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MASTER'S THESIS

Status quo of performance-based fire safety design for buildings in Norway

Status på ytelse/funksjonsbasert brannteknisk prosjektering for bygninger i Norge

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Western Norway
University of Applied Sciences

Master in Fire Safety
Supervisor: Svein Jacob Nesheim
Oslo, 02.12.2018

I confirm that the work is self-prepared and that references/source references to all sources used in the work are provided, cf. Regulation relating to academic studies and examinations at the Western Norway University of Applied Sciences (HVL), § 10.

Status quo of performance-based fire safety design for buildings in Norway

Master Thesis in Fire Safety

Author:	Author sign.
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This work is written as part of the master program for fire safety at "Western part of Norway University College". The student is self-responsible for the applied methods, the results that have been discovered and any conclusions and assessments that are made as part of the work.

FOREWORD

Norway has had a performance-based building code with functional requirements for fire safety for almost 21 years now. Of those years I have practiced performance-based fire safety design (PBFSD) for about 10. Through my work experience I have observed several changes to the fire safety sections of the building code. The changes however tend to focus on what is referred to as the pre-accepted performances, which arguably is fair considering how much they are used and needed to provide cost-effective fire safety design for traditional buildings.

My main interest in the field of fire safety engineering however, is when the prescriptive approach is not applicable, or not desired due to the constraints they may put on the building design. If you are not using the prescriptive approach, then you are doing what is referred to as PBFSD, also often referred to as analytical fire safety design. In this approach the path of compliance is through the functional and operative requirements together with verification. This design approach is where I think fire safety engineers can apply their field of expertise the most, and where they can potentially create the best value for their customers and stakeholders, and for the overall society as well.

It is my opinion that the elements that make up PBFSD should receive more attention if we want to develop and improve this design approach further. With this thesis I hope to be able to give a contribution to the improvement of PBFSD for buildings in Norway. Once, Norway stood together with the other Nordic countries at the very forefront of the development of PBFSD, and together created the "NKB model" for a performance-based building code, a model that have since inspired further development of performance-based codes in many other countries throughout the world. We have come far since then, but there is remaining work to be done. It is my wish that Norway takes a more active role in this important endeavor.

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The topic of this thesis was suggested based on my own interests and experiences in this field and has been written without any financial support. The thesis is the conclusion of my Master of Science studies, and will provide 60 credits

Jon Arild Westlund- Storm, December 2018

ABSTRACT

Performance-based building codes with functional requirements were originally developed to allow for a more goal-oriented approach to building design. Development work started in the 1970s and was deemed sufficiently mature enough to be fully implemented in the early 1990s. Performance-based building codes are however still very much in development, and in various stages of implementation in different countries around the world. The countries that implemented performance-based codes at an early stage now have multiple years of practical experience with using them. This experience has revealed issues related to the practice of performance-based design with fire safety that must be fixed if it is to be recognized as a robust and safe design approach. Two major issues are identified: lack of, or unclear, performances linked to functional requirements in the building codes, and a high degree of variability in verification of performance-based fire safety design (PBFSD) between building designers.

Norway introduced its first version of a performance-based building code with functional requirements for fire safety in 1997 (TEK97), allowing for compliance to the building code either by pre-accepted or alternative performances. The functional requirements for fire safety were developed through research efforts by The Nordic Committee on the Building Regulations (NKB) and were mostly qualitative. Some performances linked to the functional requirements were also suggested but found lacking by the building code developers and were not included. As such it was not possible identify a defined fire safety level from these functional requirements. In the transition to the new performance-based building code it was however also a requirement that the acceptable fire safety level was to remain unchanged. This fire safety level in the previous (prescriptive-only) building code was implicitly defined by prescriptive requirements, which were a collection of both performances and technical solutions. Since there was a need for performances in the new building code to define the fire safety level, a decision was made to take these prescriptive requirements from the previous building code and convert them to new pre-accepted performances. These pre-accepted performances were then attached to a relevant functional requirement where they were deemed fitting. Such it became to be that the fire safety level in the new performance-based building code was in effect defined implicitly by building requirements given by the previous prescriptive building code. This type of system is still in current effect. This is considered an issue for practice of performance-based fire safety design, as the acceptable fire safety level is unclearly defined. A change in the building code is suggested where the fire safety level is identified more by quantitative operative requirements (performance requirements) linked to the functional requirements instead of the current pre-accepted performances. Suggestions to achieve this for select areas for fire safety in the building code are given.

Many of the functional requirements in the Norwegian building code have remained largely unchanged over the following 20 years. Most of these requirements were written based on qualitative goals or functional objectives, which is how they are supposed to work in a performance-based building code. A few requirements were however written with the expectation of specific fire safety measures in mind, like use of fire compartmentation, and that exits from fire compartments must lead to an escape route defined as a separate fire compartment. Practical experience with these functional requirements over the years have revealed that they can come into conflict with modern building designs where open-plan configurations are desired. There are indicators that these functional requirements may lead to less use of fire compartmentation in such buildings just to avoid conflict with compliance. Such issues should be avoidable, and suggestions to rewrite these functional requirements are given to achieve this.

A fire safety verification method (FSVM) is a measure pursued by several countries around the world to better control the quality of verification in PBFSD. These countries have seen much of the same symptoms that can currently be found with verification in Norway. Whether Norway also should also pursue a FSVM to improve the quality therefore seems to be a reasonable question to ask. Based on investigated literature and expert interviews, the author does not recommend pursuing what is defined as a full scope of compliance FSVM. A limited scope of compliance FSVM may however be justifiable. The optimal path however, is considered to be a recognized fire safety engineering guidance document, created and maintained by a third party, preferably as a collaboration effort in the fire safety community.

SAMMENDRAG (NORWEGIAN)

Ytelsesbaserte bygningsforskrifter med funksjonskrav ble opprinnelig utviklet for å åpne opp for en mer mål-orientert tilnærming til prosjektering av bygninger. Utviklingen startet i 1970 årene og ble vurdert modent nok til å bli tatt i full bruk på tidlig 1990 tallet. Det er dog stadig i utvikling, og er implementert i varierende grad i ulike land i verden. De landene som tok dette i bruk på et tidlig stadium har nå hatt flere år med praktisk erfaring. Denne erfaringen har vist at det flere utfordringer knyttet til funksjonsbasert/analysebasert brannteknisk prosjektering som må løses dersom vi ønsker at denne måten å prosjektere bygninger på skal bli anerkjent som en robust og trygg prosjekteringsmetode.

Norge innførte sin første versjon av en ytelsesbasert bygningsforskrift med funksjonskrav for brannsikkerhet i 1997. Regelverket åpnet da for muligheten for oppfyllelse av bygningsregelverket enten gjennom bruk av preaksepterte ytelser, eller alternative ytelser (analytisk brannteknisk prosjektering). Funksjonskravene som ble utviklet gjennom arbeidet av den nordiske komiteen for bygningsregelverk (NKB), var imidlertid hovedsakelig kvalitative og manglet definerte ytelser på flere områder. De ytelsene som ble gitt, ble ikke tatt med i den nye forskriften. På grunn av dette var funksjonskravene ikke i stand til å definere noe fullstendig entydig brannsikkerhetsnivå. I overgangen fra den forrige bygningsforskriften til den nye var det imidlertid bestemt at det brannsikkerhetsnivået ikke skulle endres, men videreføres. Dette brannsikkerhetsnivået var i det forrige bygningsregelverket implisitt definert gjennom de ulike preskriptive bygningskravene, hvilket var en blanding av både ytelser og tekniske løsninger. Siden det var et behov for ytelser i det nye bygningsregelverket for å kunne definere brannsikkerhetsnivået, ble det bestemt å videreføre de tidligere bygningskravene som nye preaksepterte ytelser. Disse ytelsene ble så koblet til de ulike funksjonskravene hvor de ble vurdert passende. Slik endte Norge opp et implisitt definert brannsikkerhetsnivå i den nye ytelsesbaserte bygningsforskriften med funksjonskrav for brannsikkerhet, basert på bygningskravene fra den forrige bygningsforskriften. Denne tilnærmingen er fortsatt gjeldende, også i dagens forskrift. Dette vurderes som en utfordring for praktisering av analysebasert brannteknisk prosjektering siden det akseptable brannsikkerhetsnivået er såpass uklart definert. Det foreslås derfor en endring av bygningsforskriften hvor brannsikkerhetsnivået heller identifiseres gjennom kvantifiserte operative krav som utledes fra, og står i sammenheng med, funksjonskravene. Forslag gis for å oppnå dette på utvalgte seksjoner for brannsikkerhet i bygningsforskriften.

Flere av funksjonskravene for brannsikkerhet i den norske bygningsforskriften har forblitt uendret siden de først ble introdusert. De fleste av disse funksjonskravene ble skrevet med utgangspunkt i mål og funksjonelle krav, hvilket er intensjonene med hvordan de er tiltenkt å fungere i et slikt regelverk. Enkelte krav ble imidlertid skrevet med bakgrunn i bruk av spesifikke branntekniske tiltak, slik som bruk av brannceller, og at rømningsutganger fra brannceller som ikke leder til sikkert sted skal lede til en rømningsvei som også skal være egen branncelle. Praktisk erfaring med disse kravene gjennom de senere årene har avslørt at de kan komme i konflikt med moderne bygningsdesign, hvor det ofte er ønskelig med bruk av mer åpne arealer og områder. Det er tegn på at disse funksjonskravene kan føre til redusert bruk av branncelleinndeling, kun for å unngå konflikt med oppfyllelse av funksjonskravene. Slike problemstillinger bør være mulige å unngå, og det er gitt forslag til hvordan funksjonskravene kan omskrives for å oppnå dette.

Branntekniske verifikasjonsmetoder er et tiltak som er tatt i bruk av flere land for å få et bedre grep om kvaliteten i verifikasjon av analysebasert brannteknisk prosjektering. Disse landene har sett mange av de samme symptomene som er observert i verifikasjon utført i Norge. Det er derfor et legitimt spørsmål hvorvidt Norge også burde forfølge sporet med branntekniske verifikasjonsmetoder for å kunne forbedre kvaliteten. En anbefaling gis basert på den informasjonen som er samlet inn gjennom litteratursøk og intervjuer med personer i land hvor verifikasjonsmetoder har vært i bruk i flere år. Det er anbefalt å ikke gå for et alternativ med det som defineres som en fullstendig verifikasjonsmetode (verifikasjonsmetode som skal dekke alle aktuelle paragrafer knyttet til brannsikkerhet). En verifikasjonsmetode med mer begrenset virkeområde er mer aktuelt å forfølge. Et optimalt alternativ vurderes imidlertid være et anerkjent veiledningsdokument for analysebasert brannteknisk prosjektering, utviklet og vedlikeholdt av en tredjepart, fortrinnsvis et samarbeid i brannmiljøet.

NOMENCLATURE AND DEFINITIONS

Building code – In this report, generally references the fire safety part of a given building code unless otherwise specified. Building codes are usually either prescriptive or function/performance-based.

Prescriptive building code – Refers to a building code where the building requirements typically are specific and detailed (prescriptive) and are mandatory.

(Acceptable) Fire safety level - The level of fire safety in a building code that society accepts and is comfortable living with. Since building codes historically have been prescriptive, this fire safety level is often given implicitly through the collection of these prescriptive performances and solutions. For Norway the acceptable fire safety level is defined by what is referred to as the "pre-accepted performances".

Function-based/Performance-based building code – Refers to a building code that has functional and operative requirements as the only mandatory requirements. The operative requirements may include performances to define the acceptable fire safety level. Such building codes typically allow two distinct design paths, either by acceptable / deemed-to-satisfy solutions or by alternative design.

Performance-based fire safety design (PBFSD) – An acronym used to refer to the practice where fire safety design is based on functional requirements, or if available, quantified performances linked to the functional requirements. The approach typically requires verification that the functional requirement or performance is met, which often involves the use of fire safety engineering methods. PBFSD is also often referred to as alternative/analytical design, or alternative solutions.

Special remark: In Norway the practice of PBFSD is more recognized under the term function-based fire safety design (*"funksjonsbasert brannteknisk prosjektering"*) or analytical fire safety design. This refers to the use of the functional requirements and any new alternative performances developed as a basis for showing compliance instead of using the given pre-accepted performances. In the context of this thesis, PBFSD and what is considered function-based/analytical fire safety design in Norway are considered similar approaches.

Societal (Fire safety) Goals –Safety in case of fire in a building that the society expects that a building should be able to provide. Usually very broad and defined in layman's terms.

Functional requirements –A requirement that typically states a functional goal, objective or function defined using mostly qualitative terms. They are usually a mandatory part of a performance-based building code.

Operative requirements - Functional requirements by themselves are often not suitable to use for detailed engineering analysis, as they don't necessarily state the expected performance in quantitative terms. Operative requirements may be used to detail the intent of the functional requirement further and may be both qualitative and quantitative. As such they may be more specific/prescriptive in their structure compared to the functional requirements. Operative requirements may also be performance metrics and acceptance criteria which may be estimated through engineering methods, and thus be used to express the achieved performance in the design. Operative requirements are usually a mandatory part of a performance-based building code.

Pre-accepted performances – A special term used to identify the performances (and technical solutions) in Norwegian building code. They make up the pre-accepted path of compliance, and as such, are not mandatory. They are not part of the actual building code but located in an accompanying guidance document.

Pre-accepted solutions – A special term used in the Norwegian building regulation to refer to technical solutions that are considered to be acceptable without the need for new or additional documentation. Examples of these are well-known construction elements like walls and floors that have been previously shown over many years to fulfill the pre-accepted performances.

Acceptable solutions–Terms related to specific design solutions that will fulfill a given performance, often prescriptive. They can also include performance-based solutions developed using fire safety verification methods, as such methods are often considered part of the prescriptive path due to their specific structure.

Alternative design / Alternative solutions - Terms used to refer to the design approach where the prescriptive path is not followed. Typically requires verification against a performance given by the building code or created by the building designer.

Verification - The process of showing/documenting that the functional/operative requirement or performance is fulfilled. This is often done using fire safety engineering methods, both qualitative and quantitative.

Acceptance criteria – Typically related to fire safety engineering and expresses the maximum or minimum allowed exposure from the fire. If given by operative requirements or in a fire safety verification method, they will in effect also contribute to the definition of the acceptable fire safety level.

Fire safety verification method (FSVM) - A type of guidance document typically created by building authorities that give a more specified (prescriptive) approach to PBFSD and analytical fire safety design.

Full scope of compliance FSVM – A FSVM that is intended to provide verification for all the fire safety requirements in the building code

Limited scope of compliance FSVM – A FSVM that has a limited scope and typically only covers certain fire safety requirements in the building code.

BBRAD – An abbreviation for the Swedish fire safety verification method.

C/VM2 – An abbreviation for the New Zealand fire safety verification method.

NS (Norwegian Standard) – A standard provided by "Standard Norge", the main body regulating the development of national standards in Norway.

NS-EN – European standards adapted for use in Norway.

INSTA – Inter-Nordic Standard.

FIGURE LIST

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1. Introduction

1.1. Background

The last few decades have seen a big shift towards the use of performance-based fire safety design (PBFSD), as pointed out by Meacham [1]. With improved understanding of the underlying physics and dynamics of fire behavior and available computational power continually increasing each year, we are in a better position than ever to allow building fire safety design to be driven by scientific methods based on first principles. The transition to a performance-based building code with functional requirements and embracing the value of performance-based design, is however a hurdle that is still very much ongoing throughout the world. This is a special challenge for designers and authorities having jurisdiction in the field of fire safety, a field which for so many years has been strictly regulated through prescriptive requirements.

Historically, building codes and building requirements for fire safety in particular, have been predominantly prescriptive and specific in nature. A prescriptive building code means that for a specific type of building, layout and occupancy, there are many specific mandatory requirements on how it must be built. For fire safety the prescriptive approach has, until recent times, been considered the optimal approach due to the safety aspect of the discipline. Without proper regulations on fire safety it is easy to see that this may potentially jeopardize life safety, make critical infrastructure functions vulnerable and create large economic losses due to fire- and smoke damage.

The problem with a prescriptive building code however, is that it is next to impossible to cover all variations of different configurations that a building may have. It is also very challenging to keep up with new design methods, materials and technology that are constantly being invented and improved. Keeping a prescriptive building code up to date with this rapid development would eventually lead to a building code so massive and complex that it would be highly unpractical and difficult to use correctly. A prescriptive building code will therefore often be considered limiting in terms of design freedom and potentially act like a brake on innovation, as pointed out by Meacham [1] and Alvarez et al [2]. A prescriptive building code typically mainly changes after history (past events) shows that a requirement is missing or has not had its intended effects. For fire safety this often occurs after a major fire disaster. This means that the prescriptive building code will be constantly reacting to events after they have occurred, and less able to prevent events that has not happened before.

In a prescriptive design approach, the designers for the most part also have limited legal responsibility as long they have followed the prescriptive requirements given in the building code, even if the design should reveal itself to be lacking in the future. Arguably, such a design approach does not promote critical thinking from the designer in terms of actual risk present in the design, or whether the design is suitable or cost-optimal.

This is obviously not ideal for a society that is largely science-driven, and in constant pursuit of continuous improvement. Thus, an alternative to the prescriptive approach for fire safety was suggested in the early 1970s by the U.S General Services Administration, as pointed out by Hurley and Rosenbaum in [3], where the building code would be based on a more goal-oriented structure using fewer overarching goals, together with more qualitative functional requirements or objectives instead of many detailed and specific requirements. The Nordic Committee on the Building Regulations (NKB) continued this work by proposing their "NKB" model for goal-oriented building code [4]. This was originally referred to as function-based building code but evolved in later years to be known as a performance-based building code.

A performance-based building code with functional and operative requirements makes it possible to support a design approach that is often referred to as alternative/analytical design. There is however one very important distinction between this type of design compared to prescriptive design, and that is the responsibility of showing compliance. Prescriptive design is deemed to comply with the building code by the building authorities, so there is no need to do any further verification. In alternative design however, the responsibility of showing compliance through verification typically resides on the building designer. Verification in this context is the process of showing compliance between an alternative design solution to a functional/operative or performance requirement in the building code. Verification is often supported by engineering methods used to show that the alternative design has an acceptable performance.

There are however many different engineering methods available, with even more different ways to use them. Different methods also have varying resource needs in both person-hours and competence level. What is considered an "acceptable approach" is still up to much discussion and subjective interpretation. For the fire safety design discipline, questions such as "what is the relevant performance criteria to use", "what engineering tool or method should be used", and "what is considered a reasonable level of safety" are typical questions that are being asked, and thus a major area of ongoing conflict and discussion. This is also a particular problem for Norway, as pointed out by Forsen & Røsjø in [5].

A major source to this conflict is that, while many performance-based codes have functional requirements that allows for use of alternative design, it is often difficult to measure any minimum acceptable safety level from these requirements, as they are often defined only qualitative in nature and thus can be vague and even unclear in their intent. More detailing is necessary to communicate a certain defined level of desired performance. The functional requirements need to be backed by what is referred to as operative requirements, ideally as quantified performance requirements or metrics as suggested in [1], [2]. Meacham and the Inter-Jurisdictional Regulatory Committee also points to this in [6]. Their function is to define the functional requirement further so that they may be used as part of a verification process where it is possible to estimate the actual performance through engineering methods. These operative requirements are unfortunately often lacking. The reason for this is that creating such requirements based on fundamental scientific principles that can work universally for any building, in any configuration, is a very challenging task. Creating them can often mean that some limitations must be set on the available engineering methods that may be used, which may work against the principles of a performance-based building code and thus not be desirable. These requirements are however necessary if there is a desire to quantify the acceptable fire level based on the functional requirements and have the safety level set by the building code. When these requirements are lacking, the building designers and relevant stakeholders must try to gauge what the performance criteria or metric should be by themselves. In principle, the acceptable safety level for the building is then not set by the building authorities, but by the building designers, developers and stakeholders. This is a system based on trust and may not necessary be an issue if the building developers and stakeholders take that responsibility serious and create a robust building design. It does however mean that the perceived fire safety level of such buildings can vary greatly due to the subjective nature of the building design process. A recent article in the "Fire Protection Engineering" magazine by Meacham [7], p. 24 summarizes the issue very well, and made the following statement when he evaluated the status of PBFSD in several countries throughout the world:

"Everyone is disadvantaged by a lack of clear criteria in the regulations, clear loads against which to assess building fire safety designs, and agreed upon and accepted design and analysis frameworks, tools, and methods (even when they exist, such as ISO 32932, BS7974, IFEG, etc.)."

However, even if the building code can define quantified performance requirements and metrics, there is still a high degree of variability in the verification process of PBFSD. This variability can then also subsequently be present in the fire safety level. This may be due to errors both in the choice of a suitable verification model/method and to different ways of operating those models. Without proper knowledge and guidance on this process, the spread in results can become quite large. This particular problem has been pointed out in a round robin study on the use of the CFD-model FDS (Fire Dynamics Simulator) in Sweden in 2015 by Ekholm [8] , and a similar study was performed by the Swedish chapter of SFPE - Society of Fire Protection Engineering (in Sweden also known as BIV "Föreningen för Brandteknisk Ingenjörsvetenskap") in 2018 [9]. Such tools/models are often used as part of fire safety engineering in verification purposes. Both studies revealed that there is still a high degree of variation in the results between different practitioners, even when given specific steps on how to analyze the problem. The issue is also often a recurring topic on international fire safety conferences like the "SFPE International Conference on Performance-Based Codes and Safety Design Methods" where teams participate from different countries around the world on a specific case study that often requires the use analytical fire safety design. A significant degree of variability in the results for both fire- and evacuation modelling is often observed in these case studies.

This emphasizes a need to continue with efforts to improve the level of quality in the verification process of PBFSD. Some countries are trying to remedy some of these issues by introducing fire safety verification methods (FSVM). This is specific "cookbook approach" for verification that is considered a recognized path of compliance to a limited selection, or all, fire safety requirements in the building code. This can have a major impact on the practice of PBFSD by standardizing the practice across the field and reduce variability. It is however not without flaws as it may be viewed as a sign of returning to previous times with prescriptive design and the flaws associated with this design approach.

The current challenges with PBFSD and fire safety engineering also seem to be recognized by CEN, the European committee for standardization, in particular technical Committee 127 (TC127) concerning fire safety in buildings and workgroup 8 (WG8). This workgroup addresses the topic of fire safety engineering specifically and continues to develop and promote standardization and harmonization of the practice across the European countries.

To summarize, while PBFSD has been developed and been in practice for multiple decades already, it still has several challenges that must be overcome before it can reach its full potential. There are many different aspects that can be considered to influence the practice of PBFSD, to name a few (in parts based on suggestions given by [1], [2]):

- Education that focus on fire safety engineering
- Regulations concerning who can do PBFSD (certification, minimum level of education and minimum level of work experience)
- A performance-based building code with well-defined functional requirements and quantified operative requirements and performances
- The process of verification and use of FSVM
- Appropriate quality assurance systems and 3rd party design review

All of these aspects have some influence on the practice of performance-based design, and it is likely there is a need to cover all of them to a certain degree as they are inherently linked to each other to get PBFSD up to its fullest potential. Covering all these topics to the necessary degree is however considered outside the possible scope of this thesis. A selection is therefore made based on what is deemed to be the most time-relevant and to provide the most practical benefit for Norway. This is further explained in the chapter below.

1.2. Purpose and problem definition

The purpose of this thesis is to investigate the status of the practice of PBFSD of buildings in Norway. Based on both personal and global experience, there are signs that the practice is not working optimal, and that quality can be improved. How this can be achieved will be investigated by focusing on the following two aspects:

1. The status of functional and operative requirements in the Norwegian performance-based building code

The quality of PBFSD is inherently linked to quality of the performance-based building code. The status of some of functional and operative requirements for application of PBFSD in the Norwegian building code will be analyzed to see if there are element that may be improved upon. Inspiration from performance-based building codes from other countries will be used as part of this work.

2. Should Norway pursue a fire safety verification method

To fulfill a functional requirement without using the pre-accepted performances requires verification. For fire safety, verification can often require the use of complex engineering methods. Because of this, verification can be a challenging and time-consuming task. Experience with verification in PBFSD in the last 20 years has revealed that there can be a large variety in the level of quality of the practice. This is not a desirable trend, and there are currently ongoing discussions in the global fire safety community as to how increased quality in verification can be achieved [1], [2], [7]. One approach pursued by some countries has been to create a FSVM. The potential positive and negative effects of such an approach will be discussed, in part supported by practical experiences provided by interview subjects. A recommendation to whether Norway also should pursue the path of a FSVM will be given.

1.3. Previous work

There is a lot of activity on the international arena on the topic of performance-based codes for fire safety and the application of PBFSD. The application of this design approach is one of the most recurring topics on international fire safety conferences around the world. The author wants to recognize in particular the early pioneering work done by The Nordic Committee on the Building Regulations (NKB) through 1970-1990s, and in more recent times through the collaboration efforts by many countries in the Inter-Jurisdictional Regulatory Collaboration Committee (IRCC). Multiple individuals from countries all over the world has contributed to the development work as part of this committee. The author would especially like to acknowledge the contribution from Brian J. Meacham, which is a recognized name in the fire safety community highly dedicated to the promotion and development of PBFSD and performance-based building codes. His work has been a major inspiration to this thesis.

1.4. Scope and limitations

As pointed out in the introduction, the are other aspects that influence the practice of PBFSD not covered in this thesis. Elements such as adequate fire safety engineering education, effective regulation that ensures proper competence is involved, and standardized processes for (3rd part) design review are also considered highly important to success of PBFSD. While they are not covered in this thesis, there is ongoing work on these elements by interest organizations such as SFPE [10] and various Inter-Nordic research and standardization collaborations [11].

