function for the data above is shown below. Here the different alpha values creating the distribution are also presented.



(a) (b)

Figure 9 - Fire growth rate for accidental fires (arson excluded) in commercial buildings. (a) Histogram and PDF for estimated lognormal distribution; (b) CDF for the estimated lognormal distribution. (Fig. 2, p. 522, Nilsson, Johansson & Van Hees, 2014)

6.2.1.2 Peak heat release rate

For fire scenarios in a single room or in a room with no opening to adjacent rooms, the peak heat release rate, Q_{peak}, is determined by calculating heat release rates for ventilation-controlled and fuel-controlled fires and choosing the lower value of those two.

To establish peak HRR for a ventilation controlled fire the following equation can be used:

$$Q_{peak} = 1500\, A_0\sqrt{H_0}$$

Where $A_0\sqrt{H_0}$ is the ventilation factor, which is calculated using the compartments opening areas and their specific heights. For further guidance on ventilation controlled fire calculations see Karlsson and Quintiere (2000).

For fire scenarios where significant burning in adjacent room can be expected, the peak heat release rate should be based on the fuel-controlled heat release rate. To establish the peak HRR in these cases statistical data can be used in similar ways as for the fire growth rates above. For example the peak HRR can be simplified using the probable fire damage area in a fire and an estimated HRR per unit area (HRRPUA). The same technique can be used to model fires that do not grow to flashover. This is expressed below.

$$Q_{peak} = HRRPUA \times A_{fp}$$

Statistical data on these parameters can be found in PD 7974-7 and in EN 1991-1-2 annex E. Using this approach with the statistical data from PD 7974-7 and the HRRPUA values given in EN 1991-1-2 annex E one could establish the following probabilities for the peak HRR in an office with sprinkler protection:

Table 7 – Example of probabilities for different peak HRR in a sprinkler protected office, using data from PD 7974-7 and EN 1991-1-2 annex E.

Peak HRR	Probability	Cumulative probability
250 kW and lower	72 %	72 %
500 - 1 000 kW	17 %	89 %
1 250 - 2 250 kW	-	89 %
2 500 - 4 750 kW	11 %	100 %

This approach gives an overestimation in peak HRR since all of the fire area is assumed to burn at once. However, this gives a simple and usable estimation of peak HRR. Other methods can be used, preferably together with relevant statistical data.

6.2.1.3 Other fire parameters

Other fire parameters like yields, smoke production rates, mass burning rates, species production rates and similar shall, as far as possible, be similarly represented as the parameters above. This means that distributions should be formed from relevant statistical data based on fire testing. For examples on data for these kinds of parameters the SFPE Handbook (2015) can be used.

For parameters that cannot be represented with a statistical distribution because of restrictions in computational models or lack of data a conservative value is to be chosen.

6.2.1.4 Post-flashover fires

When the objective of the fire safety design is to ensure structural stability, compartmentation and safety for fire fighters, the post-flashover fire is to be examined. The design load is in this case characterized by a temperature-time curve assumed for the fully developed fire stage.

Different probabilities of flashover are given in PD 7974-7 where guidance on calculation of compartmentation is also given.

6.2.2 Reliability of technical systems

The reliability of technical systems that can affect the design fire scenario or the linked evacuation scenarios shall be described, preferably using relevant distributions. The reliability should be based on statistical data and fire tests, or on well-based engineering judgement.

To estimate relevant probabilities for different outcomes connected to the intervention/activation of technical systems event trees are a useful tool. More guidance on event trees are given in sub-clause 6.4.1.2.1

Data on reliability for different technical systems can be found in Annex C.

6.3 Estimating Distributions

Where required and possible, the PRA should make use of probability distributions to represent the relevant input variables to the analysis. When probability distributions are not readily available in the literature, distributions will need to be estimated. There are generally two sources of information for estimating distributions; available data and expert opinion. This section deals with some techniques to interpret data in order to derive a distribution that realistically represents the variability and uncertainty involved.

Interpreting data requires some assumptions to be made. The main assumption is that the data being interpreted is considered to be a random sample from some probability distribution that is being derived.

The data can come from a variety of sources, such as experiments and testing, surveys, research findings, literature searches, computer modelling, etc. The user needs to be satisfied that the data is both reliable and representative, and that anomalies in the data have been checked, and where required, unreliable data discarded. Consideration should also be given to possible biases in the data, such as biases introduced by the collection method, or the independence of the organisation providing the data.

Two general approaches to estimate distributions are described in this section; non-parametric (empirical) distributions, and parametric (theoretical or mathematical) distributions.

Guidance on use of statistical data is given in Annex B.

6.3.1 Data and Distribution Properties

Before estimating a distribution for a set of data, the properties of the parameter (variable) need to be considered so that the properties of the distribution, that is chosen to fit the data, match the properties of the parameter.

The following is a non-exhaustive list of considerations:

1. Is the parameter discrete or continuous? A discrete variable only has certain specific values and is usually, but not always, fitted to a discrete distribution. A continuous variable is always fitted to a continuous distribution. **Error! Reference source not found.** shows examples of discrete and continuous distributions;

2. Is it necessary to fit a parametric distribution? It is often sufficient to use the data points directly to define a non-parametric distribution without fitting a parametric distribution;

3. Does the theoretical range of the variable match that of the fitted distribution? If the range of the fitted distribution extends beyond that of the variable, unrealistic or impossible scenarios can be produced. Conversely, if the range of the fitted distribu-

tion does not extend over the possible range of the variable, then the true uncertainty will not be represented in the calculations. A distribution that has been fitted correctly will generally cover a range that is greater than the range indicated by the data, since by definition, data is rarely observed at the theoretical extremes of the variable's distribution;

4. Is the variable independent of other variables being considered? A variable may be correlated with, or a function of, another variable in the calculations, and hence needs to be treated accordingly;

5. Does a parametric distribution exist that fits the mathematics of the variable? If so, it is simply a case of determining the appropriate parameters to define the distribution;

6. Does a parametric distribution exist that is known to fit this type of variable? As with item 5, it is simply a case of finding the appropriate parameters to define the distribution.

6.4 Analysis methods

In probabilistic fire safety design verification, either standard or complex analysis methods can be used. It should be noted that methods that do not involve some form of probabilistic quantification of uncertainty are not deemed to qualify for inclusion in this section.

6.4.1 Standard Analysis Methods

Standard (also known as *simple* or *non-complex*) analysis methods are the most commonly used in PRA.

6.4.1.1 Simple statistical analysis

The analysis of statistics is the basis for most PRA. Data from actual building fires are collected and converted into information that can be used to predict the likelihood of future events. Data are often averaged, so the underlying assumptions are that historical data can be used to predict future events and that average data can be applied to a specific building. It is generally considered that this approach is less uncertain than taking no account of system failure in an analysis (the general approach to deterministic fire safety engineering calculations).

One major limitation of simple statistical analysis is that there are often insufficient data available to be able to predict high consequence/low frequency events with confidence. This class of probabilistic analysis method is best suited to high frequency/low consequence events where sufficient data are available. Further guidance on the use of statistics is given in Annex B.

Such information can then be used to predict the frequency of future events by using other probabilistic analysis methods.

6.4.1.2 Logic tree methods

In most cases it is sufficient to carry out a PRA based on the use of one or more logic trees. This is a simple method for estimating the probability of occurrence of an undesirable event, such as flashover, fire spread beyond the room of fire origin, or smoke causing untenable escape routes.

Two types of logic trees are explained in the following sub-sections.

6.4.1.2.1 Event tree method

Event trees are most useful when there is little data available about the frequency of the outcome of concern, e.g., high consequence/low frequency events such as multiple fatality fires incidents. As such, event trees can be used to predict the frequency of infrequent events by connecting a series of much more frequent sub-events, where data are available.

Event trees work forward from an initiating event (often ignition) to generate branches which define a range of outcomes resulting from secondary sub-events. Figure 10 shows a generic event tree which has a range of outcomes based on an initiating event followed by three nodal sub-events.

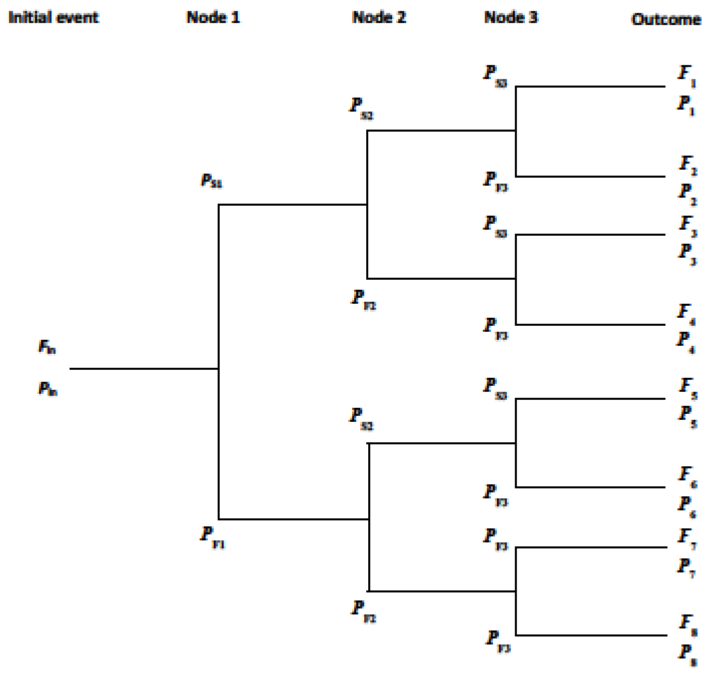


Figure 10 - Generic event tree, where eight different outcomes are identified from one initial event, through three sub-events.

Each possible outcome in the event tree consists of a chain of events which start with the initiating event.

It is very important that the event tree reflects the actual order of events, and that all the sub-events of importance are included.

The frequency (or probability) for each branch/outcome is calculated by multiplying the frequency (or probability) of the initiating event by the conditional success/failure probabilities of the subsequent sub-events.

For example, referring to Figure 10, the frequency of outcome 3 is calculated as $F_3 = F_{In} \cdot P_{S1} \cdot P_{F2} \cdot P_{S3}$, while the probability of outcome 2 is calculated as $P_2 = P_{In} \cdot P_{S1} \cdot P_{S2} \cdot P_{F3}$.

It is also important to ensure that the probabilities at each branch in the event tree sum to one.

Refer to Annex D for an example of the event tree method.

6.4.1.2.2 Fault tree method

A fault tree is a graphical representation of various parallel and sequential combinations of faults that will result in a pre-defined failure occurring.

The basic components of a fault tree are *events* and *gates*. In the fault tree diagram, a lower input event (sub-event) is connected to higher output event by a gate.

The most commonly used gates are **AND** and **OR** gates.

Consider two input events that lead to an output event. If the occurrence of either input event causes the output event then the input events are connected to the output event by an **OR** gate (parallel). If both input events must occur in order for the output event to occur, the input events are connected to the output event with an **AND** gate (sequential).

A fault tree depicts the logical interrelationships of basic events that lead to the undesired event (failure). A fault tree is constructed logically by working backwards from a top event to specify the event's causes, faults or conditions that would lead to the occurrence of the event. These causes, faults or conditions in turn become a secondary event, for which the same process is progressively applied, until ultimately a final set of base (or root) causes, faults or conditions, is established.

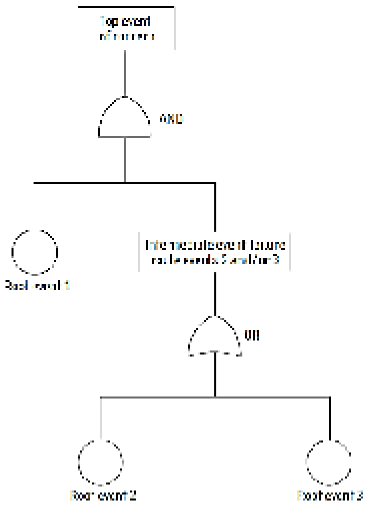


Figure 11 - Generic fault tree with three root events leading to one top event (Fig. 8, p. 25 in PD 7974-7)

The process is qualitative up until this point, but is quantified by the assignment of probabilities to the root events which are then propagated through the fault tree to derive a conditional probability for the top event.

For the case of two sub-events A and B, the probability for an **AND** gate is calculated by multiplying the root probabilities, i.e., $P_{AND} = P_A P_B$.

The probability for an **OR** gate is calculated by adding the root probabilities together and then subtracting their multiplied value, i.e., $P_{OR} = (P_A + P_B) - P_A \cdot P_B$.

The probabilities for top events can often be used as the conditional probabilities for event trees.

Refer to Annex D for an example of the fault tree method.

6.4.1.2.3 Bow-tie

Event tree and fault tree diagrams can be combined in one bow-tie diagram. Although bow-tie analysis will have its limitations when it comes to quantifying risks, it may serve as a useful tool for giving an overview or communicating risks.

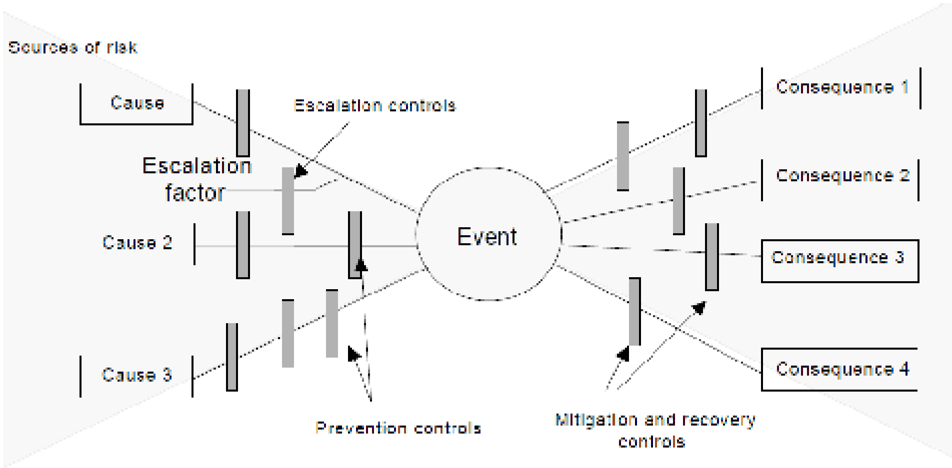


Figure 12 Bow-tie diagram (ISO/IEC 31010)

6.4.2 Complex Analysis Methods

In some cases the simple analysis methods presented above are not suitable because of the simplifying assumptions associated with them. For the cases requiring a more complex approach the methods in this sub-section can be applied.

The use of a complex analysis method does not exclude that parts of the analysis are performed using one or more of the simple methods presented above.

Several complex analysis methods are available and the designer is not bound to use the ones listed in this sub-section.

6.4.2.1 Safety index (β) method

The safety index method, or the beta method, is based on the principle that the unwanted event can be expressed as a safety index, β. The safety index, β, is basically an expression of the probability of failure. Fundamentally, the probability of failure is expressed as a limit function where failure does not occur if $g > 0$ and failure occurs if $g \leq 0$, i.e. $P_f = \text{Prob}(g \leq 0)$. If g is the function of successful evacuation in the fire case, then g would be expressed as:

$$g = ASET - RSET$$

where, g, ASET and RSET are stochastic variables. If g is normally distributed, the safety index can be expressed as:

$$\beta = \frac{\mu_g}{\sigma_g}$$

where,

μ_g is the average value of g, and

σ_g is the standard deviation of g.

In this case, the relationship between the probability of failure, P_f, and the safety index, β, is shown in the table below.

Table 8 - Relationship between P_f and β, from EN 1990, annex C.

P_f	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}
β	1,28	2,32	3,09	3,72	4,27	4,75	5,20

If g is not normally distributed, the safety index cannot be derived by these simplified equations.

In structural analysis, benchmark values for β can be found in EN 1990, annex C. The use of these values might be subject to national regulations. For loss of life in the fire case, the absolute acceptance criteria given in section 5.3 could be translated to a β value of 4,75, in accordance with Table 8 above, if the probability function is normally distributed. However, this is in relation to the risk of one individual being subjected to lethal conditions, i.e., the magnitude of failure needs to be observed as well. If more individuals are subjected to lethal conditions, the probability of failure needs to be adjusted in accordance with the societal risk levels provided in 5.3.1.2.

If an absolute acceptance criterion is not known, a possible approach is to derive the safety index, β, by using the First Order Second Moment (FOSM). In this approach the limit state equation is approximated by a first order Taylor expansion and the method uses the first and second moments, i.e. the mean and the standard deviation. One of the benefits of using this approach is that it provides a design point, at which the probability of failure (P_f) for a certain system is the highest. Further guidance is given in Frantzich (1998).

When using the safety index method, different approaches of the analysis can be applied. The different approaches are defined by the statistical data available for the analysis. The univariate and the bivariate approach are commonly used. The difference between these approaches is how the variables are treated, as discussed below. Further guidance is given in EN 1990, PD 7974-7 and in Ramachandran and Charters (2011).

Univariate approach

In the univariate approach, only one of the variables is treated as being random, while the other is treated as a constant value. An example of this could be if the failure of a fire proof construction was to be studied and the failure limit of the construction could be regarded as a constant value. An illustration of the univariate approach is shown below.

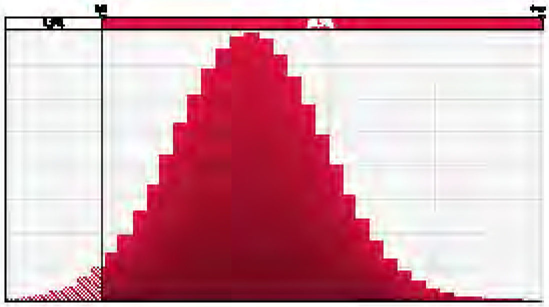


Figure 13 - An illustration of the univariate approach, where 0 is a constant limit and the function of the random variable is normally distributed.

Assuming that the variable is random and normally distributed, the equation above could be used to calculate the safety index with an adjusted mean in accordance with the constant value.

Bivariate approach

In the bivariate approach both the variables are treated as random values. This would be the case for an ASET/RSET analysis where both the ASET and RSET would be expressed as probability distributions. This is illustrated below.

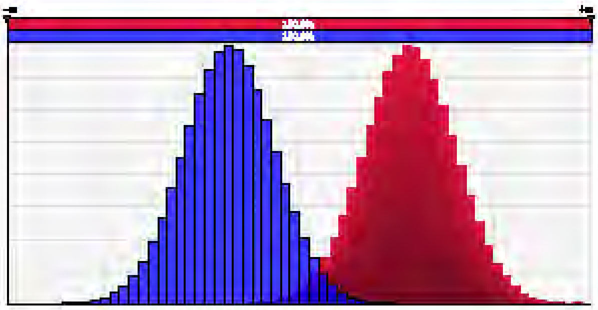


Figure 14 - An illustration of the bivariate approach, where both of the variables are normally distributed

If both variables are independent, random and normally distributed, the difference will be normally distributed with mean $\mu_{x-y} = \mu_x - \mu_y$ and variance ${\sigma_{x-y}}^2 = {\sigma_x}^2 + {\sigma_y}^2$. This can be used to derive the safety index, β, using the equation above.

6.4.2.2 Bayesian networks method

The Bayesian network model is a tool to manage uncertainty using probability. A Bayesian network is a graphical model that combines graph theory and Bayesian probability theory. Bayesian probability theory deals with the problem of reasoning under uncertainty.

If A is an event, $P(a)$ represents the probability that A is true, and $P(\tilde{a})$ denotes the probability that event A is not true. Some basic axioms can be expressed as follows:

$$0 \leq P(A) \leq 1$$

$$P(a) + P(\tilde{a}) = 1$$

If event A and event B are mutually exclusive, the probability of the union of events A and B is

$$P(A \cup B) = P(A) + P(B)$$

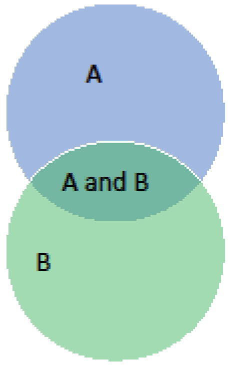
If events A and B are not exclusive

$$P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

Where $P(A \cap B)$ is called the joint probability of events A and B. The joint probability $P(A \cap B)$ can be derived by

$$P(A \cap B) = P(B|A) \cdot P(A)$$

Where $P(B|A)$ is called the conditional probability, which is the probability that event B occurs given that event A has already occurred.



$P(A \cap B)$ can also be written as

$$P(A \cap B) = P(A|B) \cdot P(B) = P(B|A) \cdot P(A)$$

Rearranging the above equations leads to Bayes theorem

$$P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)}$$

The Bayesian network (BN) is based on a fundamental assumption – the probability distributions in BN are subjected to the Markov condition. A Bayesian network consists of two components:

1. A graphical structure, called a directed acyclic graph G (DAG), G=(V,E) where V are the set of nodes representing random variables on which the Bayesian network is defined, and E are the set of directed edges representing relations among the variables. In a DAG, the family notation is often used to express the relationships between variables. For example, the parents of A are the set of variables from which there is an arrow going to Node A. The ancestors of A are the set of variables who are the parents of A, its parent´s parents and so on. The descendants of A are the set of variables who are the children of A, it´s child´s children and so on. The nodes without parents are called root nodes. The nodes without children are called leaf nodes. In Figure 15, Nodes A and B are root nodes and Node E is a leaf node. The nodes C, D are the children of Node A, and Nodes A and B are called the parents of Node D. Node A, B, C, D are the ancestors of Node E, and Node E is called the descendant of Nodes A, B, C, D. Node C is a non-descendant of Node B.

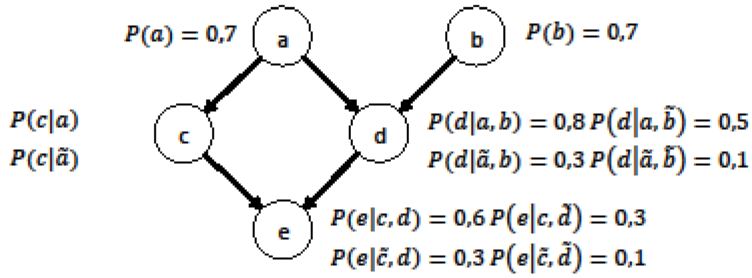


Figure 15 – Bayesian network direct acrylic graph and associated conditional probability tables.

2. A set of probabilities P, each of which is associated with a node of the DAG. Each root node possesses a prior probability distribution table. Each of the other nodes possesses a conditional probability table (CPT)

7 Uncertainty and sensitivity management

7.1 General

It is necessary to manage uncertainties in the fire safety design process in order to make sure that the required fire safety levels are met. A probabilistic analysis can be said to be a way of treating uncertainties. Hence the management of uncertainty should be an integral component of a probabilistic analysis.

The analyst must consider uncertainty in models and data.

7.2 Sensitivity analysis

Sensitivity analysis (SA) is an important aspect of any fire safety engineering design process, including PRA. This chapter provides guidance on how to perform a sensitivity analysis for the parameters not treated as random in the probabilistic approach. These limitations may be necessary due to restrictions in computational capacity.

Essentially, SA is a process whereby the impact of variation in input parameters on the results of an analysis is quantified.

SA can also be a useful way of doing an initial screening of options and to determine where more focus is required in the design process.

The need for doing SA will often be determined by confidence in the adequacy of the design. If, for example, the results of the PRA are well within the acceptance criteria, then the need for a SA is low. If, however, the results of the PRA are close to the acceptance criteria, then a SA is essential.

The first step in a SA is to identify the parameters that will have the biggest impact on the results of the analysis. The impact on the results of the analysis will generally stem from:

1. The mathematical formulation;
2. Significant uncertainty in the value of the input parameter.

With regard to the mathematical formulation, the impact of variability in a parameter to the fourth power is much greater than the impact of a parameter to the ¼ power. If an equation only has one parameter, then the impact of any variability in that parameter is more direct on the result. Similarly, where a parameter is used multiple times in an analysis, the impact of variability on the result may be higher.

There are generally three ways to conduct SA:

1. A single parameter analysis where one alternative value for the parameter is trialled;
2. A single parameter analysis where a range of values is trialled;
3. Multiple parameters analysis.

Whatever method of analysis is chosen, the purpose of doing SA is to identify what parameters the results are sensitive to. Whenever possible, uncertain parameters should be included in the probabilistic approach as random parameters reflecting the uncertainty.

7.3 Uncertainty analysis

The sensitivity analysis may be supplemented by an uncertainty analysis to specifically quantify the uncertainties in variables, criteria and outcomes. It may also be possible to quantify uncertainties that are related to lack of knowledge, e.g., missing phenomena, misapplication of data or validity, and reliability of methods.

7.3.1 Data uncertainty

With accurate data on the distribution of variables it may be possible to perform more precise estimates. When data is scarce or not directly applicable, it is recommended that the uncertainty is reflected in how the parameters are specified (see section 6.3 Estimating Distributions and Annex E). In this way the uncertainty is documented and justified systematically, increasing the credibility of the results.

When one or more aspects of the analysis are described as random values, the analyst must consider the sample size or number of iterations needed for valid results.

The adequacy of the sample size for any calculation depends on several factors; sensitivity of the parameter, the number of random variables involved, the variance of the random variables and the mathematical equations in which the random variables are used.

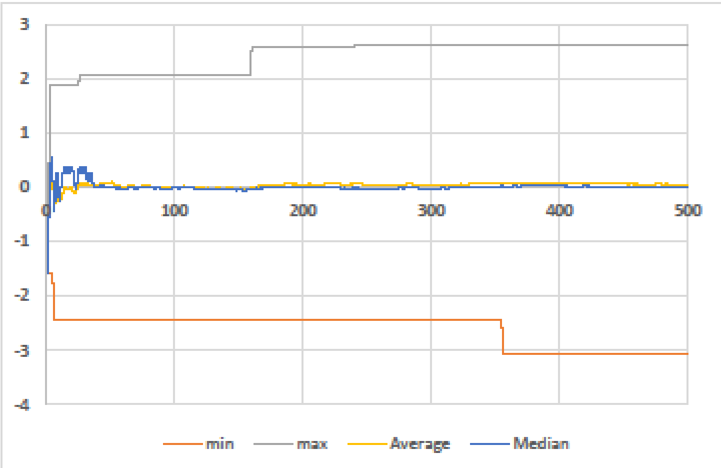


Figure 16 - Illustration of the impact of different sample sizes. Minimum, maximum, average and median values for 500 random samples (horizontal axis) from standard normal distribution (μ=0,σ=1)

Figure 16 shows how minimum and maximum values, average and median can change throughout the simulation.

The analyst should consider how the uncertain parameters are used in the analysis, to account for the uncertainty's effect on the end result; if the accuracy of the temperature estimation is ± 20 %, the uncertainty would affect the calculation of radiative heat transfer (T^4) more than it would affect the calculation of conductive heat transfer (T^1). Although it is possible in simple equations to compensate for this uncertainty by adding safety factors in the end result, it is recommended to reflect the uncertainty when defining input parameters.

7.3.2 Model uncertainty

Model uncertainty should be specified by the supplier of the software, or available through the literature in which one finds relevant equations. Generally one should allow for a considerable margin of error for empirical equations.

More information on uncertainty analysis can be found in ISO 16730 and ISO 16732-1.

7.4 Robustness analysis

The purpose of robustness analysis is to verify that the trial fire safety design is at least as robust as the equivalent reference building. Assessment of the designs robustness shall be an integral part of a probabilistic analysis. The robustness of a design is a measure of how the design is affected by:

- Failure of installed fire safety systems and passive fire safety measures;
- Non-compliance with prerequisites and constraints of use (e.g., fire load, occupant load, occupancy type).

The effects of non-compliance with prerequisites, and failure of fire safety measures are the respective probabilities of failure (the reliability, Annex C) which shall be quantified through defining design fire scenarios and design fires - see section 6.1 and 6.2.

For comparative analyses, attention should be drawn to components of the design which differ from pre-accepted solutions. Systems and measures given equal weight in the trial design and in the reference building can be omitted or simplified.

8 Documentation

The fire safety design and the fire safety strategy shall be documented to ensure transparency for review and control procedures. It is important that vital input parameters and prerequisites are documented to an extent which makes the calculations reproducible.

Any results supporting or forming a basis for conclusions shall be presented. The sensitivity analysis and, the management of uncertainties shall also be included.

All assumptions and simplifications shall be described and justified, and it shall be verified that these factors do not alter the conclusions of the analysis.

(1) NOTE: This chapter covers documentation regarding analysis and verification, which is only part of what is needed and required for documentation of fire safety in buildings.

(2) NOTE: Requirements for documentation may be set in the National Annex.

It is recommended the documentation, at a minimum, contains the following information, depending on the nature and scope of the fire safety engineering methods that were applied:

- Objectives of the fire safety engineering methods applied;
- A description of the building;
- Qualitative analysis:
    - Results of the risk identification
    - Trial fire safety design
    - Identified affected fire safety objectives and functional requirements
    - Performance criteria
    - Fire scenarios for analysis
    - Choice of verification method
- Quantitative analysis:
    - Assumptions
    - Engineering judgements
    - Calculation procedures
    - Validation of methodologies
    - Sensitivity analyses
    - Uncertainty analyses

- Robustness analysis

- Results of analysis;
- Conclusions:
  - Fire protection requirements
  - Management requirements
  - Any limitations on future use
- References:
  - Drawings
  - Design documentation
  - Technical literature

The documentation shall be transparent and draw a clear distinction between mandatory and voluntary fire safety objectives. This distinction may underline how safety of life, property protection and environmental protection are managed, so that the building owner, management and approvals body clearly understand the purpose of the proposed measures.

Annex A
(Informative)

Nationally determined parameters

Table A1 Template for the choice of nationally determined parameters to be decided by each national standardization body

Clause	Nationally determined parameter

Table A2 – Example of how nationally determined parameters may be expressed

Clause	Nationally determined parameter
4.2.2 (1)	Fire safety objectives are in country XYZ determined by checking what performance requirement the relevant pre-accepted solutions are connected to. For example, deviating from a 30 m walking distance to escape routes (according to XYZ pre-accepted solution) are only connected to fire safety objectives connected to evacuation. Fire safety objectives such as prevention of fire and smoke spread or fire brigade intervention are not deemed to be affected in this case and may be left out of the analysis.

Annex B
(Informative)

Validation of fire statistics

B1 General

Fire statistics are important in order to perform a proper quantitative risk assessment. The need for statistics is related to the type of risk assessment in question and may include:

— frequencies of a fire occurring for different types of occupancies;

— distributions of fire loads for different types of occupancies;

— probability of a fire starting in a certain object;

— probability of a fire starting in different room types;

— probability of a fire spreading beyond the room of fire origin;

— fire losses.

This annex will not give specific data but provide information on how to find suitable statistics elsewhere. Some issues that should be considered when using fire statistics are discussed.

Generally there are no fire statistics available that are fully accepted within the fire community and as such statistics should be used with proper consideration in mind. Aspects that need to be considered are:

— the significance of the data;

— the locations of the data collection and applicability for the country of the assessed building;

— the age and the representativeness of the data.

In relation to this, at least the following should be considered:

(1) Buildings are generally categorised for the presentation of fire statistics. It is important to consider whether the building category corresponding to the statistics, is representative for the assessed building or building design;

(2) Fire statistics potentially show high correlation with building features such as the floor area of a room or building. In order to avoid the use of unsafe statistics, a comparative study between statistics to search and evaluate significant features of the assessed building is recommended;

(3) Fire statistics are dependent on culture and location. It is recommended to use fire statistics that are collected in or close to the country of the assessed building or building design;

(4) The applicability of old fire statistics partly depends on the conventionality of the assessed building. Fire statistics based on conventional buildings are not directly applicable for unconventional buildings (Thureson *et al.*, 2008);

(5) Changes of regulations and developments in fire safety strategies have an influence on fire statistics. Therefore, it is recommended to use the most recently collected data that are available;

(6) It should be noted that small fires are not always reported. For probabilistic analyses using these statistics, it is required to account for the probability that fires are not reported;

(7) Wherever possible statistics should be obtained from Nordic Countries, preferably from the country of the assessed building.

The following sections discuss some of the most commonly required data and relevant aspects to consider.

B2 Frequencies of ignition for different types of occupancy

B2.1 The significance of the data

(1) The type of occupancy and described boundary conditions of the data should be applicable for the assessed building.

(2) Frequency of ignition per floor area should preferably be given as a function of the total floor area of the building. Floor area dependent fire statistics on ignition frequencies in Finland are for example given by Tillander (2004) and Rahikainen and Keski-Rahkonen (2004).

B2.2 The age and the representativeness of the data

The frequency of fires significantly changed in the past decades. Therefore, it is recommended that the most recent relevant fire statistics available are used. Dated fire statistics regarding ignition frequency are often, but not always, conservative.

B3 Fire losses

B3.1 The significance of the data

(1) Statistical data on financial losses are often quite subjective. Therefore, fire losses should, preferably, be expressed as a function of damaged areas or volumes.

(2) If applicable, an exchange rate between relevant currencies corresponding to the time of data collection should be applied.

(3) If possible, a distinction should be made between sprinklered buildings and unsprinklered buildings.

(4) If relevant, a distinction can be made corresponding to the main material of the load bearing structure.

(5) It should be noted that statistical data corresponding to low consequences and high frequencies are more reliable than data corresponding to low frequencies and high consequences.

B3.2 The age and the representativeness of the data

(1) Fire losses should, preferably, be expressed as a function of damaged areas or volumes in order to minimise the probability of using outdated statistics.

(2) It should be noted that data of financial fire losses, expressed in a certain currency, are significantly dependent on the local prices of buildings. Therefore, these data should not be used unless the fire statistics were obtained recently (within the last decade) and were determined in a location with representative building prices.

B4 Probability of a fire spreading beyond the room of fire origin

B4.1 The significance of the data

(1) Regarding the possibility of fire spread beyond the room of origin, a distinction should be made between sprinklered buildings and unsprinklered buildings.

(2) The statistics should be applicable for the specific room dividing members (walls, doors, etc.).

B5 Distributions of fire loads for different types of occupancy

Fire load densities should be chosen according to EN 1991-1-2 for the relevant type of occupancy.

B6 Relevant databases

Relevant national resources of Nordic countries regarding fire statistics are available through Nordstat. See also:

Denmark	Danish Emergency Management Agency, BRS
	Danish Institute of Fire and Security Technology, DBI
Finland	Ministry of the Interior
	Pronto
Iceland	Iceland Construction Authority, MVS

Norway	Directorate for Civil Protection and Emergency Planning, DSB
Sweden	Swedish Civil Contingencies Agency, MSB

Due to lack of generally applicable data that correspond to the conditions in the Nordic countries, data from PD 7974-7 can be used.

Annex C
(Informative)

Reliability data

Fires are relatively rare, and when they occur, not all data are recorded for use in fire safety engineering. As a result, the available reliability data will vary in terms of relevance and age, but there may also be differences in terms and definitions. It is therefore imperative that the analyst exercises caution when gathering reliability data, and that the parameters' sensitivity is reflected in the analysis.

The probability of a component of the fire safety strategy functioning as intended in case of fire (reliability) will be affected by a number of variables. Although this annex presents single-value data for reliability, these parameters can preferably be treated as distributions – either as part of an uncertainty analysis or as part of the analysis itself. Reliability can be shown as a distribution over time/age, as a function of maintenance frequency or one could utilize triangular or other distributions to quantify the uncertainty in the reliability data. The user may skew or modify the distribution to address project-specific factors.

The reliability data presented in this annex are meant as guidance in defining design parameters, rather than a representation of the current state of fire safety systems in the Nordic countries.

(1) NOTE: One can generally expect conservative results when underestimating reliability. When performing comparative analyses, reductions in reliability concerning the reference building only, may lead to an underestimation of the risk.

Unless stated otherwise, this annex collates parameters for system reliability, as these are assumed to be most relevant for fire safety engineering in buildings. If one is, e.g., to assess the effects of upgrading sprinkler pumps or other specific components of a fire safety system, component reliability may be needed. Please refer to "further reading" and the introduction to reliability analysis.

Unless stated otherwise, this annex gives general estimations for operational reliability, meaning the fire safety measures ability to perform as intended on demand. The analyst is however responsible for adjusting the reliability data based on case or scenario specific factors. The provided reliability data for, e.g., sprinkler system for life safety will not be relevant for smouldering fires or for very high ceiling areas.

Reliability data is given with reference to the following sources:

[1] PD 7974-7

[2] NFPA 1720 (2014)

[3] Effectiveness of Fire Safety Systems for Use in Quantitative Risk Assessments, (NZFSC, 2008)

[4] Methods for determining and processing probabilities, (VROM, 2005)

C1 Intended use

Reliability data in this annex is meant as a common starting-point for assessment of systems and components affecting the fire risk. The analyst shall consider the need for adjusting the data to cope with uncertainty, variation or project-specific factors. An introduction to reliability analysis is given in C8.

For crucial components/systems, or scenarios where reliability data is imperative, a reliability analysis should be conducted.

The purpose of this annex is not to preclude the use of other sources of reliability data. When more relevant or recent data is available, these should be used.

C2 Fire partitions

The following table gives examples of reliability data; probability of fire separations performing as intended on demand.

Type	Note	Minimum	Mean	Maximum	Ref
Masonry walls	(1)		0,75		[1]
Partition walls	(1)		0,65		[1]
Glazing	(1)		0,4		[1]
Door not being blocked open			0,7		[1]
Self-closing door closes correctly	(2)		0,8		[1]

(1) NOTE: Probability of the fire partition will achieve at least 75 % of the designed fire resistance (e.g. 45 minutes for partitions rated EI 60)

(2) NOTE: Excluding those blocked open

C3 Fire suppression and extinguishing systems

Considerable data is available for sprinkler system performance and reliability. The analyst should however be aware of the differences in how the data has been gathered and categorized. For example, data available through fire statistics may indicate sprinkler failure when sprinklers do not control a smouldering fire – although sprinklers are not expected to do so.

Several factors may affect the reliability and performance of suppression and extinguishing systems.

Type	Note	Minimum	Mean	Maximum	Ref
General		0,75		0,95	[1]
Sprinkler system for property protection			0,9		[1]
Sprinkler system for life safety			0,8		[1]

Frank, *et al.* (2012) conducted a study suggesting normally distributed reliability for sprinklers with a mean of 86 % and a standard deviation of 4,6 %.

C4 Fire detection, alarm and interactions

The following reliability data should be perceived as component reliability. Calculation of conditional probability of failure or operation may be necessary.

Type	Note	Minimum	Mean	Maximum	Ref
Reliability of alarm box, wiring and sounders		0,9		1,0	[1]
Reliability of commercial smoke detector			0,9		[1]
Reliability of domestic smoke detector			0,75		[1]
Reliability of aspirating smoke detector			0,9		[1]
Reliability of heat detector			0,9		[1]
Reliability of flame detector			0,5		[1]

C5 Fire service intervention

The performance of the fire service may be governed nationally and regionally, and will vary throughout the Nordic countries. The degree to which one can take fire service intervention into account in design of new buildings may also vary. Fire service intervention will however play a significant role in several fire safety objectives – hence the performance and reliability could be included in the analysis of fire risk.

Refer to national or local regulations to find a description of the expected response time, personnel and material with which the fire service can intervene.

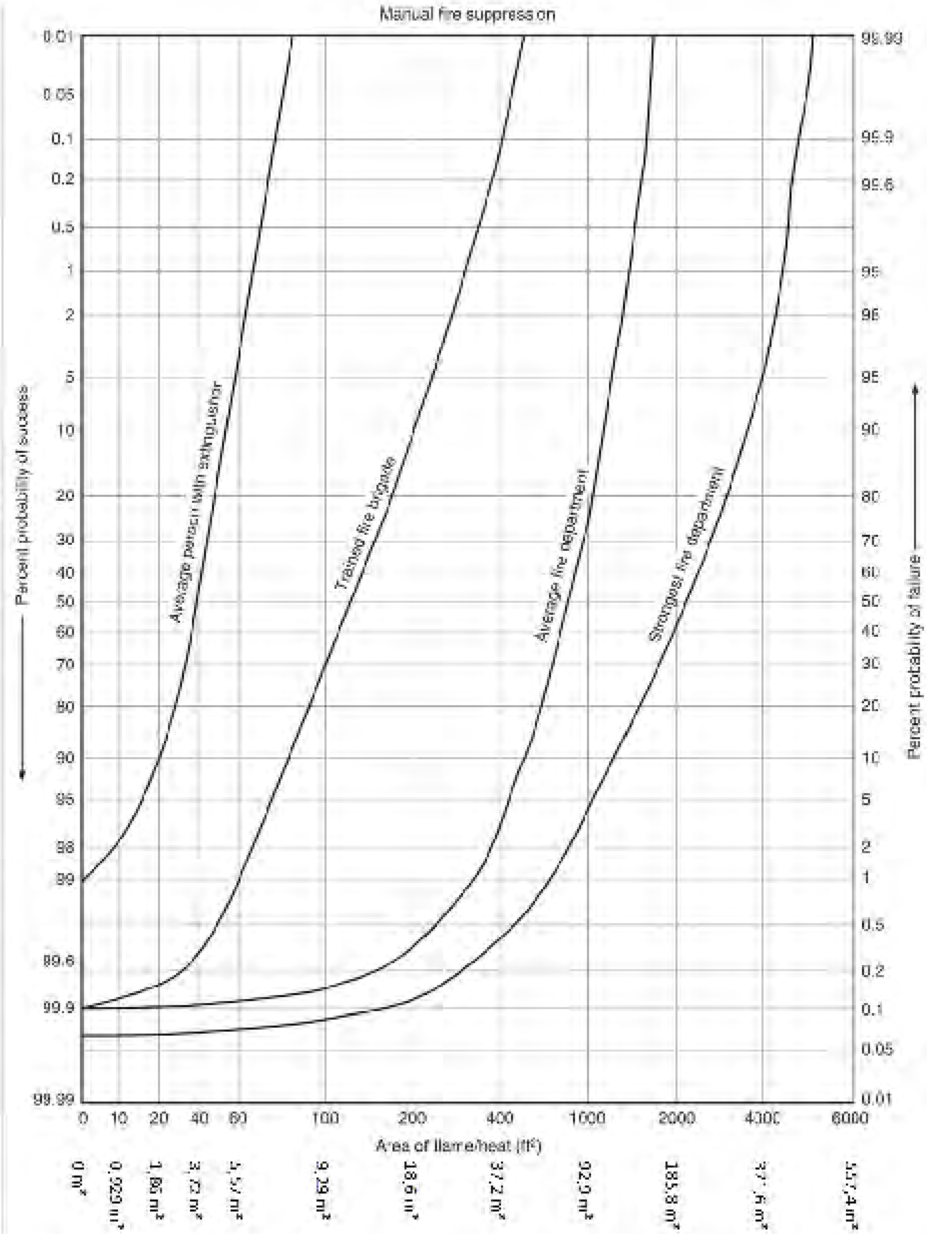


Figure 17 - Probability of successful manual fire suppression as a function of fire size in storage areas. Probabilities of failure and success are given for average person with fire extinguisher, trained fire brigade, average fire department and the strongest fire departments. (Fig. 20.17.3, p. 20-191, Fire Protection Handbook, 20th edition (2008))

C6 Other installations and systems

Type	Note	Mini-mum	Mean	Maxi-mum	Ref
Probability of successful operation of natural smoke ventilation or mechanical smoke extraction systems	(1)		0,9		[1]
Stairwell pressurisation system	(2)		0,5		[3]

(1) NOTE: Excluding integration with fire detection and alarm system

(2) NOTE: Approximation of 1) Fixed speed fan and barometric dampers (0,52), 2) Variable speed drive system (0,47) and 3) Variable speed drive and motorised damper system (0,49)

C7 Human response

Human behaviour in case of emergency is a complex topic, outside the scope of this document. Human response may however affect the outcomes of fires, and the probability of humans responding as intended should in these cases be assessed. The following data may be used when estimation of the probability of operators at control rooms, staff or members of the general public acting as intended:

Type	Note	Mini-mum	Mean	Maxi-mum	Ref
Totally unfamiliar, performed at speed with no real idea of likely consequences.		0,03	0,45	0,65	[4]
Routine, highly-practiced, rapid task involving relatively low level of skill		0,955	0,98	0,993	[4]
Respond to audible alarm in busy control room within 10 minutes			0,9		[4]

C8 Introduction to reliability analysis

As reliability data is vital input in probabilistic analysis, the analyst must consider the applicability of the data in each analysis. In a probabilistic analysis the investigation of partial or complete failure of fire safety measures may be used in event trees, as a basis for design fire, etc.