The report covers the state of PBFSD for buildings in Norway, in part based on the current Norwegian building code "Teknisk forskrift – TEK17". PBFSD can however be used for many other areas like off-shore, industrial processes, tunnels etc. The report does not cover these sectors specifically. The practice of PBFSD can however be similar even across different sectors, so some parts might still be applicable.

The report focuses on the current conditions for practice of PBFSD for buildings in Norway. While deemed as accurate as possible at the time of this writing, the practice of PBFSD could change rapidly in the next years, both national and international.

1.5. Report structure

This chapter explains how the content in the thesis is structured.

Chapter 1 provides a brief introduction to the topic of the thesis, and points to the current challenges faced with PBFSD. This leads into the problem definition of the thesis, which outlines the main goal and limits the scope.

Chapter 2 provides an introductory theoretical background on both history and practice of PBFSD and the development of the performance-based building code, both globally and nationally for Norway, Sweden and New Zealand. In addition, a brief introduction to the fire safety verification methods for Sweden and New Zealand is presented.

Chapter 3 presents a summary of the research methodology for the thesis. The chapter provides specific research questions, and discusses the topics of data and literature review, source reliability and validity, and author bias.

Chapter 4 contains analysis and discussion of select sections of the Norwegian performance-based building code related to fire safety, as well as a comparison study. The functional and operative requirements in these sections are analyzed and evaluated with respect to how well they support PBFSD. Comparisons to the equivalent requirements in the Swedish and New Zealand building code are then given. Suggestions are given on how the various sections in the Norwegian building code can be improved. Finally, discussion is provided on the potential positive and negative consequences of these improvement suggestions.

Chapter 5 contains analysis and discussion on the use of fire safety verification methods for verification of PBFSD. Practical experiences on their use from other countries are discussed, both from available literature and from interview subject. Potential positive and negative effects from implementing a fire safety verification method is considered, and a recommendation to whether Norway should pursue this path is given.

Chapter 6 provides additional discussion on topics that were uncovered as part of the theoretical background study, but not covered by chapter 4 and 5.

Chapter 7 and 8 provide the conclusion and potential areas that may be considered for future work.

Chapter 9 contains a list of all the references used in the thesis.

Chapter 10 provides informational appendices that contains information that was considered not necessary include as part of the main report, such as additional building code text and written summaries of the various interviews.

2. Theoretical background

2.1. History and development of performance-based building codes for fire safety and performance-bases fire safety design

"If it ruins goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built, and it fell, he shall re-erect the house from his own means."

The text above is from a translated excerpt from King in [12], line 232, of the code (law) of Hammurabi, a building law in Babylonia dated circa 1780 BC. It is an example of a well-defined functional requirement that is possible to verify, which is considered a fundamental part of a performance-based building code. In a performance-based building code, a set of goals, functional requirements and operative requirements are used to regulate a building design instead of many specified and detailed (prescriptive) requirements. The paragraph from Hammurabi is included here to illustrate that the concept of functional requirements is not really a modern invention. There are numerous examples of these requirements in various building codes throughout our history, even though we do not consider those building codes performance-based as such. For the most part, building codes and especially requirements for fire safety, have been predominantly prescriptive throughout the early days of building regulation.

The motivation for something other than a prescriptive building code seems to stem from a desire for simplification of the regulatory system, promoting new technology and able to cope with new and potential undiscovered issues, as Meacham states in [1], p.2:

"The motivation for change included reducing regulatory burden, reducing costs to the industry and the public, increasing innovation and flexibility in design, and being better positioned to address emerging issue".

It is not difficult to envision that it is challenging to rely just on prescriptive requirements in the modern world, especially when there is a need to keep adding additional new requirements to keep up with the rapid pace of new developments and technology.

For the field of fire safety, the concept of functional goal-oriented building code requirements were first introduced in the beginning of the 1970s when the U.S General Services Administration developed a goal-oriented approach to building fire safety [3]. Before this, fire safety was regulated through highly prescriptive/specific requirements, and new requirements were mostly driven by large fires that resulted in tragic outcomes and subsequent a societal demand for change. The Nordic Committee on the Building Regulations (NKB) followed up in the late 1970s by proposing the "NKB-model" [4], which became an internationally recognized model. Illustration below is reproduced from [6], p. 29.

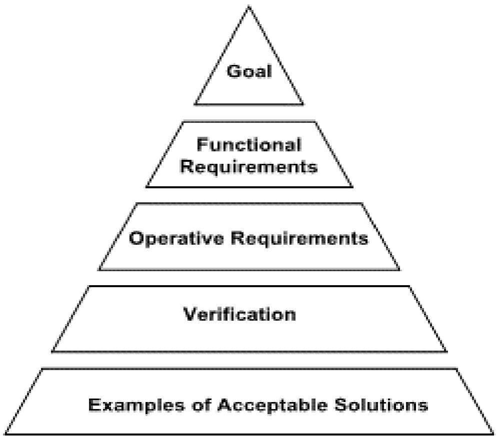


Figure 2-1 The NKB-model for a goal-oriented building code

This model provides a good insight into the various elements that make up what is considered a performance-based building code with functional requirements. Broad societal goals are on the top of the pyramid and acts as the main driver for building regulation. Increasing details are provided as you move further down, but it is always possible to trace a path between the more detailed requirements and the overarching goals and functional requirements on top. [6] provides a discussion of the various levels in the pyramid, summarized below.

Societal goals – The motivation behind any legislative regulation should be that of the interests from the overall society it governs. Buildings are an important part of the everyday life of a society, and as such, a common interest in that these buildings are safe to occupy and use, are universally recognized. Such goals are however not adequately specified to identify desired functions that should be fulfilled, there is a need to detail further to communicate both the desired function and performance. With further detailing there is a risk of losing track of the original intention It is therefore important that all levels of the pyramid remain transparent and visible, so that the intention behind any detailed requirement can be traced back to its origin.

Functional requirements – Societal goals may be a common part in both a prescriptive and performance-based building code. Functional requirements are however where the two different approaches divide. Whereas a prescriptive code would give detailed and specified ways of construction of a building to comply with the goal, a performance-based building code instead focus on a few functional requirements, often just qualitative to express the desired objective or function.

Operative requirements – There is a need for further detailing of functional requirements to be able to pinpoint a defined performance that is considered to fulfill the function. This is typically done through operate requirements, which provide additional explanation that expands the intent of the functional requirements further (qualitative) or quantitative performance requirements (performance metrics).

Verification (verification methods) – Instructions or guidelines for verification, for example through engineering analysis or use of certain test methods to show compliance to the operative requirements.

Examples of acceptable solutions – A set of supplemental solutions, often prescriptive, that are deemed to satisfy or comply with the operative and functional requirements without the need for providing any further verification.

After the introduction in the 1970s, performance-based codes slowly developed through the 1970s and 1980s until it started to really gain momentum in the 1990s and early 2000. This is evident by the numerous publications from various countries related to the topic that were published at that time, as listed by Hurley and Rosenbaum [3], p. 3-4:

"

- *Publication of the performance-based New Zealand Building Code in 1992 and the New Zealand Fire Engineering Design Guide in 1994*
- *Publication of the Performance Building Code of Australia and the Australian Fire Engineering Guidelines in 1995*
- *Publication of the Performance Requirements for Fire Safety and Technical Guide for Verification by Calculation by the Nordic Committee on the Building Regulations in 1995*
- *Publication of the SFPE Engineering Guide to Performance-based Fire Protection Analysis and Design of Buildings in 2000*
- *Publication of the Japanese performance-based Building Standard Law in 2000*
- *Publication of the ICC Performance Code for Buildings and Facilities in 2001*
- *Publication of the performance option in NFPA Building code in 2003 "*

In particular, the work and role of the Inter-Jurisdictional Regulatory Collaboration Committee (IRCC) on development of performance-based building codes with functional requirements starting from the mid-1990s must be mentioned. Initially a group of four countries that early sought to introduce a performance-based building code, it has now grown to a be group of 14 countries, including Norway. The group meets twice a year, and exchanges experiences in relation to the development of performance-based codes and the practice of performance-based design in each of their respective countries. The group has produced several key documents for promotion and development of performance-based codes since their founding. While the NKB model has served as a solid foundation on which PBFSD has been applied successfully, experience through the years since its introduction has revealed that there are some challenges, more specifically to what performance and performance level is given by the building code. As such, the IRCC developed the NKB-model further by adding additional tiers to the pyramid, tiers that provide more detail to the process of identifying a more defined performance level with quantified performances criteria for areas where such is possible [6], p. 30:

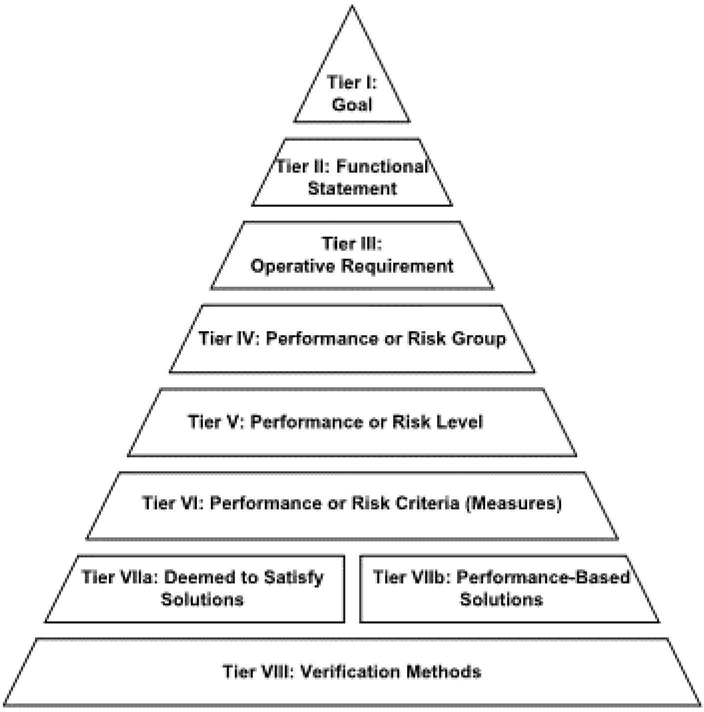


Figure 2-2 The 8-tier IRCC model, evolved from the previous NKB-model

Here, tier IV, V and VI are introduced to try to organize the various buildings into different risk groups based on their perceived risk or importance level, and to better define what are the tolerable building performances, as shown in the example on egress safety below, from [6], p.31:

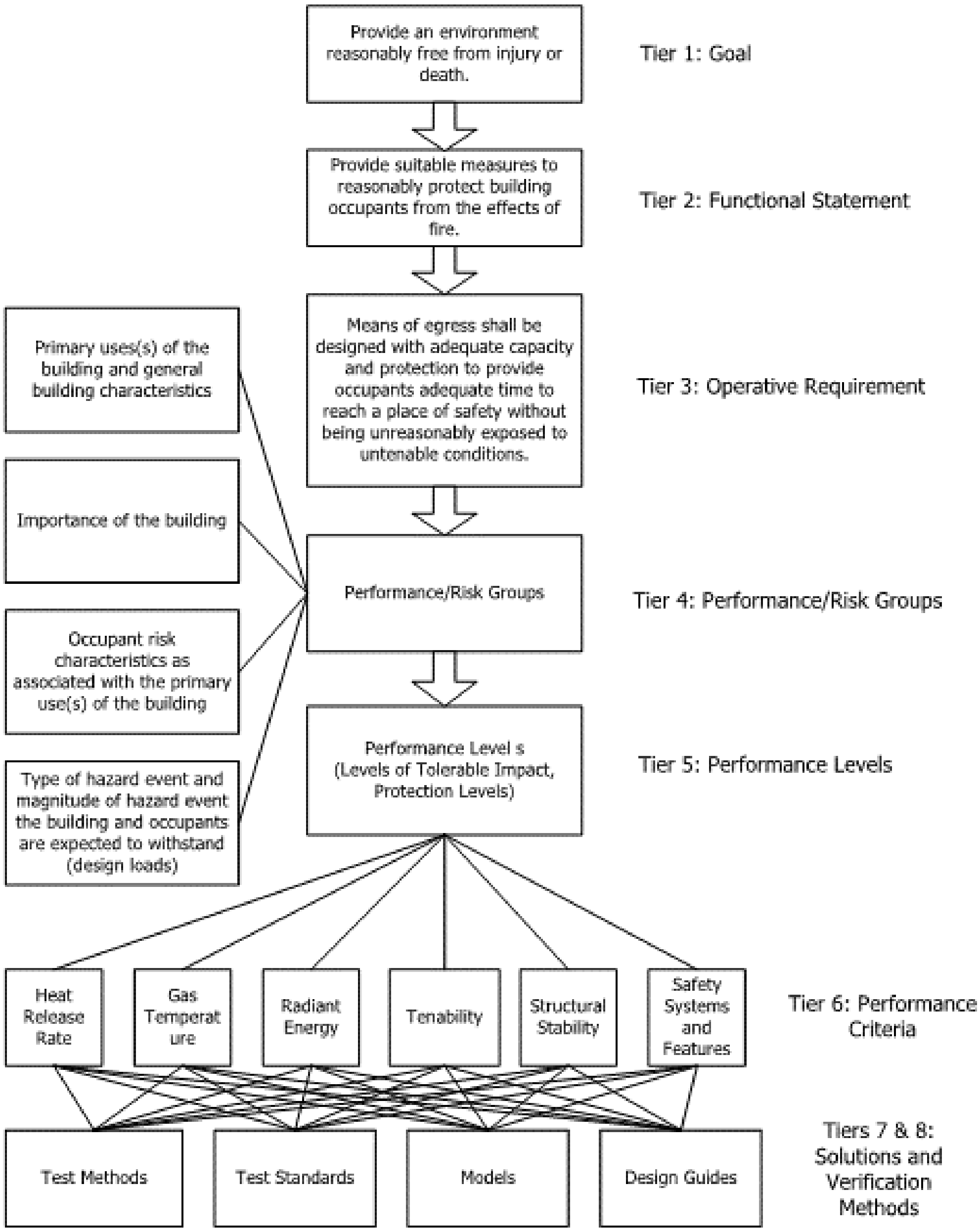


Figure 2-3 The 8-tier IRCC model explained with an example of safe egress environment

By introducing performance/risk groups, performance levels and performance criteria to the model, it is possible to diversify what is considered the acceptable risk between the major building groups. It would for example be possible to quantify certain thresholds for exposure levels for a building occupancy such as offices. Those same thresholds may however not be desirable to use for a building occupancy such as a hospital or health care facilities where occupants are more vulnerable, and where evacuation would be expected to take a longer time. Such buildings may be desirable to design with more robustness in mind, and this may be reflected in the performance levels and performance criteria linked to that specific performance/risk group.

Creating a building code for fire safety that is able to deliver on all the levels defined in the 8-tier IRCC model is however a major challenge, not only because it is difficult to quantify the operative requirements into defined quantitative performances, but also because it is dependent on political and societal accept of how much freedom and authority oversight on the building design process that the respective country desires. Countries that have transitioned, or are currently in the process of transitioning, to a performance-based building code will typically find themselves in function-based, objective-based or performance-based approach, as discussed by [6]. The following is summarized:

Function-based approach

An approach where the building code is based on goals and functional requirements at a general high level only, without specifying any operative requirements, or suggest how to meet the functional objective. This allows for a very high degree of design freedom and flexibility. However, since it is very difficult to get a sense of the minimum acceptable safety level from mostly qualitative functional requirements, the acceptable solutions* are the most used design approach. This also holds true when an alternative solution is desired, as the acceptable solutions then provide a reference fire safety level that may be used in a comparative analysis, as long as a suitable reference building is possible to identify.

* In Norway, these acceptable solutions are what referred to as the pre-accepted performances. See 2.4 for further details.

Objective-based approach

The objective-based approach provides some additional detail to the function-based approach through the addition of more defined objectives through operative requirements. These may be still qualitative, but they form a more visible link between the acceptable solutions and the functional requirement, so that is easier to compare alternative solutions to the acceptable solutions.

Performance-based approach

Performance requirements can be considered a final form of an operative requirement. This is a clearly identified and quantified requirement, and thus it may be measured through an engineering method and used in verification. In essence, this will provide defined performance metrics in the building code, which then may be used in a verification of alternative solutions to demonstrate compliance. If acceptance criteria are also given for the metrics, the fire safety level can be identified by just the functional and operative requirements, without the need to use the acceptable solutions as a reference for the acceptable fire safety level.

In a fully developed performance-based approach the performance requirements are matched together with recognized verification methods, which together will provide the demonstration of verification of compliance to the building code requirements.

Summary

Performance-based buildings had a slow start in the 1970s but came into full blossom in the 1990s. The Nordic countries drove much of the early development through the collaboration effort in the Nordic Committee on the Building Regulations "NKB". A more international collaboration effort, IRCC, followed up on those developments in the mid-90s and continues to this day to meet to assist in the development and implementation of performance-based codes further. 3 distinct levels of degree in how far a country has come in the transition to a fully performance-based building code are outlined, objective-based, functional-based and performance-based approaches.

2.2. Defining performance-based fire safety design, performance-based engineering and performance-based codes

There is a need to properly define PBFSD and performance-based engineering in the context and environment of a performance-based building code.

[6] p.27 provides the following definition of a 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. Acceptable solutions and verification methods for demonstrating compliance with code requirements shall be referenced by the code. (This definition also applies to objective-based regulation (code).) "

While Bjelland and Njå [13] p.2 provide a definition for the difference between performance-based engineering and performance-based codes:

"A separation was made between performance-based engineering and performance-based codes. The former is the process where stakeholders establish performance criteria for a specific building, while the latter is the process where code writers establish performance criteria in the regulations. "

Another recognized definition is given in the *"SFPE Engineering Guide to Performance-based Fire Protection"* [14] . It defines performance-based design in relation to fire protection[1] as follows:

"An engineering approach to fire protection based on

1) Agreed upon fire safety goals and objectives,

2) deterministic and/or probabilistic analysis of fire scenarios and

3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies and performance-criteria. "

Thus, practice of PBFSD does not require a performance-based building code, it only requires that the fire safety goals and objectives (performances) are agreed upon, which may be achieved by the building stakeholders, without the involvement of a building code. In this context performance-based engineering and PBFSD may thus be viewed as similar practices.

A performance-based building code would however ideally be able to provide guidance and relevant input to make sure that step 1-3 in the process outlined above is performed to a satisfactory level of quality. The building code may however not be in a state to be able to do so due to the challenge of creating quantified performance requirements. The building authorities may also not want to provide that level of specification as it may be considered to reduce flexibility be counter-productive to the philosophy of a performance-based building code. In such a situation, the responsibility of defining the necessary quantified performance requirements is put on the building designers and building stakeholders. Successful use of PBFSD in these situations depend on if the building stakeholders can decide upon acceptable goals, objectives and performances.

[1]The term fire protection is often used in the USA instead of fire safety, but the terms are considered to be inter-changeable.

Summary

PBFSD and performance-based engineering are similar terms that can be viewed as an engineering process to create alternative solutions (and in the case of Norway, alternative performances), and verification of compliance with the requirements in the building code. A performance-based code aims to support PBFSD and performance-based engineering by providing defined performances which can communicate the acceptable fire safety level.

2.3. Benefits and challenges: Performance-based vs prescriptive fire safety design

This chapter summarizes the benefits and challenges of the two main approaches for fire safety design. The need for transitioning to a performance-based building code discussed in previous chapters also make up some of the benefits. Some additional advantages and disadvantages are also included, in part discussed in [3]:

- Less regulatory burden
- Potential for reduced costs
- Promoting innovation and supporting new technologies
- Increased design flexibility
- Tailored design, able to address unique building features
- Promotes a better understanding of how a fire will impact the specific building
- In a better position to be able to address hazards or risk not yet identified or present

While performance-based design can sound like a wonder cure, practical use can be a challenge, as history have shown us:

- Requires verification to show compliance
- Can be time and resource-consuming
- Requires higher competence and expertise
- If quantified performance requirements and guidance on verification are not given, then this may lead to variable quality due to differences in design approaches
- Since PBDFSD offers the option to tailor the design, sensitivity to change can be a challenge if this is not specifically addressed
- Potentially difficult for authorities having jurisdiction or 3rd parties to judge if acceptable

Prescriptive fire safety design can be defined as a design process where the designer is following a set of given specifications. This is often compared to following a "cookbook", where all ingredients, how much of each and how to mix them is given. The benefits can be summarized as follows:

- Easy to use, just follow the performance and solution as it is given without need for additional verification
- Requires no further verification beyond that prescriptive approach is possible in the given building
- Less time-consuming
- Provides a design that can be easily controlled and reviewed by authorities having jurisdiction

The challenges become apparent as soon as the prescriptive requirements do not really fit or perhaps do not exist at all for the building in question. The challenges can be summarized as follows:

- Limited scope of use for certain building geometries
- Can create designs that are not optimal with respect to cost-benefit

- Can create designs that do not properly account for risks, or do not uncover hidden risks
- Provides little insight and understanding in terms how the building will react to a fire

It is clear that both design approaches have their benefits and challenges, and they seem to complement each other well. This also seems to be the consensus from the various interviews conducted with people with experience of building regulation and fire safety design in Norway, Sweden and New Zealand (see Ch. 10.2 - 10.8.) There is a need for both design approaches to be supported in the building regimes to be able to provide fire safety design for all relevant buildings. The prescriptive approach will cover the most traditional and common building layouts. For large and novel buildings which require non-traditional layouts that typically deviates from performances and solutions given by the prescriptive approach, there is a need to allow for, and support of, a performance-based design approach.

<u>Summary:</u>

Prescriptive and performance-based design have each their own strengths and weaknesses. Both are however required to support building design in a modern society.

2.4. Development of the first performance-based building code for fire safety and performance-based fire safety design in Norway

The purpose of this chapter is to give an introduction to the development of the first performance-based building code in Norway, and how the practice of PBFSD has evolved from this.

In 1997 the first performance-based building code with functional requirements in Norway, "TEK97" was published [15] . Functional requirements for fire safety in a building were included based on previous research and development by the Nordic Committee on Building Regulation (NKB). This included work in the 1970s on a model for a new goal- and function-oriented building code [4], in later years referenced as the "NKB-model", as described in chapter 2.1. Almost 20 years later this fundamental work led to development of functional requirements for fire safety in the report *"Functional requirements for fire safety and technical guidance on verification"* published in 1994, by NKB [16]. As the title indicates this report had two distinct parts, one being functional requirements for fire safety and the other being guidance on verification of performances linked to these functional requirements. The functional requirements outlined in this report are almost a perfect match to the functional requirements for fire safety in the Norwegian performance-based building code, even in the current version. Norway was the only country in the Nordic collaboration effort that fully implemented these functional requirements in the form as they were written (see interview with building authorities, Ch. 10.3).

The technical guidance on verification part of the NKB report have some similarities with what we today often define as a guidance document or even a "fire safety verification method". This concept is further explained in chapter 5. The technical information in this part could have been used to create quantified operative/performance requirements and acceptance criteria to supplement the new functional requirements for "TEK97". This technical guidance could then have supported "TEK97" by giving examples of appropriate calculation methods that could have been used as part of verification efforts of those performance requirements. This part was however unfortunately at the time not able to give sufficient input data to use for several of its calculation methods, and thus the practical usability of the document was in certain ways limited. Most of that technical guidance on performances and verification were therefore not referenced or used further by "TEK97". Some of it was however used in national standard for risk analysis of fire, "NS 3901:1998". This has since been replaced by a 2012 version that has removed most of the previously included technical guidance on verification.