C8.1 Definition of reliability

Reliability can be defined as the ability of an item to operate under a given set of operating conditions, for a specific given period of time. As such, reliability can be expressed as a probability of either failure, P_F, or success, P_S. Since a system always will be in a state of either failure or success, the sum of their probability will be 1. Thus, probability of failure or success can be expressed by knowing just one variable. This can be expressed mathematically as:

$$P_S = EXP(-\frac{\Delta t_S}{\Delta t_F})$$

$$P_F = 1 - P_S = 1 - EXP(-\frac{\Delta t_S}{\Delta t_F})$$

where Δt_S is the time interval in which success is required and Δt_F is the mean time between failures.

C8.1 System versus component reliability

While the reliability of a single component can be simplified to a small set of variables, system reliability can be a lot more complex. The system reliability is the sum of reliability of its components, but there are also a number of other important factors to consider. Factors like suitability of the components for the particular application and test and maintenance procedures for the system can have a large impact on the resulting system reliability. It is therefore important to know the background of a given system reliability value before using it in a probabilistic analysis.

For some systems it might not be readily apparent if a give value includes all needed components if this is not explicitly given. For example, if a reliability value for a gas extinguishment system is given, does it include the reliability of all needed components for success like both detection of fire and the gas delivery system, or is it just the gas delivery system? Such dependencies can be very important, and will influence the resulting system reliability greatly.

If a system is comprised of many different components, and also has dependencies on other systems, then it is recommended to use, for example, reliability block diagram methods, fault tree methods or event three methods - see section 6.4.1.2.

C8.3 Models for analysis of reliability

System reliability can be assessed by describing all components or events through logic trees as described in clause 6.4.1.2. Logic trees may be useful for addressing case-specific properties or conditions that can advocate for adjusting data provided in this annex. This method may also serve to estimate the reliability of systems not covered by this document, by analysis of the known or estimated reliability of the system's components.

While age and maintenance rate are obvious parameters affecting a fire safety measure's reliability, there are numerous other parameters in a fire scenario that can lead to a much earlier failure of the whole system or a component of the system. There are parameters like high temperature, high concentrations of combustion products, radiative heat and volume flows, etc. For these phenomena a stress-strength interference model could be applied to better account for the different stresses that a fire-scenario inflicts. This model and others are further explained in sub-section 6.4.2.

C8.4 Failure and hazard rate

Failure in an item can be expressed as a function called instantaneous failure rate or hazard rate, h(t). Hazard rate can be interpreted as the probability of the first and only failure of an item, meaning failure only happens once and thus leads to a hazard, since it is not repairable. For repairable items the term failure rate, or rate of occurrence of failure is the most appropriate term. The rate function is obtained via life test data of the item.

The instantaneous hazard/failure rate can be expressed as follows:

$$h(t) = f(t)/R(T)$$

where $f(t)$ represents the time to failure probability distribution function of a component, while $R(T)$ is its reliability function.

This rate is an important function in reliability analysis as it shows the changes in probability of failure over the lifetime of a component. It will often produce a bathtub like curve with failure rate as a function of time, as shown in Figure 18:

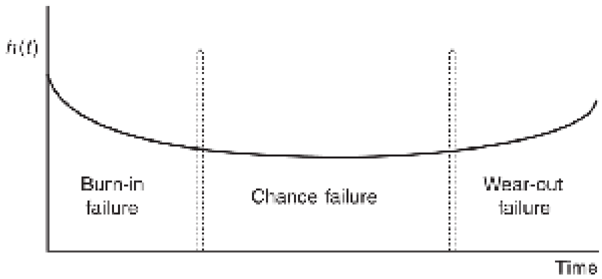


Figure 18 - Typical bathtub curve, showing raised hazard rate shortly after construction/ installation and towards the end of the lifespan of the system/ component (Fig. 5-3.3, p. 5-27, SFPE Handbook (2002))

C8.5 Probability distributions

Failure probabilities as a function of time should be expressed as probability distribution functions rather than just using single-point values. Using only single-point values can at best lead to a less cost-effective (conservative) design, but may also lead to underestimating the risk, and thus result in insufficient safety of life or property.

Guidance on creating probability distributions is given in section 6.3.

Annex D
(Informative)

Worked examples

D1 Event tree method

Figure 19 shows an example of PRA being used to assess the risk/cost benefit of fire safety systems for the design objective of property protection.

The client for this exercise was concerned about the risk to business continuity of a fire in their vehicle garage, and whether it was cost-effective to invest in the installation of a fire sprinkler system in the facility. Because of the considerable cost for a fire sprinkler system, a study was undertaken to quantify the costs and benefits involved.

The details of the scenario for this worked example are as follows:

- The event of concern is a fire that randomly starts in one bus resulting in fire spread to adjacent buses in the parking garage, thus causing significant property damage and disrupting the transport operator's business;
- The initiating event is a seat fire that is assumed to start at three separate locations on a double-deck bus that is parked amongst other double-deck buses in a garage;
- The risk parameter selected is "cost of fires per calendar year", with two value thresholds being established of "damage less than €200 000" and "damage greater than €500 000";
- The following series of Yes/No events is used, with a probability for each estimated from a combination of historical data, expert judgement, modelling and experimental testing:
    - "Is the fire noticed at an early stage?" $P_Y = 0{,}6 \; P_N = 0{,}4$
    - "Is the fire extinguished using extinguishers?" $P_Y = 0{,}93 \; P_N = 0{,}07$
    - "Does the fire spread to neighbouring buses?" $P_Y = 0{,}8 \; P_N = 0{,}2$
    - "Do sprinklers control the fire?" $P_Y = 0{,}95 \; P_N = 0{,}05$
    - "Does the fire brigade control the fire?" $P_Y = 0{,}95 \; P_N = 0{,}05$
    - "Is the damage less than €200 000?" $P_{Y1} = 0{,}2 \; P_{N1} = 0{,}8$

      $P_{Y2} = 0{,}1 \; P_{N2} = 0{,}9$

      $P_{Y3} = 0{,}5 \; P_{N3} = 0{,}5$
    - "Is the damage more than €500 000?" $P_Y = 0{,}2 \; P_N = 0{,}8$.

(1) NOTE: For the "Is the damage less than €200 000?" Y/N event, the probability is dependent on the preceding sequence of events, whereas the other Y/N events are independent of each other.

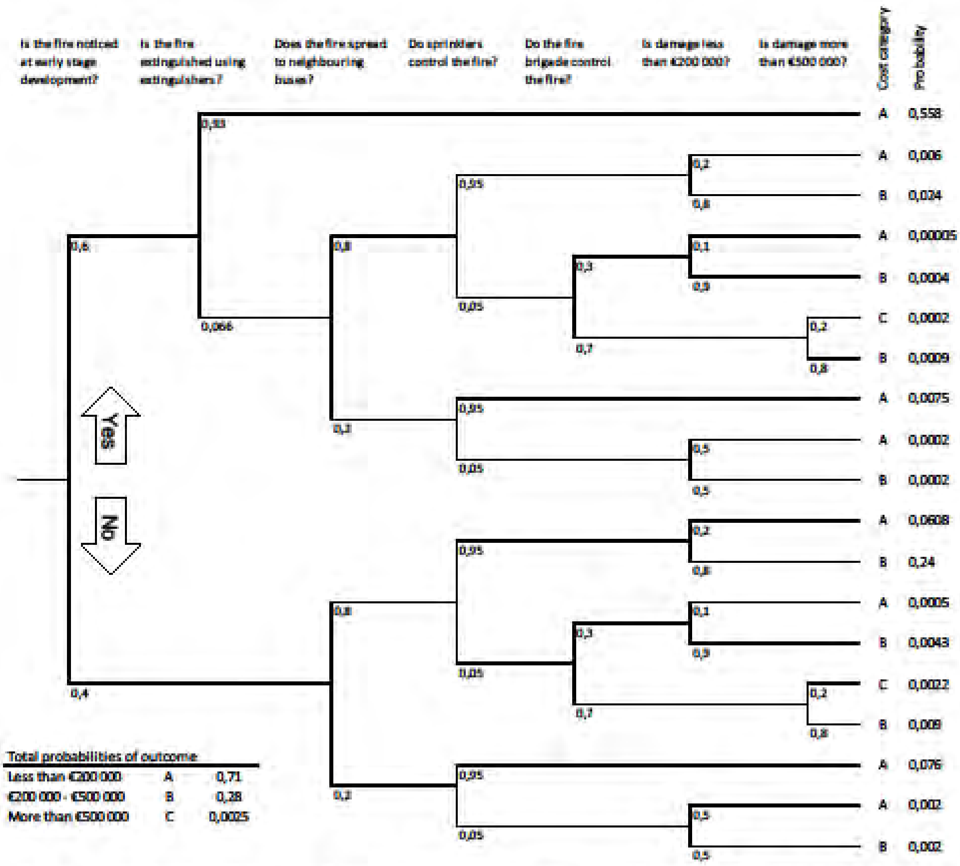


Figure 19 - Example of PRA using an event tree (based on Fig. 7, p. 22 PD 7974-7)

The probability of each outcome (sequence of events) is then calculated, based on the individual event probabilities.

At the same time, each outcome is put into an outcome cost category: category A – "less than €200 000; category B – "€200 000 - €500 000"; and category C – "more than €500 000". The probability of each cost category is simply determined by summing the probability for each outcome in the particular cost category.

It can be seen from Figure 19 that not all Y/N events are applicable to each sequence of events; it depends on whether preceding events have a Y or a N result. For example, for the top branch in the event tree diagram, once the fire has been extinguished using extinguishers, i.e., it is a small localised fire, the subsequent events are no longer relevant, and the damage is by default less than €200 000.

Once the PRA illustrated in the event tree diagram is completed, a frequency for fires has to be determined, and then this parameter, in conjunction with a detailed cost/benefit analysis, is the basis for informing a decision on whether to invest in a sprinkler system for the bus garage facility in question.

D2 Fault tree method

Figure 20 shows a qualitative example of a fault tree diagram which relates to a hypothetical case where the "top" event is "failure to detect a fire within 5 minutes of ignition". The causes of the top event can be followed through to four root causes, namely; A. "no automatic detector present", B. "failure to detect fire" (i.e., failure of the detector), C. "area not observed by staff", and D. "failure to detect fire" (i.e., by staff that were present).

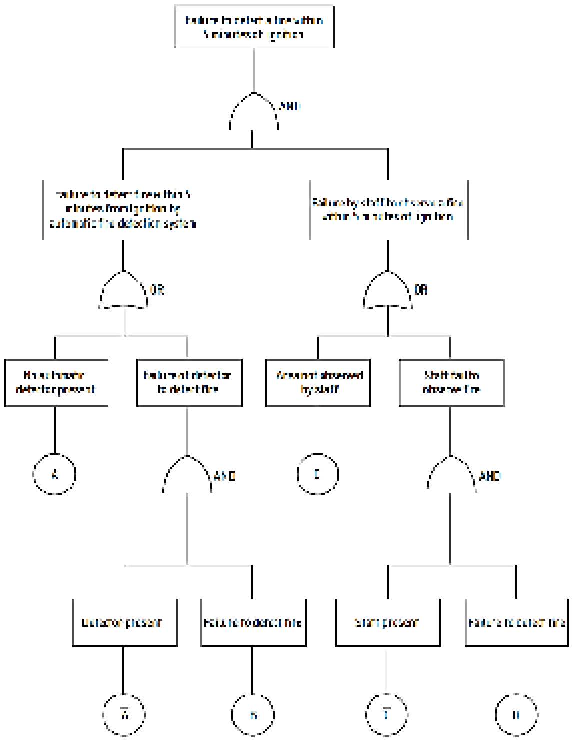


Figure 20 - Qualitative fault tree diagram (Fig. 9, p. 26 in PD 7974-7)

For the purposes of the worked example hypothetical probabilities are assumed for each of the root cause "events" in Figure 20. For the building in question, the following assumptions are made:

A. 75% of the floor area has fire detector coverage, i.e., $P_A = 0{,}25$ and $P_{\bar{A}} = 0{,}75$;

B. The fire detectors are 95% reliable, i.e., $P_B = 0{,}05$;

C. Staff are present in the building 8 out of 24 hours per day, i.e., $P_C = 0{,}67$ and $P_{\bar{C}} = 0{,}33$;

D. Staff fail to detect a fire in 25% of cases, i.e., $P_D = 0{,}25$.

The next step is to calculate the probabilities at each gate in the fault tree diagram, using the simple **AND** and **OR** gate formulae given in sub-clause 6.4.1.2.2.

$$P_{\bar{A}B} = P_{\bar{A}} \cdot P_B = 0{,}75 \times 0{,}05 = 0{,}0375$$

$$P_{A(\bar{A}B)} = (P_A + P_{\bar{A}B}) - (P_A \cdot P_{\bar{A}B}) = (0{,}25 + 0{,}0375) - (0{,}25 \times 0{,}0375) = 0{,}278125$$

$$P_{\bar{C}D} = P_{\bar{C}} \cdot P_D = 0{,}33 \times 0{,}25 = 0{,}0825$$

$$P_{C(\bar{C}D)} = (P_C + P_{\bar{C}D}) - (P_C \cdot P_{\bar{C}D}) = (0{,}67 + 0{,}0825) - (0{,}67 \times 0{,}0825) = 0{,}697225$$

$$P_{A(\bar{A}B)C(\bar{C}D)} = P_{A(\bar{A}B)} \cdot P_{C(\bar{C}D)} = 0{,}278125 \times 0{,}697225 = 0{,}193916$$

Based on the hypothetical probabilities for each of the root cause events, the probability of failure P_f to detect a fire within 5 minutes of ignition is estimated to be $P_f \approx 0{,}2$.

D3 Bayesian network model

There are different methods to protect against fire and smoke spread via the HVAC-system:

i. Separate systems for each fire compartment;

ii. Fire- and smoke dampers in fire compartment penetrations;

iii. Smoke is allowed to enter the HVAC-system, but the smoke is extracted by exhaust fans.

In a building using method iii, there are many variables that will affect the outcome of a fire scenario. However, in this scenario only four variables are chosen:

1. The function of an automatic sprinkler system (function / no function)
2. The function of the smoke detection system in the HVAC ducts (function / no function)
3. The flow of the exhaust fan (normal flow / increased flow / no function)
4. The fire growth rate (slow / medium / fast)

Other important variables, e.g., if windows are open or closed, or if kitchen hoods are in use or not, could also be included in the model, but is left out for the sake of simplicity. Also, the assumed failure rates are not based on actual data and should only be seen as examples. An influence diagram for the simplified case is shown in Figure 21.

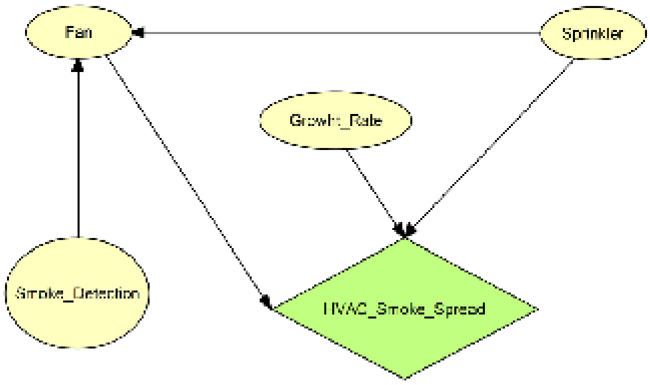


Figure 21 - Influence diagram for HVAC smoke spread

The following assumptions are made:

1. The sprinkler system is assumed to have a reliability of 95 %;

2. The smoke detection system is assumed to have a reliability of 95 %;

3. The exhaust fan can be controlled to increase its flow either by a signal from smoke detection activation or sprinkler activation. It is assumed that the fan has a failure rate of 1 % when it comes to increase its flow if it gets a signal from either system, or from both. It is also assumed that there is a general failure rate of 1 % for the fan, which is independent of the function of the sprinkler system and the smoke detection system, i.e., the fan is completely shut off.

4. The fire growth rate is assumed be slow (25 %), medium (50 %) or fast (25 %).

Node tables for the influence diagram are shown in Table 9 through Table 12. In the utility line for HVAC smoke spread,
Table 13, 0 means that smoke does not spread between fire compartments and 1 means that there is smoke spread. This needs to be calculated separately for each of the 18 scenarios, e.g., by hand calculations or by flow simulations in appropriate software. In this example, smoke will not spread if the sprinklers activate and the fan increases its flow. However, if the sprinklers do not activate, the increased flow is only effective for a small or medium fire growth. If the fire has a fast growth rate, there will be smoke spread to other fire compartments.

The total probability of smoke spread can be calculated by hand, using Bayes theorem. This is described further by Raiffa (1997). There are also many software programs that can be used to simplify this process. In this example, the total probability of smoke spread is $2{,}4 \cdot 10^{-2}$ in case of fire. The importance of different safety systems can easily be evaluated by, e.g., changing the probability of sprinkler failure to 100 %, which increases the risk of smoke spread to $2{,}9 \cdot 10^{-1}$. Doing the same for the smoke detection system only increases the risk of smoke spread to $4{,}7 \cdot 10^{-2}$.

Table 9 - Input for fire growth rate

Growth_Rate	
Slow	0,25
Medium	0,5
Fast	0,25

Table 10 - Input for sprinkler

Sprinkler	
Yes	0,95
No	0,05

Table 11 - Input for smoke detection

Smoke_Detection	
Yes	0,95
No	0,05

Table 12 - Input for fan operability

Fan				
Smoke_Detection	Yes		No	
Sprinkler	Yes	No	Yes	No
Normal flow	0,01	0,01	0,01	0,99
Increased flow	0,98	0,98	0,98	0
No function	0,01	0,01	0,01	0,01

Table 13 - Utility line for HVAC smoke spread (1) or not (0)

HVAC_Smoke_Spread						
Fan	Normal flow		Increased flow		No function	
Sprinkler	Yes	No	Yes	No	Yes	No

Growth_Rate[1]	S	M	F	S	M	F	S	M	F	S	M	F	S	M	F	S	M	F
No function	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	1	1	1

One could perform the same analysis using an event tree. However, this would require a tree with 36 outcomes. Also, it is more difficult to get a clear view of the conditional probabilities using an event tree, especially if more variables are added to the scenario.

D4 Safety index (β) method

Below are short examples of how to apply the safety index method, for both the univariate and the bivariate approach.

D4.1 Univariate approach

The univariate approach can be useful when studying the probability of failure where the load is represented by a known probabilistic distribution and the criteria can be treated as a constant value. For example, if the expected fire load in a compartment can be represented by a normal distribution with a mean of 250 MJ/m^2 and a standard deviation of 50 MJ/m^2 then the equivalent time of fire exposure can be calculated using the following equation from annex F in EN 1991-1-2:

$$t_{eq} = q_f * k_b * w_f$$

Where

q_f is the fire load,

k_b is representing material properties, can be chosen to 0,07 min m^2/MJ,

w_f is the ventilation factor, according to CIB (1986), 1.5 is a conservative value if this is not known.

Using this formula, the equivalent time of fire exposure can be calculated for each value of the expected fire load. This gives a normal distribution of the equivalent time of fire exposure with a mean of 26,25 minutes and a standard deviation of 5,25 minutes.

This equivalent time of fire exposure can be used to assess the resistance of an EI 30 fire compartment. Assuming no variation in the resistance, i.e., the resistance is treated as a constant, and that EI 30 gives exactly 30 minutes of resistance for the equivalent fire time, then the probability of failure of the compartmentation can be calculated using:

$$P_{failure} = P(t_{eq} > 30)$$

This gives a probability of failure of 23,8 %.

[1] S, M and F represent fire growth rates slow, medium and fast respectively

The probability of failure is above the criteria set in section 5.5, so the design must be reconsidered, or more detailed analysis is needed.

D4.2 Bivariate approach

In the bivariate approach, both of the studied variables are represented by probabilistic distribution. An example of this would be the case with and ASET/RSET analysis if both the times could be expressed as reliable distributions. An example of this case is given in clause 6.4.2.1, but is also briefly given below.

Assuming that both the ASET and the RSET times are reliable distributions, the resulting probability of failure can be found by:

$$P(Failure) = P(ASET - RSET \leq 0)$$

Symmetrical distributions (normal distributions)

If ASET and RSET are independent random variables, normally distributed, the difference will be normally distributed with mean $\mu_{ASET-RSET} = \mu_{ASET} - \mu_{RSET}$, variance $\sigma_{ASET-RSET}{}^2 = \sigma_{ASET}{}^2 + \sigma_{RSET}{}^2$, and hence standard deviation $\sigma_{ASET-RSET} = \sqrt{\sigma_{ASET}{}^2 + \sigma_{RSET}{}^2}$

Hence the probability of a failure can be found by the cumulative distribution function:

$$P(Failure) = \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right] = \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{0 - \mu_{ASET-RSET}}{\sigma_{ASET-RSET}\sqrt{2}}\right)\right]$$

(1) NOTE: Functions for cumulative distribution are available for a number of distributions in spreadsheet software.

For this example, the characteristics of the distributions are $\mu_{ASET} = 600$, $\mu_{RSET} = 400$, $\sigma_{ASET} = 60$ and $\sigma_{RSET} = 60$. Hence, the probability of failure is:

$$P(Failure) = \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{0 - (600 - 400)}{\sqrt{60^2 + 60^2} \cdot \sqrt{2}}\right)\right] \approx 0{,}92\ \%$$

$$\beta = \frac{\mu_{ASET-RSET}}{\sigma_{ASET-RSET}} = \frac{600 - 400}{\sqrt{60^2 + 60^2}} \approx 2{,}36$$

Assuming the analysis is made for a fire compartment with a limited number of people, one could conclude that ASET is greater than RSET, as that is the outcome of 99 % of the assessed scenarios.

Asymmetrical distributions

For asymmetrical distributions of ASET and RSET, P(Failure) may be a more complex calculation. If no applicable formulas can be found, one can apply the same principles shown above using Monte Carlo simulations. Refer to section 6.3 Estimating Distributions (parametric).