The new Norwegian performance-based building code was based on the following structure, as illustrated by Stenstad in [17], p.2 (translated):

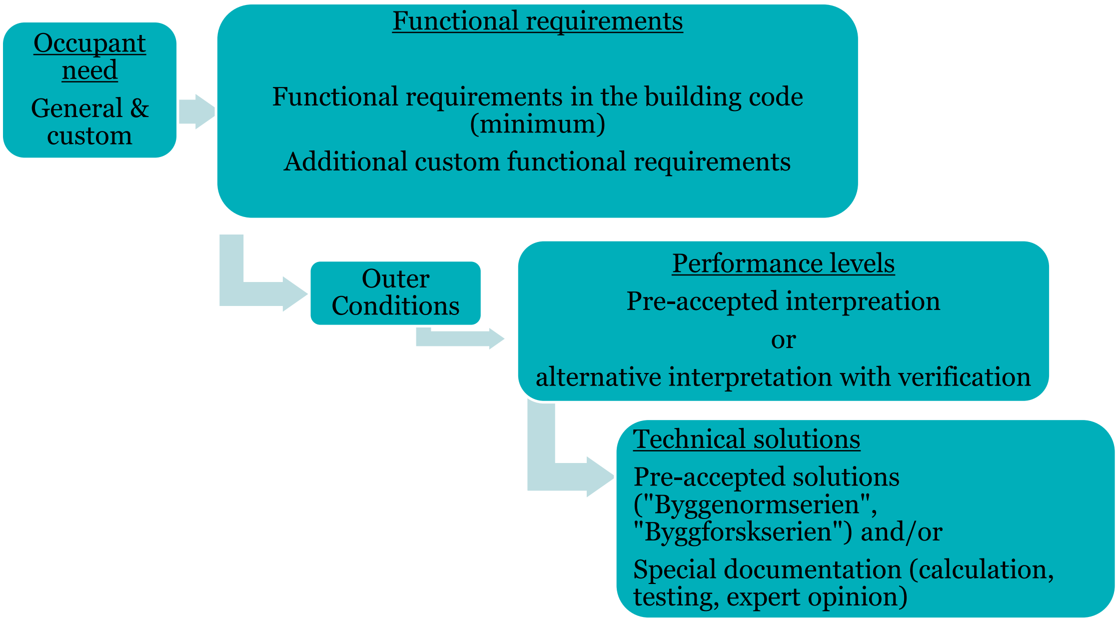


Figure 2-4 Structure of the Norwegian performance-based building code in 1997

Functional requirements are typically qualitative and objective-based and often not able to define a specific performance level by themselves. As such they need additional detailing, which is normally given through the addition of operative requirements. While the work done by NKB [16] provided the main structure of the functional requirements for fire safety in "TEK97", they were not able to provide a complete set of operative requirements that could express performance levels and identify a defined acceptable fire safety level. In the transitions between the previous prescriptive building code "BF87" [18] and the new performance-based building code "TEK97" it was however also a requirement that the overall acceptable fire safety level should not change, as both building codes were to comply with the same building act of 1985, "PBL85" (see interview with building authorities, Ch. 10.3). In "BF87", the societal acceptable fire safety level was defined implicitly through all the combined prescriptive requirements. As such, it was difficult to quantify the fire safety level. The solution to this was to take the previous prescriptive requirements from "BF87", convert them to what was referred to as "pre-accepted performances" and match them with the most appropriate and relevant functional requirement in "TEK97". The operative requirements (performances) from the NKB report were however not included. This meant that there were no calibration or harmonization efforts between the new pre-accepted performances and the functional requirements. The pre-accepted performances were deemed to comply with the new functional requirements in "TEK97" by default and became the pre-accepted path of compliance for the new building code. In effect they then also expressed the acceptable fire safety level implicitly, just as they had done in "BF87". These pre-accepted performances were not part of the actual building code but included in an accompanying guidance document called "Guidance to the building code", "VTEK". This type of structure has been retained since its introduction and is also present in the current version of the building code.

The prescriptive building requirements in the "BF87" building code were however a mix of both performances and technical solutions, as is often necessary in a prescriptive building code. Examples of this are requirements for fire resistance of 60 minutes for a wall (performance), and requirement for a specific stairwell configuration (technical solution). This makes it difficult to point out in the hierarchy of the Norwegian building code what are performances (which according to the IRCC model should be operative requirements) and what are acceptable solutions (which should be the non-mandatory pre-accepted design path). This has led to statements in the guidance to the building code such as "the pre-accepted performances must be interpreted as the minimum acceptable level of safety". Statements like this has since somewhat been amended in later versions of the building code but remain to a certain degree. Likely this is due to the fact that stating the pre-accepted performances are the "minimum safety level" is a potential gray-area with respect to the principle of legality, as they are not part of the actual building code itself, as pointed out by "Advokatfirmat Hjort" in [19].

This leads further to an important issue, an issue that has affected the practice of PBFSD in Norway since it became a recognized design path in "TEK97". The issue is the question of what should define the societal acceptable fire safety level in a performance-based building code. According to the IRCC model, the fire safety level in a fully developed performance-based building code should be identified and defined by the functional and operative requirements with fundamental performance metrics linked to these requirements that allow for verification. Instead the Norwegian performance-based building code relies on an implicitly defined fire safety level based on a previous buildings code. Having the current pre-accepted performances define the acceptable fire safety level in a performance-based code environment, is however not considered ideal. They are in large part based on previous prescriptive building code requirements, which has been influenced by multitudes of inputs from the society, ranging from environmental concerns, politics, major disasters and lobbying from various stakeholders over many years. While a lot of effort goes into trying to keep a uniform level of fire safety throughout these pre-accepted performances by the building authorities, it is next to an impossible task in the long run as the different performances and solutions add up over time and will inadvertently affect each other at certain points. This leads to an inconsistent fire safety level with respect to actual perceived risk and may lead to building designs that are not optimal. That inconsistency can then be introduced into PBFSD as well when pre-accepted performances as the reference fire safety level are used.

Thus, true PBFSD in Norway with verification using only functional and operative requirements, is challenging, as it requires the identification of alternative performances to define the fire safety level. Comparative analysis with the pre-accepted performances as the reference fire safety level have thus become the primary means of verification. This is supported by an investigation by Bjelland and Njå presented on the "9th International Conference on Performance-Based Codes and Fire Safety Design Methods" in 2012 [13]. 75 different building projects in Norway in the time frame of 2000-2011 were investigated based on chosen deviations from the pre-accepted performances and applied verification approaches. Comparative analysis was the most common type of verification, often with just qualitative statements and low use of quantitative methods.

A study of using comparative analysis of the Swedish acceptable solutions (general recommendations) by Yndemark et al [20] was presented at the "10th International Conference on Performance-Based Codes and Fire Safety Design Methods" in 2014. While generally positive to the use of comparative analysis, it points out that there are some pitfalls with the method that allow it to be both misused and abused to show that an alternative solution is satisfactory, even though that is not the case. Comparative analysis is also especially sensitive to the process of selecting a reference prescriptive building design and requires special consideration from the designer. Thus, it can be a relatively straight-forward task to show that an alternative performance/solution is as safe as a pre-accepted performance, even if the actual risk can be considered high. The use of comparative analysis remains high, even in more recent times. The fact that an inter-Nordic standard for comparative analysis was introduced recently in 2014, "INSTA/TS 950 "Analytical fire safety design – Comparative method for verification of fire safety in buildings" [21], and that it is referenced as an appropriate guidance document in the guidance to the current version of the building code as well, shows that the status of this verification approach is still relevant and very much in use.

Most of the development effort for fire safety in the Norwegian building code seems to have gone into the pre-accepted performances, both removing outdated and adding a few new based on feedback from the building market, the fire safety community and from various fire safety research projects. Several operative requirements of prescriptive nature (mandatory) have also been introduced to the building code, effectively reducing the freedom and flexibility of the performance-based design approach. Examples of this are requirement for automatic extinguishment systems and automatic fire alarm systems for buildings in risk class 6 (hotels and health care) and risk class 4 (housing) where elevators are required. While the intention behind such a measure definitively was to improve life safety, it had a big impact on the design freedom in these buildings as well, since automatic extinguishment systems typically are one of the most used fire safety measures for supporting alternative design, by way of a "technical trade-off". Since comparative analysis can be considered the primary method of verification, the heightened fire safety level of these occupancies makes it more difficult to justify any alternative performances and solutions, as they already have mandatory requirements for most of the fire safety measures that can be used to increase safety. That may however have been the intent from the building authorities (see interview in 10.3) since there seems to be a desire to reduce the use of alternative solutions, at least for the traditional and simple buildings.

Some positive efforts on the functional requirements however have also been done. Additional guidance text to understand the purpose of the functional requirements has been provided in the guidance document to the building code in the more recent versions. This guidance text also suggests in certain places standards or methods for verification. This guidance text has been a major improvement to the understanding of the building code and to the understanding of the link between the pre-accepted performances and the functional requirements. Such efforts are very useful and should be applauded. In recent years inter-Nordic collaboration efforts also seem to have increased again, and inter-Nordic standards such as INSTA/TS 950 have contributed with much needed practical guidance for fire safety engineering. Presentations on ongoing development work of the building code the last years by the building authorities also suggest a potential new structure for TEK21 [22][23]. This could trigger further improvements as well.

Challenges with verification of PBFSD in Norway remain in present times. A report on evaluation of requirements of documentation for building design in Norway by Forsen & Røsjø was recently published in April 2018 [5]. The report states that "*in general the respondents are positive to the requirements for documentation, but that the requirements are too strict for smaller building projects"*. The report also contains the feedback from the various respondents. The feedback from "RIF – Rådgivende Ingeniørers Forening" – the main interest group for consulting engineers in Norway, has particularly interesting comments about the fire safety discipline, p.33-34, translated quotation by the author included below.

"

- *We do not experience any big debate on scope of documentation, or requirements for documentation among our member companies, except fire safety. Fire safety is the area where the building authorities have been most involved in and where they try to regulate themselves. The building authorities do not leave this work to "Norwegian Standard" or similar standards. It remains a paradox that the area with most discussions is the area where the authorities have been most involved.*

- *On the topic of fire safety there are disagreements on the level of documentation needed, both inside the community, between the different fire safety engineers and with the building authorities. The guidance document to the building code is vague on many areas. A common design standard does not exist, there is only the guidance document to the building code. NS 3901 could be used a lot more.*

- *None of our member companies complain about the scope of documentation, but there are disagreements on what is considered a "good enough" level. There are large variations in terms of how much documentation is needed. The guidance document to the building code is not clear enough on this aspect.*

- *We do not necessarily need a detailed cookbook, but the performances must be sufficiently defined so that the reason is clear for why they are included. A red thread must be present between the building code and the guidance document. An example of where this has been a problem is fire safety related to ventilation systems, which has never been properly defined. The text given in the guidance document is more comparable to a functional requirement than a pre-accepted performance. This drives the cost of the design potentially up, as designers want to make sure that the proposed design will be comply with the building and thus add potentially unnecessary requirements to be on the safe side. "*

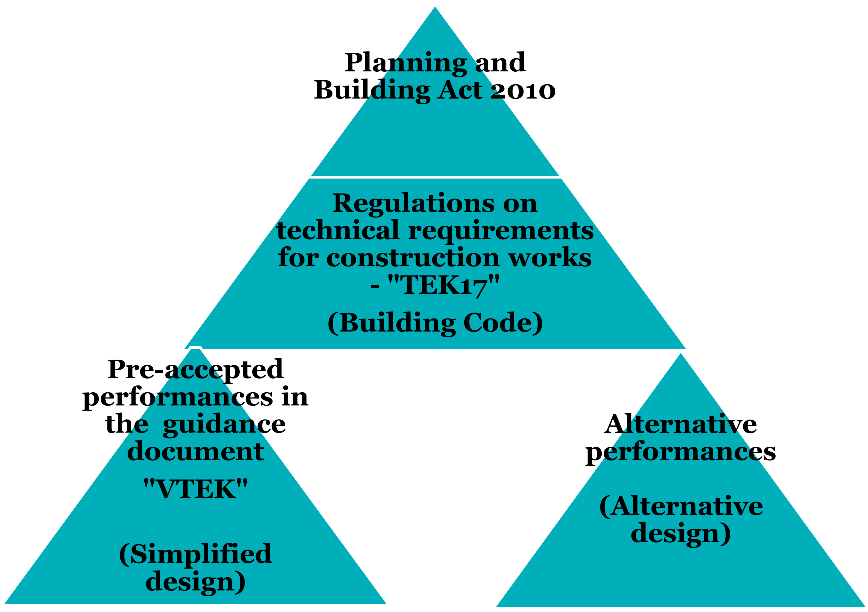
These statements are much in line with the view of the author, based on the accumulated work experience of practice with PBFSD in Norway for more than 10 years. The statements indicate there are still issues with both the requirements in the building code itself, and the guidance document that provides the pre-accepted performances.

<u>Summary</u>

The development of the first performance-based building code with functional requirements for fire safety, "TEK97", seems to have had some issues in defining performance requirements based on the new functional requirements. Instead, efforts to create performances based on prescriptive requirements from the previous building code were made, now referred to as the "pre-accepted performances". This also had the benefit of retaining the same fire safety level in the transitions between the building codes. This approach has however influenced the practice of PBFSD in the following years considerable, especially through use of comparative analysis as a verification method. This also holds true for the current version of the building code "TEK17". Issues related to the amount of documentation needed when doing verification, and what is "good enough" documentation is still very much prevalent in projects where PBFSD is applied.

2.5. Path of compliance and structure of the Norwegian building code

The following section aims to explain the paths of compliance for the current Norwegian performance-based building and give a brief overview of the various sections of the building code that make up the fire safety requirements.



The sections concering fire safety in the building code has for the most part functional requirements, but some sections also have some operative requirements with a prescriptive nature that must be followed. The functional requirements can be fulfilled with two distinct compliance paths. One option for compliance is using the pre-accepted performances which are located in the "guidance to the code" document, "VTEK". This document is not considered a part of the building code. These solutions are deemed to comply with the functional requirements without any further need for verification. This is also often referred to as simplified or prescriptive design, since it requires little effort beyond just confirming that the pre-accepted performances are chosen and considered applicable for the given building.

The other option of compliance is what is often referred to as alternative performances or analytical design. This option has little guidance, and it is entirely up to the designer to decide on a suitable performance and solution. There is however a requirement that the designer provides verification of compliance for this solution. This means that it must be shown, typically through recgonized engineering methods, that the chosen solution is able to fulfil the functional/operative requirement or performance in the building code.

It is the functional and operative requirements in the building code that are the legal binding and mandatory elements with respect to the complying with the building act. The pre-accepted performances are not part of the building code, and therefore located in the guidance document. They are however referred to in the building code as a possible path of compliance. The reason for this particular approach is most likely that process of revisioning the builing code is more complex than revisioning just the guidance document, and there is a desire to be able to revision the guidance document in a less complicated way. This does however potentially place the principle of legality in a gray area when the pre-accepted performances are unclear and allow for subjective interpretation, as pointed out in [19].

Guidance text for further interpretation of the functional and operative requirements in the building code is also located in the guidance document. This guidance text is usefull when trying to understand the goals and objectice of the building code requirements.

The main sections that make up building code requirements for fire safety in the building code are shown below. Chapter 4 provides details on functional and operative requirements in some of these sections.

I. GENERAL REQUIREMENTS RELATING TO SAFETY IN CASE OF FIRE

Section §11-1 Safety in case of fire

Section §11-2 Hazard classes

Section §11-3 Fire classes

II. LOAD-BEARING CAPACITY AND STABILITY IN CASE OF FIRE AND EXPLOSION

Section §11-4 Load-bearing capacity and stability

Section §11-5 Safety in case of explosion

III. MEASURES TO PREVENT IGNITION AND THE DEVELOPMENT AND SPREAD OF FIRE AND SMOKE

Section §11-6 Measures to prevent the spread of fire between construction works

Section §11-7 Fire sections.

Section §11-8 Fire compartments

Section §11-9 Properties of products and materials exposed to fire

Section §11-10 Technical installations

IV. FACILITATING ESCAPE AND RESCUE

Section §11-11 General requirements relating to escape and rescue

Section §11-12 Measures that influence escape and rescue times

Section §11-13 Exits from fire compartments

Section §11-14 Escape routes

Section §11-15 Facilitating rescues of domestic animals

V. FACILITATING THE EXTINGUISHING OF FIRES

Section §11-16 Facilitating the manual extinguishing of fires

Section §11-17 Facilitating the work of rescue and firefighting personnel

2.6. Structure of the Swedish performance-based building code and path of compliance

2.6.1. Introduction

Sweden is the closest neighbor to Norway, sharing a common border throughout most of the country and have much of the same geography and environment. There currently is, and have been for many years, much collaboration on many different fields between these two countries, fire safety included, as has been illustrated by the NKB efforts [4] [16]. As such, one would expect many similarities in the building regulatory system between the two countries. While this is generally true, there are also some noticeable differences. This makes the Swedish building code a logical and reasonable candidate for a comparison study on the fire safety sections in the performance-based building code.

Sweden took the leap from a prescriptive building code to a performance-building code in 1994. Since then, the building code has had one major revision, which occurred in 2012 as discussed by Cronsioe et al [24]. The revision work however started already in 2006, when the Swedish Board of Housing, Building and Planning conducted a pre-study for the fire safety regulations led by Jönsson et al [25]. Before this, Lundin [26] had also pointed out major issues with how the current system was working in his doctoral thesis, potentially creating dangerous buildings, p. iii-iv in the abstract:

"In this doctoral thesis some fundamental problems concerning society's ability to control the safety in buildings in the case of fire by issuing performance-based building regulations are identified and analysed. Fire protection documentation from forty-six projects was studied, together with a detailed analysis of the Swedish building regulations and an extensive risk analysis of a class of buildings. The results show that there is a lack of regulation and guidance on how to perform verification, which leads to arbitrary design decisions. It can be questioned whether the approach taken by many practitioners today is sufficient to fulfil the requirements laid out in the building regulations, that is society's demand for fire safety. Few tools are available to address these issues in a practical way. This thesis presents a procedure for verification and suggests general quality demands for verification as a means of addressing these issues."

The results of the pre-study set the main objectives to create clearer and defined fire safety requirements, as the study revealed that the building code from 1994 had introduced large uncertainties as to what was the minimum acceptable level of safety. This pre-study identified three key factors as summarized by [24], p.1:

" *1) No national guide for FSE*

2) No guidance from the legal system

3) Function-based regulations with few performance-levels or acceptable solutions "

Based on this, large changes to the performance-based code were made to have fire safety requirements with well-defined performance levels. A structure based on the previous work done by NKB [4][16], and more modern work by the Inter-jurisdiction Regulatory Collaboration Committee (IRCC) [6] was used as inspiration, illustration from p.2:

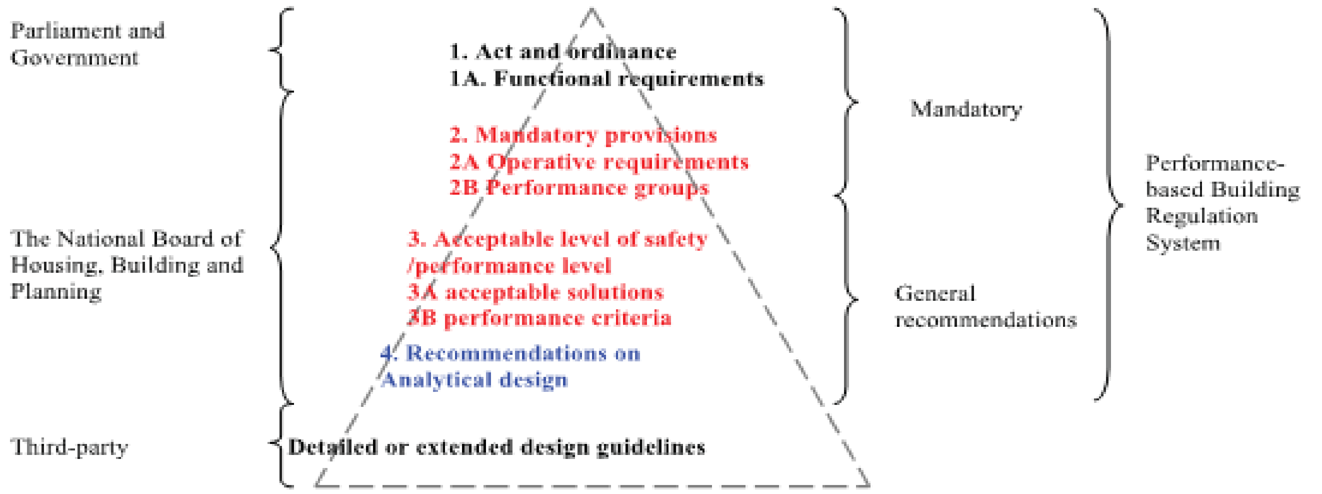


Figure 2-5 The structure of the Swedish building regulation system

The paths of compliance using the analytical design are shown below, figures reproduced from [24], p.5:

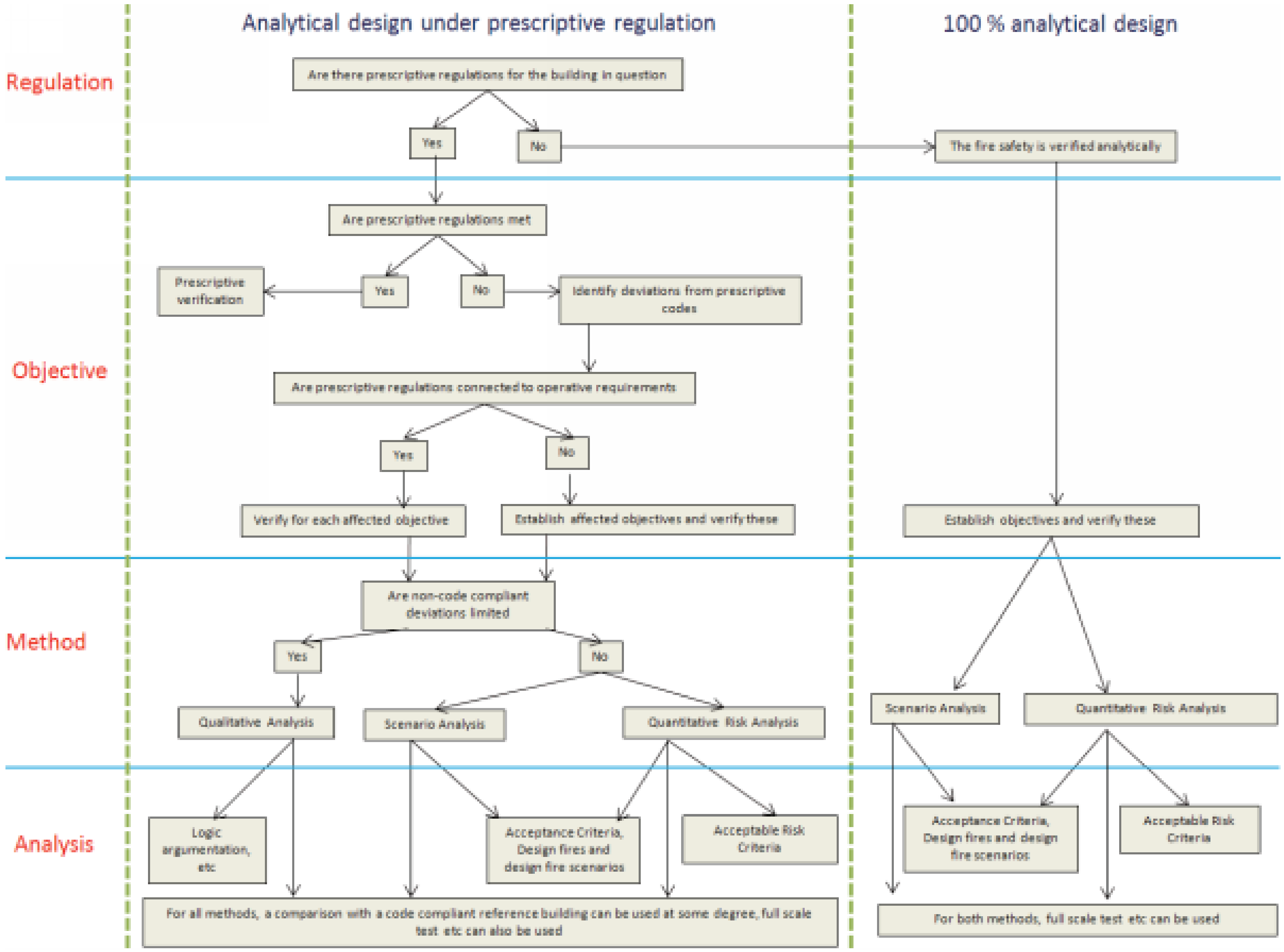


Figure 2-6 Paths of compliance for the Swedish building code

As can be seen, two main approaches for showing compliance is available:

1) Deemed-to-comply route, in which you can use both acceptable solutions and verification methods. Using any of these options is deemed to comply with the building code requirements.

2) Alternative solutions route, in which the responsibility of verification and showing compliance to the building code rests on the designer.

Chapter 5 of the building code (BBR) outlines the provisions for safety in case of fire.
These sections are as follows:

5.1 General conditions

5.2 Fire resistance classes and other conditions

5.3 Ability to escape in case of fire

5.4 Protection against the outbreak of fire

5.5 Protection against the development and spread of fire and smoke in buildings

5.6 Protection against the spread of fire between buildings

5.7 Possibilities of rescue responses

5.8 Requirements for fire protection during alterations to buildings

There are multiple functional and performance requirements under each of these main sections. Some of these are further investigated in the comparison analysis in chapter 4.

Due to their EU-membership SE have the fire safety requirements related to load-bearing construction works for buildings in a separate document from the BBR, which is called the EKS – (European Construction Standards - Eurocodes). The fire safety requirements for load-bearing construction works are in section C chapter 1.1.2. These are more detailed and covered in chapter 4.5.

2.6.2. Verification method "BBRAD"

"Boverkets allmänna råd om analytisk dimensionering av byggnaders brandskydd" (BBRAD) is the verification method for analytical design of fire safety [27] the Swedish Building Authorities introduced in 2012. It was published together with the major revision of the performance-based building code in 2012 and was the biggest change in the fire safety regulations since the introduction of the performance-based code in 1994. Between 1994 and 2012 the practice of PBFSD was for the most part left to interpretation by the fire safety engineer. The practice could then be heavily influenced by assumptions and subjective interpretations. As was pointed in [26], this practice was deemed problematic. There was a lack of national guideline for how to practice fire safety engineering. The purpose creating a FSVM according to [24] was then to:

1) Provide a framework for performance-based design and

2) to provide specific guidance on acceptable level of safety for certain design situations.

The motivation and purpose of creating a FSVM is also stated in the consequence study for BBRAD [28] p. 113-114 (translated by the author):

"Multiple studies have shown that large variations across the country exist when deviating from BBR and in verification for this. Because guidance on analytical design has been missing, the interpretation of the building code requirements has led to large individual variations between

different designers. The lack of guidance has also led to tailoring design fires to fit the purpose of the design of the architect, with the consequence of lowering the safety level. The rules and recommendations given in the general recommendations for analytical design will provide equal design conditions, which defines the requirements and will improve the practice. Through recommendations and requirements for documentation it will become easier to comply with the regulation and also to control that the requirements are being met. The design fires and design fire scenarios that should be a part of the verification give the designer a more defined directive on what is expected from the building if exposed to a fire. This is also a measure to create a healthier environment for business competition. With these recommendations the safety level is more defined and will provide a more consistent quality on the fire safety throughout the land."

BBRAD thus provides both methods and relevant input data to use for the most common verification tasks that is faced in PBFSD. The chapters are as follows:

1. Introduction
2. The design processes
3. Facilitating escape during a fire
4. Protection against spread of fire and smoke in the building
5. Protection against the spread of fire between buildings
6. Documentation and control

As can be seen, the chapters generally line up together with the main articles for fire safety in the building code. This creates a transparent link between the proposed verification methods and the functional requirements they are to support. Using BBRAD starts with identifying the scope of the verification to choose a fitting verification approach. A tool (matrix) is provided to help with mapping the number of deviations from the general recommendations and whether additional measures have been added to compensate. A translated version of the tool included in BBRAD [27], p.2 is shown below. This provides a qualitative overview if all deviations have been accounted for, and if a certain measure is used to account for several deviations and thus particular sensitive to failure.

	Part of the fire protection	**Deviations from simplified design**									
		Deviations					Added measures				
		1	2	3	4		1	2	3	4	
5:2	Fire classes and other assumptions										
5:3	Possibility of escape in fire										
5:4	Protection against fire										
5:5	Protection against fire- smoke spread through the building										
5:6	Protection against fire spread between buildings										
5:7	Facilitating for fire- and rescue services										
Sect. C, ch. 1.1.2 in EKS	Load-bearing capacity in fire										

Figure 2-7 Tool in BBRAD for mapping deviations from the general recommendations

Three different verification approaches of increasing complexity included in BBRAD are shown below [27], p.3-4. Their applicability is generally based on the overall risk identified with the deviation from the general recommendations identified by the tool in Figure 2-7.

Verification through qualitative assessment

Qualitative assessments can be used when there are limited deviations (from the general recommendations), and the uncertainty with chosen design is small. Using qualitative assessment should be based on the risk identification performed in conjunction with the analytical design. Qualitative assessments can be based on logical reasoning, statistics, experimentally tested designs, simple calculations etc. Using previous experiences should be verified with respect to that risks and conditions may have changed over time.

Verification through scenario analysis

Verification using a scenario analysis requires that the fire safety measures of a building is tested to one or several scenarios. Applicable scenarios are based on risk identification, and scenarios for further consideration should be based on what is considered to be the probable worst-case. Scenarios can be based on calculation methods and tenability criteria given in chapter 3-5. For all chosen design scenarios, the level for acceptable exposure should be met. The scenario analysis should include a sensitivity analysis to identify variables that have big impact on the level of safety. Such variables should be treated with conservatism. Examples of variables that may be part of a sensitivity analysis is the heat release rate, flame temperature, movement velocity of occupants and occupant distribution on emergency exits. Those variables that values are given for in the general recommendations in chapter 3-5 generally do not require being a part of the sensitivity analysis however. The result of the sensitivity analysis should be included in an assessment to decide whether the proposed fire safety design is satisfactory.

Verification through quantitative risk analysis

Verification using quantitative risk analysis should be based on distributions of input variables. The distributions of the variables should mirror those conditions that may be expected through the normal life cycle of the building. Verification using quantitative risk analysis should include a sensitivity analysis to identify variables that have big impact on the level of safety. Such variables should be treated with conservatism. An uncertainty analysis may be used to complement the sensitivity analysis to study such variables in-depth. The result of the sensitivity analysis should be included in an assessment to decide whether the proposed fire safety design is satisfactory. Examples of variables that may be part of a sensitivity analysis is the heat release rate, flame temperature, movement velocity of occupants and occupant distribution on emergency exits. Results from a quantitative risk analysis may be presented with goals based on individual or societal risk.

Of special note in BBRAD are the referenced design fire scenarios for evaluating life safety in the evacuation phase. These are further detailed below, [27], p.7-8.

"

Design fire scenario 1

This scenario is recognized by a serious fire development with rapid fire growth and high heat release rate, a probable worst-case scenario. Technical fire safety measures available in the building can be expected to work as intended, and the effect of these may be accounted for. The fire developments should be modelled from the following conditions and specifications:

- *The fire development (fire growth rate, maximum heat release rate and combustion products are chosen based on table 5 and 6.*
- *Automatic extinguishment systems may affect the fire development according to the chapter "Effect of automatic extinguishment systems"*

Design fire scenario 2

If the building is not equipped with an automatic fire alarm system covering the complete building, the analysis should include design fire scenario 2. Design fire scenario 2 is recognized by a fire in an area where occupants normally are not present but is still in connection with an area where many occupants may be present. Technical fire safety measures available in the building can be expected to work as intended, and the effect of these may be accounted for. The fire developments should be modelled from the following conditions and specifications:

- *The fire development (fire growth rate, maximum heat release rate and combustion products are chosen based on table 5 and 6.*

- *Automatic extinguishment systems may affect the fire development according to the chapter "Effect of automatic extinguishment systems"*

Design fire scenario 3

Design fire scenario 3 is recognized as a fire development with a reduced impact on the building but is occurring at the same time as a specific technical fire safety measure is not working as intended. The individual fire safety measures that should be considered in this scenario are as follows:

- *Automatic fire alarm*
- *Automatic extinguishment systems*
- *Automatic smoke ventilation or other similar system for limiting the spread of fire and smoke*
- *Elevators used for evacuation*
- *Following error should be considered if several systems can be made unavailable due to dependency on a sub-system, for example like power outage or fault with activation signals.*

The fire developments should be modelled from the following conditions and specifications:

- *The fire development (fire growth rate, maximum heat release rate and combustion products are chosen based on table 5 and 6.*

Automatic extinguishment systems may affect the fire development according to the chapter "Effect of automatic extinguishment systems", with the exception when this specific system is considered not available. "

2.7. Structure of the New Zealand performance-based building code and path of compliance

2.7.1. Introduction

The reason for choosing New Zealand as one of the countries to compare the building regulations against is mainly their extensive experience with a performance-based code. Norway implemented its performance-based building code in 1997. New Zealand however is considered to be the very first country in the world to adopt a performance-based building code as presented by Duncan in [29], having their first version made available already in 1992 A major revision was also performed in 2012. It is therefore reasonable to look to the experience New Zealand has accumulated when developing their performance-based code. New Zealand also shares some similar features with Norway with respect to building materials, population size, topography and environment. This makes the New Zealand building code a fitting candidate for a comparison study on the level of applicability for PBFSD.

The path of compliance for the New Zealand building code is shown in the illustration below, figure reproduced from website of New Zealand Ministry of Business Innovation and Employment (MBIE) [30]:

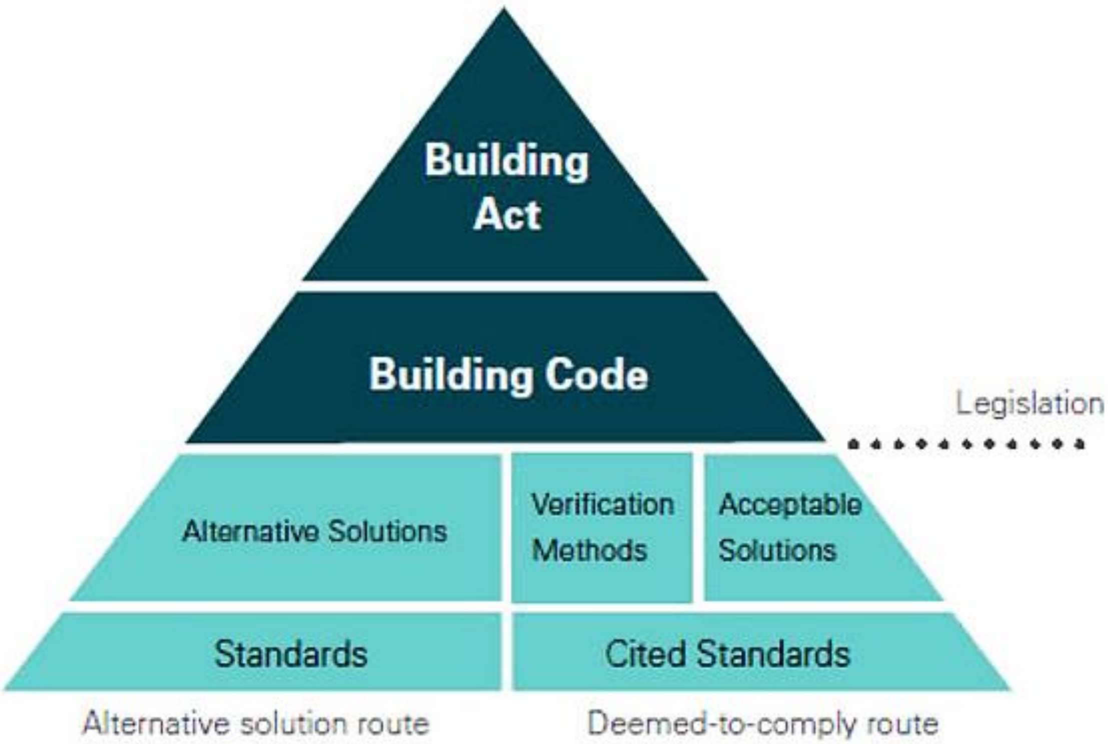


Figure 2-8 The structure of the New Zealand building regulation system

As can be seen, two main approaches for showing compliance is available for New Zealand is available as well, although the deemed-to-comply (prescriptive) route is shown split into acceptable solutions and verification methods:

1) Deemed-to-comply route, in which you can use both acceptable solutions and verification methods. Using any of these options is deemed to comply with the building code requirements.

2) Alternative solutions route, in which the responsibility of verification and showing compliance to the building code rests on the designer.

The current version of the New Zealand building code had its last major change in 2012. Much experience had been gained since the introduction of the first performance-based code in 1992. The practice of PBFSD between 1992- 2012 was without much guidance on analytical design, and the building code performances were vague and broad-based and not much quantified. Because of this, the acceptable solutions were used as the benchmark for the safety level, and alternative solutions were verified using mainly comparative analysis, often in just a qualitative way. This led to varying level of verification from the designers, where the same problem would be faced when the design was presented for peer review. The outcome of a verification was far from certain, and a previously accepted design was not guaranteed to be accepted the next time as discussed by Duncan [29] and James [31].

A new building act was introduced in 2004, and a review of the New Zealand building code was performed in 2007 [32] to check if it was consistent with the new building act. This new building act introduced a requirement that it must be possible to measure compliance with building code requirements. This in turn requires performance requirements in the building code to be well-defined and quantified, which became an important focus area of the review. Beever et al [33] p.38 summarizes the outcome of that review for fire safety:

"

- *The fire safety performance requirements are not clear, and there is no consistent New Zealand approach for fire safety design. This has resulted in a range of problems around interpretation and inconsistency.*

- *The Compliance Document does not provide specific requirements to fire engineers about performance requirements, design scenarios or design fires. This has led to inconsistent interpretations about the implied requirements of the Building Code, and disputes about the safety of fire designs for proposed buildings*

- *The performance requirements for multi-storey residential buildings, and the provisions for means of escape, have been the subject of several determinations by the Department.*

The lack of clarity about fire safety performance requirements has led to inconsistent interpretation of the regulations, and in the absence of clarity, debate and dispute over the application of the regulations. Innovation and development of new building systems becomes unattractive where regulatory boundaries are unclear or inconsistent, and costly delays are incurred while compliance is debated. The result is stifled innovation, more conservative design, and lengthy and costly compliance debates (e.g. developers amassing and arguing evidence to territorial authorities who have to engage in technical debate, often by contracting external expertise). "

The review followed up with some recommendations to remedy these issues, in part by specifying a need for design fire scenarios and performance requirements for the purpose of verification. This would typically be in line with the current practice for other engineering fields, for example like structural engineering. The impetus for the changes made to the building conde in in 2012 according to Duncan [29] p.28 were among the following considerations:

"

- *Commercial pressures and commoditization of fire engineering – questioning of quality*
- *Comparative and qualitative methods predominantly used for performance-based design*
- *Design solutions benchmarked against acceptable solutions (Deemed-to-Satisfy)*
- *Engineering assessments "judgement" rich*
- *Perception of "tame" peer reviews*

- *Driving down quality*
- *Limited holistic approach to fire engineering* "

Based on these experiences, a major revision in 2012 was made, where the previous building code structure for fire safety was rearranged into six main clauses, C1-C6 [34] :

C1 – Objectives of clauses C2-C6 and Clause A3 Building Importance Levels

C2 – Prevention of fire occurring

C3 – Fire affecting areas beyond the fire source

C4 – Movement to place of safety

C5 – Access and safety for firefighting operations

C6 – Structural stability

New quantitative performance-criteria were also included for most of these clauses in order to be able to comply with the requirement in the building act that states that building code compliance must be measurable, as pointed out by Beever et al [35].

The acceptable solutions were restructured in 7 different documents based on risk groups C/AS1-C/AS7. In addition, they also created a new verification method, C/VM2. This verification method can be viewed as a prescriptive approach of analytical verification. The benefit of this this is to promote design that still has some of the flexibility given by using engineering methods for design, but the freedom as to how that engineering method is performed and what input data to use in it, is limited to what is outlined in the verification method. If the verification method is chosen, it must be followed completely. Even with this prescriptive approach for analytical verification, New Zealand retains the "alternative solutions" path, where the option of "full design freedom" is given. The building authority (MBIE) also created a guide to support the process of developing such an alternative solution.

2.7.2. Verification method "C/VM2"

C/VM2 [36] is the acronym of the verification method the building authorities in New Zealand introduced along with its major revision of the building code in 2012.

The motivation behind introducing the verification method in New Zealand is similar to that of Sweden; A high degree of subjective interpretation in the applicability of PBFSD with low use of quantitative methods. Based on feedback from the building code review in 2007, the department of Building and Housing together with leading fire safety engineers undertook an effort to create a fire safety design framework that would seek to remedy these faults. This eventually led to the publication of the verification method C/VM2 in 2012 along with a major revision of the building code and the acceptable solutions. This verification method was however in the end made a path of compliance for the building code, as an independent part of the "acceptable solutions/ deemed-to-comply" route. If the method was followed, compliance to the building code was deemed fulfilled.

Since its introduction in 2012, there have been 5 amendments to the C/VM2. While the scope of C/VM2 has been somewhat amended since its introduction, it still provides a method of verification that will cover all the relevant requirements for fire safety in Clause C.

The current version of the C/VM2 has the following structure.

- Introduction and scope
- Rules and parameters for the design scenarios

- Movement of people
- Design scenarios
- Appendix A: Establishing group numbers for lining materials
- Appendix B: Critical Radiant heat flux values for some flooring materials

Figure 2-9 illustrates the main process for using C/VM2, reproduced from [36], p.13. As shown, the design fire scenarios form the backbone of the verification method in which all trial designs must be checked against. The various design scenarios are briefly summarized below, reproduced from [36] p.45-66 :

" *BE – Fire blocks exit. Demonstrate that a viable escape route (for multiple routes where necessary) has been provided for building occupants.*

UT – Fire in a normally unoccupied room threatening occupants of other rooms. Demonstrate ASET>RSET for any rooms or spaces that can hold more than 50 people given a fire occurs in the normally unoccupied space. Solutions might include the use of separating elements or fire suppression to confine the fire to the room of origin.

CS – Fire starts in a concealed space. Demonstrate that fire spread via concealed spaces will not endanger occupants located in rooms/spaces holding more than 50 people. This scenario is deemed to be satisfied by the use of separating elements, automatic detection or suppression.

SF – Smoldering fire. Provide an automatic smoke detection and alarm system throughout the building that has been designed installed to a recognized national or international standard.

HS – Horizontal fire spread. Demonstrate that the criteria in C3.6 and C3.7 are not exceeded by calculating the radiation from unprotected areas in the external wall to the closest point on an adjacent boundary and at 1.0 m beyond an adjacent boundary, and specifying exterior cladding materials with adequate resistance to ignition. Control horizontal fire spread across a notional boundary to sleeping occupancies and exitways in buildings under the same ownership.

VS – Vertical fire spread. Demonstrate that the buildings external claddings do not contribute to excessive vertical fire spread using on the methods described.

IS – Rapid fire spread involving internal surface linings. Demonstrate that surface finishes comply with these performance requirements.

FO – Firefighting operations. Show that performance requirements are satisfied.

CF – Challenging fire. Demonstrate ASET>RSET for design fires in various locations within the building

RC – Robustness check – Demonstrate that if a single fire safety system fails, where that failure is statistically probable, the building as design will allow people to escape and fire spread to other property will be limited. "

More guidance in terms of both scenario description and applicable approaches for each of the design scenarios are given in chapter 4 in C/VM2.

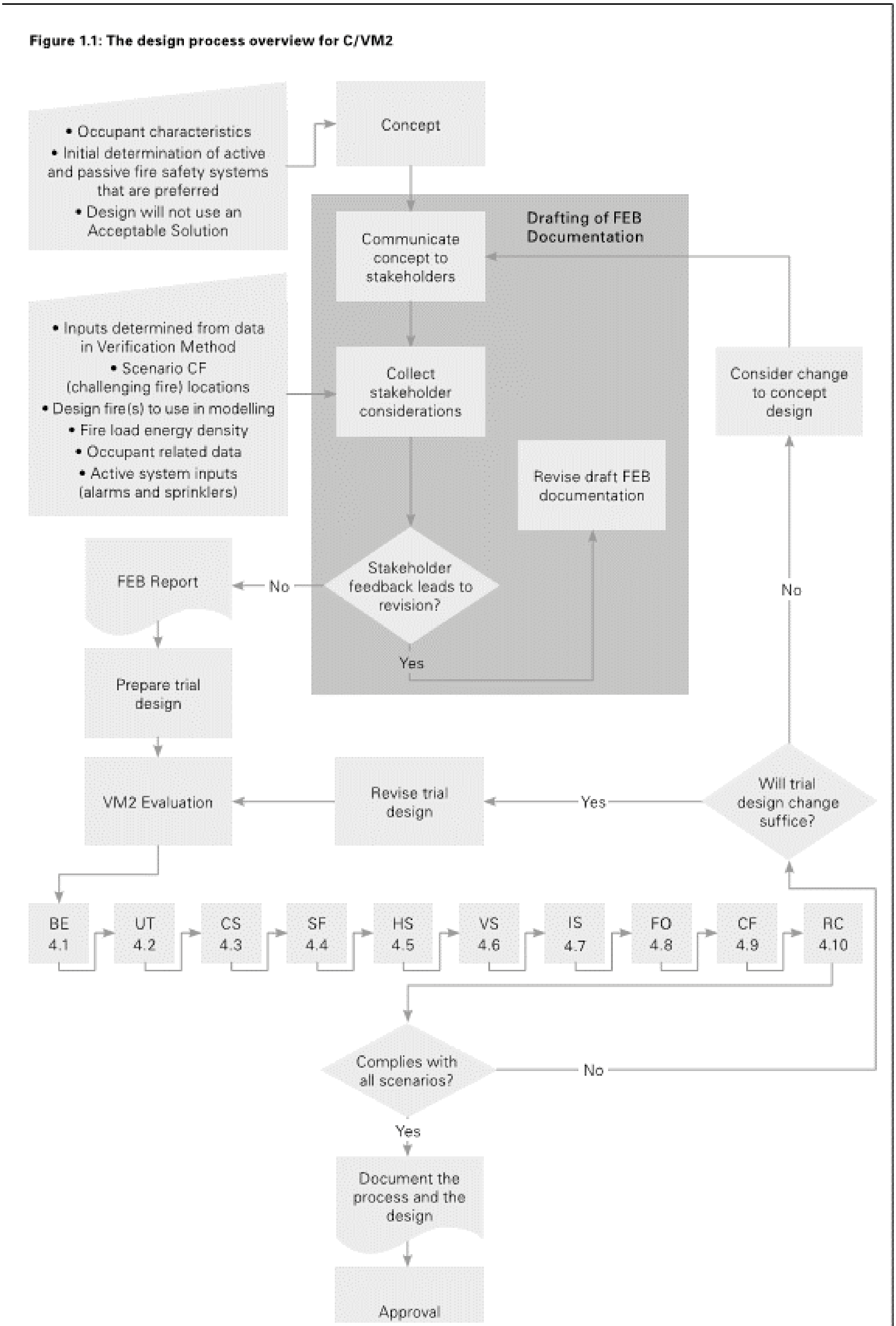


Figure 2-9 Design process overview for C/VM2

3.Methodology

This chapter presents the research methodology used in this thesis. The main research questions that form the scope of the thesis is listed initially. A brief description of the various available research methods is then given, with focus on the methods that are considered relevant and applied to the thesis. How relevant data has been collected, analyzed and used will be summarized, and in addition, the validity and reliability of the reference sources will be considered. Lastly, the question of author bias will be discussed.

3.1.Research questions

The major question asked in this thesis is, what is the status of PBFSD for buildings in Norway. Based on personal experiences from practice of PBFSD in Norway and early research into the international status on this practice, issues have been identified. These are issues that detrimental to the perceived quality of PBFSD, and need be corrected if we want PBFSD to be considered as a scientifically robust design approach. There are however several areas that influence the practice, and a choice have been made on what to focus on to narrow the scope of the thesis. Based on this, the following research questions are identified:

I. What is the international status of PBFSD and performance-based building codes for fire safety

II. What is the status of PBFSD and performance-based building codes for fire safety for Norway

III. How well does the functional and operative requirements in the Norwegian performance-based building code support PBFSD, and how to they do compare against performance-based building codes for fire safety of other similar countries

IV. Should Norway pursue the path of a fire safety verification method to increase quality in verification

3.2. Research strategy

The research questions posed in this thesis are not of a quantitative nature, and as such answers will not be found through lab experimentation or engineering calculations. They require the collection data on building codes and fire safety verification methods from other countries as part of a comparison study, as well as gathering accumulated knowledge from people that have in-depth personal experience with the practical use of these documents. When reading up on appropriate research methods, it became clear that the answers to the questions asked in the thesis would have to be acquired through some form of a qualitative research method. There is however a very wide range of different qualitative methods available. Based on suggestions for suitable research strategies on social sciences by Mehmetoglu [37], the strategies of empirical theory and case study seemed the most promising and were pursued further. A brief summary of each of these strategies is included below, based on discussion given in [37], as well as a conclusion to which method was chosen.

Empirical theory: The method of empirical theory seems to be one of the more structured and defined qualitative research methods. The method follows a rigid structure with a well-defined set of steps for how to analyze data. Based on this, the method seems particularly suited for research on topics that have had little previous research, but where there is potentially a large amount of data that can be analyzed in order to formulate new theories.

Case study: The method of case study is a less defined method compared to empirical theory, and a unified definition still seems be a topic of argument among researches. The method seems to be suited for research into a case or system, limited by time and space. This case or system may be a wide range of different objects, for example historical events, a defined process or certain people. Whereas the method of empirical theory is often used to formulate new theories based on the presented data, the method of a case study seems to be more focused on "the why and the how" behind the data.

The goal of the thesis is not to find or create a better alternative method/theory of practice than PBFSD, the goal is to try to improve it at a more national level. This is achieved by investigating available international and national research, and then applying relevant findings from that research into suggestions for specific changes for the practice of PBFSD in Norway. The main motivation is investigation into why there are challenges with the practice, and to gain insight into how those challenges may be solved.

Based on the specific characteristics of the thesis topic, the amount of already available research and that the primary means of data collection is through personal experience, literature review and a limited number of interviews, the method of a case study seemed to be the most suitable research method. The thesis can be considered as a case study into the current practice PBFSD in Norway, and how we may potentially improve it.

3.3. Data collection

PBFSD has been one of the main work areas in most of the author's professional life. The early interest into this design approach led to curiosity on the international development and practice of PBFSD and performance-based codes, both the historically origin, and where it is currently headed. In order to practice this design approach in a building code environment with minimal guidance, there is a need to pursue relevant knowledge elsewhere, through various scientific research journals, magazines and books. As such, a large repository of relevant literature related to this has been accumulated throughout the work career.

In particular, there has been an interest into seeing how PBFSD has been practiced outside of Norway. Fortunately, there are multiple arenas for exchanging such information and experience through conferences and symposiums. One conference in particular stood out when researching which conference would be the most relevant, *"International Conference on Performance-Based Codes and Safety Design Methods"* arranged by SFPE - "Society of Fire Protection Engineers" biannually. The author attended this conference first in 2010 and have attended the subsequent four conferences. These conferences have given an insight into the international arena of PBFSD, where experiences from both building authorities and building code practitioners from many different countries have been shared. The proceedings from these conferences have been one of the most important sources of knowledge and literature for this thesis.

The building codes from Norway, Sweden and New Zealand have been freely acquired from the website of the respective building authority. These serve as the main data input for the comparison study between the building codes. Literature review, previously accumulated work experiences, and discussions with colleagues on using the building code of Norway, and data from the building codes of the countries, are the main source of knowledge used to be suggest potential improvements of the Norwegian building code.

It was recognized at an early stage that it would be necessary to collect practical experiences with the use of verification methods in the countries chosen for the comparison study, Sweden and New Zealand. Some of this information was deemed necessary to acquire through interviews. The interviews were performed both as semi-structured live interviews and structured written interviews. For all live interviews an interview guide outlining the relevant questions was sent ahead of the interview. Two live interviews were performed with fire safety engineers from Sweden, Daniel Rosberg from WSP and Anders Johansson from Boverket. WSP is a major international multi-disciplinary engineering company, while Boverket is the Swedish building authorities. Selecting these two interview candidates made it possible to have balanced view between the industry practicing the building code and the verification method and the public that is responsible for writing and maintaining these documents.