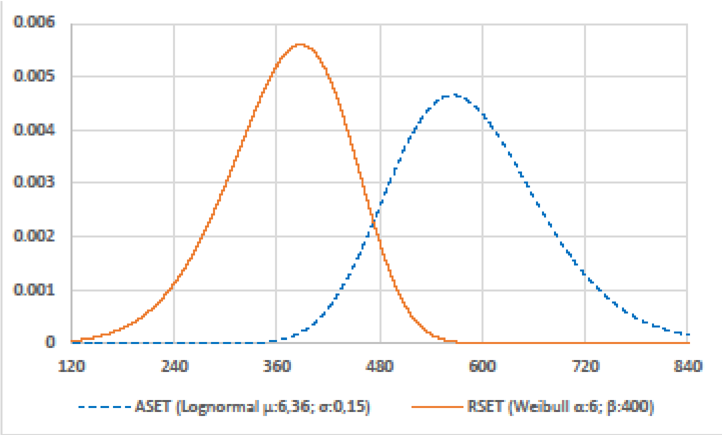


Figure 22 - Example of two asymmetrically probability density functions for ASET and RSET. Lognormal (μ=6,36, σ=0,15) and Weibull (α=6,0, β=400) respectively.

The example in Figure 22 shows two probability density functions, where ASET is assumed Lognormal distributed and RSET is assumed Weibull distributed. The resulting P(Failure) can be found through Monte Carlo simulations, where the safety margin is calculated by

$$Safety\ margin = ASET - RSET = f(\text{ASET}; \mu, \sigma) - f(RSET; \alpha, \beta)$$

And hence

$$P(Failure) = P(Safety\ margin < 0)$$

=RiskLognorm2(B3;B4)

	A	B	C
1		ASET	RSET
2	Distribution	LOGNORM	WEIBULL
3	μ	6,36	-
4	σ	0,15	-
5	α	-	6
6	β	-	400
7	Sample	584,788358	371,087733
8	Safety margin		213,700624

Figure 23 - Screen dump from spread sheet

Figure 23 shows how the calculation may be done in a spreadsheet based Monte Carlo simulation. Cells B7 and C7 are set as random parameters (lognormal and Weibull distributed, respectively), whilst cell C8 is defined as output (=B7-C7).

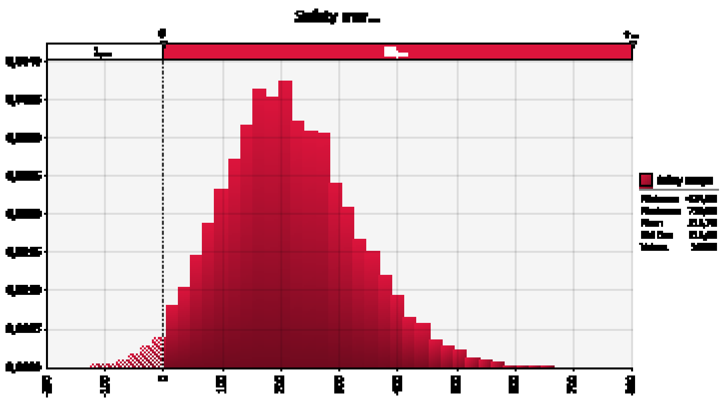


Figure 24 - Results from 10 000 iterations of Monte Carlo simulations showing probability distribution for the safety margin, ASET-RSET.

Figure 24 indicates acceptable probability of failure (P < 0,05) for the probability density functions, yielding safety margin greater than zero for 98,1 % of the assessed cases. The example also shows that there are scenarios yielding a negative safety margin of almost 2 minutes. These should be assessed by the designer, as to determine mitigating measures for the high consequence scenarios, or if the combined probability renders the scenarios negligible. Estimates of number of casualties in each scenario with negative safety margin and their respective probabilities should be held against criteria in clause 5.3.1.2 or, if applicable, 5.2.1.

D5 Probability of Incapacitation, based on FED

Assuming the following FED values are calculated for 10 individuals, although the same procedure could be used if the calculated FED values were probability distribution functions:

Individual	A	B	C	D	E	F	G	H	I	J
FED	0,44	0,74	0,33	0,11	0,1	0,11	0,96	0,9	0,74	0,55

ISO 13571:2012 states that the uncertainty in FED calculations are ± 35 %.

In a concervative, deterministic approach one would add 35 % to the calculated FED values, and compare to a single tenability criteria of FED 0.3 (refer to the static values in Figure 26). FED 0.3 is suggested as tenability criterion in many handbooks (Nysted 2011), and corresponds to a probability of incapacitation of 11.4 %. This approach yields a total number of 7 individuals exposed to untenable criteria. A less concervative tenability criteria of FED 1.0 would however yield a total number of 4 individuals exposed to untenable criteria.

In a probabilistic approach, the uncertainty is implemented by triangular distributions, where min is 65 %, mode is 100 % and max is 135 % of the calculated FED values, and the log-normal distribution provided in chapter 5.3.1 is used as tenability criterion.

Montecarlo simulations are conducted, where each individual's tolerance is defined as a log-normal distribution, with a mean of 0.0 and a standard deviation of 1.0 (as per 5.3.1).

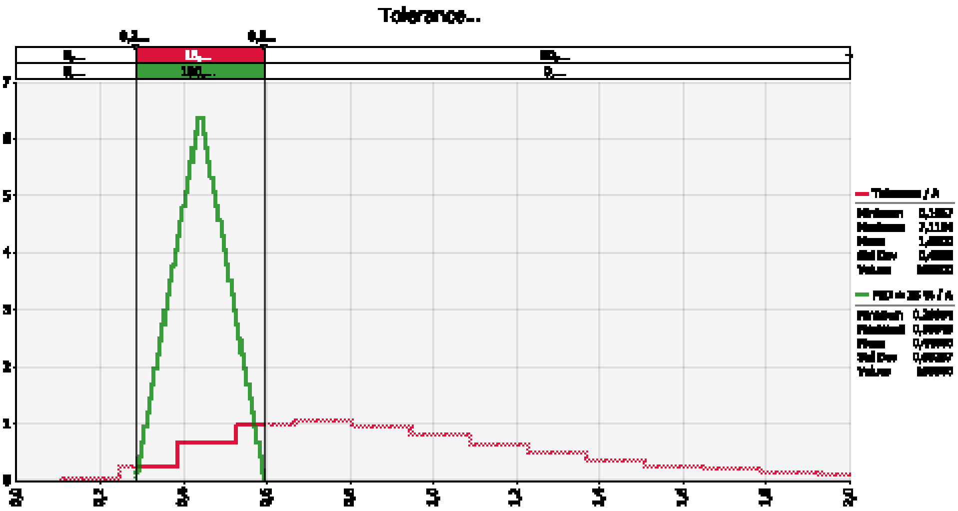
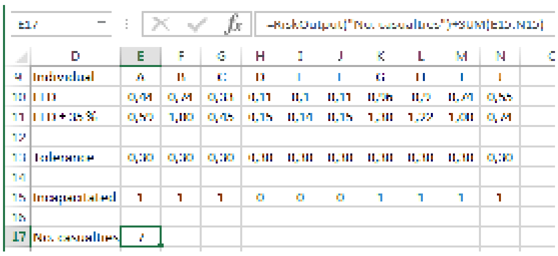


Figure 25 - Comparison between tolerance (log-normal) and exposure (triangular 0,44 ± 35 %) for individual A

As shown in Figure 25, the calculated exposure of individual A falls into the lower region of the tolerance curve: Most individuals will have a tolerance higher than the calculated exposure. P(exposure>tolerance) is found to be 7,1 % for individual A.

The above described procedure is repeated for all individuals in a spread sheet, introducing a formula, assuming casualties where exposure > tolerance.



E17 =RiskOutput("No. casualties")+SUM(E15:N15)

	D	E	F	G	H	I	J	K	L	M	N
9	Individual	A	B	C	D	[illegible]	[illegible]	G	H	I	J
10	FED	0,44	0,74	0,31	0,11	0,1	0,11	0,96	0,9	0,74	0,55
11	FED + 35 %	0,59	1,00	0,45	0,15	0,14	0,15	1,30	1,22	1,00	0,74
12											
13	Tolerance	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30	0,30
14											
15	Incapacitated	1	1	1	0	0	0	1	1	1	1
16											
17	No. casualties	7									

Figure 26 - Screen dump from spread sheet

Row 15 contains IF-formulas yielding "1" when values in row 11 are exceeding values in row 13. Cell E17 sums the number of casualties for each iteration.

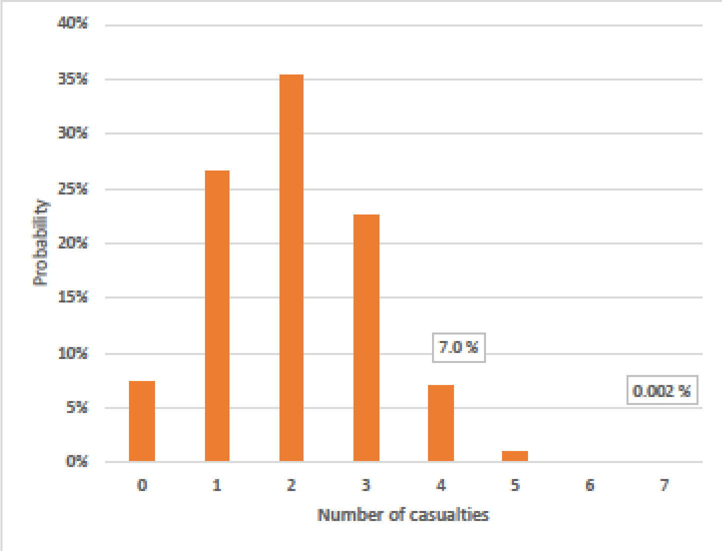


Figure 27 – Probability distribution of number of casualties

As shown in Figure 27, the probabilistic approach reveals a more neuanced picture than the deterministic approach. A outcome of 7 casualties (as assumed where FED 0.3 was used as tenability criteria) has a probability of 0.002 %.

Assuming a fire frequency of 1 fire per 100 years, and that the previously studied fires are representative for the occupancy, the following FN-curve may be produced, to compare the fire risk with the criteria given in chapter 5.3.1.2.

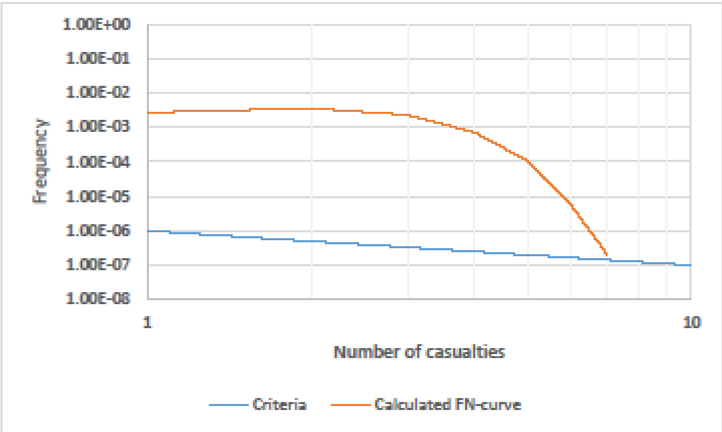


Figure 28 - FN-curve

Figure 28 reveals an unacceptable fire risk, which requires redesign or a more detailed analysis.

Annex E
(Informative)

Basic Concepts of Statistics

E1 Probability Density Function and Probability Mass Function

The probability density function (PDF), or density of a continuous random variable, is a function that describes the relative likelihood of the random variable having a given value, represented mathematically as:

$$f(y) = P(x = y)$$

The PDF is non-negative everywhere and the integral over the entire range is one, i.e.:

$$\int_{all\ x} f(x)dx = 1$$

Two examples of a PDF for a continuous variable are shown in **Error! Reference source not found.**(a).

The probability of a continuous random variable taking on a specific value is actually zero, whereas the probability of the continuous random variable falling within a particular range is given by the integral of the variable's density over that range. For example, the probability of a continuous random variable taking on the hypothetical value 3,5000000… is effectively zero, while the probability of the variable lying in the range 3,49 to 3,51 will have some value between zero and one, determined by evaluating the integral of the associated PDF over that range.

The probability mass function (PMF) is a function that gives the probability that a discrete random variable is exactly equal to some value. All values of a PMF must be non-zero and sum to one, i.e.:

$$\sum_{all\ x} f(x) = 1$$

The PMF is often the primary means to define a discrete probability distribution.

An example of a PMF is shown in **Error! Reference source not found.**(b).

A PDF differs from a PMF in that a PDF is associated with a continuous, rather than discrete, random variable.

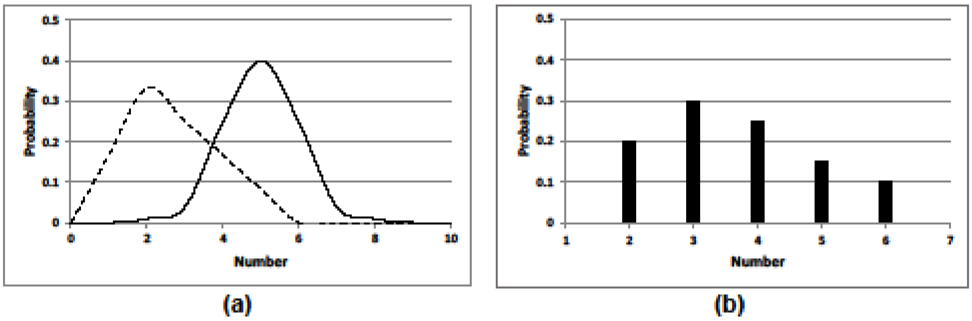


Figure 29 - Distribution types: (a) Continuous; (b) Discrete.

E1.1 Cumulative Distribution Function

The cumulative distribution function (CDF) is a mathematical function that gives the probability, at that value of x, that the random variable will take on that or a lesser value than x. For a discrete distribution, this is the sum of the PMF up to x, while for a continuous distribution, this is the area under the PDF up to x, i.e., for a discrete distribution:

$$F(y) = P(x \leq y) = \sum_{x \leq y} f(x)$$

and for a continuous distribution:

$$F(y) = \int_{x \leq y} f(x)dx$$

Examples of CDF's are shown in **Error! Reference source not found.** for both discrete and continuous distributions.

The CDF (whether in mathematical or graphical form) can be used to determine percentile values, i.e., what percentage of the sample lies below (or above) a certain threshold value of x. For example, if one has a CDF plot of fire load densities for an occupancy of interest, then the CDF plot can be used to determine, say, an 80-percentile value for the fire load density for a fire safety engineering calculation or modelling exercise.

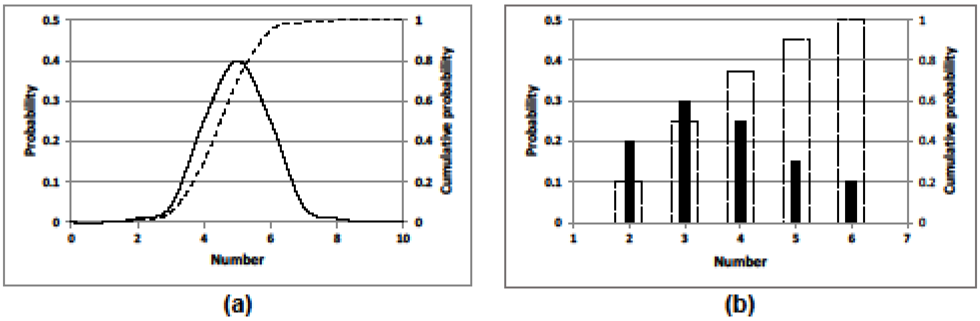


Figure 30 - Distribution types: (a) Continuous; (b) Discrete.

E1.2 Sample Mean and Sample Standard Deviation

It is assumed that the data is a sample from a larger population. When each value has the same probability, the mean of the sample is calculated as:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

The corresponding sample standard deviation is calculated as:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Where the values have different probabilities of occurring, then the sample mean is calculated as:

$$\bar{x} = \sum_{i=1}^{n} p_i x_i$$

The corresponding sample standard deviation is calculated as:

$$s = \sqrt{\sum_{i=1}^{n} p_i (x_i - \bar{x})^2}$$

E2 Estimating Non-Parametric Distributions

In this subsection techniques for fitting non-parametric distributions to data are described. A first order fitting is when only the variability is estimated, while a second order fitting also includes an estimate of the uncertainty.

E2.1 Continuous Random Variables

Where the data set is not too large, it is often sufficient to use a cumulative frequency plot of data points to define the data's probability distribution. The process is as follows:

1. Rank the data in ascending order between the minimum and maximum values;
2. Subjectively determine a minimum and maximum for the non-parametric distribution, noting that these two values will generally be beyond the range of the actual data;
3. Calculate the cumulative probability for each sequential data point as:

$$F(x_i) = \frac{i}{n+i}$$

Where i is the rank of the ascending data points and n is the number of data points.

i	x_i	$F(x_i)$
0	0	0,00
1	2,1	0,05
2	4,4	0,11
3	5,3	0,16
4	7,3	0,21
5	8,3	0,26
6	9,6	0,32
7	9,8	0,37
8	11,4	0,42
9	12,2	0,47
10	14,4	0,53
11	15,6	0,58
12	17,6	0,63
13	19,8	0,68
14	21,1	0,74
15	23,9	0,79
16	26,8	0,84
17	33,9	0,89
18	38	0,95
19	45	1,00

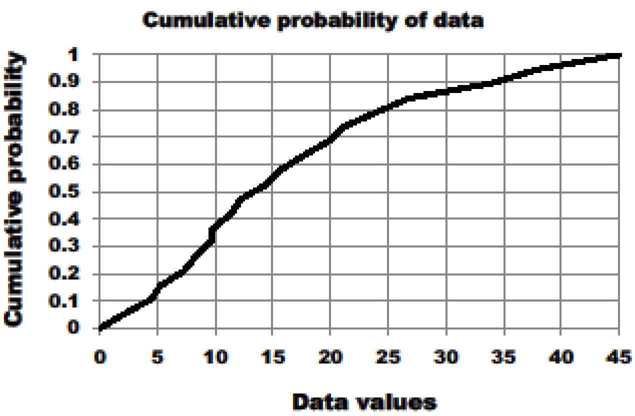


Figure 31 - Fitting a continuous non-parametric distribution to data using a CDF (based on data from Fig. 10.3, p. 270 in Vose (2008))

It can be seen in **Error! Reference source not found.** that a minimum value of $x_0 = 0$ and a maximum value of $x_{n+1} = 45$ have been added at each end of the range of the $n = 18$ sequential data points. The mean of the sample is calculated as $\bar{x} = 15.6$ and the sample standard deviation as $s = 10.1$.

If the dataset is large, the procedure described above can be impractical. In the latter case, the data are batched into "bins", which correspond to bars in a histogram.

Data					
Histogram bars		Midpoint	No.	$f(x_i)$	$F(x_i)$
0	20	10	0	0	0
20	40	30	4	0,000905	0,0181
40	60	50	25	0,0056561	0,1312
60	80	70	45	0,010181	0,3348
80	100	90	44	0,0099548	0,5339
100	120	110	32	0,0072398	0,6787
120	140	130	26	0,0058824	0,7964
140	160	150	11	0,0024887	0,8462
160	180	170	10	0,0022624	0,8914
180	200	190	10	0,0022624	0,9367
200	220	210	5	0,0011312	0,9593
220	240	230	6	0,0013575	0,9864
240	260	250	2	0,0004525	0,9955
260	280	270	1	0,0002262	1,0000
280	300	290	0	0	1,0000
		Σ	221		

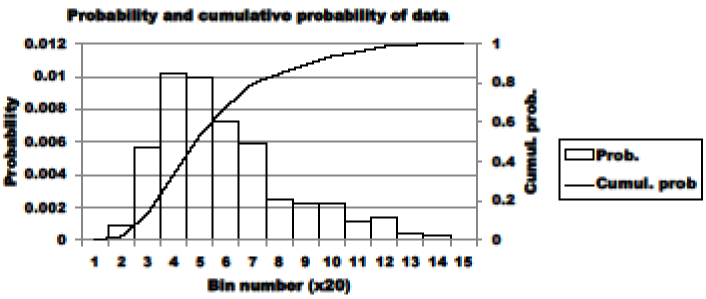


Figure 32 - Fitting a continuous non-parametric distribution to data using a CDF (based on data from Fig. 10.4, p. 271 in Vose (2008))

In the example shown in **Error! Reference source not found.**, there are 221 data points which are allocated into 15 "bins" covering the range from 0 to 300, i.e., a range in value of 20 per bin or histogram bar. It can be seen from the tabulated data in **Error! Reference source not found.** that the actual values are between 20 and 280. The frequency for each bin is simply the number of values per bin divided by the total sample size, n. It should also be noted that the data in **Error! Reference source not found.** have been plotted using the midpoint of each bin/bar.

For the data sample presented in **Error! Reference source not found.**, the sample mean is estimated to be $\bar{x} = 107{,}8$ and the sample standard deviation, $s = 49{,}1$. These statistics are described as being "estimated" since they are not based on the actual 221 data values, but rather the simplifying assumption is made that the average value of each bin is the midpoint value of the bin.

E3 Estimating Parametric Distributions

In this subsection techniques for fitting parametric distributions to data are described. Parametric distributions are required, for example, as input for Monte Carlo simulations, where each simulation will sample randomly from each applicable input distribution. The most common way of estimating parametric distributions is to use one of the readily available software packages that are designed for this purpose.

E3.1 Triangular Distribution

The triangular distribution is a parametric distribution that is widely used by risk analysts, due to its simplicity, its flexibility, and its ease of use. It is used as a rough modelling tool where it is possible to estimate the range and most likely value. The distribution consists of a triangular shape that is defined by three input parameters; the minimum value, the mode, and the maximum value.

The statistical properties of the triangular distribution are derived from its geometry, as follows:

$$f(x) = \frac{2(x - \min)}{(mode - \min)(max - min)} \quad if\ min \le x \le mode$$

$$f(x) = \frac{2(max - x)}{(max - min)(max - mode)} \quad if\ mode < x \le max$$

$$F(x) = 0 \quad if x < min$$

$$F(x) = \frac{(x - min)^2}{(mode - min)(max - min)} \quad if\ min \le x \le mode$$

$$F(x) = 1 - \frac{(max - x)^2}{(max - min)(max - mode)} \quad if\ mode < x \le max$$

$$F(x) = 1 \quad if max < x$$

$$\bar{x} = \frac{min + mode + max}{3}$$

$$variance = \frac{min^2 + mode^2 + max^2 - min \cdot mode - min \cdot max - mode \cdot max}{18}$$

In **Error! Reference source not found.** the data from **Error! Reference source not found.** has been plotted as a non-parametric PDF (dashed line) and then a triangular parametric distribution has also been overlaid, as an approximation of the non-parametric distribution that had been previously fitted to the data, with the three input parameters of $min = 10$, $mode = 70$, and $max = 290$.