A former colleague that had moved to New Zealand was able to help with facilitating interviews there. Interview subjects did not want to have the company name included, and as such it is not referenced in this thesis. All the interviews were performed as structured written interviews due to the time zone difference. Because of this it was possible to do more interviews and there were several people available that were willing to answer the written interview. The interview subjects are considered to have widely different backgrounds with different education and varying previous work experiences. As such they are considered to give a nuanced view of the building regulation and practice of the fire safety verification method in New Zealand.

It also became clear through the data collection process that an interview with the building authorities in Norway would add much needed perspective and confirmation on the previous and current development of the Norwegian performance-based building code. Vidar Stenstad, the main responsible for the fire safety section in the building code, fortunately agreed to do a live interview.

3.4. Reference source validity and reliability

The literature referenced in this thesis is a combination of both academic research from recognized researchers in the fire safety community, as well hands-on practice from individuals working at engineering companies that want to share their experiences with practice of PBFSD with others. Many of these are also researchers or have previous background from working as such. The topic of PBFSD is considered to be a topic that requires input from research academia and practical experiences from engineering firms if we want to develop it further. Research is needed to develop tools and methods f, while practical experience on how those tools and methods work in realistic conditions are needed to improve the tools further.

Many of the reference sources can be traced back to multiple occurrences of a single conference, the "SFPE International Conference on Performance-Based Codes and Safety Design Methods". While this may be perceived as a weakness with respect to source variability, it is considered acceptable as presenting literature based on the practice of PBFSD is the main goal of such a conference. The material provided to this conference is based entirely on voluntarily efforts, with only a minor discounted attendance fee as a given benefit. An international jury also reviews and selects the presenters based on the relevance and quality of their proposals. As such, the quality of literature presented at this conference is considered to be reasonably high.

Some of the references are from the same individual. While this can be considered a weakness, it is also something that is difficult to prevent in smaller disciplines such as fire safety. Where critical viewpoints or suggestions are given with respect to the thesis topic, multiple sources are sought as to increase the validity and reliability.

It is recognized that more countries could be used as reference for the building code comparison, and that this would strengthen the suggestions for improvement. The chosen countries Sweden and New Zealand are however considered highly relevant to compare against as they are among the countries in the world that has had the most development on performance-based codes.

3.5. Author bias

The potential effect of author bias is not possible to deny, as the author is highly motivated for a continuation of the development and practice of PBFSD. However, effort has been made to present the practice from a neutral standpoint, where recognition for design approaches are included as well. This is also reflected in the questions in the interviews, where both positive and negative experiences are sought.

4. Analysis and discussion of functional and operative requirements for fire safety in the Norwegian performance-based building code

4.1. Introduction

This chapter covers results and discussion from the investigation of the functional and operative requirements for fire safety in the Norwegian building code. Discussion is included at the end of each subchapter.

Not all sections are covered however, as this would be outside the possible scope. Select sections have been identified to have more fundamental challenges compared to the rest, due to how the functional requirements in these sections are stated. The analysis included for these sections focus mainly on how the functional requirement is written and defined in the building code. The following sections are covered:

- §11-8 Fire compartments
- §11-13 Exit from fire compartments
- §11-14 Escape routes

Other sections that typically affect or are used in particular for performance-based designs, are included to investigate if they can be improved to allow for easier verification. These sections are also compared to equivalent sections in the Swedish and New Zealand building codes. The sections that are covered are:

- §11-2 Hazard classes
- §11-3 Fire classes
- §11-4 Load-bearing capacity and stability
- §11-6 Measures to prevent the spread of fire between construction works
- §11-11 General requirements for life safety

4.2. Section §11-8 Fire compartmentation

As shown in chapter 2.5, the Norwegian building code has a total of 5 main paragraphs for fire safety, which is further split into 17 sections. Each section then has a few functional and operative requirements linked to it. While most of the sections have titles attributed to some overarching goal or functional objective for fire safety, certain sections focus on specific measures instead. An example of this is §11-8 Fire compartmentation. Fire compartmentation is a fire safety measure used to limit the spread of fire and smoke beyond the area of the fire source. There is however no apparent reason as to why this specific measure needs to have its own main section and have the functional requirement linked to only use of this specific measure. The building code has several requirements for the use of specific fire safety measures, but these are usually given either as operative requirements or as part of the pre-accepted performances, and not as part of the functional requirement.

Focus on specific fire safety measures instead of goals or qualities in the functional requirement take away from the goal/objective-based structure, giving the impression that the specific measures are building code requirements. This is to some degree remedied by the building code by stating in the functional requirement that the measure may not be necessary if the same level of safety is obtained by other means, [38], §11-8 :

"(1) Construction works shall be appropriately divided into fire compartments. Areas posing differing risks to life and health or in which the risk of fire occurring differs shall be separate fire compartments unless the same level of safety can be obtained by other means."

Such a specification should however not be necessary if the functional requirement is defined using a desired quality, function or objective instead. Buildings may obviously be built without the use of fire compartmentation and still have acceptable fire safety, as there are many examples of such buildings in use today. The need to state that buildings shall be divided in fire compartments in the functional requirement thus seems unwarranted.

Suggestions for improvements

The section should be renamed to "Preventing spread of fire and smoke throughout the building". This new section could then also contain requirements for the use of fire sections, which is currently located under §11-7 Fire sections.

The functional requirement should be rewritten in such a way so that it does not specify the use of fire compartmentation specifically. The key performance of limiting spread of smoke and flame throughout a building to safeguard life safety should be clearly communicated. Additionally, the functional requirement should also state that flame- and smoke spread from the originating fire location should be limited in such a way that allows for effective fire service intervention. The following functional requirement is suggested as a possible replacement:

- "Buildings must be designed in such a way that flame- and smoke spread from an originating fire location to the rest of the building is limited, and do not pose a threat to occupants that are not close to the fire source."

The functional requirement may also be supplied with additional operative requirements and performances. A few examples are given below:

- "Occupants that are close the fire location shall still have reasonable means of egress even though they may be affected by fire and smoke during the time needed for evacuation. "

- "Occupants that are remote from the fire location shall have means of safe egress where they are not affected by the effects of the fire and smoke during time needed for evacuation.

- "Verification of egress conditions where an alternate/analytical design approach is used, shall be verified by estimating the available and required safe egress time based on the life safety acceptance criteria given in §11-11."

- "The amount of spread of flame and smoke throughout the building must be limited to so that the local fire service can effectively and safely locate and extinguish the fire. The fire service must be able to attack the fire from a location where they are not exposed to conditions that they are not equipped to withstand or expected to be able to cope with."

- "Both active and passive fire safety measures may be used to fulfill the functional and operative requirements listed in this section."

4.2.1. Discussion

The suggested renaming of this section and the new functional and operative requirements are considered to better support the use of PBFSD and alternative design. The functional requirement is written with a specific function in mind, which is to prevent the spread of fire and smoke throughout the building. Operative requirements and performance metrics for life safety and for the safety and support of the fire services are also given and written to promote the use of quantified fire safety engineering when alternative design is used. If acceptance criteria for life safety may be defined in the building code (or an equivalent recognized document like a fire safety verification method) the acceptable fire safety level for life safety will also be defined without the need for the building designer to create such performances themselves. The same may also done with the safety for the fire service if quantified criteria are given based on what exposure they are able to withstand with their protective gear. Implementing changes such as these will likely lead to reduced variability in verification when creating alternative solutions.

The potential negative consequences of the suggested changes may be an increase in buildings that use more active fire safety measures like automatic fire suppression instead of passive measures like fire compartmentation. Whether this is a negative consequence may be argued, as such systems are very effective when operating as intended. An argument can however be made that active systems are less robust and vulnerable to changes in the building. That argument may however also be used for passive measures. Active measures typically also have requirement for periodic control and maintenance, and even constant automatic self-supervision. Passive measures like walls and doors must followed up manually, and usually don't have such stringent requirements for periodic control and maintenance.

The new requirements are also written in such a way that considerable quantified verification is expected if alternative design is chosen. This should maintain the use of pre-accepted performances for more traditional and simpler buildings, as this likely would be more cost-optimal.

4.3. Section §11-13 Exit from fire compartment and §11-14 Escape routes

The focus on the need for fire compartmentation in the building code requirements creates problems in other areas of the building code as well. A relevant example that often creates problems in many modern building projects is section §11-13 Exits from fire compartments. The following functional requirement is given for this section:

"(1) Fire compartments shall have at least one exit to a safe location or exits to two independent escape routes or one exit to an escape route that has two alternative directions of escape that lead to independent escape routes or safe locations."

The problem occurs when this definition is used together with the definition of how a building should be divided into fire compartments with respect to varying risk. Many rooms in a building can have different risk, and as such could be interpreted from the functional requirement to be required to be separate fire compartments. This in turn quickly creates a problem because the functional requirement for §11-13 states that an egress exit from a fire compartment must to lead to a safe location (typically considered to be different fire section or safely outside the building), or to defined escape route(s). This leads to the next problem, which is in the functional requirement for §11-14:

"(1) Escape routes shall, in a clear and easily understandable way, lead to a safe location. They shall be of adequate width and constructed as a separate fire compartment designed for speedy and efficient escape."

Per §11-14, an escape route must also be a separate fire compartment. While it not stated in the building code that this needs to be an enclosed corridor, the interpretation of what is considered safe escape routes in the pre-accepted performances leave little doubt that such areas must be separate from other building areas. As such, an egress exit from a fire compartment usually means exit to a closed corridor unless the fire compartment is directly connected to a stairwell (also defined as an escape route). This issue will often lead to problems in buildings where there is a desire to not use enclosed corridors, but still maintain a traditional fire compartmentation. This makes it difficult to comply with the functional requirements, as shown in the examples below:

- Open-plan schools and kindergartens/nurseries where open spaces are used instead of the traditional class- and department rooms as separate fire compartments that lead to a defined enclosed escape route (corridor).

The open spaces can however in many scenarios still be defined as separate fire compartments, because there are other elements such as acoustics that must be considered and would require physical barriers in which fire resistance may also be applied to create fire compartments. Unless each of these open spaces could have their own separate exits to either a stairwell, to a separate fire section or to outside of the building, defining these open spaces as separate fire compartments without a corridor system working as a defined escape route would be problematic. Moving through other open spaces or moving through "common rooms" not considered to be enclosed escape routes would then be considered to be in violation of the functional requirement for §11-13.

- Open-plan office buildings that wants to support multiple companies without having an enclosed corridor system

It is often a desire to have a company fire-separated from other companies if you reside in the same building. That is usually not a problem if the companies are located on separate floors. If located on the same floor, it would typically require fire-compartmentation using enclosing walls. That is however difficult to do if the building does not have a corridor system, since each company would then require a separate exit to either a stairwell, to a separate fire section or to outside of the building to comply with functional requirement for §11-13.

- Hotels with open lobbies and restaurants/bars

Hotels often want to have open-plan solutions in connection with the lobby level. This is however also usually the main entrance to the building, and as such also one of the main exit points. While an enclosed corridor system is often present in hotels, having the open lobby or restaurant area connect to this corridor, or a stairwell from this corridor, could be considered a problem, since exit from the hotel rooms is required to lead to an escape route that is a separate fire compartment. As such, this could be violation of the functional requirement for §11-13.

The effect these functional requirements has on fire safety design of a building is that there is sometimes a desire to reduce the number of fire compartments, because it is next to impossible to comply with the functional requirement for §11-13 and §11-14 unless the use of escape corridors is a possible and desirable design approach.

The focus on fire compartmentation and the stringent requirements for exits from fire compartments to be separate fire compartments seems to stem from [16], the research work done as part of the development of functional requirements for fire safety for a performance-based building code. The definitions given in this report are almost sentence for sentence equal to what is stated in the current version of the building code. Thus, there have been very few changes in these functional requirements in the building code since they were first introduced. The design approach intended in these functional requirements seems to be based on a design philosophy that was more common in earlier years of building design where the use of passive fire safety measures was a requirement to ensure satisfactory fie safety. It does not seem to work well with the more modern approaches where there is a desire for open, large spaces with fewer passive barriers and more active fire safety measures. As such, it may be an appropriate time to modernize and update some of these functional requirements to allow for easier and more flexible building design.

Suggestions for improvements

The functional requirements in §11-13 and §11-14 define how exits from fire compartments and how escape routes should be designed, and currently depend heavily on the use fire compartmentation. The functional requirements in these two sections are linked to facilitating means of safe egress routes, which are considered to be adequately covered by the current functional and operative requirements given in TEK17 §11-11 (see 4.7 for further details).

As such, one possible option would be to remove the functional requirements for §11-13 and §11-14 entirely. The pre-accepted performances linked to these two sections could then be moved to §11-11 instead. It is however recognized that the current requirements in these two sections are providing a certain insight into how egress routes should be fundamentally planned with respect to having multiple options of escape in a fire situation. There may be a desire to make sure this principle is still accounted for by stating it in an operative requirement. As such, the following additional operative requirement to §11-11 as a replacement to the functional requirements in §11-13 and §11-14 is suggested:

" Evacuation from a location within a building must be possible by a minimum of two separate directions. A single direction may be acceptable in certain conditions as long as it may be verified that there are safe egress conditions along the single direction in the time required for evacuation. "

4.3.1. Discussion

Similar recommendations to allow escape from fire compartments without requiring dedicated escape routes as fire compartments were also a part of a possible change study [39] for the current version of the building code, "TEK17". While the proposed change was more limited in scope than what is suggested here, it was recommended to change the functional requirements to allow for escape through other fire compartments. These recommendations were also part of a public draft proposal for the new building code. The recommendations were however not included in the final version of the building code that was made official and put into effect 1sth of July 2017.

The proposed changes are also supported by the fact that the functional and operative building code requirements in the Swedish and New Zealand building codes do not specify that exits from fire compartments must to lead to escape routes, and that escape routes must be defined as separate fire compartments. In fact, the New Zealand acceptable solutions C/AS5 for "Buildings used for Business, Commercial and Low Level Storage" even references escape through other fire compartments as a possible design approach, see illustration below [40] p.46:

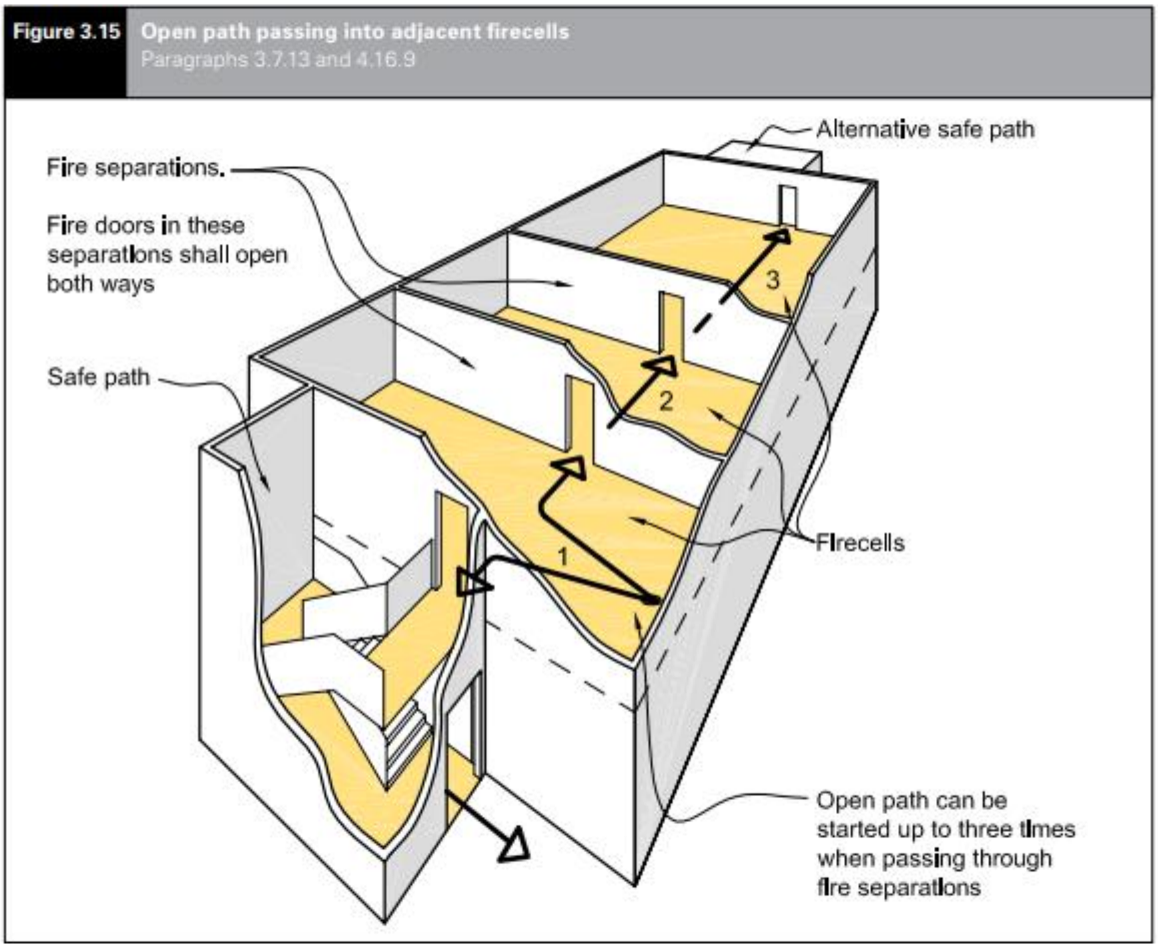


Figure 4-1 New Zealand Acceptable solutions C/AS5 allowing escape through other fire compartments

Since the principle goals for fire safety and safe egress remain much the same across these building codes, it should be possible for Norway to change and update the functional requirements so that such design approaches would be possible as well.

The proposed changes are considered to achieve the same intent as the original functional requirements, but without referencing specific measures or design options. If the building authorities deem it necessary that for certain areas or buildings the use of specific measures such as fire compartmentation must be mandatory, it may be given through additional operative requirements. Operative requirements that specify specific measures should however be kept to a minimum as it will impact the level of applicability of performance-based design. A more optimal approach would be to have requirements for the use of such specific measures part of the pre-accepted performances instead.

Positive consequences are considered to be increased design freedom and flexibility in fire safety design, with building code requirements that are more in line with the expectation of a fully developed performance-based building code. New and potentially better design options would be possible since it would be possible to facilitate egress from a specific area through other fire compartments. This also means that if there is a desire to have a rigid fire compartmentation in the building, the building code will not punish this design approach by requiring a separate exit from each fire compartment or require use of separate escape route corridors. Some examples of new egress design options that would be possible with the proposed changes are shown below. Walls with red color indicate fire compartmentation, green floors are considered defined escape routes and green arrows possible paths of escape.

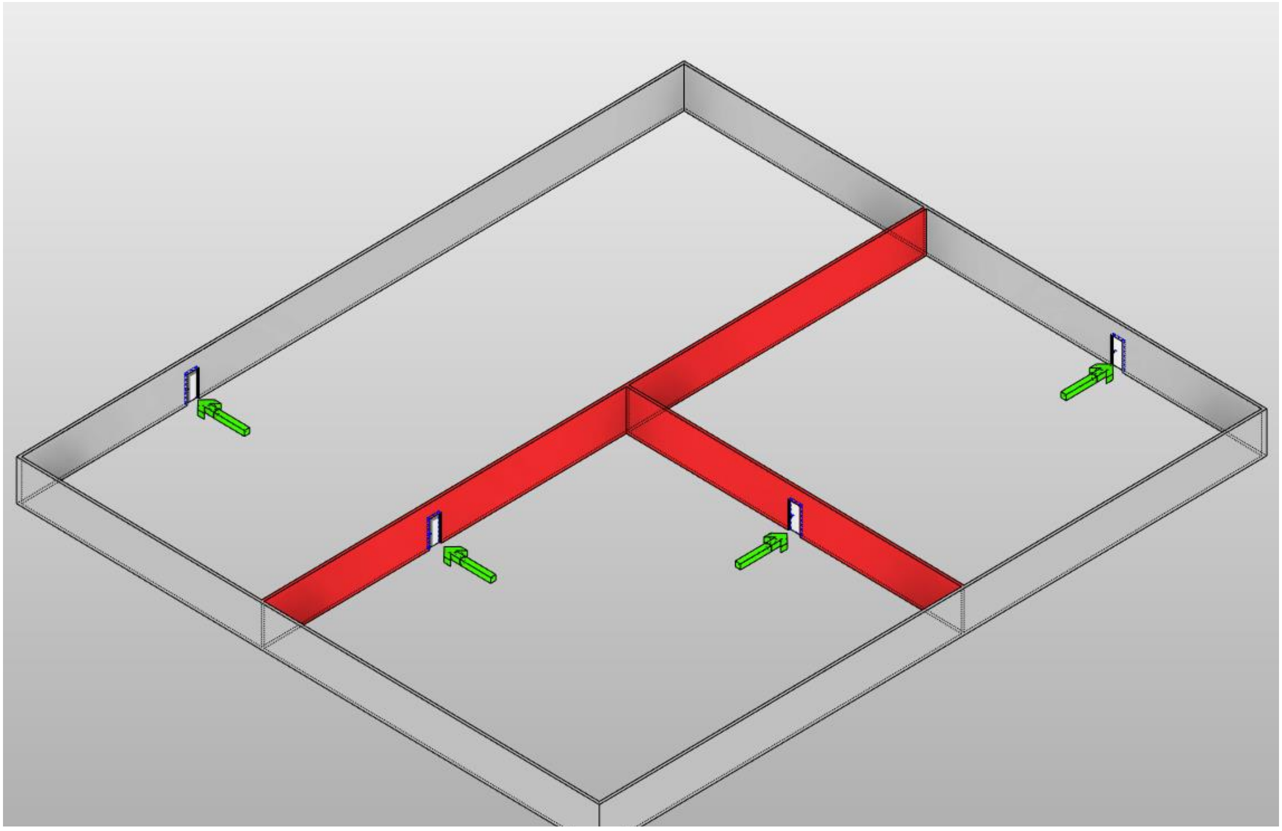


Figure 4-2 Example of possible new egress design option 1

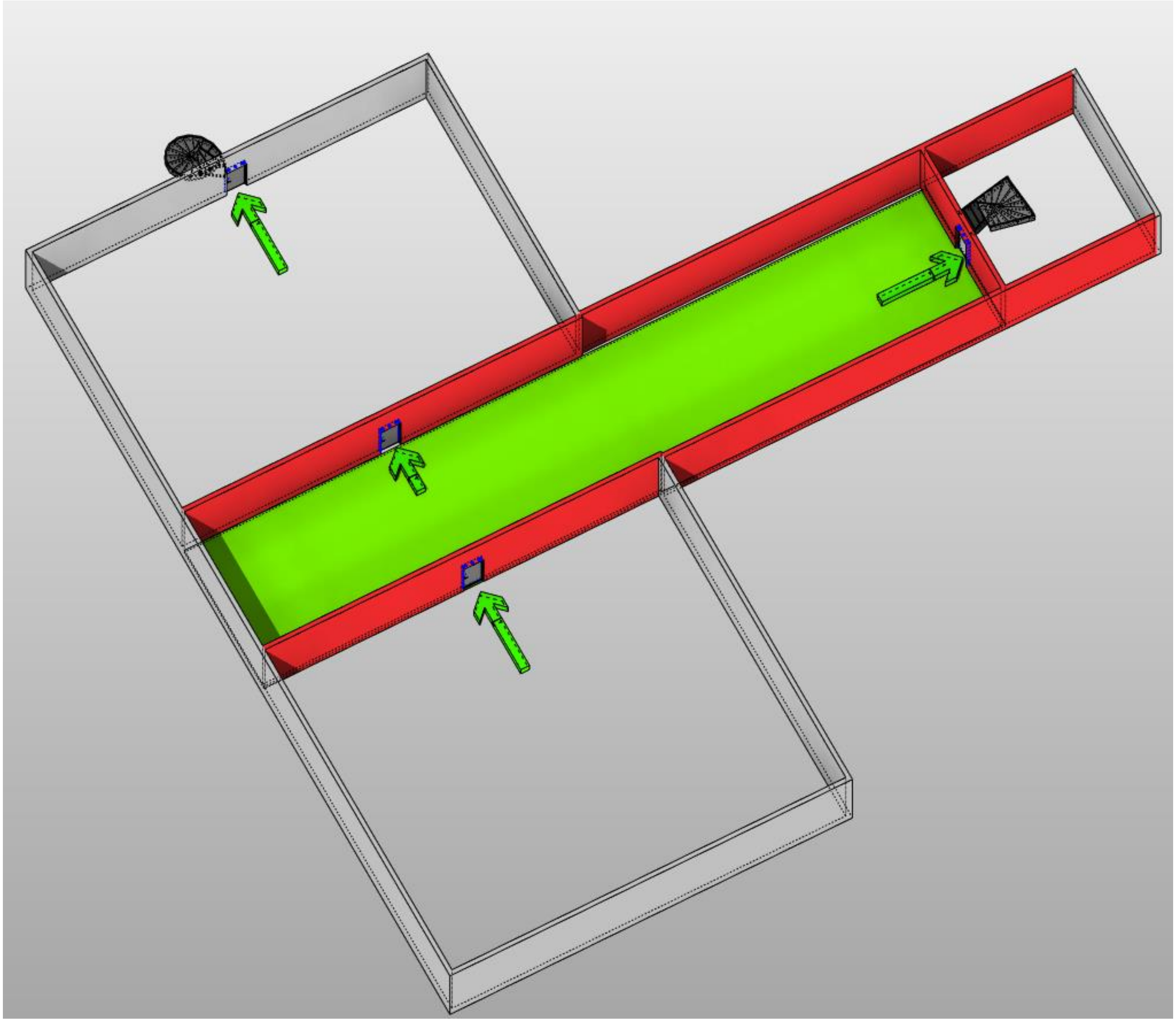


Figure 4-3 Example of possible new egress design option 2

The proposed changes would also lead to fewer application of deviations from the building code requirements due to the reduction in the amount of specification. This is considered very beneficial, as these deviations need to be evaluated and approved by the local building authorities, which often have limited or inadequate resources to effectively handle such cases. The outcome of such applications is therefore highly uncertain, and often denied as the local building authorities are uncomfortable with taking such a responsibility.

The potential negative consequences of implementing the proposed changes could be that the building code would allow for new design solutions that are currently prohibited, and by some viewed as potentially riskier. New design solutions could allow to move through other fire compartments or allow more fire energy load along egress routes. These new egress designs would however likely be alternative performances designed through PBFSD that would require verification. Depending on the specifics of the design, verification could be challenging, especially if using a comparative analysis. This could in turn lead to verification with variable quality, and in a worst-case scenario lead to unsafe design. The proposed changes are however not considered to lead to potentially more unsafe design than what is already possible to do within the current regulation system. If the building authorities should be particularly concerned that the proposed changes could lead to more unsafe design if alternative solutions are misused or abused, then implementation could be delayed until evidence of improvement in the quality of the current verification practice is evident.

It is also recognized that the proposed new operative requirement may lead to challenges related to dead-end- corridors and -pathways. Such configurations are to a certain extent allowed in the pre-accepted performances, so they should be allowed in alternative design as well. An effort to account for this is provided in the operative requirement, where single direction is allowed if safe egress may be verified along the single direction of travel. Verifying this without the use of extensive quantification for shorter distances is not deemed to be a problem for buildings with fire detection and alarm system, which is a mandatory requirement for almost every building in the current version of the Norwegian building code.

4.4. Section §11-2 Hazard classes and §11-3 Fire classes

This chapter contain requirements for classifying hazard and fire classes. The hazard with respect to fire in the building related to its expected occupancy and its occupants is defined with the hazard class. The impact and consequence of a fire in the building is defined with the fire class. Together these two sections provide the main performance/risk groups and performance levels used by the building code. Some of the functional requirements and performances, and many of the prescripted performances, are based on these two classifications. As such, it is critical to be able to define them properly.

Hazard classes

The hazard class varies from 1 being the lowest through 6 being the highest, and is dependent on answering yes or no to the following statements, from [38] §11-2:

"Based on the threat a fire could entail in relation to danger to life and health, construction works, or different areas of use in construction works, shall be categorized into hazard classes pursuant to the table below. The hazard classes shall provide a basis for design and construction to ensure escape and rescue in case of fire."

Table: Hazard classes

Hazard classes	Construction works designed for only the sporadic presence of people	People in the construction work are familiar with the opportunities for escape, including escape routes, and can get to safety unassisted	Construction works designed for overnight stays	Intended use of the construction work does not represent a serious fire hazard
1	yes	yes	no	yes
2	yes/no	yes	no	no
3	no	yes	no	yes
4	no	yes	yes	yes
5	no	no	no	yes
6	no	no	yes	yes

Figure 4-4 §11-2 Hazard classes

The pre-accepted performances for hazard class classification provide a table with explicit examples of occupancies and its correlating hazard classification, without the need for going through the yes/no statements outlined above.

The following guidance text to the functional and operative requirements for hazard classes are given, [41] §11-2:

"Buildings with sporadic presence of occupants are buildings expected to have occupants only occasionally present, and only for short periods of time. This could for example be storage buildings, shacks or car parks without dedicated working areas.

The term "Intended use of the construction work does not represent a serious fire hazard" is meant to indicate buildings that do not have a specific occupancy or activity that can typically easily lead to a fire, for example as part of an industrial process."

The hazard class is defined based on the occupancy (intended use of the building) that is defined, and the expected conditions that the occupants will face to bring themselves to safety in case of fire."

Fire classes

The fire classes are defined from 1 for a low impact up to 4 for very serious impact of fire. The following functional requirement is given,[38] §11-3:

"Based on the consequences a fire could entail in relation to danger to life and health, social interests and the environment, a construction work, or different areas of a construction work, shall be categorized into fire classes pursuant to the table below. The fire classes shall provide a basis for design and construction to ensure the construction work's load bearing capacity in case of fire."

Table: Fire classes

Fire class	Impact
1	Slight
2	Moderate
3	Serious
4	Very serious

Figure 4-5 §11-3 Fire classes

The guidance text to the functional and operative requirement provides some more detail as to what is implied with the different fire impacts [41] §11-3:

"The consequence of a fire is dependent on the presumed use of the building (hazard class), the number of occupants, the size of the building, building layout, fire load energy and more."

The rest of the guidance text gives some details on fire class 4, which is a fire class typically reserved for the most complex and critical buildings, often linked to societal infrastructure. There is also some guidance on the special case of a building with only one floor with hazard class 1, which will not have a fire class, and thus require very few fire safety requirements.

Possible issues identified

- The hazard class categories can be confusing in terms of the actual risk they can represent, especially when they are compared with the pre-produced list in the pre-accepted performances. A good example is kindergartens, which typically are defined in hazard class 3 in the pre-accepted performances. Kindergartens however contain small children, which potentially would need assistance with evacuation by adults, and kindergartens also often have dedicated sleeping areas. Both of these aspects would indicate hazard class 6 if just the "yes/no statement scheme" is used without any further special consideration. These two different hazard classes would lead to kindergartens with very different levels of safety.

- Although attempts to define the qualitative terms "sporadic presence" and "serious fire hazard" is made in the accompanying guidance text, the text is arguably weak since it just invokes new qualitative terms like "only occasionally", "short" and "easily". These terms are not further quantified or exemplified in the building code, and thus vulnerable to subjective interpretation. The guidance text in the guidance document give a few examples of typical building types however, which is helpful to better understand what these terms typically apply to.

- The different fire classes and their expected impact are only described in very qualitative terms. Some guidance is given further in the accompanying guidance text as to what is important to consider, but no quantification to the levels are defined. This is left up to the designer to consider. The fire classes are therefore vulnerable to subjective interpretation. Fire class 4 is however an exception to this, as the guidance text suggest some typical buildings that might be in this fire class.

- While not mentioned or defined in the building code requirements, the guidance text to the building code refers to the pre-accepted performances for the special case of buildings defined in hazard class 1 with only one level. According to the pre-accepted performances, these buildings do not have a fire class (fire class 0), and as such the pre-accepted performances do not cover these buildings. There are two problems with this, the first one being that no fire class or fire class 0, is not even defined in the building code requirements.

  The second problem is that, since the risk is perceived very low in such buildings, requirements for fire safety are left up to the designer to choose what is appropriate, as long as it fulfills the building code requirements. This seems to be a case where performance-based design is encouraged to define a more reasonable level of fire safety than what would be provided by the pre-accepted performances. Practical examples have revealed however that problems can still occur, as discussed in [42] where large storage buildings with sporadic occupancy, cold storage buildings in particular, can be defined without a fire class and are potentially vulnerable for very large fires. When freedom is given to not consider the pre-accepted performances without recognizing it as an alternative/analytical design, problems related to what is considered "acceptable (private) property loss" or what is considered adequate facilitation for the fire service to be able to fight a fire in the building, may potentially arise.

4.4.1. Occupancy and building hazard classification in the Swedish building code

Sweden employs a similar building classification system as Norway, with chapter 5:21 Occupancy classes and chapter 5:22 Building classes. The following text is reproduced from [43], ch.5:

"

5:21 Occupancy classes
Spaces in buildings shall, based on the intended occupancy, be divided into occupancy classes.

5:211 Occupancy class 1 – Industrial, offices, etc.
The occupancy class includes spaces where residents are likely to have good local knowledge and have the ability evacuate without assistance and are likely to be awake

5:212 Occupancy class 2 – Places of assembly etc.
The occupancy class includes places of assembly and other premises where residents are likely to have good local knowledge and have the ability to evacuate without assistance and are likely to be awake. A place of assembly means any premises or group of premises within a fire compartment designed for a large number of people. Spaces shall be divided into occupancy classes 2A, 2B or 2C.
2A: *Occupancy class 2A refers to premises for up to 150 people.*
2B: *Occupancy class 2B refers to a place of assembly for more than 150 people*
2C: *Occupancy class 2C refers to a place of assembly that is designed for more than 150 people and where alcohol is served to a significant extent*

5:213 Occupancy class 3 – Dwellings
The occupancy class includes dwellings where residents are likely to have good local knowledge and have the ability to evacuate without assistance and cannot assume to be awake. Occupancy class 3A includes dwellings referred to in the first paragraph not included in occupancy class 3B.
3A: *Occupancy class 3A includes dwellings referred to in the first paragraph not included in occupancy class 3B*
3B: *Occupancy class 3B includes shared lodging.*

5:214 Occupancy class 4 – Hotels etc.
The occupancy class includes spaces where residents are not likely to have good local knowledge, but have the ability to make themselves safe and cannot be assumed to be awake

5:215 Occupancy class 5 – Healthcare environments etc.
The occupancy class includes areas where residents have limited or no ability to evacuate without assistance. The spaces shall be divided into occupancy classes 5A, 5B, 5C or 5D. Occupancy class 5A includes spaces intended for activities conducted during day time and that satisfy the provision's first paragraph. The occupancy class also includes similar activities conducted during night time.
5A: *Occupancy class 5A includes spaces intended for activities conducted during day time and that satisfy the provision's first paragraph. The occupancy class also includes similar activities conducted during night time.*
5B: *Occupancy class 5B includes means-tested special accommodation for people – with physical or mental illness, – with disabilities, – with mental retardation, – with dementia or – who otherwise have a limited ability to place themselves in safety.*
5C: *Occupancy class 5C includes premises for healthcare and nursing.*
5D: *Occupancy class 5D includes premises for people who are kept under lock and key*

5:216 Occupancy class 6 - *Includes premises with an increased probability of the occurrence of fire or where a fire can progress very rapidly and substantially.*

Rules for the handling of flammable and explosive goods are issued by The Swedish Civil Contingencies Agency.

5:22 Building classes

Buildings shall be divided into classes, Br, based on the need for protection.
– Buildings with a very high need for protection shall be designed in building class Br0.
– Buildings with a high need for protection shall be designed in building class Br1.
– Buildings with a moderate need for protection shall be designed in building class Br2.
– Buildings with a low need for protection shall be designed in building class Br3.

In assessing the need for protection account shall be taken to a probable fire progress, potential consequences of a fire and the complexity of the building. "

Summary of Swedish requirements

The Swedish system for hazard classes do not employ the same "yes/no statement" scheme in terms of occupant behavior like in the Norwegian system. Rather they describe the expected occupancies for the occupancy class and give example of the expected occupant behavior in that occupancy. This seems to provide more information to be able to classify the occupancy better. It is however also more prescriptive in nature and would have challenges with new occupancies not listed, or new changes in existing occupancies.

One potential benefit seems to be the use of sub-classes within a major occupancy class. A good example is occupancy class 5, which typically contains healthcare buildings where people can have limited to no ability to self-evacuate and require assistance. There is however, a very wide range of health care buildings, from major hospitals to small day-assisted living homes. Having all these buildings within the same occupancy class would indicate the same risk and thus the same fire safety level and need for same risk-reducing measures. This could potentially drive building costs up unnecessarily, as there are obvious differences in risk between these sub-classes of occupancies. These sub classes provide some much-needed flexibility in the occupancy classification to be able to differentiate the risk.

The building class classification is based on the expected protection requirement of the building in question, with classes from Br 0 to Br 3. The protection requirement is defined and based on probable fire scenarios, potential consequences with respect to a fire, and the complexity of the building. These classes and expected performances are not quantified or detailed further in the code text, and terms like "probable", "potential consequence" and "complexity" are left to the designer to interpret unless the general recommendations are used as a reference level.

The general recommendations give some further detailed guidance on classification and lists explicit examples of building types and their respective building class. While most of this information is prescriptive, some of it could be considered as a guidance text for the functional requirements as well.

4.4.2. Occupancy and building hazard classification in the New Zealand building code

New Zealand also employs a form of a building classification system as a basis for the other fire safety requirements. This is achieved with an occupancy classification and a building importance classification. The major difference compared to the Norwegian and Swedish codes is that the occupancy classification is not a part of the functional requirements in the building code. Rather, the acceptable solutions are divided into their respective occupancy types called risk groups.

All though the main focus of interest here is the functional requirements and performances in the building code and not the prescriptive/acceptable solutions, the occupancy classes for the New Zealand building code are listed for easier comparison to the Norwegian and Swedish building code.

The following occupancy types (risk groups) are used to divide the acceptable solutions into separate documents:

C/AS1 - Buildings with Sleeping (residential) and Outbuildings (Risk Group SH)

C/AS2 - Buildings with Sleeping (non-institutional) (Risk Group SM)

C/AS3 - Buildings Where Care or Detention is Provided (Risk Group SI)

C/AS4 - Buildings with Public Access and Educational Facilities (Risk Group CA)

C/AS5 - Buildings used for Business, Commercial and Low-Level Storage
(Risk Group WB)
C/AS6 –Buildings used for High Level Storage and Other High-Risk Purposes
(Risk Group WS)

C/AS7 –Buildings Used for Vehicle Storage and Parking (Risk Group VP)

Building importance levels are however a part of the building code, as there are references to the levels given in the functional and operative requirements.

Clause A3 - Building Importance levels

This clause classifies buildings in importance levels based on the risk they pose to human life, the environment or the economic cost if it should fail. The importance levels are reproduced below, from [34] p.11-13.

Importance level	Description of building type	Specific structure
Importance level 1	*Buildings* posing low risk to human life or the environment, or a low economic cost, should the *building* fail. These are typically small non-habitable *buildings*, such as sheds, barns, and the like, that are not normally occupied, though they may have occupants from time to time.	• Ancillary *buildings* not for human habitation • Minor storage facilities • Backcountry huts
Importance level 2	*Buildings* posing normal risk to human life or the environment, or a normal economic cost, should the *building* fail. These are typical residential, commercial, and industrial *buildings*.	• All *buildings* and facilities except those listed in importance levels 1, 3, 4, and 5
Importance level 3	*Buildings* of a higher level of societal benefit or importance, or with higher levels of risk-significant factors to *building* occupants. These *buildings* have increased performance requirements because they may house large numbers of people, vulnerable populations, or occupants with other risk factors, or fulfil a role of increased importance to the local community or to society in general.	• *Buildings* where more than 300 people congregate in 1 area • *Buildings* with primary school, secondary school, or daycare facilities with a capacity greater than 250 • *Buildings* with tertiary or adult education facilities with a capacity greater than 500 • Health care facilities with a capacity of 50 or more residents but not having surgery or emergency treatment facilities • Jails and detention facilities • Any other *building* with a capacity of 5 000 or more people • *Buildings* for power generating facilities, water treatment for potable water, wastewater treatment facilities, and other public utilities facilities not included in importance level 4

Table 1 Clause A3 Building Importance levels 1-3 in the New Zealand building code

Importance level	Description of building type	Specific structure
Importance level 3 (continued)		• *Buildings* not included in importance level 4 or 5 containing sufficient quantities of highly toxic gas or explosive materials capable of causing acutely hazardous conditions that do not extend beyond property boundaries
Importance level 4	*Buildings* that are essential to post-disaster recovery or associated with hazardous facilities.	• Hospitals and other health care facilities having surgery or emergency treatment facilities • *Fire*, rescue, and police stations and emergency vehicle garages • *Buildings* intended to be used as emergency shelters • *Buildings* intended by the owner to contribute to emergency preparedness, or to be used for communication, and operation centres in an emergency, and other facilities required for emergency response • Power generating stations and other utilities required as emergency backup facilities for importance level 3 structures • *Buildings* housing highly toxic gas or explosive materials capable of causing acutely hazardous conditions that extend beyond property boundaries • Aviation control towers, air traffic control centres, and emergency aircraft hangars • *Buildings* having critical national defence functions • Water treatment facilities required to maintain water pressure for fire suppression
Importance level 4 (continued)		• Ancillary *buildings* (including, but not limited to, communication towers, fuel storage tanks or other structures housing or supporting water or other *fire* suppression material or equipment) required for operation of importance level 4 structures during an emergency
Importance level 5	*Buildings* whose failure poses catastrophic risk to a large area (eg, 100 km^2) or a large number of people (eg, 100 000).	• Major dams • Extremely hazardous facilities

Table 2 Clause A3 Building Importance levels 4-5 in the New Zealand building code

Summary of New Zealand requirements

The New Zealand building code uses a completely different occupancy classification than Norway and Sweden. Occupancy classification is mainly used the acceptable solutions and have been separated into individual documents based on what is defined as risk group. This is essentially the same as the hazard or occupancy class.

The risk groups are similar to occupancy classes of the other building codes, except for the risk group containing "Buildings Used for Vehicle Storage and Parking".

The building classes, in the New Zealand building code defined as the "building importance levels", are a part of the building code however. The building importance levels range from level 1 (lowest risk) to level 5 (highest risk. Fairly detailed descriptions of the definitions of the different importance levels are included. Typical examples of the structures belonging to the different importance levels are also given. These building importance levels are actively used in the building code for both functional requirements and in the performances and helps to differentiate the requirements based on the perceived risk of the buildings where needed.

The flexibility for changing or applying additional limits to the building code requirements are retained in the building code, as there is a column next to the functional requirements and performances in the building code named "Limits on application". This structure seems to provide a large level of freedom for the application of PBFSD, but at the same time allows the building authorities to apply direct limits on application if such a need should occur.

4.4.3. Suggestions for improvements

Functional and operative requirements in the Norwegian building code are based on the respective hazard class and fire class of a building. Thus, they form a fundamental input for the rest of the fire safety requirements, even for PBFSD. While there are obvious similarities on the hazard and building classification system between the three different building codes, there are also some noticeable differences. These can potentially be used to improve the classification system in the Norwegian building code.

- The current Norwegian hazard/occupancy and fire class system is prone to subjective interpretations. Subjective interpretation on the hazard/occupancy class is more difficult with the system used by the Swedish building code, as the occupancy classes are identified by more detailed descriptions and explicit examples of building types. As such, a suggestion for switching to the Swedish system could be made. The Norwegian classification system is however not without merit in this context. While the classification system used in the Swedish building code seems to be easier to use, it is in fact a more prescriptive approach. If new occupancies should be introduced, or the existing occupancy types should change, there would be a need to revise the Swedish building code text. In that aspect, the "yes/no statement" system on the occupant behavior the Norwegian building code currently uses is arguably better equipped to account for such changes without requiring any revisions to the building code. This system can classify new occupancy trends like "AirBNB" and gig economy. However, in practical use, the resulting hazard class would usually be viewed as too stringent. An example of this would be to rent out a single-apartment house to different people on different days of the week. It is not immediately clear whether it may be claimed that the customers are as familiar with the building layout and escape plan as a normal resident would have been. As such, the house could potentially be classified as a hazard class 6 building. Such occupancies have mandatory provisions for automatic suppression system in the building code. This would be quite an expensive upgrade for most single-apartment houses. In summary, although the building hazard classification Norway currently uses is deemed to be supporting a performance-based approach, it is currently suffering from a lack of guidance and lack of explicit examples*. Given that the occurrence of new occupancies (and changing of existing occupancies), is rare, adding more detailed descriptions to the different hazard classes in the code text should be possible without creating unreasonable amount of workload on maintenance of the building code. If the existing "yes/no statement" scheme is to be retained, providing more detailed guidance text on what building types the different hazard classes cover seems to be a reasonable way of improving §11-2.

*While it can be argued that examples on hazard classes can be inferred from the pre-accepted performances, it should not be a requirement to refer to these when doing a performance-based design with verification that does not rely upon comparative analysis with the pre-accepted performances.

- One of the weaknesses pointed out with the Norwegian building hazard classification system is that the different hazard classes are considered too general. For some of the hazard classes there can be large variety of building types with different risk levels associated with them. This seems to be better covered with the classification system the Swedish building code uses where sub-classes for a specific occupancy class is used. This allows the building code to diversify the fire safety requirements on larger selection of building types. Other than a minor increased workload for maintaining the code with additional hazard classes, there seems to be no apparent drawback to diversify the classes a bit further. It would potentially contribute to better quality in performance-based design and could also have a big impact on the prescriptive requirements.

- While New Zealand has most of the occupancies like Norway and Sweden, it does have a unique occupancy class for "Buildings Used for Vehicle Storage and Parking". Due to new drivetrain technology like electricity and hydrogen on a quick rise in Norway, there have been a recent research on fires in cars with new alternative drivetrain technology like batteries [44], and when such fires occurs in car parks by Reitan et al [45]. In this work an observation was made that car parks have traditionally had low level of protection in the various versions of the building code, even though the impact of a fire in such a building can lead to very high material/property losses. A recent article from NFPA on the different materials and drivetrains in modern cars compared to older cars also points out the potential fire safety issue it represents for car parks [46] .Tailoring the protection level for such buildings might therefore be necessary and also cost-effective. Thus, having a new building hazard (sub) class linked to "Vehicle Storage and Parking" could be beneficial to adjust the risk in these specific occupancies.

- To improve upon the building fire classifications so that they are more suitable for use in a performance-based approach, there is a need to supplement the current fire impact terms "slight, moderate, serious or very serious" with more measurable terms. Some indication on the allowed impact can be interpreted by the pre-accepted performances, but, as previously mentioned, it should not be necessary to be dependent on the pre-accepted performances for this.

  As a minimum, the current fire classes should be provided with some more guidance text to get a better feel for the level of risk associated with them. Looking to what guidance New Zealand has provided for defining the building importance levels, it should be possible to do something similar for the fire classes. Some specific keywords to consider when deciding the fire class could be occupancy class/type, occupant load, fire energy load, critical for societal infrastructure, presence of sensitive/toxic/hazardous materials, remote location etc. Defining societal acceptable loss limits for each fire class for these keywords would make it easier to choose the right fire class.

- With recent research and development of probabilistic methods for fire safety design, acceptable limits for each fire class could potentially also be expressed as a statistical probability. If it is possible to estimate the likelihood of fire start and estimate the probability for loss of life and loss of property to within certain limits in the building, for example based on risk associated with number of building levels, total square area and fire energy load, the building could be rated in fire class 1-4 based on this probability.

  An example of how this is done with risk for avalanches near building locations in the Norwegian building code §7-3 (2) is shown below.

Safety class for avalanche	Consequence	Largest nominal annual probability
S1	Low	1/100
S2	Medium	1/1000
S3	Large	1/5000

Table 3 Safety classes for location of buildings in avalanche-prone areas

4.4.4. Discussion

The suggested improvements are considered to improve the ability of the building code to differentiate the risk between different occupancies and the buildings. The addition of subclasses to the hazard classes, and the addition of the concept of building importance levels to the fire classes should make it easier to identify a more reasonable risk profile to a given building. This could remove much of the conflicts that are observed today, including the previous example given for a kindergarten. This would also have positive effects on the prescriptive performances, as they could be further tailored to more specific occupancies.

A negative consequence of the suggested improvements would be that that a larger part of the building code requirements and the pre-accepted performances would need to be rewritten.

4.5. Section §11-4 Load-bearing capacity and stability

This chapter covers the fire safety requirements for preventing structural collapse during a fire. Five separate functional requirements are given, together with some guidance text which aims to define the expected performance. Building code requirements are reproduced from [38], §11-4 while guidance text is reproduced from [41] §11-4:

(1) *Construction works shall be designed and constructed to ensure that the construction works as a whole, as well as its individual parts, attain an adequate level of safety with regard to load-bearing capacity and stability.*

Guidance text: *"The main purpose with fire safety requirements for load-bearing construction works is to achieve satisfactory load-bearing ability and stability to resist an expected fire impact so that the building does not collapse during the fire but retain its stability and load-bearing in the required time for escape, rescue and firefighting.*

The roof construction is considered part of the secondary load-bearing system when it is not a part of the primary load-bearing system of a building or contributes to stabilizing this."