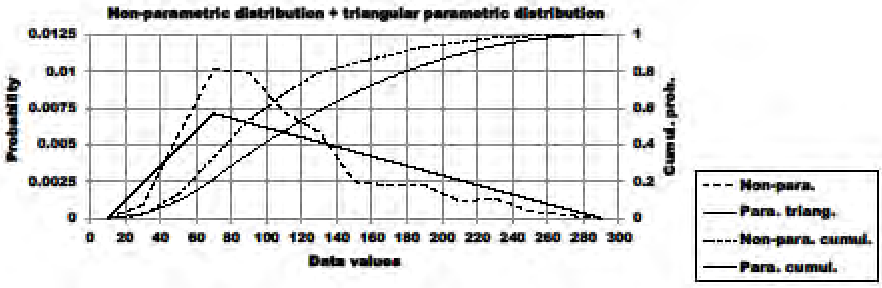


Figure 33 - Non-parametric PDF plus triangular parametric distribution

The mean for this parametric triangular distribution is calculated as $\bar{x} = 123{,}3$ and the standard deviation, $s = 60{,}2$. This compares to calculated values for the non-parametric distribution fitted to the data of a sample mean $\bar{x} = 107{,}8$ and the sample standard deviation, $s = 49{,}1$.

Bibliography

BS 7974. Application of fire safety engineering principles to the design of buildings. Code of practice. British Standards Institution, 2001.

BS 9999. Code of practice for fire safety in the design, management and use of buildings: British Standards Institution, 2008.

The European Parliament and Council, Council Directive 2008/114/EC of 8 December 2008 on the Identification and Designation of European Critical Infrastructures and the Assessment of the Need to Improve Their Protection.

The European Parliament and Council, Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 Laying Down Harmonised Conditions for the Marketing of Construction Products and Repealing Council Directive 89/106/EEC.

Frank, K., Gravestock, N., Spearpoint, M., Fleischmann, C. (2013). A Review of Sprinkler System Effectiveness Studies. *Fire Science Reviews, 2*(6). doi:10.1186/2193-0414-2-6.

Frantzich H. Time For Escape. Tid För Utrymning Vid Brand [In Swedish] Statens Räddningsverk, 2001.

Inter-jurisdictional Regulatory Collaboration Committee (IRCC) (2010). Performance-Based Building Regulatory Systems - Principles and Experiences. B. Meacham, Inter-jurisdictional Regulatory Collaboration Committee (IRCC).

Karlsson, B, and Quintiere, J. G. Enclosure Fire Dynamics. CRC Press, Boca Raton, FL, USA, 2000.

Law M. Heat radiation from fires and building separation, Fire Research Station, UK, 1963.

NFPA 101. Life safety code, National Fire Protection Association, 2012.

NFPA 204M . Guide for Smoke and Heat Venting, National Fire Protection Association, 1985.

NFPA 1720. Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Volunteer Fire Departments, National Fire Protection Association, 2014.

Nilsson, M., Johansson, N., and van Hees, P. A New Method for Quantifying Fire Growth Rates Using Statistical and Empirical Data – Applied to Determining the Effect of Arson, Fire Safety Science-Proceedings of the Eleventh International Symposium, International Association for Fire Safety Science, pp. 517-530, 2014. DOI: 10.3801/IAFSS.FSS.11-517.

NKB 1994:07. Funktionsbestemte brandkrav og teknisk vejledning for beregningsmæssig eftervisning. Del 1 og 2 [in Norwegian]. Nordiska kommittén för byggbestämmelser, NKB. Brandutskottet. 1994.

NS 3901.E. Requirements for risk assessment of fire in construction works, 2012.

Nystedt F. Verifying Fire Safety Design in Sprinkled Buildings, Report 3150, Department of Fire Safety engineering, Lund University, 2011.

Nystedt F. Case Studies on the Verification of Fire Safety Design in Sprinklered Buildings, Lund University, 2012.

Nystedt F. Östman B., Tekniska byten i sprinklade byggnader – Fallstudier [in Swedish]. SP Rapport 2012:33, SP Technical Research Institute of Sweden, 2012.

NZFSC, 2008. *Effectiveness of fire safety systems for use in quantitative risk assessments, NZFSC Research Report Number 89*. Wellington: New Zealand Fire Service Commission.

Rahikainen, J, Keski-Rahkonen, O., The Ignition Frequency of Structural Fires in Different Premises in Finland, Fire Technology 40, p.335-353, 2004.

Ramachandran, G., and Charters, D. Quantitative Risk Assessment in Fire Safety, Spon Press, London, Oxon, England, 2011.

Thureson, P., Sundström, B., Mikkola, E., Bluhme, D., Steen Hansen, A., Karlsson, B., The use of fire classification in the Nordic countries – Proposals for harmonization, 2008, SP REPORT 2008:29. SP Fire Technology, Sweden.

Tillander, K (2004) Utilisation of statistics to assess fire risks in buildings. Department of Civil and Environmental Engineering, Helsinki University of Technology, VTT Publications 537.

Trbojevic, V.M., Risk Criteria in EU, ESREL'05, Poland, 27-30 June 2005.

Vose, D. Risk Analysis – A Quantitative Guide (3rd ed.), John Wiley & Sons, Chichester, West Sussex, England, 2008.

VROM, 2005. *Methods for determining and processing probabilities, Publication series on dangerous goods 4 (PGS 4)*. The Hague, Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieu (VROM) (Ministry of Housing, Spatial Planning and the Environment).

Wolski, A., et. al., Accomodating perceptions of risk in performance-based building fire safety code development, Fire Safety Journal 24 (2000) 297-309

Further reading

Angerd M., and Frantzich H., The use of uncertainty analysis in performance based design. In: Proceedings of the 4th International Conference on Performance-Based Codes and Fire Safety Design Methods, Melbourne, Australia, 20-22 March 2002, pp. 179-189, Bethesda, USA, Society of Fire Protection Engineers.

Bryan J L. Behavioural Response to Fire and Smoke, chapter 3-11, SFPE Handbook of Fire Protection Engineering, 4th edition, Society of Fire Protection Engineers, US, 2008.

BRE. Design Fires Database, v. 1.2, Building Research Establishment, 2002.

Bukowski R., Budnick E. and Scemel C., Estimates of the Operational Reliability of Fire Protection Systems In: Proceedings 3rd International Conference on Fire Research and Engineering (ICFRE3). SFPE, NIST and IAFSS. October 4-8, 1999, Chicago, IL, Society of Fire Protection Engineers, Boston, MA, 87-98 pp, 1999, 2002.

CEN\TR 12101-5, Smoke and heat control systems - Part 5: Guidelines on functional recommendations and calculation methods for smoke and heat exhaust ventilation systems.

EN 12845, Fixed firefighting systems – Automatic sprinkler systems – Design, installation and maintenance.

EN 13501-1, Fire classification of construction products and building elements - Part 1: Classification using data from reaction to fire tests.

EN 13501-2, Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services.

Fire Code Reform Centre. Fire performance of wall and ceiling lining materials, CRC Project 2 – Stage A, Fire Performance of Materials, Project Report FCRC – PR 98-02, Fire Code Reform Research Program, FCRC, Sydney, 1998.

Hietaniemi J., Mikkola E. Design fires for fire safety engineering, VTT Working papers 139, 2010.

Holborn P, Nolan P and Golt J. An analysis of fire sizes, fire growth rates and times between events using data from fire investigations. Fire Safety Journal. 2004; Vol. 39: 481–524.

INSTA 900-1, Residential sprinkler systems - Design, installation and maintenance.

INSTA 900-2, Residential sprinkler systems - Part 2: Requirements and test methods for sprinklers and their accompanying rosettes.

ISO/TR 13387-1, Fire safety engineering – Part 1: Application of fire performance concepts to design objectives.

ISO/TR 13387-2, Fire safety engineering – Part 2: Design fire scenarios and design fires.

ISO/TR 13387-3, Fire safety engineering – Part 3: Assessment and verification of mathematical fire models.

ISO/TR 13387-4, Fire safety engineering – Part 4: Initiation and development of fire and generation of fire effluents.

ISO/TR 13387-5, Fire safety engineering – Part 5: Movement of fire effluents.

ISO/TR 13387-6, Fire safety engineering – Part 6: Structural response and fire spread beyond the compartment of fire origin.

ISO/TR 13387-7, Fire safety engineering — Part 7: Detection, activation and suppression.

ISO/TR 13387-8, Life safety – Occupant behaviour, location and condition.

ISO 13571, Life threatening components of fire – Guidelines for estimation of time to compromised tenability in fires.

ISO/TR 16738, Fire safety engineering – Technical information on methods for evaluating behaviour and movement of people.

ISO 19706, Guidelines for assessing the fire threat to people.

ISO 23932, Fire safety engineering – General.

Lundin, J. (2005). Safety in Case of Fire – The Effect of Changing Regulations. Department of Fire Safety Engineering, Lund University.

NS 3901. Requirements for risk assessment of fire in construction works. Krav til risikovurdering av brann i byggverk (in Norwegian). Norwegian Standard, 2012.

NFPA 130. Standard for Fixed Guideway Transit and Passenger Rail Systems. National Fire Protection Association, 2010.

Raiffa, H. Decision Analysis: Introductory Lectures on Choices Under Uncertainty. McGraw-Hill College ,1997.

Schüller, J. C. H, Committee for the Prevention of Disasters, Methods for Determining and Processing Probabilities: Red Book, 4th edition, 2005.

SFPE Engineering Guide to Human Behavior in Fire, Society of Fire Protection Engineers, 2003.

SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition, Society of Fire Protection Engineers, US, 2007.

SFPE Handbook of Fire Protection Engineering, 5th edition, Society of Fire Protection Engineers, US, 2015.

Statens Bygningstekniske Etat. Prosjektering – brannsikkerhetsstrategi. Rettleiing for tillsyn i byggjesaker [in Norwegian], HO-3, 2007.

Staffansson, L. Selecting Design Fires, Report 7032, Department of Fire Safety engineering, Lund University, 2010.

8 Appendix D: Control in the building process

Date: 2017-05-14

Fire Safety Engineering –

Control in the Building Process

Contents

Page

Introduction ... iv

1 Scope ... 1

2 Normative references ... 2

3 Terms and definitions ... 3

4 The planning and building process ... 8
4.1 General ... 8
4.2 Planning and design phase ... 8
4.3 Construction phase ... 9
4.4 Operation and maintenance phase ... 10
4.5 Control and review of fire safety aspects ... 10

5 Fire safety design within the building process ... 11
5.1 General ... 11
5.2 The fire safety design process ... 11
5.3 Documentation and communications ... 13

6 Review and control in the planning and design phase ... 15
6.1 General ... 15
6.2 Purpose ... 15
6.3 Scope of a peer review ... 15
6.4 Details of a peer review ... 16
6.5 Choice of a peer reviewer ... 19
6.6 Conduct of a third-party peer review ... 20
6.7 Report of a peer review ... 20
6.8 Review and control of other disciplines´ documentation ... 21

7 Construction phase ... 22
7.1 General ... 22
7.2 Inspection and testing plan (ITP) ... 22
7.3 Procedure ... 22
7.4 Integrated system testing ... 25
7.5 Verification of compliance statement ... 26
7.6 As-built documentation ... 26
7.7 Fire prevention on construction sites ... 26

8 Operation and maintenance ... 27
8.1 General ... 27
8.2 Procedure ... 27
8.3 Operations and maintenance ... 28
8.4 Facility changes ... 28

Annex A (Informative) Nationally determined parameters ... 30

Annex B (Informative) Details of full control of the fire safety design documentation (fire safety strategy) ... 31

Annex C (Informative) Example of a checklist for control of others disciplines´ construction documents ... 33

Annex D (Informative) Example of an inspection and testing plan for the construction phase ... 35

Annex E (Informative) Example of a quality checklist for operation and maintenance ... 38

Annex F (Informative) The control systems within the Nordic countries ... 40

Bibliography ... 42

Further Reading ... 43

Introduction

Using a performance based approach in fire safety engineering, compliance with fire safety regulations can be demonstrated, either by the use of pre-accepted solutions that are selected by the local building authorities, or by using fire safety engineering methods.

Fire safety engineering methods can be used to demonstrate fire safety in two ways:

1. The use of comparative fire safety engineering methods in order to compare a design to pre-accepted solutions;

2. The use of fire safety engineering methods for the evaluation of a design against absolute criteria.

This Technical Report provides guidance about review and control of fire safety design in the building process. It is based on previous Nordic work (NKB, 1994), work conducted by ISO TC92/SC4 on fire safety engineering and SFPE Guidelines (SFPE, 2007 and 2009).

Fire Safety Engineering - Control in the Building Process

1 Scope

This Technical Report provides guidance for when and how to conduct review and control within the field of performance based fire safety design as a part of the overall building process.

The aim of the process that has been developed is to facilitate verification of building solutions including innovative and sustainable solutions and to harmonize the process for control within the field of fire safety engineering in the Nordic countries.

The focus for the process is on a general level for review and control, independent of national legal matters in the Nordic countries, with a primary focus on technical issues within fire safety engineering. But the process will also, to some extent, give guidance on how the fire safety design process, including engineering approaches, can be a normal part of the overall control and review of the building process and define eligibility criteria for those doing the control.

This specification includes:

- when to perform controls within the building process and within the specific fire safety design process;
- how to perform the controls;
- why the controls should be performed and their purpose.

This specification is intended to be used as a reference document for building authorities and for use in connection with regulations by consultants, local authorities and stakeholders in the building industry.

(1) NOTE: Limitations regarding the use of this specification may be set in the National Annex.

The user of this specification must verify that the described processes are valid to the relevant design situation and that national requirements are met. It does not detail all the engineering knowledge required for the building fire safety design.

2 Normative references

The following referenced documents are recommended for application of this document. For dated references, only the cited edition applies. For undated references, the latest edition of the reference document, including any amendments, applies.

EN-ISO 13943, Fire safety – Vocabulary

INSTA/TS 950 Fire safety engineering – Comparative method to verify fire safety design in buildings

ISO 16730, Fire safety engineering – Assessment, verification and validation of calculation methods

3 Terms and definitions

For the purpose of this document, the following terms and applicant definitions apply.

3.1
Acceptance criteria
defined criteria or defined level of safety to fulfil when designing the fire safety independent of used method.

[SOURCE: EN-ISO 13943]

3.2
Approving body
the individual or institution that is authorised to approve the design of a building. Depending on the national legislation, the approving body may be local or national authorities or privately held third party consultants with the necessary notification. Alternatively, the consulting companies responsible for designing the building may be authorised to "approve" their own work.

3.3
Authority having Jurisdiction (AHJ)
an organization, office, or individual responsible for approving designs, equipment, installations, materials and/or procedures.

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.4
Building material/product supplier
manufacturers or distributors who provide raw materials, semi-manufactures or entire building components for the construction of the building. Usually, they provide the documentation for the various physical properties.

3.5
Building owner
the building owner is an individual, a company or an institution that initiates the design and construction of a building. The objective may be to use the building for their own use, to let it out or to sell it upon construction completion. Usually, the building owner owns the building site. When the building is let out, the responsibility for maintenance of the fire safety measures in the building may stay with the building owner or it may be assigned to the tenant (building user).

3.6
Building user
the building user is one or several individuals, companies or institutions that use the building for its intended use. The building user may be responsible for maintenance of the fire safety measures in the building.

3.7
Concept design
generally takes place after feasibility studies and options appraisals have been carried out and a project brief has been prepared. The concept design represents the design team's initial response to the project brief.

3.8
Contractor
the company that is responsible for the physical construction of a building. A *turnkey contractor* is also responsible for the design of the building. The contractor company may hire *sub-contractors* for execution of tasks where they do not themselves hold the necessary resources or competencies. Usually, the contractor or sub-contractor is obliged to procure all technical documentation for building products and on-site control and hand it over to the building owner.

3.9
Design fire scenario

specific fire scenario on which a fire safety engineering analysis is conducted.

(1) NOTE: Amended from EN-ISO 13934

3.10
Design fire
quantitative description of assumed fire characteristics within the design fire scenario.

(2) NOTE: It is, typically, an idealized description of the variation with time of important fire variables such as heat release rate, flame spread rate, smoke production rate, toxic gas yields and temperature.

[SOURCE: EN-ISO 13934]

3.11
Design objective
description of the performance benchmark against which the predicted performance of a design is evaluated.

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.12
Design review
overall review process during the design. See also "Peer review"

(3) NOTE: Amended from SFPE Guidelines for Peer Review in the Fire Protection Design Process.

3.13
Detailed design
process of taking on and developing the approved concept design.

3.14
Fire Scenario
set of conditions that defines the development of fire and the spread of combustion products throughout a building or portion of a building, the reaction of people to fire, and the effects of combustion products.

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.15
Fire safety design
design of fire safety selected for implementation from the successful trial design.

(4) NOTE: Amended from SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition.

3.16
Fire safety engineer
part of the design team and is engaged either as a sub-consultant or directly by the contractor or building owner.

(5) NOTE: The individual responsibility to ensure a sufficient level of fire safety may be set in the National Annex.

3.17
Fire safety engineering
application of engineering methods based on scientific principles to the development or assessment of designs in the built environment through the analysis of specific fire scenarios, or through the quantification of risk for a group of fire scenarios.

[SOURCE: EN-ISO 13943]

3.18
Fire safety design brief
summarizing the agreed upon performance criteria and methods that will be used to as a basis for the fire safety design.

(6) NOTE: Amended from SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition.

3.19
Fire safety design documentation
describing the fire safety strategy and includes both the fire safety design brief and the complete verification of sufficient safety due to what level of fire safety engineering aspects been verified.

(7) NOTE: Amended from SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition.

3.20
In-house peer-reviewer
an individual from the same company as the fire safety engineer who is responsible for the internal review (quality assurance) of the fire safety strategy and the detailed design before communicating the result to other stakeholders.

3.21
Other technical consultants
the individuals or companies who are responsible for the design disciplines other than fire safety, e.g. HVAC, electrical, structural, architectural, acoustics etc. Often, there is a high degree of interdependency with the work performed by the fire safety engineer.

3.22
peer review
the evaluation of the conceptual and technical soundness of a design.

[SOURCE: SFPE Guidelines for Peer Review in the Fire Protection Design Process]

3.23
Performance-based design
design that is engineered to achieve specified objectives and acceptance criteria.

[SOURCE: EN-ISO 13934]

(8) NOTE: Performance-based design may include simple qualitative verification methods or more complex methods such as deterministic or risk-based verification methods. Performance-based design of fire safety is referred to as fire safety engineering.

3.24
Performance based regulation (Code)
a document that expresses requirements for a building or building system, in terms of societal goals, functional objectives and performance requirements, without specifying a single means for complying with the requirements. Pre-accepted solutions and verification methods for demonstrating compliance with code requirements shall be referenced by the code.

[SOURCE: IRCC – Inter-Jurisdictional Regulatory Collaboration Committee]

3.25
Performance criteria
criteria that are stated in engineering terms, against which the adequacy of any developed trial designs will be judged.

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.26
Pre-accepted solution(s)
a solution that has been determined by the authority having jurisdiction (AHJ) to comply with the objectives set in the fire safety requirements.

(9) NOTE: The definition may vary between different countries. Other terms are for example deemed-to-satisfy solutions, acceptable solutions, prescriptive solutions.

[SOURCE: INSTA/TS 950]

3.27
Prescriptive-Based Design Option
option within a code whereby compliance is achieved by demonstrating adherence to specified construction characteristics, limits on dimension, protection systems, or other features.

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.28
Project Scope
identification of the range of extent of the design matter being addressed, including any specific limits of a performance-based design.

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.29
Quality assurance
process to ensure right quality during an internal quality control review.

3.30
Quality design review
first step in the fire safety design process with focus to conduct an initial risk screening to identify possible ways in which a fire hazard might arise within the fire safety objectives.

3.31
Stakeholder
who has a share or an interest, as in an enterprise.

(10) NOTE: Example stakeholders are as follows:

- Building owner
- Building manager
- Design team
- Authorities having jurisdiction (AHJs)
    - Fire
    - Building
    - Insurance
- Accreditation agencies
- Construction team
    - Construction manager
    - General contractor
    - Subcontractors
- Tenants

- Building operations and maintenance
- Emergency responders
- Peer reviewer

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.32
Third party peer reviewer
an individual who is independent of the fire safety consultant and the building project and conducts the peer review.

3.33
Trial Design
fire safety system design Intended to achieve the stated fire safety goal and expressed in terms that make it possible to assess whether the fire safety goals have been achieved.

[SOURCE: SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition]

3.34
Verification methods
different methods that prescribe one way to comply with the building requirements.

(11) NOTE: Verification methods may include: qualitative arguments, calculation methods, using recognized analytical methods and mathematical models; laboratory tests, using tests (sometimes to destruction) on prototype components and systems; tests-in-situ, which may involve examination of plans and verification by test, where compliance with specified numbers, dimensions or locations is required (non- destructive tests, such as pipe pressure tests, are also included).

[SOURCE: IRCC – Inter-Jurisdictional Regulatory Collaboration Committee]

(12) NOTE: Verification of computer models is defined differently and is considered as process of determining that a calculation method implementation accurately represents the conceptual description of the calculation method and the solution to the calculation method.

[SOURCE: ISO 13934]

4 The planning and building process

4.1 General

The design and construction process can generally be described as in Figure 1 with different stages and steps.

For the different stages in the process the need for different kinds of control and review varies depending on the complexity of the project. A combination of the different types of control is often the most effective in each step.

In Annex F, a short description of each Nordic country's building process is presented.