(2) *The thermal load from the energy of a fire and the expected progress of a fire in the construction work must be taken into account when designing for adequate load bearing capacity and stability in case of fire.*

Guidance text: "*If design of load-bearing capacity during a fire by means of calculation is performed, the fire energy load can be estimated based on relevant and recognized statistics using "NS-EN 1991-1-2:2002+NA:2008: Eurocode 1: Laster på konstruksjoner - Del 1-2: Allmenne laster - Laster på konstruksjoner ved brann."*

(3) *Load-bearing systems in construction works in fire classes 1 and 2 shall be designed to maintain adequate load-bearing capacity and stability for a minimum of the time necessary to escape and rescue persons and domestic animals in or on the construction work.*

Guidance text: None

(4) *Main load-bearing systems in construction works in fire classes 3 and 4 shall be designed to maintain adequate load-bearing capacity and stability for the complete duration of a fire, insofar as this can be modelled.*

Guidance text: *"Prescripted solutions for fire class 3 is given. For primary load-bearing construction works in buildings with fire class 4, the load-bearing capacity must be verified using calculations that account for the complete fire duration. A fire with complete fire duration can be modelled in accordance with 3.3 in "NS-EN 1991-1-2:2002+NA:2008: Eurocode 1: Laster på konstruksjoner - Del 1-2: Allmenne laster - Laster på konstruksjoner ved brann."*

(5) *Secondary construction works and construction works that are only load-bearing for one storey or for the roof shall be designed to maintain adequate load-bearing capacity and stability for the time necessary to escape and rescue persons and domestic animals in or on the construction works.*

Guidance text: None

Possible issues identified

Sub article 1 seems to be the main functional requirement in this section, indicating that construction works concerning load-bearing capacity and stability should have adequate safety. Adequate is a vague word which is difficult to derive the expected performance from. This is however discussed in the accompanying guidance text. The guidance text indicates that the load-bearing system should be able to retain its stability with respect to an expected fire development in a time period that facilitates escape, rescue and firefighting. The guidance text helps to defines adequate safety in more defined terms that can potentially be used for verification using engineering methods:

- The time a load-bearing construction can withstand a certain fire impact
- Time needed to escape a building
- Time needed for rescue
- Time needed for firefighting

How to define the expected fire development is discussed in sub article 2, while time needed for escape is covered by a different section in the building code (§11-11). Time needed for rescue and firefighting are however elements that are not so easily verified.

In sub article 2 the expected fire development is discussed further. The requirement links the thermal load from the energy in the fire, and the expected progress of fire in the respective construction works. The guidance text further suggests a suitable standard, "NS-EN 1991-1-2" [47], to use for the calculation procedure. The main problem with this is that practical use of the suggested standard can be limited, as there are multiple conditions and constraints for applicability of the standard. A few examples of this can be seen among others in Appendix A and F, as shown below.

Appendix A – Parametric temperature-time curves

(1) The following temperature-time curves are applicable for fire compartments with floor area up to 500 m² without openings in the roof and with a room height of 4 m. It is assumed that the fire load in the fire compartment is fully consumed.

(2) If specific fire load is defined without consideration to the combustion properties (see Appendix E), this method should be limited to fire compartments with fire load primarily from cellulosic materials.

Appendix F - Equivalent fire exposure time

(1) The following method may be used in those cases where design of construction works is based on table data or other simplified rules related to a standard fire exposure.

> *Note: The method given in this appendix is material-specific. It does not apply to composite constructions with steel and concrete, or wood constructions.*

(2) If specific fire load is defined without consideration to the combustion properties (see Appendix E), this method should be limited to fire compartments with fire load primarily from cellulosic materials.

As illustrated, the building in question may often not be within the scope of the standard due to the constraints and limits on the calculation procedure set by the standard.

Sub article 3 provides more detail on the expected performance when the building is defined in fire class 1 or 2. As stated in chapter 4.4 about fire classes, this would be buildings where a fire would be expected to have a small to medium impact. The expected performance of a load-bearing system in buildings defined with fire class 1 or 2 is that it is only required to maintain stability in the time that is necessary for escape and rescue of persons and domestic animals. Verification of time needed for escape of persons in a building is covered in section §11-11 and is possible to estimate using known engineering methods. Time needed for rescue however is not as straightforward to verify. While rescue is a term that is widely used throughout the building code, it is however not properly defined. KBT-"Kollegiet for brannfaglig terminology" [48], a service provided by multiple interest organizations for defining fire safety related terminologies in the Norwegian language, defines rescue as: *"Emergency measures that are applied in an accident to prevent loss of, or limit injury on, life and health. For environment and material value, see salving."* In this context with regards to evacuation from a fire, rescue is interpreted to be an emergency measure that is performed by the local fire service if occupants have not been able to self-evacuate before they arrive.

Verification of time needed for rescue would indicate a need to estimate the following:

- the fire service response time, which is the time they receive the alarm signal and are ready for intervention at the location
- time they require to search the building and
- the time required to assist occupants with leaving the building

It is not entirely clear if estimating time required for rescue is something that can be adequately verified in the current practice. There is certainly a lack of guidance and applicable verification methods for such a verification and considering the large number of variables that can influence this time parameter, proper guidance on verification is highly needed. While the fire service is generally the fastest emergency responder to a fire location, their response time is still vulnerable to conditions like weather, traffic along the route and other emergencies occurring at the same time. Once at the building location, their time needed for performing a rescue will be even further impacted by conditions at and in the specific building, like the type of fire occurring, occupancy of the building and occupant load and what state they are in. If the designer is to account for all these variables when trying to estimate the rescue time, it can potentially drive the design time far beyond what is currently used in the pre-accepted performances. While that may be justified in certain cases, the rescue time in an alternative design would be potential long for most buildings if all the listed variables must be accounted for, and generally not able to compete with the time the prescripted solutions typically use. As such, in its current state, this apparent performance requirement is somewhat of a camouflaged prescriptive requirement, as it is currently unclear how verification of the rescue time is to be performed.

Sub article 4 states that the main/primary load-bearing systems in fire classes 3 and 4 should be designed to maintain its stability and withstand a complete fire duration. This can be interpreted such that the building should not suffer a complete collapse, even if the expected fire is allowed to burn out its full duration. A partial collapse of secondary load-bearing systems however seems to be acceptable, as will be clear in the next sub article. A link to the "NS-EN 1991-1-2" is given for verification here as well. Modelling a fully developed fire and the duration of it is a challenge due to the many potential variables. This is even more challenging when the Norwegian national amendment must be applied, which limits how fire safety measures in the building can be accounted for drastically, as shown in figures given below, from [47] appendix E:

Tabell E.2 – Faktor δ_{ni}

δ_{ni} Funksjon for aktive brannbekjempelsestiltak									
Automatisk brannslokking		Automatisk branndeteksjon og -alarm			Manuell brannslokking				
Automatisk vannslokkesystem	Uavhengig vannforsyning 0 | 1 | 2	Automatisk branndeteksjon og -alarm, ved varme	Automatisk branndeteksjon og -alarm, ved røyk	Automatisk alarmoverføring til brannvernstyrke	Brannvernstyrke i bygningen	Brannvernstyrke utenfor bygningen	Fri atkomst	Brannslokkeutstyr	Røykventilasjon
δ_{n1}	δ_{n2}	δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}
0,61	1,0 | 0,87 | 0,7	0,87 eller 0,73		0,87	0,61 eller	0,78	0,9 eller 1 eller 1,5	1,0 eller 1,5	1,0 eller 1,5

Figure 4-6 Original safety factors for fire safety measures, appendix E in NS-EN 1991-1-2

Tabell NA.E.2 – Faktor δ_{ni} avhengig av aktive brannsikringstiltak

δ_{ni} Funksjon for aktive brannsikringstiltak									
Automatisk brannslokking		Automatisk branndeteksjon og -alarm			Manuell brannslokking				
Automatisk vannslokke-system	Uavhengig vann-forsyning	Automatisk branndetek-sjon og -alarm		Automatisk alarm-overføring til brannvern-styrke	Brann-vernstyrke i bygningen	Brann-vernstyrke utenfor bygningen	Fri atkomst	Brann-slokkeut-styr	Røyk-ventila-sjon
	0 | 1 | 2	ved varme	ved røyk						
δ_{n1}	δ_{n2}	δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}
1,0 [1)]	1,0 | 1,0 | 1,0	1,0		1,0	1,0		1,0	1,0	1,0

[1)] For automatiske slokkesystemer settes δ_{n1} normalt lik 1,0. Ved brannteknisk analyse kan det benyttes verdier ned til 0,6 forutsatt at fastsettelsen av valgt verdi for δ_{n1} inngår som en del av brannsikkerhetsstrategien for byggverket.

Figure 4-7 Revised safety factors as required by the Norwegian national amendment,

The table suggest safety factors for various fire safety measures that will influence the calculations in such a way that a lower fire resistance is needed. In the Norwegian national amendment most of these factors are ignored (factor=1). Only automatic water extinguishment system can be accounted for, and only if it is incorporated as part of a fire safety engineering analysis and the fire safety brief for the building in question. The consequence of this is that a calculated fire duration often that extends well beyond what the current pre-accepted performances require for fire resistance for construction works.

Sub article 5 is mostly a follow-up on sub article 3 and 4 and details further the expected performance of a secondary load-bearing system, and load-bearing systems for a single level or roof. The performance is the same as outlined in sub article 3, and thus have the same challenges. It should however be pointed out that it is considered a practical specification of a performance from a verification stand point, as it seems reasonable to allow for the consequence of a partial collapse of a construction work in a building as long as it can be verified that time for escape and rescue for that specific area is satisfactory accounted for.

4.5.1. Load-bearing capacity and stability in the Swedish building code

Sweden have their functional requirements and expected performances for fire safety for load-bearing capacity during a fire in the EKS. The following information is given for the fire safety requirements, reproduced from [49], ch.1.1.2 p.29-35.

"Building Fire safety class

2 §

Buildings shall be placed in fire safety classes in accordance with table C-2, based on the life safety risk if the building construction should collapse during a fire. In the evaluation the following shall be considered:

a) The risk that people, like escaping occupants or emergency personnel, are hurt in the affected area

b) Secondary effects that can arise, like rapid falling debris affecting parts of the load-bearing system and

c) Effect on systems in the building that have a critical role in supporting evacuation and fire fighting

Table C-2 Fire Safety Class is defined according the following table	
Building Fire Safety Class	*Risk for life safety in case of collapse in the construction work*
1	*Negligible*
2	*Low*
3	*Medium*
4	*Large*
5	*Very large*

3 § *Construction works required to maintain the function of a fire compartment or other separating construction, shall be designed so that the function is fulfilled in its designed time frame.*

Stairwells that are the only means of escape shall always be designed with accident load.

Documentation

4 § *Descriptions of the design of the load-bearing capacity with respect to fire shall be a part of the fire safety brief mandated by paragraph 5:12 in BBR*

National chosen parameters

5 § Overview of areas where national parameters have been chosen

Location in the standard	*Comment*
2.4(4) Note 1	*National parameters chosen*
2.4(4) Note 2	*National parameters chosen*
3.1(10)	*National parameters chosen*
4.3.1(2)	*National parameters chosen*
Appendix A	*National parameters chosen*
Appendix C	*National parameters chosen*
Appendix E	*National parameters chosen*
Appendix F	*National parameters chosen*

Part 2.4(4) Note 1

Nominal temperature- time curves

6 § When designing by classification (nominal temperature- time curves) construction works shall be made so that they do not collapse during the time period defined in table C-7 with fire load as defined in chapter 4.2 in SS-EN 13501-2. The first column (f≤800 MJ/m²) in table C7 can be used without any further consideration for housing- and office occupancies, schools, hotels, car parks (small cars), grocery stores, storage areas for housing and comparable fire compartments.

Table C-7 Fire resistance rating for use in load-bearing capacity			
Fire Safety Class	*Fire resistance rating in specific fire loads*		
	f≤800 MJ/m²	***f≤1600 MJ/m²***	***f>1600 MJ/m²***
1	***0***	***0***	***0***
2	***R15***	***R15***	***R15***
3	***R30 (R15*)***	***R30 (R15*)***	***R30 (R15*)***
4	***R60***	***R120 (R90*)***	***R180 (R120*)***
5	***R90 (R60*)***	***R180 (R120*)***	***R240 (R180)***

** If an automatic water sprinkler system in accordance with chapter 5:252 and 5:2521 in the BBR is installed*

Part 2.4(4) Note 2

Modeling natural fire

7 § If design by a natural fire model is used, construction works shall be designed according to the fire duration outlined in table C-8

Table C-7 Fire resistance rating for use in load-bearing capacity	
Fire Safety Class	***Fire duration***
1	*0 minutes*
2	*15 minutes (of a full fire duration excluding cool-off phase)*
3	*30 minutes (of a full fire duration excluding cool-off phase)*
4	*Full fire duration (including cool-off phase)*
5	*Full fire duration with a 50 % increased fire load (including cool-off phase)*

Fully developed fire

8 § The fire duration and the temperature development in a fire compartment in a fully developed fire shall be calculated using heat- and mass-balance equations (natural fire model)

Localized fire

9 § *The fire duration and the temperature development in a localized fire shall be calculated with respect to the conditions in the building that can be expected.*

Technical systems

10 § - The effect of permanent installed technical systems that reduce the probability of flashover, limits the temperature in the room of fire origin, or in any way limits or extinguishes the fire, can be used in design under the condition that the total probability for collapse does not increase. A condition for allowing such systems to be utilized is that their reliability is accounted for.

Risk reducing effects of such technical systems can be accounted for by reducing the fire load in the design of fully developed fire, or by reducing the localized fire. The reliability of such systems must be considered.

Part 3.1(10)

11 § *If designing a building to withstand a fire a nominal temperature-time duration or a natural fire duration may be used. For classification of fire resistance only nominal temperature-time duration may be used.*

Part 4.3.1(2)

12 § *According to 11 §, chapter 0 in section B in this document, the greatest variable load shall be assigned to its most frequent value ($\Psi\ Q_{k,1}$) in a fire.*

Using informational appendices

15 § *Appendix E shall not be used. The design value of a fire load shall be within 80 % of the observed values in a representative statistical distribution.*

16 § *Appendix F shall not be used. "*

Summary of Swedish requirements

The Swedish regulation on load-bearing capacity for construction work during a fire in the EKS is noticeable different compared to the requirements in the BBR. The immediate first impression is that it is more prescriptive in nature, with more mandatory provisions. This is to be expected considering the harmonization against a common EU standard, which must be applicable for all member countries. Since different countries are at different stages in their building code development, a prescripted approach is arguably easier to agree upon for a common desired performance.

An important part of defining the requirements for load-bearing construction works in the EKS is defining the "building fire safety class". This should not be confused with the building class defined in BBR, as "building fire safety class" is something specifically used only in EKS, even though they are dependent on building classes in BBR. The building fire safety classes suffers from the fact that the different classes and the expected performance are only described in qualitative terms, much like the same challenge as with the building classes in BBR and fire classes in the Norwegian building code. Some guidance as to what should be considered when evaluating the different classes is included, but no recognized approach or verification method for doing this is suggested. It is therefore unclear how this evaluation should be performed. Without the aid of the general recommendations given in EKS, deciding on the appropriate class will likely be influenced by subjective interpretation.

After defining the building fire safety class, the code outlines two possible approaches. The first is using a nominal temperature-time duration, which can be viewed as a prescriptive approach, as the fire resistance for the load-bearing construction is then defined directly. The second approach is modelling a natural fire duration, which can be considered a performance-based approach. Several constraints are however in effect:

- Required fire duration is linked to the building fire safety class. For building fire safety class 4 and 5, it is required to use full fire duration.

- For estimating a fire resistance on a construction work it is not allowed to use the natural fire approach.

The Swedish regulations on the load-bearing construction works are more directly connected to EN 1991-1-2 compared to the Norwegian regulations. They do however provide more hands-on guidance on the alternative design approach when using the methods in the Eurocode. Many of the same limits with respect to the applicability of the Eurocode will be in effect. It is however observed that technical fire safety measures can be accounted for in the calculation of the fire load (in contrast to Norway).

4.5.2. Load-bearing capacity and stability in the New Zealand building code

The following functional requirements and expected performances are given in clause C6, reproduced from [34] C.6:

" Functional requirement

C6.1 *Structural systems in buildings must be constructed to maintain structural stability during fire so that there is: (a) a low probability of injury or illness to occupants, (b) a low probability of injury or illness to fire service personnel during rescue and firefighting operations, and (c) a low probability of direct or consequential damage to adjacent household units or other property.*

Performance

C6.2 *Structural systems in buildings that are necessary for structural stability in fire must be designed and constructed so that they remain stable during fire and after fire when required to protect other property taking into account: (a) the fire severity, (b) any automatic fire sprinkler systems within the buildings, (c) any other active fire safety systems that affect the fire severity and its impact on structural stability, and (d) the likelihood and consequence of failure of any fire safety systems that affect the fire severity and its impact on structural stability.*

C6.3 *Structural systems in buildings that are necessary to provide firefighters with safe access to floors for the purpose of conducting firefighting and rescue operations must be designed and constructed so that they remain stable during and after fire.*

C6.4 *Collapse of building elements that have lesser fire resistance must not cause the consequential collapse of elements that are required to have a higher fire resistance. "*

Summary of New Zealand requirements

The New Zealand building code seems to have the most design freedom among the three countries, as there are very few operative requirements and performances in this section. There is only one functional requirement and it clearly states what the expected role of structural systems in a building should be in case of fire; Life safety, safety for fire service personnel and safety for adjacent buildings/other property. Interestingly, property safety for the building with the fire is not described.

This could however be argued to a degree be accounted for when measures to make sure load-bearing construction works remain stable during a fire for life safety and safety for fire fighters are in place.

The expected performances for this functional requirement outlines further what should be accounted for in the verification. The fire severity, fire safety measures to reduce fire severity and possible impact on structural stability, noting automatic sprinkler systems specifically, and the likelihood and consequence of failure of those fire safety measures, should be accounted for. These specifications are considered beneficial when doing verification, as the code clearly support that fire safety measures can be accounted for, if you also consider the reliability and consequence to the structural stability if the fire safety measures should fail. What the performances do not detail further however is a specific term repeatedly used in the functional requirement, "low probability". What constitutes a low probability is not discussed further, either in qualitative or quantitative terms, and the same term is applied for both life safety, safety for firefighters and property safety. This can therefore lead to a degree of subjective interpretation.

4.5.3. Suggestions for improvements

As it currently stands, the impression of the Norwegian building code on this section falls somewhere between Sweden and New Zealand`s approach on the scale of design freedom and usability for performance-based design. There is freedom to use alternative solutions, but you must still adhere to the defined fire classes. Those fire classes can however be defined in an alternative solution by the building designer as well. The fact that the functional requirements also state that it is acceptable for a building to collapse for the lower fire classes, as long as escape and rescue is accounted for, is important knowledge for verification. It is very beneficial that this information is included in the actual building code. The following suggestions for further improvements are given:

- The Norwegian national amendment of "NS-EN 1991-1-2" should be considered revised with respect to be able to account for technical fire safety measures beyond just automatic extinguishment systems. Much of the approach used in "NS-EN 1991-1-2" is based on the use of safety factors to adjust the calculation of fire energy load density up and down, based on occupancy risk and size of the building, and available fire safety measures. Currently all safety factors that result in an increase in the fire energy load must be applied, while almost none of the technical fire safety measures that result in a decrease is allowed (with fire extinguishment systems the only exception). Sweden in comparison seems to allow to account for all these fire safety measures. Since Sweden and Norway have comparable fire safety requirements for this section, an argument could be made that the same approach should also be possible for Norway.

- Additional sources for verification and calculation of the fire development and the response to structures other than "NS-EN 1991-1-2" should be pursued. The applicability of calculations given in "NS-EN 1991-1-2" to determine the expected fire duration is limited for larger, open rooms with increased ceiling height. Rackauskaite et al [50] also points out the need for such an alternative, and suggest a concept called "Travelling Fires Methodology" (TFM). This approach considers that a fire is more likely to travel across bigger rooms, leading to a moving localized fire (flame in the near-filed and hot smoke in the far-field). While it is outside the scope of this thesis to go into the specific details of this method, the method seems robust and based on scientific first principles coupled with real-life experience of such fires. There are current ongoing validation efforts of the method by the Imperial College of London [51]. The method has been well received in the fire research and fire safety engineering community and is therefore arguably worth to look further into. The image below illustrates the concept, reproduced from [50] p.252 :

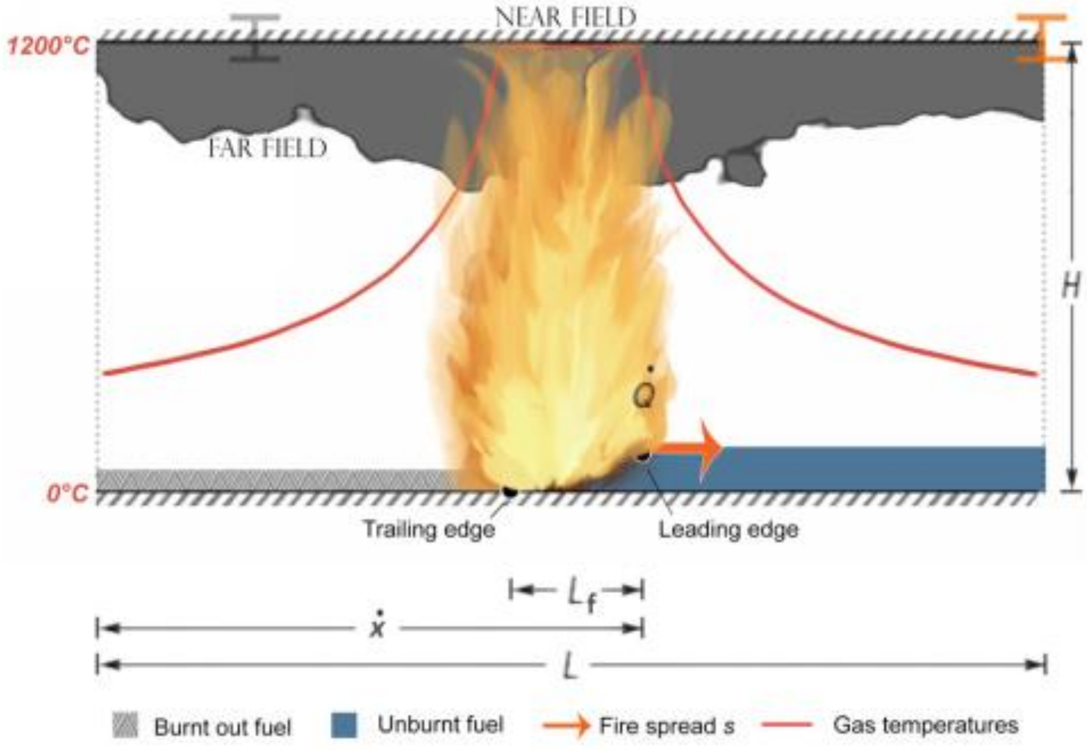


Figure 4-8 Concept of "Travelling Fires Methodology"

- Other approaches that can be considered is the creation of a verification method that provides additional guidance on verification of post-flashover fires and complete fire burnouts. This approach is used by New Zealand in their verification method C/VM2. While this verification method also references the "EN 1991-1-2" for some of the engineering calculations, the verification method gives additional guidance on how the different equations should be used.

  Another approach is to bypass the calculation of the fire load and the calculation of a fully developed fire. Instead a suitable large fire size, fire growth and fire duration to be used for design of structural elements in various occupancies could be prescribed instead. This bypasses the problems with calculating the fire energy load and trying to estimate out how fast that energy should be released.

  In both approaches the thermal effect and the mechanical response of this fire exposure could then be calculated using recognized engineering tools like two-zone-models and CFD-models (Computational Fluid Dynamics). It could also be used in combination with the travelling fires concept discussed in the previous point.

- The functional requirement in the Norwegian building code uses a phrase in which the time required for rescue is to be accounted for when fulfilling the functional requirement for load-bearing construction works. To be able to verify this, time required for rescue should be more clearly defined, and perhaps only limited to certain buildings where there is a higher probability of rescue being needed. Deterministic verification of this in simpler buildings with traditional low fire resistance on load-bearing construction works could be very challenging. A practical example would be low office and storage buildings. There are examples of buildings in the pre-accepted performances with this type of occupancy where the requirement of fire resistance of the load-bearing construction works is only 10-15 minutes. It could be argued that such a small time-frame do not allow the firefighters to perform rescue operations given a severe fire. If this is an acceptable level in the prescripted solutions, then this level should also be acceptable in a performance-based design as well. Currently there are no requirements or information given in the building code that indicate this is acceptable.

Time required for rescue could potentially be accounted for using some sort of a safety factor. This safety factor could be based on the time required for escape. Where escape would take a longer time due to complex building layout or high occupant load, this would also be reflected in increased time required for rescue. This connection would also be logical as longer escape time typically can be expected to give a higher probability that not all occupants will have managed to escape by the time the fire service arrives. Thus, the fire service would need longer time for rescue of the occupants as well.

A different safety factor could be applied to different building occupancies, to account for increased probability of the need of rescue. What a reasonable safety factor should be would need further research, but some preliminary considerations are given. Required safe egress times are normally on the order of 5-15 minutes dependent on the specific occupancy. A rescue safety factor of 1.5-2 does not seem unreasonable in this regard which would indicate time required for rescue to be about 30 minutes when evacuation takes a long time and about 10 minutes when evacuation takes a short time. Very simple buildings such as low office and storage buildings could potentially have a rescue safety factor 1-1.5 as there should be a very low probability of needing rescue.

If the building in question is to be designed to account for rescue by the fire service, then the fire service response time should also be accounted for. The currently minimum fire service response time in Norway is dependent on the building occupancy, but not lower than 10 minutes and recommended not to be higher than 30 minutes based on the code for design capacity of the fire service intervention [52]. This response time would need to be accounted for if estimating the time required for rescue by the fire service.

4.5.4. Discussion

The recommended approach to support verification of load-bearing capacity is to create a separate guidance document, which may or may not be a mandatory verification method. It should provide additional guidance on the calculation of the fully developed fire and the thermal impact from it. This is in effect what is currently used by Sweden through EKS, and by New Zealand through C/VM2. This guidance or verification method should also suggest alternative calculation models or input where the "NS-EN-1991-1-2" is not considered sufficient.