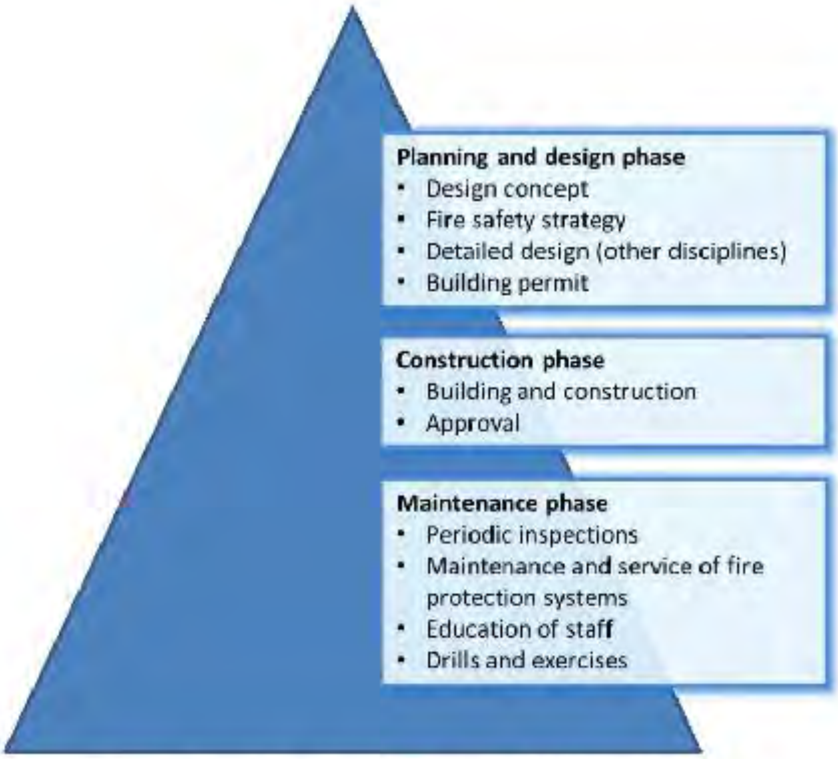


Figure 1 – Description of the different steps within the building process.

4.2 Planning and design phase

4.2.1 Design concept and fire safety strategy

In this phase the overall fire safety strategy and design concept is laid down. Key players in this stage are the stakeholders or owner of the building and the architect. It is important to define all stakeholders at this stage e.g. if it's possible at this stage the owner also needs to communicate with any future tenants and take their needs and demands into consideration. But also, other stakeholders when it comes to fire issues it is important for the fire safety designer to be involved in the process as early as possible. The main issues in this stage are:

- What is the general purpose and use of the building? Are there any restrictions in the buildings use, number of persons, type of activities, fire load, etc.?;
- What are the main features, or main restrictions of the building, main areas for movement of people, are there any open spaces and atriums, etc.?;
- What are the building design parameters that affect fire safety design (e.g., structural materials)?;
- Whether the building should be designed with fire safety engineering methods of any kind or mainly pre-accepted solutions.

After these questions are answered a general fire safety design brief can be produced (see section 5.3).

4.2.2 Detailed design

In this step the actual design process and detailed solutions are chosen. In this phase the key players are not only the owner of the building and the architect but also the entire consultant team, such as electrical, structural and water and heating consultants.

It is important to create a strong team and to explain the main features of the fire safety strategy to the team as clearly as possible. Since the drawings and documents produced by the other technical consultants are the ones that are used for construction, it is essential to make sure that the fire safety solutions from the fire safety design documentation are incorporated into these drawings and documents.

4.2.3 Building permit

In order to start the actual building activities a permit from the local authority is normally required. This could differ between different countries. In some countries you would need a special building permit and then another permit to start the actual construction activities. These two permits could also be in the same decision from the building authority.

If the permits are divided into two steps the building permit controls compliance with general plans for the local area, height and architectural issues such as facade color and so on. The starting permit is then required to control the technical requirements and the builder's control and inspection scheme.

Whether the building authority checks the specific design, or just the building organization's competence and control system, varies in different countries. In some countries, the fire department could also check the fire safety design documentation as a separate decision from the building authority.

4.3 Construction phase

4.3.1 Building and construction

In the actual construction phase it should be noted that the fire safety design specifications are integrated in design documents of other technical disciplines. The documents and drawings from other technical disciplines are used as a basis to do the actual construction works. However during the construction phase it is common that alterations are made in the building's layout, in technical solutions or in details of technical systems. In that case it's important to be able to go back to the fire safety design documentation and redesign a solution that fulfills the fire safety concept.

4.3.2 Approval

In order for the building be occupied and used, some kind of decision from the local building authority is normally required. This could be based on checking if the builder's inspection scheme has been followed and by onsite inspections by the building authority. Often a combination of the two is used and to ensure that the fire related aspects are fulfilled is usually one of the most important aspects for the approval.

4.4 Operation and maintenance phase

4.4.1 Service lifespan

This step is not part of this Technical Report. However, when designing the building, it is of great importance to consider how the fire safety systems should be maintained during the building's service life. The key players in this phase are the owner of the building, the tenants and the real estate manager, if different from the owner. The most important step is to pass on the knowledge of the fire safety systems, how they work and how they should be maintained, to the owner and the manager of the building. If this is not done there is a risk that the fire safety features will not work in a future, and lead to a real incident.

4.5 Control and review of fire safety aspects

A schematic proposal of the review and control process for fire safety aspects within the overall building process is described in Figure 2.

(10) NOTE: national determined process for review and control may be set in the National Annex.

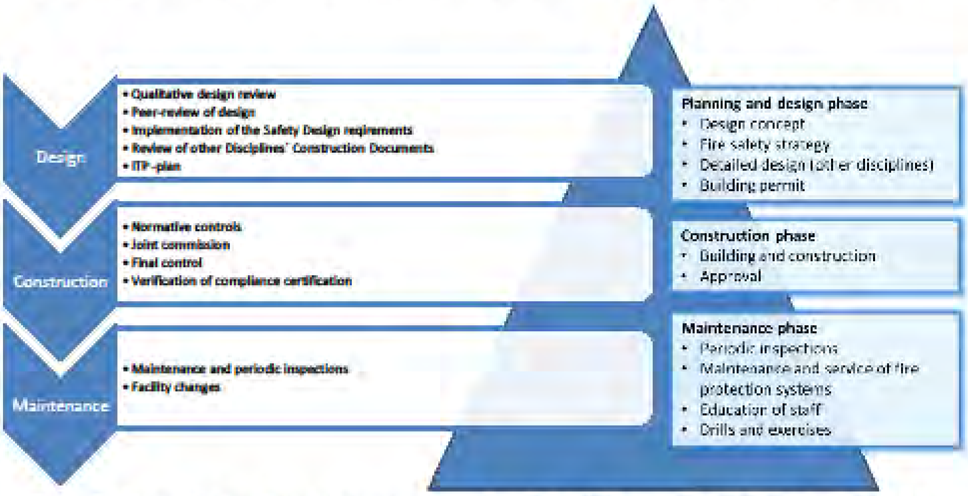


Figure 2 - The review and control process regarding fire safety aspects within the overall building process.

The different steps within the planning and design phase are described in more detail in chapter 5 and6. The different steps within the construction phase are described in chapter 8. Some overall description regarding operational and maintenance aspects that may be important to consider, ensuring the fire safety within the building over time, are described further in chapter 9.

5 Fire safety design within the building process

5.1 General

Two principal methods are available when designing fire safety in a building within the Nordic countries:

- Prescriptive-based design based on pre-accepted solutions;
- Design based on fire safety engineering methods, i.e. analytical design.

Prescriptive-based design uses general recommendations and approved documents to establish the fire safety design. The design method does not allow for deviations from these recommendations and documents, and the need for verification is limited. The designer must ensure that the proposed building and its intended use fits in the regulatory system for prescriptive design by considering architectural design, occupant characteristics and relevant fire safety objectives. A number of design alternatives are usually allowed within the scope of prescriptive-based design and these are well described in the general recommendations in the building regulations.

If there is a need for deviations from the prescribed solutions, the engineer needs to show that the proposed design meets all relevant performance criteria by verification methods, which can be fire safety engineering methods. The objective for the designer is now to verify that the building meets the performance criteria. The key point is to show that the regulatory requirements are met.

The fire safety features of a building are commonly designed by a mixture of pre-accepted solutions and those verified by the use of fire safety engineering methods. Due to this, there is a need for an overall understanding of the fire safety design process and the relationship between the pre-accepted solutions and the fire safety engineering design approach(i.e. analytical design), through the planning and design phase within the overall building process.

5.2 The fire safety design process

A number of publications such as NKB (1994), BS 7974 (2001), and SFPE (2007) provide information about the fire safety design process. These guidelines are primarily focusing on fire safety engineering principles. The guidelines do not describe the relationship between the pre-accepted solutions and fire safety engineering approach. Due to this, the process described by Nystedt (2012) is a more realistic way of describing the process within the Nordic countries, as outlined in Figure 3.

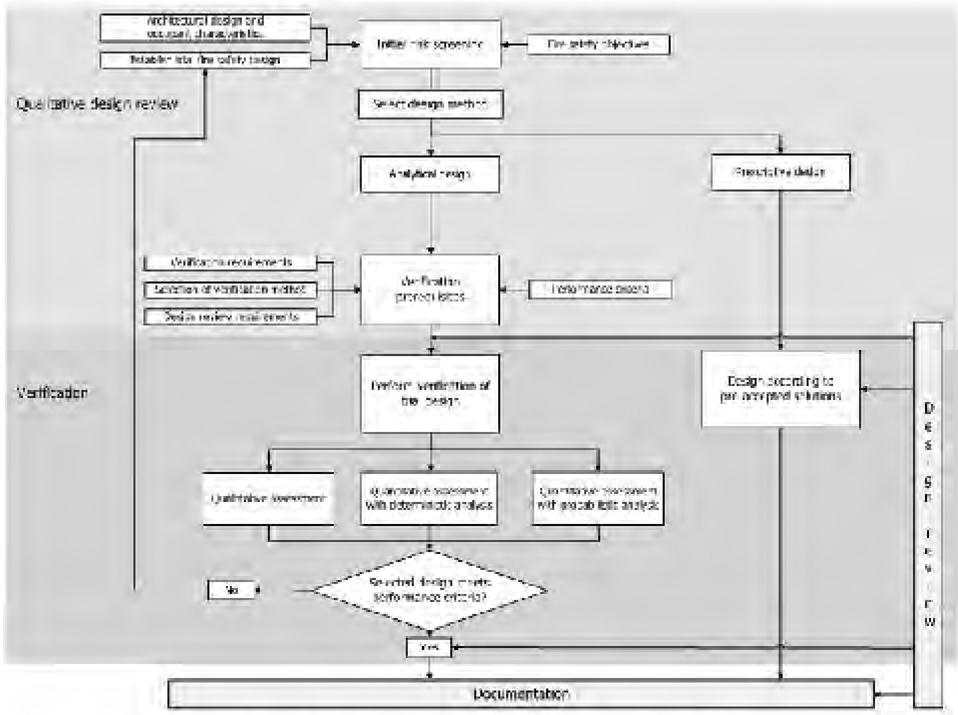


Figure 3 - Fire safety design based on Nystedt (2012).

The design process in Figure 3 is discussed in more detail in the following sub-sections, with emphasis on the qualitative design review, verification, design review and documentation. In chapter 6, there is a more in-depth presentation about design review, such as a peer-review during the planning and design phase.

5.2.1 Qualitative design review

The fire safety design process starts with the qualitative design review and the initial risk screening, which should be conducted no matter which principal design method (prescriptive-based or analytical) is selected at a later stage. The initial risk screening could vary in extent depending on the complexity of the building and its intended use as well as on the proposed deviations from prescriptive design. In INSTA/TS 950 there is an in-depth description about how to perform a qualitative design review within fire safety design.

If a pure prescriptive design solution is selected, the design process is finalized by describing relevant requirements and solutions in the fire safety design documentation. However, if there is a need (or demand) for a fire safety engineering approach, the design process continues by establishing fire scenarios and the prerequisites for verification. This work consists of an evaluation of the verification requirements, the selection of the verification method and the requirements for design review. The selection of measures to be included in the trial design should be made based on the prescribed design solution, in order to make sure that all necessary aspects of fire safety are being addressed.

5.2.2 Verification with fire safety engineering methods

There are a number of verification methods available to be used when evaluating a trial design and the selection of a method is dependent on which deviations from the prescribed solutions are proposed during the fire safety engineering procedure. Most of the methods are based on the use of risk equivalency. Naturally, all relevant performance requirements must be met in order to show sufficient safety and it is the roll of the designer to verify that the proposed design solution has equivalent safety. Nystedt (2011) outlines the following methods:

- Qualitative risk assessment;
- Quantitative assessment with deterministic analysis;
- Quantitative assessment with probabilistic analysis.

The selection of the verification method is mainly influenced by the following variables:

- Voluntarily or mandatory use of a fire safety engineering approach;
- The number of design alternatives compared to a pre-accepted design solution;
- The complexity and robustness of the trial fire safety design solution.
- Uncertainty analysis

(11) NOTE: Limitations regarding which methods to use for verification may be set in the National Annex.

5.2.3 Design review

Fire safety engineering design has a need for a more extensive design review than a design based entirely on pre-accepted solutions. Design reviews should be carried out throughout the whole design process and the demand for reviews should be established at an early stage in the process.

In order to ensure an effective design process, there is a need for a review of the design brief before the verification of the trial design is conducted (i.e., before performing the verification). A review at this early stage minimizes potential surprises (and major changes to the design) in a later stage of the process.

The degree of design review depends on the complexity of the proposed solutions and ranges from an in-house peer review check to the use of a third party peer-review. A proposed process for the design review is presented in chapter 6.

5.3 Documentation and communications

There is a need to document the verification as the process moves forward to a final fire safety design solution that will be communicated to other stakeholders within a project. The first document to be produced is the fire safety design brief, which could be finalized after the initial qualitative design review. The second document, often referred to as the fire safety design documentation, which describes the fire safety strategy and includes both the design brief and the complete verification of sufficient safety due to the level of fire safety engineering aspects that have been verified. Usually the requirements on the documentation follow the degree of fire safety design complexity and the choice of verification method.

Proper documentation of the fire safety design is critical to give a record of the whole process and highlight important aspects for the overall fire safety strategy, including both pre-accepted solutions and design based on fire safety engineering methods. Proper fire safety design documentation will also ensure that the different stakeholders involved understand what is necessary for the fire safety design implementation. It will also ensure that the design is implemented in the other design disciplines' construction documents, and ensure appropriate maintenance, and hence the continuity of the fire safety during a building's service life.

(12) NOTE: specific content in the fire safety design brief and/or fire safety design documentation may be set in the National Annex.

5.3.1 Fire safety drawings and models

Fire safety drawings or fire safety models (such as BIM-models) represent the results of the fire safety design from a graphically point of view. Detailed drawings or models should be a part of the fire safety documentation and at least include evacuation routes, construction features of fire safety measures (such as fire compartmentation and fire protection of load bearing construction), and locations of different fire safety devices such as emergency lightning, sprinklered areas and areas with fire alarm. If needed, specific aspects resulting from the fire safety engineering should also be highlighted on the fire safety drawings or model.

(13) NOTE: specific content on fire safety drawings or models or specific standards to follow may be set in the National Annex.

5.3.2 Communication with other stakeholders

The fire safety design documentation and drawings are useful tools for communication to better ensure understanding of the fire safety process for different stakeholders..

(14) NOTE: the role that different stakeholders have in the building process and the fire safety design process may be set in the National Annex.

6 Review and control in the planning and design phase

6.1 General

This chapter addresses the process for review and control in the planning and design phase of a fire safety design. The chapter addresses issues such as when to use a peer reviewer, the choice of reviewer, the scope of the review, the agreements needed, the documentation of the peer review, and other related details. It also describes the decisions that a stakeholder should make in establishing and conducting a peer review.

Peer review is a tool that can be used to help a stakeholder make decisions regarding the suitability of a design. Typically, a peer review is sought to provide a second opinion regarding the design's likelihood of achieving the stated objectives. However, other situations may also necessitate a peer review.

A peer review may be conducted on any or all components of a design, such as the conceptual approaches (trial design), application or interpretation of code requirements, the fire safety design brief and the fire safety verification. A peer review is to be performed by appropriately qualified individuals based upon a scope of work agreed upon by the stakeholders.

In the Nordic countries, the third-party peer review may be called third-party control or independent control. The in-house peer review may also be called internal design review.

This chapter is based on the SFPE Guidelines for Peer Review in the Fire Protection Design Process (2009) and the Guidelines for Independent Control from Direktoratet for byggkvalitet (2012), and is adjusted to fit the process in the Nordic Countries.

6.2 Purpose

The scope of the review is applicable for an in-house peer review as well as a third-party review. In addition, it can be used by the designer to assess his own work before it undergoes a peer review. It can also be used as a basis for surveillance performed by the local building authorities (or AHJs). The given guidance intends to work both from a regulatory peer-review (compliance with regulations), as well as from a technical peer review point of view.

(15) NOTE: specific content on of the peer review process may be set in the National Annex.

6.3 Scope of a peer review

The scope of the peer review may be a complete review of the entire fire safety design documentation, including compliance with applicable codes and standards and the appropriateness of the assumptions, engineering methods and input data used to support the design. Alternatively, the scope of the peer review may be limited to specific aspects of the design documentation, such as specific models or methods and their associated input data and conclusions drawn from the output data.

Agreement on the scope of the peer review should be achieved between the contracting stakeholder and the peer reviewer. The scope should be explicitly identified at the time of execution of the agreement to undertake the peer review. Any changes to the scope must be agreed to by both the contracting stakeholder and the peer reviewer.

The peer review should be limited to only the technical aspects of the design documentation. The peer review should not evaluate the education, experience or other personal aspects of the person or company that prepared the design.

The peer review should examine both the internal and external appropriateness of the design. External appropriateness considers whether the correct problems are being solved. Internal appropriateness considers whether the problems are solved correctly.

(16) NOTE: specific content regarding the scope of a peer review may be set in the National Annex.

6.3.1 Choosing the level of control

Not all construction projects require the same level of control. The choice of appropriate level must be based on the complexity of the building, the composition of occupants (number and physical capabilities) in the building and the complexity of the verification tools used.

Three levels of control were defined by Lundin (2001):

1. The individual in charge of the fire safety design and verification controls his/her own work;
2. In-house peer review;
3. Third-party peer review.

Table 1– Levels of peer review due to complexity.

Complexity of the construction	Composition of occupants[1]	Verification method				
			Analytical design			
		Pre accepted design	Simplified verification methods such as qualitative arguments, simple and well known hand calculation methods.	Normal Verification methods such as novel hand calculation methods	Verifications methods with the use of advanced simulation tools on normal applications and non-complex constructions	Verifications methods with the use of advanced simulation tools with unusual application and complex constructions
Simple	Low risk	1	1	2	2	2
	High risk	2	2	2	2	3
Medium	Low risk	2	2	2	2	3
	High risk	2	2	3	3	3
High	Low risk	2	2	3	3	3
	High risk	3	3	3	3	3

[1] *Low risk: Few occupants with good mobility, high risk: Large number of occupants or occupants with low mobility*

(17) NOTE: appropriate level for control may be set in the National Annex.

6.4 Details of a peer review

Whether the scope of the peer review is the complete documentation of a project or some specific aspect of it, the peer reviewer should consider the following, as appropriate to the design being reviewed:

- Performance criteria with their motivation;
- Acceptance criteria with their motivation;

- Assumptions made by the designer (e.g., design fire scenarios, material properties used in correlations or models.);

- Technical approach used by the designer;

- Choice of verification method;

- Appropriateness of models and methods used to solve the design problem and their verification and validation

- Applicable codes, standards and guidelines;

- Input data to the design problem and to the models and methods used;

- Appropriateness of recommendations or conclusions with respect to the results of design calculations;

- Uncertainty analysis

- Correctness of the execution of the design approach (e.g., no mathematical errors or errors in interpretation of input or output data).

(18) NOTE: specific content regarding the content of a peer review may be set in the National Annex.

(19)NOTE: for guidance regarding uncertainty analysis, see INSTA/TS 950 Fire safety engineering – Comparative method to verify fire safety design in buildings

For peer-review of specific technical disciplines (e.g., CFD-simulations, design of structural fire resistance or active fire safety systems) the reviewer is encouraged to seek specialised literature on agreed best practice for the relevant discipline, preferably, as product-specific as possible. See the chapter Further reading for further guidance on external reports.

6.4.1 Initiation of a peer review

The decision to initiate a peer review is typically made by a project stakeholder, whose interest may be based on safety, financial, environmental or cultural aspects. A peer review is often commissioned by an enforcement official; however, other stakeholders may also commission such a review. This decision usually follows the design development of a project and is occasionally a prescribed part of the design review and approval. A determination to initiate a peer review may be made by a stakeholder during a preliminary project meeting, when presented with a fire safety design brief.

Given that the use of a peer review may add time to the critical path of the design process, a stakeholder who wishes the advice of a peer reviewer should begin the process of identifying and contracting for the peer review as early as possible, but no later than at the design review and approval stage.

(20) NOTE: how to initiate a peer review may be set in the National Annex.

6.4.2 When to conduct a peer review

The decision as to whether or not to conduct a peer review is up to individual stakeholders or AHJ. The motivation may be a desire to have a better understanding of the quality, completeness or the scientific bases of the design. The decision to conduct a peer review may also be made by a stakeholder who has resource limitations and/or lack of competencies and wishes to bring in outside assistance to evaluate the fire safety features of the design. Another possible reason to initiate a peer review may be to provide additional quality assurance for the design.

(21) NOTE: when to conduct a peer review may be set in the National Annex.

It is recommended that a peer reviewer is involved at four different steps (internal design review) of the fire safety design process - see Figure 4. The scope of each review is described in Figure 5.

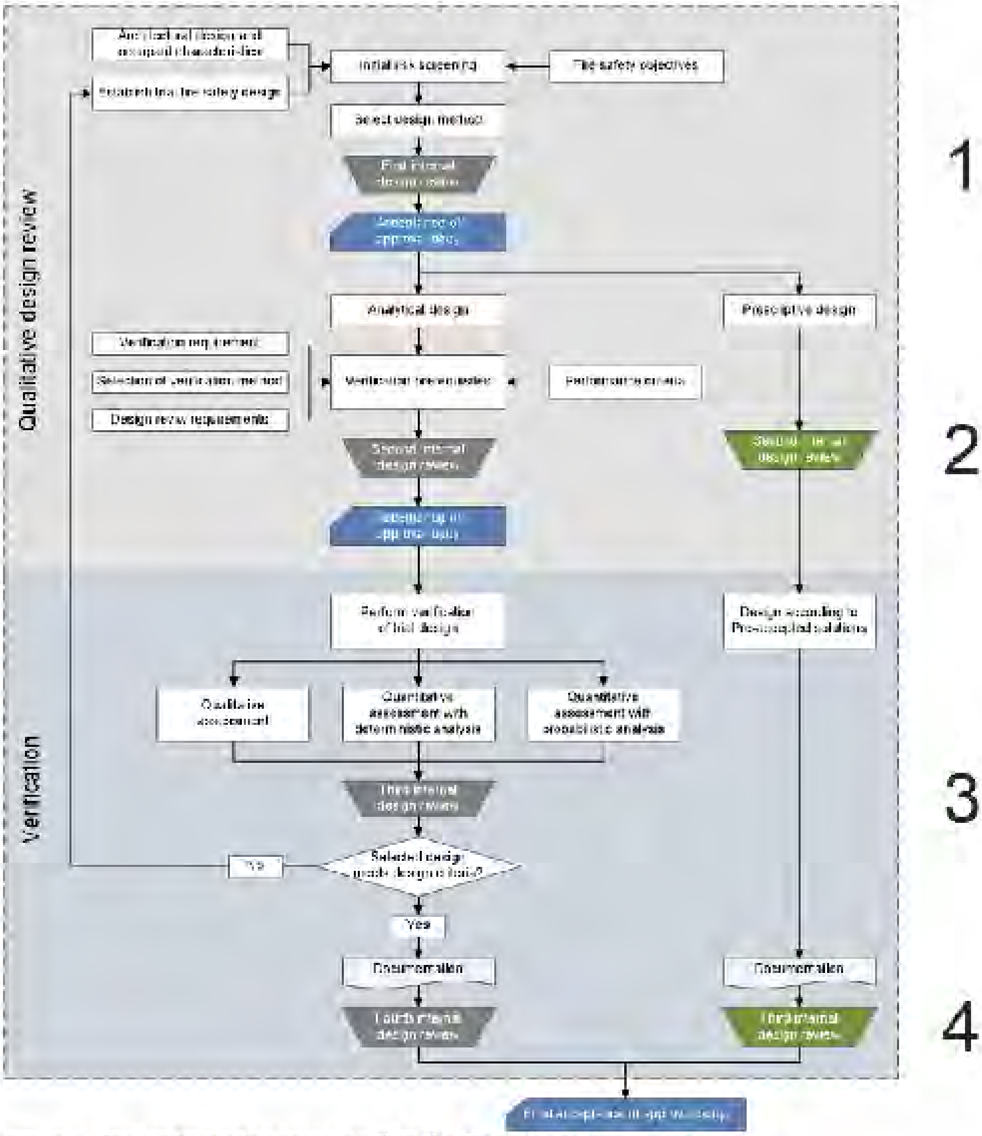


Figure 4 - The design review process within the fire safety design process.

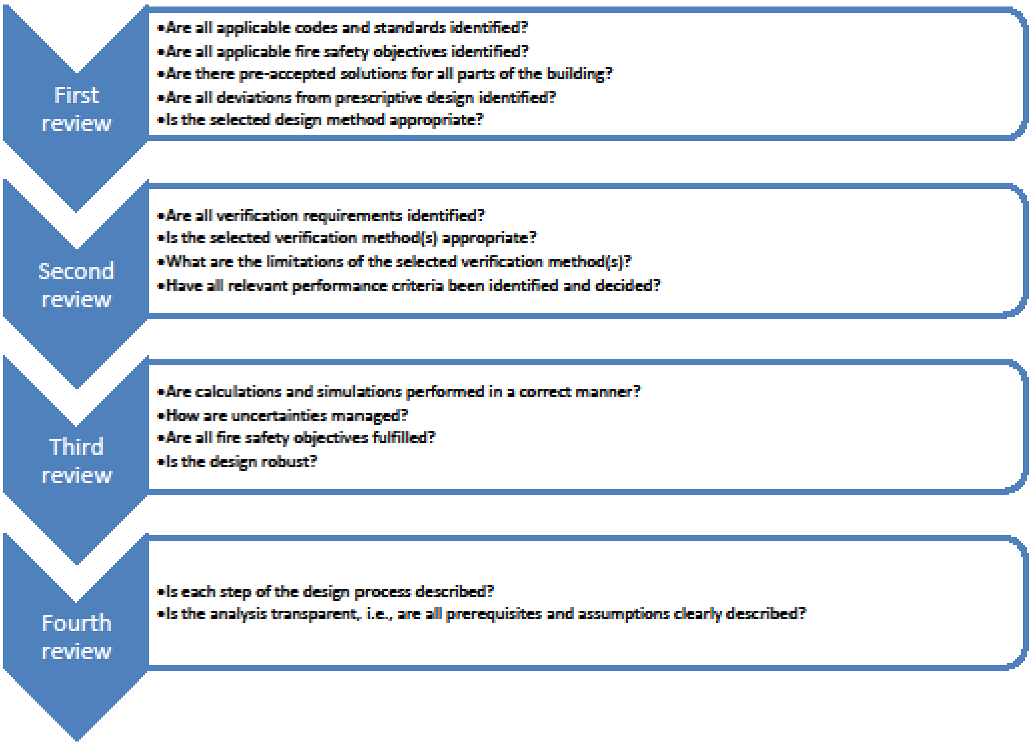


Figure 5 - scope of each review step.

More detail of the aspects that a full review should include, are presented in Annex B.

(22) NOTE: the scope of a peer review may be set in the National Annex.

(23) NOTE: the acceptance of approval body can include third-party peer review and may be set in the National Annex.

6.5 Choice of a peer reviewer

Any peer reviewer should have the necessary knowledge and fire safety engineering experience or fire science expertise to understand and evaluate the design that is being reviewed. For example, a peer reviewer should at least have the necessary knowledge and fire safety engineering experience to prepare an acceptable design that is similar in scope to the design being reviewed. Any specialized expertise that will be necessary to undertake the peer review, for example in using specific tools or models, should be identified.

(24) NOTE: required competence for a peer reviewer may be set in the National Annex.

The peer reviewer should be objective and have no personal or corporate conflict of interest in the project. Any candidate being considered as a third-party peer reviewer should disclose to the contracting stakeholder any conflict of interest. If a third party peer reviewer discovers deficiencies that fall outside of the scope of the review, those deficiencies should be brought to the attention of the contracting stakeholder.

(25) NOTE: how to choose third-party reviewer may be set in the National Annex.

6.5.1 Identification of agreement to perform a peer review

Prior to commencing a third-party review, the peer reviewer should execute an appropriate agreement with the ordering stakeholder. Once this agreement has been formalized, the contracting stakeholder should notify the design engineer of record, and other appropriate parties, of the initiation of a peer review as required by applicable ordinances, engineering practice acts, canons of ethics, etc.

(26) NOTE: the process for contracting a third-party review may be set in the National Annex.

6.5.2 Responsibility

Unless otherwise agreed, the fire safety designer is always responsible for the final fire safety design. The in-house or third-party reviewer is only responsible for performing a proper control.

(27) NOTE: the responsibility of a peer reviewer review may be set in the National Annex.

6.6 Conduct of a third-party peer review

6.6.1 Communications between a peer reviewer and designer

Technical discussions between the designer and the peer reviewer can be a part of the review process, as long as the stakeholders are aware of the communication.

(28) NOTE: when, how and on what subjects communicated between a peer reviewer and a designer during the review process may be set in the National Annex.

6.6.2 Standard of reasonableness

Peer reviewers should not be influenced by matters of their own design preference.. Instead, any available generally accepted codes, guidelines and best practice (formal as well as informal) should be used as a benchmark. Technical issues that the peer reviewer would not expect to have a significant effect on the performance of the design should be identified as observations or findings rather than as deficiencies. When the peer reviewer finds any significant deviations from codes, guidelines or best practice the reviewer should ask on what basis the choice was made rather than report it as a discrepancy. This may cause several loops of review but the process will be more constructive.

If there are issues where the designer and peer reviewer cannot agree upon a solution it is up to the building owner/designer to present a design that fulfils the requirements, and the authority will decides if they approve it or not.

(29) NOTE: the process to address disagreements between a peer reviewer and designer may be set in the National Annex.

6.6.3 Tools required for review

Peer reviewers should have sufficient documentation of the validity of the tools and data that were used in the development of the design. A full evaluation of a design may require that the designer provide the peer reviewer with access to the tools and input data used to develop the design. In such cases, the peer reviewer should respect any confidentiality issues associated with the tools, and should use the tools only for conducting the specified peer review. In some peer reviews, it may be necessary to use additional or alternative tools and data to perform checks on the results that were obtained during the development of the original design.

6.7 Report of a peer review

6.7.1 Documentation

At the conclusion of a review, the peer reviewer should prepare a written record that identifies the scope of the review and the findings. The report should identify whether, in the peer reviewer's opinion, the design meets the design objectives. The items shown in section 0 should be addressed in the report. Peer reviewers should substantiate any comments on appropriateness by references to published technical documentation.

(30) NOTE: mandatory aspects to document during a peer review may be set in the National Annex.

6.7.2 Supplemental information

Resolution of differences in the conclusions between the design team and the peer reviewer may require supplemental technical documentation. It is not unusual for these differences to take several iterations between the peer reviewer and the designer to resolve. It is important for the designer and the peer reviewer to have in mind that peer review is only a tool to make an informed decision.

6.8 Review and control of other disciplines´ documentation

Due to the fire safety designer's overall influence on the entire design team, it is important that the fire safety designer, as a part of the builders' control and inspection scheme, also controls the requirements in the fire safety design document that have been incorporated in other disciplines drawings models and documents.

It is essential to verify that each discipline) have understood and implemented the requirements that have an impact on their work. When designing the fire safety by fire safety engineering methods, the transformation of the concept design into a construction document or models is of critical importance. .This can be done by, e.g., participating in joint review meetings or by crash control of models.

Important aspects to consider when reviewing other disciplines' construction documents are presented in annex C.

(31) NOTE: a specific process and aspects to consider during the review of other discipline's document may be set in the National Annex.

7 Construction phase

7.1 General

This chapter addresses the process for verification of compliance of fire safety during the construction phase.

The chapter is based on the SFPE Engineering Guide to Performance-Based Fire Protection (2009) and the guidelines for verification of fire safety within the building process by the Swedish Chapter of SFPE, BIV (2013) and is adjusted to fit the process in the Nordic Countries.

7.2 Inspection and testing plan (ITP)

As a part of the documentation of the fire safety design and the outcome of the design process, an inspection and testing plan (ITP) needs to be defined. The ITP need to focus on what aspects to control and inspect for different fire safety systems installed in building when finalizing a building after construction. The ITP is the link between the fire safety design and the construction phase and it is important to ensure that all affected stakeholders understand and the inspection and testing plan. Within some Nordic countries, the ITP may be a part of the builder's control and inspection scheme, and will then also need to be approved by the AHJ.

The ITP should specify the required inspection procedure, measurement techniques and required results for the validation and also acceptable tolerances for the performance metric. In the ITP, division of responsibility for different inspections and tests should be clarified to ensure that all who participate are aware of the required actions and the given time schedule for different actions. (SFPE , 2007)

Special inspections due to fire safety engineering design should be highlighted and especially considered due their impact it may have on the fire safety strategy. With regards to the inter-dependency of several fire safety design systems and to ensure the defined fire safety strategy, an integrated system testing and a coordinated inspection protocol need to be defined, coordinated, and communicated before the final controls.

Example of aspects to consider when developing an inspection and testing plan are presented in Annex D and further information about integrated system testing are presented in chapter 7.4.

(32) NOTE: specific content in the inspection and testing plan may be set in the National Annex.

7.3 Procedure

The general process for verification of compliance in the construction phase is described in Figure 6. The process is intended to be used as guidance during the construction of the building and to ensure that all needed fire safety measures are built as described in the fire safety documentation and construction documents. Each step in the process will be described in detail in the ensuing sections. While the process is described as a step-by-step procedure, the process may in reality be iterative.

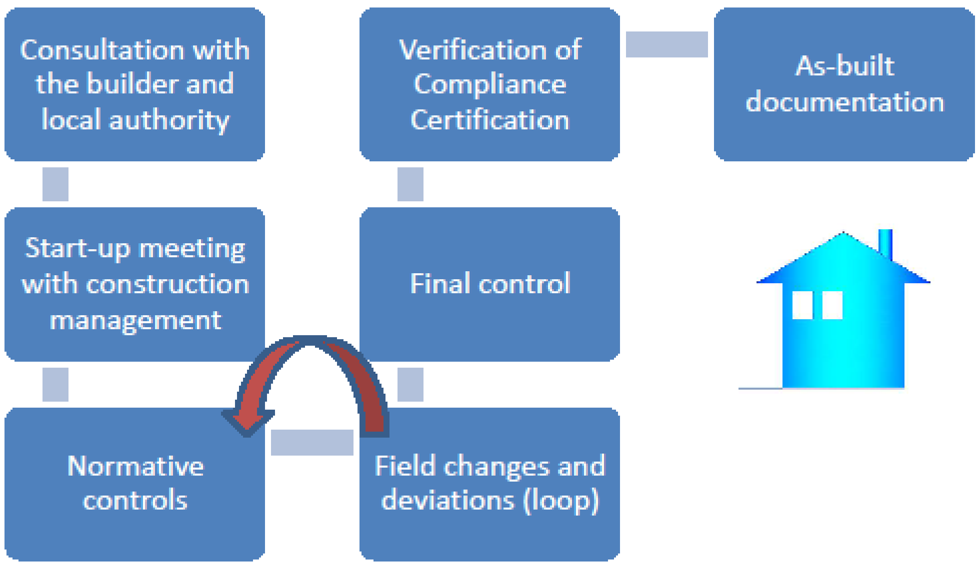


Figure 6 – Process for verification of compliance within the construction phase.

7.3.1 Consultation with builder and local authority

The one doing the control should participate in the consultation with the builder and the local authority.

The following should be determined during the consultation:

- Which documents should be used for the control and inspection of the fire safety measures;
- In which phases should the fire safety measures be controlled and inspected:
  - At a minimum an early control (before load bearing structures and shafts are enclosed) and a final control;
  - If parts of the building are taken into use in multiple stages, more controls are needed;
  - If the construction affects existing occupancies more controls may be needed;
- Which controls each contractor should perform and when they should be performed.

During the joint consultation the procedure within the project for identifying and documenting field changes and deviations from the defined fire safety concept should be defined.

(33) NOTE: the procedure for joint consultation and how to document field changes and deviations may be set in the National Annex.

7.3.2 Start-up meeting with construction management

When the building management has been chosen, a startup meeting between the controller and a representative from the building management should be held. The following should at least be handled at the meeting:

- All fire safety documents should be reviewed and uncertainties sorted out;
- Controls and inspections should be planned and uncertainties sorted out;
- The construction project organization should be clarified for the controller.

If new building management is appointed, a new start-up meeting may be needed.

(34) NOTE: the procedure for start-up meetings may be set in the National Annex.

7.3.3 Normative controls

It is important that the controls include parts of the execution where experience shows that errors often occur. Examples are among others the installation of fire doors, glass structures, ventilation.

If the design has deviations from the pre-accepted solutions, execution of the performance-based measures should be the focus of special controls.

Control of the execution includes control of the documentation for construction products to ensure that the intended use of the product corresponds with the documentation.

Unless it is shown clearly as unnecessary continuous controls are required during the construction phase. The conditions should be made clear during the consultation with builder and local authority. As a minimum, an early control before load bearing structures and shafts are enclosed should be performed in order to be able to inspect parts that will be unavailable for inspection at later stages.

The following general procedure for the controls should be used:

- The control is performed together with a representative from the construction management;
- The contractor's controls and the routines for these controls are reviewed;
- The control is made according to the document agreed on during the consultation with the builder and local authority;
- Special consideration of the fire safety measures during the building phase should be taken if adjacent occupancies could be influenced in case of fire;
- The controls should be documented by dated and signed check lists or inspection reports and photographs should be used wherever appropriate.

(35) NOTE: the procedure for normative controls and when to perform these may be set in the National Annex.

7.3.4 Field changes and deviations

When deviations from the fire safety design documents and construction documents occur during the construction phase, the fire safety designer responsible for the design should to be notified. Evaluation, assessment and reporting of the deviations need to be carried out to evaluate the magnitude of the deviation.

If the fire safety design is based on fire safety engineering methods, all deviations that exceed the predetermined design tolerances must be evaluated in the context of the overall design to ensure that the defined level of safety is met. (SFPE, 2007)

The evaluation and assessment may be qualitative such as comparing properties and performance of specific products to those actually provided. The assessment should occur in the context of the overall design and should evaluate the effects of the deviations on other systems. If the assessment reveals major deviations, the fire safety designer will be required to revisit the fire safety design and revise key assumptions and/or calculations. (SFPE, 2007).

All deviations should be reported and documented a Any impact that may occur on the control and testing procedures as defined in the ITP, should be incorporated in a revised version of the ITP. The changes should be communicated to stakeholders such as AHJ if it approves the fire safety design. Upon evaluation, approval and documentation of field changes and deviations, the fire safety designer should notify all inspectors and provide direction to the construction team members of the proposed resolutions of the deviations.

7.3.5 Final control

A final control is always required before the building, or a part of the building, is occupied and used, as follows:

- The control is performed together with a representative from the construction management;
- The contractor's controls and routines should be documented;
- The control is made according to the document agreed on during the consultation with the builder and local authority;
- The final control should be documented.

(36) NOTE: the procedure for final control may be set in the National Annex.

7.4 Integrated system testing

During the final control, integrated testing of fire safety and life safety systems should be conducted.

The scope of integrated system testing is the verification of the completeness and integrity of the building construction, ensuring that individual system function, operation and acceptance as required in applicable installation standard tests, and to ensure the completion of pre-functional tests of integrated systems (NFPA, 2015)

Integrated testing should focus on that the final system installation complies with the specific design objectives and the aspects defined in the fire safety design document and constructions documents.. Documentation of the testing and inspection should be provided.

Further guidance on integrated system testing can be found in NFPA 4: Standard for integrated Fire Protection and Life Safety system testing, (NFPA, 2015)

(37) NOTE: the procedure for integrating system testing may be set in the National Annex.

7.5 Verification of compliance statement

The Verification of Compliance statement certifies that all performance and prescriptive code provisions have been met regarding inspections and commissioning reports, as well as first hand observations throughout the construction process.

(38) NOTE: the procedure for normative controls and when to perform these may be set in the National Annex.

7.6 As-built documentation

In preparation of the Verifications of Compliance documentation, the fire safety engineer should identify any field changes made during construction. The fire safety engineer should ensure that they have been reviewed as described in chapter 6, in some case being approved by the AHJ, and properly included in the as-built documentation.

As-built drawings or fire design models should be updated upon any change to accurately describe the current conditions in the building of the finalization of the construction. These documents will serve as a basis for future operation of the building..

To ensure continued compliance with the constructed fire safety throughout a building's service life, the fire safety designer should address critical input data,bounding conditions and limitations on design due to fire safety engineering solutions and include information about which the facility may be assessed and monitored for change and a procedure for addressing those changes to ensure continual compliance with the fire safety scope.

(39) NOTE: the needed documentation for the as-built documentation may be set in the National Annex.

7.7 Fire prevention on construction sites

During the construction phase it is also important to reduce the risk of fire on the construction site. This aspect is not included in the scope of this report, but it is recommended that the CFPA Guideline Fire Prevention on Construction Sites (2009) is taken in consideration to reduce risk and the severity of fires that occur on the construction site.

8 Operation and maintenance

8.1 General

This chapter addresses the process for review and control of the fire safety throughout a facility's service life.

The chapter is based on the SFPE Engineering Guide to Performance-Based Fire Protection (2009) and is adjusted to fit the process in the Nordic Countries.

8.2 Procedure

The success of a fire safety design requires adherence to the design aspects throughout the service life of the facility. The service life involves operation and maintenance as well as changes in a facility. The changes can involve changes in individual stakeholders; such as owners, facility tenants and maintenance staff, as well as changes in the facility configurations, use and its occupancy. It is critical that these changes are managed to facility maintenance manuals and established procedures for the approval and documentation of facility changes. The general process for managing the fire safety during operation and facility changes is described in Figure 7.

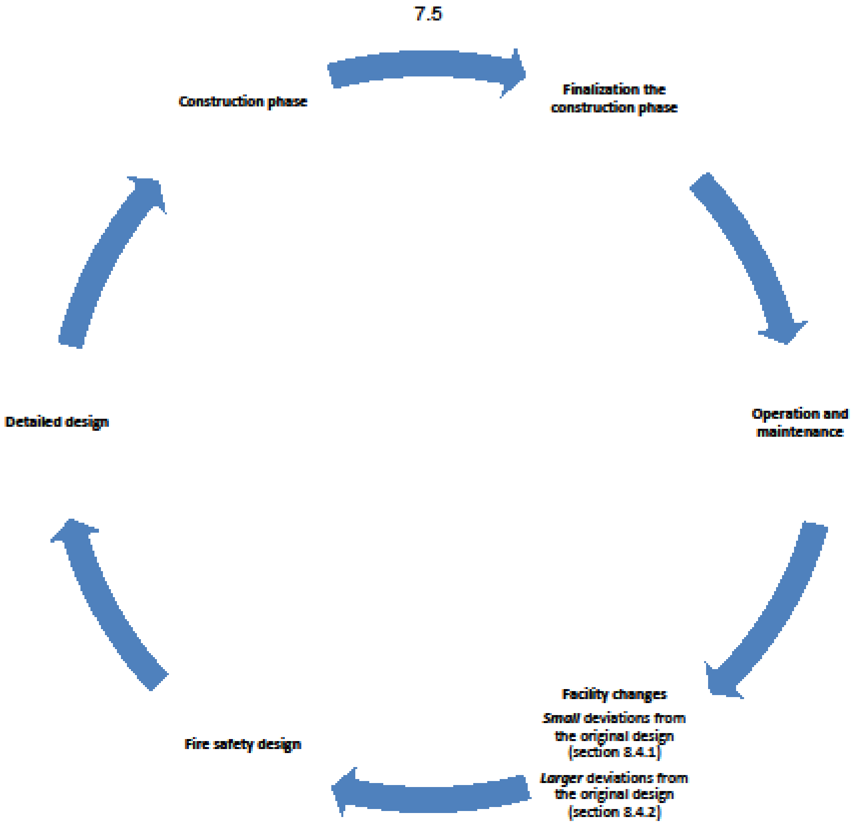


Figure 7 - The fire safety process during operation and facility changes.

8.3 Operations and maintenance

To ensure the intended level of fire safety during a building's (or facility's) service life, a building operator is required to ensure that the fire safety measurements are in place and operating properly.

As part of the as-built documentation, Operation and Maintenance Manuals should be defined. An Operation and Maintenance Manual describes the commissioning requirements and the interaction of the different systems interfaces. (SFPE, 2007).

8.3.1 Operations and maintenance manuals

In the Operations & Maintenance Manuals (O & M manuals), all subsystems and associated inspections and testing regimes and schedules are presented and acceptable results are identified. While some systems can be tested and inspected individually, the interconnection between systems should be periodically tested. (SFPE, 2007).