Based on the authors own work experience, the current practice of structural performance-based fire safety engineering in Norway is deemed to be low. The positive consequences of the proposed improvement could therefore be significant. Structural performance-based fire safety engineering could see a big increase, allowing more untraditional structural elements without requiring extensive passive fire protection measures, and it would be to easier to verify issues with the load-bearing construction works in buildings with high fire load densities such as storage and ware houses.

The potential negative consequence of this suggestion may be a perceived limit in the design freedom, as such a guidance document will probably not be able to cover every design approach that is available. It would however be able to cover the most recognized methods and provide proper guidance on how to use those methods. That could be considered an acceptable tradeoff, especially when considering the low amount of guidance for verification that is currently given on this section. Such a document may also be revised at any time to include new methods or new knowledge on existing methods. Depending on whether the guidance document would be a mandatory fire safety verification method, it would also be possible to allow for methods not covered by the guidance document

4.6. Section §11-6 Measures to prevent the spread of fire between construction works

This chapter covers the fire safety requirements for preventing a fire from spreading from one building to another. The following functional and operative requirements with accompanying guidance text are given, reproduced from [38] and [41], §11-6:

(1) *Fires shall be prevented from spreading between construction works:*
a) in order to maintain the safety of people and domestic animals; and
b) so that a fire does not cause unreasonably large financial losses or societal consequences.

Guidance text: *The first section describes the intention with the requirements in §11-6.*
Fire spread between construction works can be prevented by:

a. establish satisfactory distance between the construction works so that heat flux, flame impingement and falling embers do not ignite the neighboring construction works

b. use fire-rated separating construction works with adequate fire resistance, load-bearing capacity and stability

(2) *The distance between low-rise construction works shall be at least 8.0 m, unless measures are taken to prevent fires spreading between the construction works during the time required for escape and rescue in the other construction works. This provision does not apply to low-rise construction works that together comprise only one housing unit.*

Guidance text: *Low-rise buildings are buildings with a ceiling of up to 9 m. The height is measured on the wall that is facing neighboring constructions.*

Low-rise buildings that are used together can for example be a house with an annex. Low-rise buildings that are used together with a distance of less than 8 m between them must be assessed with respect to requirements for fire compartmentation when the buildings are designed.

Buildings that typically connect to recreational vehicles and camping wagons (large tents) are considered low-rise buildings and need to comply with the defined requirements for such buildings. Smaller tent porches of aluminum glass fiber or plastics that can be easily deconstructed and move, are not considered low-rise buildings. Combustible constructions that have a height more than 0,5 m above the terrain (porch floors, separating wind walls etc.) are considered part of the building.

A safety distance of 3 m between different camping units (RVs, camping vans, tents including similar constructions, porch floors and wind walls etc.) will not be adequate to prevent fire spread. Fire spread will be able to occur quick, especially in strong winds, height differences or presence of large amounts of vegetation. To prevent such fire spread the distance must be increased considerably. The safety distance of 3 m will however increase the probability of limiting and delaying the fire spread such that occupants close to the fire are able to escape, and to increase the ability of putting out the fire.

(3) *"When low-rise construction works are constructed with a distance of less than 8.0 m between them, the construction works' total gross external area shall be limited so that a fire does not result in unreasonably large financial losses, unless other measures are implemented to prevent such losses. "*

Guidance text: *"Calculation of gross square area is explained in guidance text for §1-3 Definitions."*

(4) *"High-rise construction works shall be a minimum distance of 8.0 m from other construction works, unless the construction works are constructed to ensure that fire will be prevented from spreading throughout the full duration of a fire."*

Guidance text: None

(5) *"Firewalls shall be designed and constructed so that they prevent fire spreading from one construction work to another, regardless of the fire service's extinguishing efforts."*

Guidance text*:* *"Specific fire energy load in table 1 is fire energy pr. m² room surface area. Specific fire energy load can be calculated or estimated based on relevant recognized statistics in accordance with NS-EN 1991-1-2:2002+NA:2008: Eurocode 1: Laster på konstruksjoner - Del 1-2: Allmenne laster - Laster på konstruksjoner ved brann."*

(6) *"Construction works that, either due to their inherent properties or the activity taking place in them, entail a particularly high probability of fire spreading shall be designed, constructed and protected or sited to ensure that the particularly high probability of fire spreading to other construction works is reduced to an acceptable level. "*

Guidance text: *"The danger of fire spread will be especially large in buildings with high fire energy load or building at a location where the response time of the fire service is long. Such buildings can be industrial- and storage buildings, wood storage buildings, agriculture buildings, and remote hotels and accommodation housing for workers."*

Possible issues identified

The first sub article explains the intended purpose behind the requirements in §11-6, which is linked to life safety and property safety in terms of financial losses and societal consequences. The wording in this requirement, "shall be prevented", gives the impression that the expected performance is absolute, i.e. that no risk of spread of fire between buildings is acceptable. This impression is however to a certain degree rectified in subsequent sub articles.

A verification with basis in this requirement is deemed only partially possible in the current practice. The guidance text states that heat flux, direct flame impingent and falling burning construction works must be accounted for when considering adequate safety distance. Engineering methods to determine the maximum radiative heat flux and flame depth/length from a given fire size in a building are available through "NS-EN 1991-1-2", although with much of the limitations previously mentioned. The main challenge is thus to estimate the probability of falling burning construction works starting a fire at neighboring buildings. It is unclear whether falling burning construction works also include falling embers transported by wind in this aspect. Falling embers can retain their ignition heat for a long time period and can also travel a long distance of several hundred meters under the right wind conditions as pointed out by Hagen [53]. Not even the operative requirement of a safety distance of 8 meters, or the pre-accepted performance of using separating construction works with fire resistance, seem to adequately prevent this.

The guidance text details what acceptable safety measures can be used to achieve the functional requirement, and it only mentions safety distance and separating construction works with fire resistance. The guidance text seems to be limiting the freedom that the functional requirement allows in this context, as technical fire safety measures such as automatic extinguishment systems have the capability of limiting a fire long before there is a danger of fire spread to other buildings. Such fire safety measures should not be limited by the guidance document.

In the second sub article, a design choice is given for low-rise buildings between two performances, either a safety distance of 8 m or use fire safety measures that prevent the spread of fire between the construction works in the time that is required for escape and rescue in the neighboring building. This section seems to provide some relaxation to the absolute requirement stated in the first section regarding the risk of fire spread, at least for low-rise buildings. Fire spread can occur, as long as escape and rescue from the neighboring buildings is possible. Time required for escape from neighboring buildings is a potential challenge to verify in this context, as the fire will be igniting the neighboring building on the outside. This could delay fire detection and alarm time considerable compared to a fire originating inside the building. Time required for rescue is also potentially difficult to verify, as mentioned in previous chapters.

The guidance to this sub article is a large text that among others explains the definition of low and high-rise buildings, which is very useful for interpreting what buildings the functional requirement is intended for. The rest of text however is linked to specific pre-accepted performances regarding the minimum safety distance of 3 m between camping units.

While the second sub article allows some flexibility and relaxation for low-rise buildings to allow building tighter than 8 m, the third sub article put some limits to that freedom by stating that the total gross square area of buildings that are built closer than 8 m apart shall be limited to avoid unreasonable economic losses if a fire occurs and spreads, unless other fire safety measures are used to reduce such loss.

The guidance to this sub article is limited to calculate the gross square area. While the performance given in this sub article does somewhat limit the freedom of performance-based design, it is considered to be a reasonable requirement that also supports multiple solutions. It is however only applicable for low-rise buildings.

The fourth sub article deals with high-rise buildings. In contrast with the second sub article that gave the definition of a low-rise building in the guidance text, the definition of a high-rise building is located under the pre-accepted performances. There seems to be no logical reason for this, and the definition should be in the functional requirement or in the accompanying guide text. Comparable to the second sub article, the fourth section allows for two different mandatory provisions; Either safety distance of 8 m or construct the building with measures in such way that spread of fire does not occur through a complete fire duration. In this section the absolute requirement from the first section is thus back in effect.

The fourth section does however specify that you can choose something other than safety distance and fire-rated separating constructions, which is considered beneficial to include in the building code in terms of allowing solutions based on PBFSD that often relies on technical fire safety measures. Option number two is what would be considered the performance-based design approach and requires verification that can show that fire spread does not occur through a complete fire duration. The same challenges in modeling a complete fire duration as was discussed in chapter 4.5 are however in effect here as well.

A noteworthy observation is that the functional requirement for both low-rise and high-rise buildings can be fulfilled by a safety distance of 8 m. High-rise buildings involve more floors and thus more total fire load leading to a potential for a larger building fire and thus higher risk of fire spread, compared to low-rise buildings. Thus, having an 8 m distance between low-rise buildings might indicate that there is some extra safety margin present.

The fifth sub article defines what constitutes a firewall, which is a barrier to prevent a fire from spreading from one building to the other building, independent of the fire service intervention. A firewall is the pre-accepted performance that can be chosen instead of a safety distance of 8 m, as it is a solution that uses a fire-rated separating construction for preventing fire spread instead.

The guide text refers to "NS-EN 1991-1-2" for calculating the fire energy load that goes into calculating the fire duration. While not explicitly stated in the code text, it seems logical that a firewall should be designed to be able to withstand an expected complete fire duration. No other method of verification is suggested however, which as previously pointed out can be a challenge.

The sixth and final sub article of chapter §11-6 concerns potentially highly hazardous building types, stating that such buildings must be designed and considered with special care with respect to the risk of fire spread. The guidance text provides some examples for when this should be considered and suggests some specific buildings where it is relevant.

Such buildings can potentially be difficult to address using the pre-accepted performances as the risk of each individual building can have high variations, potentially leading to both dangerous and conservative designs.

4.6.1. Preventing fire spread between construction works in the Swedish building code

The following functional requirements and performances are given for preventing fire spread between buildings in the Swedish building code, reproduced from [43] Ch. 5:6 .

5:6 Protection against the spread of fire between buildings

The provisions in Section 5:61 do not apply to accessory buildings that have a building area limited to 15 m^2.

5:61 General

Buildings shall be designed with adequate protection against fire spread between buildings.

5:62 Roof covering

Roof coverings on buildings shall be designed to ensure ignition is made difficult, fire spread is restricted and that they only give a limited contribution to a fire.

Summary of the Swedish requirements

The functional requirements and performances given in chapter 5:6 concerning fire spread between buildings seems very limited when compared to the level of detail for the other fire safety requirements in the building code. There is no mention of specific safety goals with respect to life safety, property safety or facilitation for the fire service, nor is there any mention of difference in risk between low- or high-rise buildings. There is also no mention of the specific mechanisms like radiative heat flux exposure, convective exposure (direct flame contact), or fire spread by falling embers. The typical solutions for preventing fire spread between buildings like safety distance or fire-rated separating construction work are all located in the general recommendations. Thus, it would seem that there is a high level of freedom with respect to using performance-based design (alternative solutions) for this particular section, as the building authorities have provided few mandatory performances, with one exception to roof coverings. There is however limited guidance on what the expected performance is, as "adequate protection against fire spread between buildings" is a broad and undefined provision. The designer must therefore decide the performance.

No methods of verification are suggested, not even in the general recommendations. This seems a bit strange, as the Swedish verification method (BBRAD) includes a chapter that discusses calculation of radiative heat flux exposure, with quantified performances for both outgoing heat flux levels and acceptance criteria incoming heat flux. It would seem beneficial to mention this option in this section.

The general recommendations also point out that requirements and general recommendations for preventing horizontal and vertical fire spread, and fire spread from adjacent roofs are in chapter 5.5 as well, indicating that the risk of fire spread between buildings in the Swedish building code is covered in several sections.

4.6.2. Preventing fire spread between buildings in the New Zealand building code

The following functional requirements and performances are given for preventing fire spread between buildings in the New Zealand building code [34] C.3. Please note that only requirements directly related to fire spread between buildings is included here. They are a part of a chapter that also covers fire spread internally in the building where the fire originated.

"

C3 FIRE AFFECTING AREAS BEYOND THE FIRE SOURCE

Functional requirement

C3.3 *Buildings must be designed and constructed so that there is a low probability of fire spread to other property vertically or horizontally across a relevant boundary*

Performance

C3.6 *Buildings must be designed and constructed so that in the event of fire in the building the received radiation at the relevant boundary of the property does not exceed 30 kW/m² and at a distance of 1 m beyond the relevant boundary of the property does not exceed 16 kW/m².*

C3.7 *External walls of buildings that are located closer than 1 m to the relevant boundary of the property on which the building stands must either:*

(a) be constructed from materials which are not combustible, or

(b) for buildings in importance levels 3 and 4, be constructed from material that, when subjected to a radiant heat flux of 30 kW/m² do not ignite for 30 minutes, or

(c) for buildings in importance levels 1 and 2, be constructed from materials that, when subjected to a radiant heat flux of 30 kW/m² do not ignite for 15 minutes

C3.8 *Firecells located within 15 m of a relevant boundary that are not protected by an automatic fire sprinkler system, and that contain a fire load greater than 20 TJ or that have a floor area greater than 5,000 m2 must be designed and constructed so that at the time that firefighters first apply water to the fire, the maximum radiation flux at 1.5 m above the floor is no greater than 4.5 kW/m2 and the smoke layer is not less than 2 m above the floor.*

C3.9 *Buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety system intended to control fire spread. "*

Summary of the New Zealand requirements

The impression of the New Zealand building code on this section is that an effort has been made to create a functional requirement and relevant quantifiable performances that fully supports a performance-based design approach. This allows for a material-independent approach and potentially allows for many different building design solutions. There is no mention of specific safety goals with respect to life safety, property safety or facilitation for the fire service, nor is there any mention of difference in risk between low- or high-rise buildings.

There are only two specific requirements that must be met:

1. The received radiant flux at the property boundary and 1 m beyond must not exceed the defined acceptable levels.

2. The materials used on external walls must be able to withstand a defined level of radiant heat flux for a given design time that is linked to the building importance levels. If the material is not tested, non-combustible materials can be used without need of testing.

The first requirement can be estimated using common recognized engineering verification methods and the second requirement can be performed at most test facilities for fire resistance classification. These two requirements cover the fire spread mechanisms of radiative and convective exposure. No mention of the fire spread mechanism by falling embers is however given. The wall surfaces might be covered by covered by the second requirement, but embers often fall on roofs as well. It would make sense to provide some performance to the roof as well, especially as the wall-roof interface is a vulnerable area for exterior fire spread.

A specific type of building that seems to pose increased risk is mentioned specifically as a separate requirement. This is buildings with a firecell with a very high fire load or a high gross square area. While not specified, this is thought to be large storage buildings or large single-space buildings like multi-purpose halls and arenas. Specific quantified performances for radiant heat flux and smoke layer height for these buildings are given. These performances are possible to estimate using recognized engineering verification methods.

Technical fire safety measures can be used as part of the design, but as the last article states, the likelihood and consequence of failure must be considered.

4.6.3. Suggestions for improvements

The functional requirements for preventing fire spread in the Norwegian building code have some potential for improvement when considering the similar requirements in the other building codes. The following suggestion are given:

- This section in the New Zealand building code seems to have a been written with the intent to allow a high degree of performance-based design. Quantified performances for acceptance criteria for radiative heat flux are given to verify if fire spread occurs. This sets a very clear and measurable acceptable fire safety level. The same approach should be considered included in the Norwegian building code. Estimating the likelihood of fire spread between buildings due to radiative heat flux is a frequent verification task, especially when the distance is below 8 m. It can however be a challenging task as the current version of the building code does not suggest any quantified performance for this. Having a defined and recognized performance level with regards to radiant heat flux would simplify the verification process. Acceptance criteria may even be included, for example in the form of the following statement:

  "Maximum radiant heat flux or temperature exposure must be below the expected ignition level for the receiving façade material. "

- Much of the verification on whether fire spread can occur is linked to estimating the full fire size and duration of the fire. As pointed out in the chapter on load-bearing constructions, it is difficult enough just to estimate the thermal impact of a construction that is located inside the building in a fully developed fire. Estimating how a fully developed fire spreads to the exterior boundary adds a new level of complexity. While "NS-EN 1991-1-2" also has a method for calculating this, the applicability is severely limited. Having a simplified approach not based on the calculation of the fully developed fire would allow for easier verification. This could for example be a defined maximum outgoing radiant heat flux pr. m² for a certain building occupancy. If that is coupled with an acceptable limit of received heat flux, heat flux calculations and the geometry of the two buildings can be used to verify an acceptable safety distance. This approach is also used in the Swedish and New Zealand fire safety verification methods [27][36]. As a minimum, an acceptance criteria for incoming radiative heat flux could be included, as a performance criteria for this (~15 kW/m²) was even suggested by NKB in the part covering guidance for technical verification [16]. A similar level of radiant heat flux level is suggested by Hadjisophocleous et al [54] as well. While including such information in the actual building might not be considered practical, it could be part of the guidance text to the building code requirements, or in a separate fire safety verification method.

- The risk of embers/falling burning constructions works leading to fire spread need to be better addressed. It is currently unclear to what degree wind need to be accounted for when evaluating this risk in an alternative / performance-based solution. Wind is major challenge for the spread of fire, especially in areas prone to high wind and low humidity. This was recently shown in the historic heritage wood village "Lærdal", where a fire in 2014 caused massive amounts of damage throughout the area as discussed by Log [55]. There are records of fire spread occurring over several hundred meters. As such, deriving a performance metric and acceptance criteria based on a deterministic approach that will be in balance with the current acceptable fire risk is difficult. A possible conclusion from this could therefore be that preventing fire spread from falling burning construction works is limited to the main components of the building like the walls and the roof that will typically land in close proximity to the originating building if they wall. Efforts to find alternative performance metrics, acceptance criteria and suitable engineering methods to estimate this risk is needed, for example probabilistic methods such a fire risk indexing.

4.6.4. Discussion

Adding quantified performance metrics and acceptance criteria linked to ignition based on received radiative heat flux or maximum temperature exposure are suggested in the results. These performance metrics are considered to be based on recognized first principles for spread of fire and possible to estimate using a wide range of different engineering methods. As such it would not be considered limiting on design freedom to include these metrics in the building code itself. It may also be possible to state that other performance metrics are not excluded but would need additional documentation to be used.

Certain standardized and uniform materials like wood with reasonable conservative ignition values may be included to prevent unnecessary scope of fire testing of the façade material. Specific values would need to be properly evaluated. Such a requirement would define a clear acceptable fire safety level with respect to fire spread through radiative heat flux and flame impingement and expected to reduce the variability in verification of alternative solutions.

The suggestion of a simplified method for estimating radiant heat flux where the outgoing exposure is given, would likely reduce the variability in the results of the engineering methods considerably. The reason for this is that calculation of exterior fire spread through openings or walls in a building is linked to the available fire load energy and the ventilation conditions. Window and doors may be closed or open at the start of the fire, and that state may also change during the fire. This leads to a high degree of uncertainty. The proposed simplified method where outgoing radiant heat flux pr. m² bypasses this problem.

Negative consequences of these proposed changes could be that it could be potentially easier to create building designs with reduced distance to other buildings. If this is done for multiple buildings in a large scale in an area, that may create new risks that are not sufficiently accounted for when just evaluating fire spread to and from a single building. An example of this issue could be that a large residential area where distance between buildings are only 2-4 m, but where every building has an automatic extinguishment system. As long as this system is in place and works as intended, the risk for fire spread to other buildings would be very low. Local failure of the system in a single building would increase the risk and potential for increased damages to buildings in the immediate vicinity, but risk for fire spread to the whole residential area would still be reasonably low. However, if the main water supply to this entire area would for some reason be shut off and fire occurred at the same time, the risk of increased damages to the whole area compared to prescriptive/acceptable solutions using safety distances or fire-rated walls could be significantly higher. The risk of fire spread would then be entirely dependent on the response time and capabilities of the local fire department. If fire should spread to multiple buildings, the local fire department may not be able to handle this fire size on their own. As such, additional operative requirements that require that this issue be investigated may be warranted. This risk is however present in the current practice as well, as there are no required specific solutions for preventing fire spread in the building code as part of the operative requirements. Alternative solutions may be designed and verified using different engineering methods and different acceptance criteria for ignition. Defining a common understanding what is the minimum acceptable fire safety level through the suggested performance metrics and acceptance criteria should help to remove alternative designs that are unsafe due to misuse or abuse in the choice of verification approach. It would arguably also be easier to account for active measures like automatic extinguishments systems to prevent fire spread, since active systems can have significant impact on the fire size and thus in effect also on the flame size and amount of radiative heat flux.

4.7. Section §11-11 General requirements relating to escape and rescue

This section covers §11-11 "General requirements relating to escape and rescue" from a building. The section defines the principal goal of life safety in a building and provides functional requirements and performances for verification of life safety conditions. This section is therefore of special interest for PBFSD, as verification of life safety is often a frequent verification task.

The following functional requirements and performances are given; reproduced from [38] and[41], §11-11:

" *§11-11*

(1) *Construction works shall be designed and constructed to allow speedy and safe escape and rescue. Account shall be taken of people with disabilities.*

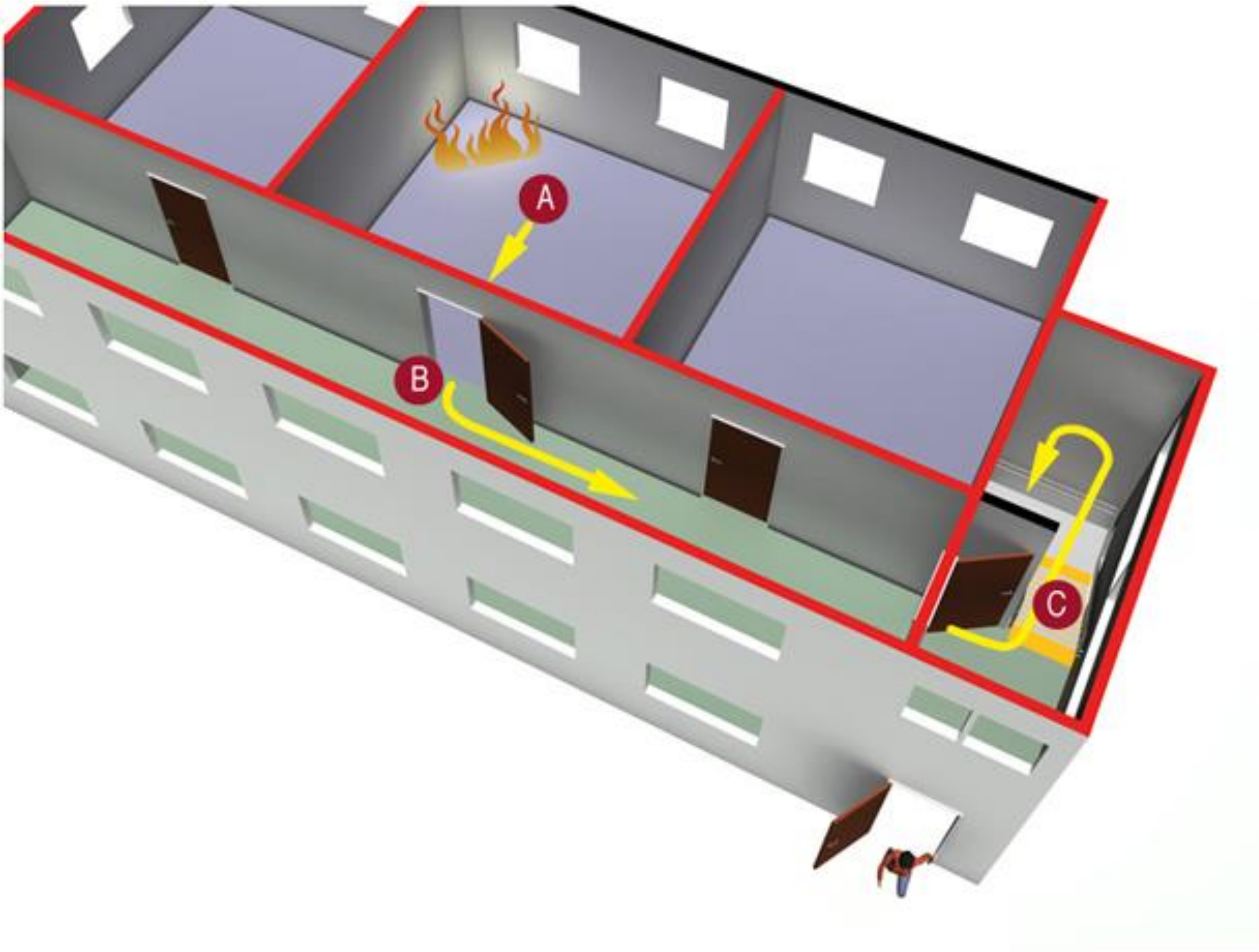
Guidance text: "*Escape from buildings can be split into the following three phases, as seen in figure 1:*

> *a. Movement within the fire compartment of origin. This is not considered a part of the defined escape path.*
> *b. Movement in a corridor defined as an escape path.*
> *c. Movement in the stairwell which is part of the escape path to the exit of the building*

The time it takes to escape a building will be dependent on conditions related to the occupants, the building and the fire. Because of this, when planning and designing escape paths it is not just the escape path length and width that will influence the level of life safety. The building occupancy type and the ability of the occupants to self-evacuate will have a great impact on the safety of the evacuation, which is the reason for the definition of the building hazard classes. The building hazard classes are defined in §11-2 and must be used as part of the design of the means of evacuation.

In public assembly buildings/areas where alcohol is served, in occupancies like discotheques, nightclubs and similar, it might be necessary to do a life safety assessment independent of the occupant load.

It might be requirement for special equipment in order to facilitate