The O&M manuals should include a procedure for inspections and checklists for documentation of the performance and results of system testing. The manual should also give instructions to the building operator on important boundary conditions and restrictions placed on building operation due to the fire safety design and especially if the design is based upon fire safety engineering methods. Critical aspects could be fire load, sprinkler design, building use and occupancy within different parts of a building. The manual can also be used to communicate, to tenants and occupants, boundary conditions and limitations as well as detail the tenants' responsibilities to operate the facility.

The design components that are critical to the achievement of the fire safety must be maintained and a maintenance plan for those components must be developed and documented. A quality control checklist is an example of a useful tool that an inspection team could use to identify changes in facility safety systems, facility usage and tenant characteristics and operation, (SFPE, 2007). An example of aspects to consider when developing a quality control checklist is presented in annex E.

(40) NOTE: the scope and content operation and maintenance manuals may be set in the National Annex.

8.4 Facility changes

The ability to ensure that facility modifications meet the original fire safety design objectives relies directly on the amount and accuracy of existing design and construction documentation as well as facility commissioning, inspections and maintenance reports, (SFPE, 2007)..

All changes to the building must be addressed. However, the manner in which the changes are addressed and the amount and type of documentation needed for the changes vary depending on the amount of deviation from the original fire safety design.

8.4.1 Minor deviations from the initial fire safety design

If the deviations from the initial design are small in connection to the original fire safety design documentation, changes may be made without need for new analysis or recommissioning of the fire safety systems.

If the changes or renovations are small and fall within the latitude and within the boundary conditions of the original design, these changes should be presented to the AHJ as part of the notification or permitting process within each country. The deviations should be recorded and included in the facility fire safety documentation in order to monitor changes over time within the facility.

(41) NOTE: what changes that are defined as minor may be set in the National Annex.

One should have in mind that although the individual changes may not affect the defined fire safety level or the original design, the cumulative effects of multiple changes, even if all are conceded minor, might result in a reduced total fire safety level within the facility. This is of major importance if the fire safety design is based upon fire safety methods.

8.4.2 Major deviations from the initial fire safety design

Major deviations or renovations that fall outside the latitude and boundary conditions of the initial design require a new fire safety design process. The process should follow the steps used to design a new fire safety strategy within the facility.

The new analysis and design process should address the specific changes, whether it affects the total building, a system within the building, or a subsystem in the building. Based on the analysis and design process, the fire safety consultant should propose the modifications needed to be incorporated to maintain the defined level of safety (defined by the AHJ or other stakeholders).

After the fire safety engineer has determined the modification that is needed to be implemented, the fire safety design may be a part of a new building permit given by the AHJ. The change should be documented and include the original design intent, the scope of the change and necessary modifications to provide a facility that complies with the building regulation or other stakeholder-defined level of safety (SFPE, 2007).

If a renovation is major and requires new goals and objectives, a completely new fire safety design concept should be produced, following the process described in section 4.5.

(42) NOTE: the procedure and requirements regarding renovation and major changes may be set in the National Annex.

Annex A
(Informative)

Nationally determined parameters

Table A1 Template for the choice of nationally determined parameters to be decided by each national standardization body

Clause	Nationally determined parameter
(1)	The recommendation is used.

Table A2 – Example of how nationally determined parameters may be expressed

Clause	Nationally determined parameter
6.(18)	The recommendation is not used due to the national building regulation.

Annex B
(Informative)

Details of full control of the fire safety design documentation (fire safety strategy)

1. Control of the fire safety design brief/documentation	Pre-accepted design	Design verified by FSE
Is it described who has performed the design (company and consultants)?		
Is the scope of the project defined? - Design of a new building, reconstruction of existing building, etc.		
Is the building clearly defined and described? - Building classes, risk classes, fire classes (depending on applicable code)		
Are the fire safety related conditions and limitations for the building described? - Occupant load - Fire load density - Local fire rescue service capacity - In case of partial reconstruction or conversion of an existing building, the extent and boundaries for the project		
Is the choice of design model described, i.e., pre-accepted solutions or fire safety engineering analysis?		
When pre-accepted solutions are used, is it confirmed that the guidance for the applicable building code ("deemed-to-satisfy") is followed?		
Is the main design of the building and all required installations clearly described and sufficient for detail design? This normally includes the following main points: - Stability and load-bearing capacity in case of fire - Protection against the spread of fire between buildings - Fire compartmentation, including protection of HVAC systems - Requirements for materials used in insulation, cladding and surfaces - Means of egress: number of escape routes, capacity, travel distances, signage and consideration for disabled people - Fire detection and alarm systems - Extinguishing systems - Smoke ventilation and smoke control systems - Manual fire extinguishing equipment - Services and safety for rescue operations		
Are there fire safety drawings showing fire compartmentations, fire safety installations, escape routes and access routes for fire rescue services?		

2. Control of the fire safety verification	Pre-accepted design	Design verified by FSE
Basis and assumptions: - Are the fire safety objectives identified? - Are the deviations from pre-accepted solutions identified, and are the affected fire safety objectives derived? - Is the choice of verification method (qualitative analysis, comparative analysis or probabilistic risk analysis) assessed and justified? - Is the choice of methods of analysis (calculation/simulation methods) and acceptance criteria assessed and justified, including the prerequisites and limitations of the methods? - Are assumptions, simplifications and input values for calculations described in a transparent manner? - Is the choice of fire scenarios for analysis assessed and justified?		
Special considerations for qualitative analysis: - Is the choice of a purely qualitative analysis evaluated and justified? - Is the analysis substantiated by statistics, experience, studies, fire tests, etc., with specific references?		
Special considerations for probabilistic risk analysis: - Are the acceptance criteria evaluated and justified? - Are the referenced statistics relevant and applicable for the building?		
Special considerations for comparative analysis: - Is the reference building sufficiently described? - Is the reference building realistic and suitable for the analysis? - Is there an overview of the deviations from the pre-accepted solutions? - Are all deviations treated in the analysis?		
Implementation and results: - Are consequence analyzes performed for the chosen fire scenarios? - Are sensitivity analyses performed? - Is there an assessment of uncertainties? - Is there a clear summary of the results provided (referring to the purpose and objective of the analysis)? - Are the results assessed in relation to the acceptance criteria? - Are the results sensible and reasonable in relation to the basis and assumptions of the analysis? - Is there a description of fire safety measures to include in the fire safety concept, e.g., what standards to use for the proposed installations? - Are important aspects to consider and communicate during the detail design phase described clearly? - Are important aspects to consider and communicate during the on-site tests and controls, e.g., coordinated tests and controls, described clearly? - Are important aspects to consider and communicate during the operational phase of the building described clearly?		

Annex C
(Informative)

Example of a checklist for control of others disciplines' construction documents

Abbreviations
A = Architect
V = HVAC
C = Construction
E = Electrical
L = Landscape

Important aspects	A	V	C	E	L
External building components					
Roof	A				
Windows and French doors	A				
Balconies	A				
Internal building components					
Fire sections	A				
Fire compartments	A				
Doors in fire compartments	A				
Fire locks	A				
Shaft	A	V		E	
Stairwell	A				
Linings	A				
Electrical installations				E	
Load-bearing constructions					
Load-bearing constructions			K		
Accident loads			K		
Ventilation system					
Ventilation concept		V			
Ventilation fans		V			
Smoke and fire dampers		V			
Flue		V			

Important aspects	A	V	C	E	L
Control and supervision	A	V			
Installation and Equipment					
Smoke ventilation system	A			E	
Alarm				E	
Guiding markings	A			E	
General lighting				E	
Emergency power				E	
Rescue services					
Access to fire hydrants					L
Response route					
Accessibility for rescue operation	A				

Annex D
(Informative)

Example of an inspection and testing plan for the construction phase

Abbreviations
Doc = documentation needed (such as self-monitoring protocols (SM), inspection protocol (IP), etc., *see below*)
Controller = who is going to do the control
Scope = How the control should be performed
Comments = important aspects to consider during the control
SM = self-monitoring protocols
IP = inspection protocols
Cert = a specific certification is needed.
Fire = the control is performed by a fire safety controller
Other = the control is performed by an inspector for the specific area such as an electrical inspector.
Acc samp = acceptance sampling
Extensive = an extensive control where all aspects of a specific function are controlled

General	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Control of the documentation for construction products	SM	Fire	Acc samp			
Operations and maintenance manuals	SM	Fire	Acc samp			
Evacuation	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Accessibility	SM	Fire	Extensive			
Doors	SM	Fire	Extensive			
Windows	SM	Fire	Extensive	Ensure the use of the rescue service's equipment		
Knob/lock	SM	Fire	Extensive			
Refugee area	SM	Fire	Extensive			
Fire compartmentation	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Walls	SM	Fire	Acc samp			
Doors	SM (installation certificate)	Fire	Acc samp			
Fire protected glass	SM (installation	Fire	Acc samp			

	certificate)					
Elevators	SM	Fire/Other	Extensive	Functional test		
Hidden spaces	SM	Fire/Other	Acc samp			
Sealed fire compartmentation	SM	Fire/Other	Acc samp			
Linings	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Linings in evacuation routes	SM	Fire	Acc samp			
Linings in other rooms	SM	Fire	Acc samp			
Pipe isolation	SM	Fire/Other	Acc samp			
Roof	SM	Fire				
Outer wall	SM	Fire				
Load-bearing constructions	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Lining	SM	Fire	Acc samp			
Fire protection painting	SM	Fire	Acc samp	measuring of the paint's thickness		
Eave	SM	Fire	Acc samp			
Suspended ceiling	SM	Fire	Acc samp			
Fire spread between buildings	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Fire wall	SM	Fire				
Protection against the outbreak of fire	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Fire place	SM	Fire/Other	Extensive			
Flue	SM	Fire/Other	Extensive			
Ventilation	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Insolation	SM	Fire/Other	Acc samp			
Suspension	SM	Fire/Other	Acc samp			
Fire dampers	SM	Fire/Other	Extensive	Functional test		

Fire protection functions	SM	Fire/Other	Extensive	Functional test		
Electrical cables	SM	Fire/Other	Acc samp			
Fire extinguisher system	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Sprinkler system	IP	Other	Extensive	Certified controller		
Indoor fire hydrants	SM	Fire/Other	Extensive			
Standpipe	SM	Fire/Other	Extensive			
Smoke ventilation	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Staircase	SM	Fire/Other	Extensive	Functional test		
Elevator	SM	Fire/Other	Extensive	Functional test		
Basemen	SM	Fire/Other	Extensive	Functional test		
Attic	SM	Fire/Other	Extensive	Functional test		
Alarm & lightning	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Fire alarm	IP	Other	Extensive	Certified controller		
Evacuation alarm	IP	Other	Extensive	Functional test		
Guiding lightning	SM	Fire/Other	Extensive	Functional test		
Emergency lightning	SM	Fire/Other	Functional test	Functional test		
Lightning	SM	Fire/Other	Extensive			
Rescue service	**Doc**	**Controller**	**Scope**	**Comments**	**Status**	**Signature**
Accessibility		Fire	Extensive			
Rescue service route		Fire	Extensive			
Rescue service elevator	SM	Fire/Other	Extensive	Functional test		

Annex E
(Informative)
Example of a quality checklist for operation and maintenance

Description	Intervals
Escape routes	
Door handles	Each month
Escape routes, doors and windows	Each month
Escape routes, staircase	Each month
Evacuation plans	Each year
Guiding Lightning	
Function and location	Current
Test of the back-up electric function	Each year
Emergency lighting	
Function and location	Each month
Test of the back-up electric function	Each year
Fire alarm system	
Revision and Inspections	Each year
Evacuation alarm	
Function test by facility manager	Every three month
Smoke detectors	
Function and location	Each month
Fire sprinkler system	
Revision and inspections	Each year
Screening by facility manager	Current
Elevators	
Elevator function at point of signal from the fire alarm system is in accordance with to the requirements in the fire protection documentation	Each year
Fire Extinguisher System	
Fire extinguisher	Each month

Description	Intervals
Function test of fire extinguisher	Each year
Screening of standpipe	Every three months
Test pump and pressurized standpipes	Each year
Smoke ventilation system	
Smoke extraction fans in cellar or garage	Each year
Smoke extraction fans in stairwells	Each year
Smoke extraction fans in stairwells can be started from the ground floor	Each year
Fire compartmentation	
Doors: Door closers manual, door closers automatic function test (push-button), coordinator	Each month
Sealed fire compartmentation - no holes	Each month
Load bearing structures	
Load bearing structures are properly marked	Each year
Ventilation system	
Screening of the fire protection functions of the ventilation system	Each year
Screening of flue	Every second year
Rescue service routes and assembly points	
Accessibility	Current
Snow removal	current
Free from obstructing vegetation	Each year
Guiding signs	Each year
Joint Commission	
Joint commission of interrelated fire protection systems/functions	Each year

Annex F
(Informative)
The control systems within the Nordic countries

In this annex the different control systems during the building process in the Nordic Countries are briefly described.

Denmark
The applicant has complete responsibility towards the authorities, and he may fulfill his obligations the way he finds suitable. There are no qualification requirements on the applicant, or to his organization (except for safety reasons, construction calculations, gas, etc.).

The main principle is that the general internal quality control is performed by the applicant, on his own terms and without public supervision of this. The public building control concentrates on the issues of public interest. The officers perform the control based on dialogue and construction site inspections including document control.

There are no formal requirements for internal control performed by the applicant or his organization. But they have some voluntary certification systems for companies, helping the applicants' quality checks.

Finland
Finland has formally placed the responsibility for sufficient control onto the applicant shared with public authorities. The reason is to allow the authorities to take over the task if they consider it necessary. In practice, normal procedure is 'delegation' to the applicant, while public control concentrates on the supervision process within the mandatory building inspection report.

The Building Control (BC) Office handles the issuing of building permits, but the office is divided into two sections – one for compliance with the local plan, and the other for all other requirements set by central or local authorities, such as competence by the construction companies and certification of actors. This sector also performs the control tasks.

Approvals can be divided in stages in large or complicated projects, and the BC Office then defines the stages. The control work is regarded as starting with the start-up meeting after issuing of the building permit, and participants at this meeting are the BC Office, the site manager, and the main actors for design and construction. The site manager shall present a control plan, but this plan is not to be approved by the BC Office. This plan is used for defining milestones where new meeting and site inspections will be carried out.

Iceland
The applicant has the formal responsibility towards the authorities. But since there are traditionally a high numbers of non-skilled one-time applicants and even self-builders, the system provides several tools to support the applicants.

First, there is a very strong public control, working on a more detailed level than building control offices in other countries where the intention is to support the applicant.

Secondly, the law requires a "project manager", having professional skills, to be assigned to the building project, responsible for the quality of the building works, both towards the authorities and to the applicant. The project manager must be insured against possible faults, but it is the applicant's responsibility to correct faults discovered by the public control.

Norway
The applicant has the formal responsibility towards the authorities. But according to the legislation, all other actors in the building process have responsibility for the quality of their own work, not only to the applicant, but also directly towards the authorities.

Municipal building control was phased out in 1997, and was replaced by private control and a municipal surveillance. Compulsory third party control was introduced in January 2013. Regarding fire safety this includes the control of the verification of fire safety (the fire safety strategy) in all larger building (project class 2 and 3).

There are competence requirements on all actors (except the Applicant), related to their role in the projects: designers, contractors, controllers of both design and construction works, and of site managers. The competence requirements are also related to the complexity of the projects.

Sweden
An approved building permit is mandatory for most building activities. For some minor construction projects a notification to the building authority is sufficient.

The handling of applications for a building permit according to the Planning and Building Act is initially assessed in relation to approved local plans. However, an approved building permit is not sufficient to start construction works; you will also need a clearance from the building committee.

Work which requires a building permit, demolition permit, land permit or notification may not be commenced until the building committee has issued clearance. In order to obtain clearance, the developer must be able to show that the measure can be considered to fulfill the requirements defined in the Planning and Building Act with associated regulations. If the building committee is to be able to decide whether the measure can be considered to fulfill the requirements or not, the developer must submit a proposal for an inspection and test plan (ITP) and necessary technical documentation. The building committee establishes the ITP in the clearance.

The main rule in the Planning and Building Act is that there must be one or more inspectors when work requiring a building permit or notification is being carried out, though there are some exceptions to this. Inspectors must be certified by an accredited certification body.

In most cases, technical consultation will be held at the building committee. The consultation includes going through how the work will be planned and organized, the ITP proposal and general documentation. Technical consultation is not required if an inspector is not required.

In most cases, the building committee shall visit the site where the works are being carried out at least once during the process. The need for the building committee to make a worksite inspection is defined during the technical consultation.

Once the construction work covered in the technical consultation is complete, a final consultation is held, before a final approval is issued.

A final approval is required for all work covered by the clearance. To obtain a final approval, the developer must show that all requirements that apply to the measure in accordance with the permit, the ITP, the clearance, or any decision concerning additional terms, are met, and the building committee doesn't find reasons to intervene with an inspection. If the requirements for final approval are not met, the building committee may, under certain circumstances, issue an interim approval pending a final approval.

Bibliography

BS 7974. Application of fire safety engineering principles to the design of buildings. Code of practice. British Standards Institution, 2001.

BS 9999. Code of practice for fire safety in the design, management and use of buildings: British Standards Institution, 2008.

Direktoratet for byggkvalitet. Temaveiledning – Tilsyn av prosjektering - brannsikkerheitsstrategi, Melding HO-3/2007, Oslo 2007. [In Norwegian]

Direktoratet for byggkvalitet. Temaveiledning – Uavhengig kontroll, Oslo 2012. [In Norwegian]

The European Parliament and Council (2011). Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC, CPR. EU, the European Parliament and of the Council.

Frantzich H. Time for escape. Tid för utrymning vid brand Statens räddningsverk, 2001. [in Swedish]

Föreningen för brandteknisk ingenjörsvetenskap BIV, Kontroll av brandskydd i byggprocessen, BIV, Lund, 2013. [in Swedish]

Inter-jurisdictional Regulatory Collaboration Committee (IRCC) (2010). Performance-Based Building Regulatory Systems - Principles and Experiences. B. Meacham, Inter-jurisdictional Regulatory Collaboration Committee (IRCC).

Law M. Heat radiation from fires and building separation, Fire Research Station, UK, 1963.

Lundin, Verifiering, kontroll och dokumentation vid brandteknisk projektering, report 3122, LTH, 2001. [In Swedish]

NFPA 4: Standard for Integrated Fire Protection and Life Safety System Testing, National Fire Protection Association, 2015.

NFPA 101. Life safety code, National Fire Protection Association, 2012.

NKB 1994:07. Funktionsbestemte brandkrav og teknisk vejledning for beregningsmæssig eftervisning. Del 1 og 2 Nordiska kommittén för byggbestämmelser, NKB. Brandutskottet. 1994. [in Norwegian].

Nystedt F. Verifying Fire Safety Design in Sprinkled Buildings, Report 3150, Department of Fire Safety Engineering, Lund University, 2011.

Nystedt F. Case Studies on the Verification of Fire Safety Design in Sprinklered Buildings, Lund University, 2012.

SFPE Guidelines for Peer Review in the Fire Protection Design Process, Society of Fire Protection Engineers, 2009 (revised).

SFPE Engineering Guide to Performance-Based Fire Protection, 2nd edition, Society of Fire Protection Engineers, 2007.

Further Reading

Bengt Dalgren AB, - brandskydd rätt utfört, handbok om utförandekontroll, Göteborg, 2013. [In Swedish]

Best Practice gruppen CFD Best Practice, Copenhagen, 2009. [In Danish]

Briab Brand & Riskingenjörerna AB, Vägledning - brandgasfyllnad Extern version, 2012-12-01, Briab, Stockholm, 2012. [In Swedish]

Briab Brand & Riskingenjörerna AB, Vägledning - utrymningsanalys Extern version, Briab Brand & Riskingenjörerna AB 2013-04-15, Briab, 2013. [In Swedish]

CFPA Europe, Guideline No 21:2009 - Fire Prevention on Construction Sites, Zürich, 2009

Föreningen för brandteknisk ingenjörsvetenskap, CFD-beräkningar med FDS, Lund, BIV 2013. [In Swedish]

ISO/TR 13387-2, Fire safety engineering – Part 2: Design fire scenarios and design fires

ISO/TR 13387-3, Fire safety engineering – Part 3: Assessment and verification of mathematical fire models

ISO/TR 13387-4, Fire safety engineering – Part 4: Initiation and development of fire and generation of fire effluents

ISO/TR 13387-5, Fire safety engineering – Part 5: Movement of fire effluents

ISO/TR 13387-6, Fire safety engineering – Part 6: Structural response and fire spread beyond the compartment of fire origin

ISO/TR 13387-7, Fire safety engineering — Part 7: Detection, activation and suppression

Lundin, J. (2005). Safety in Case of Fire – The Effect of Changing Regulations. Department of Fire Safety Engineering. Lund, Lund University.

NS 3901. Requirements for risk assessment of fire in construction works. Krav til risikovurdering av brann i byggverk Norwegian Standard, 2012. [In Norwegian].

SFPE Engineering Guide to Human Behavior in Fire, Society of Fire Protection Engineers, 2003.

SFPE Handbook of Fire Protection Engineering, 4th edition, Society of Fire Protection Engineers, US, 2008.

Statens Bygningstekniske Etat. Prosjektering – brannsikkerhetsstrategi. Rettleiing for tillsyn i byggjesaker, HO-3, 2007. [In Norwegian]

Through our international collaboration programmes with academia, industry, and the public sector, we ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society. Our 2,200 employees support and promote all manner of innovative processes, and our roughly 100 testbeds and demonstration facilities are instrumental in developing the future-proofing of products, technologies, and services. RISE Research Institutes of Sweden is fully owned by the Swedish state.

I internationell samverkan med akademi, näringsliv och offentlig sektor bidrar vi till ett konkurrenskraftigt näringsliv och ett hållbart samhälle. RISE 2 200 medarbetare driver och stöder alla typer av innovationsprocesser. Vi erbjuder ett 100-tal test- och demonstrationsmiljöer för framtidssäkra produkter, tekniker och tjänster. RISE Research Institutes of Sweden ägs av svenska staten.

RISE Research Institutes of Sweden AB
Box 857, SE-501 15 BORÅS, Sweden
Telephone: +46 10 516 50 00
E-mail: info@ri.se, Internet: www.ri.se

Safety
RISE Report 2017:42
ISBN: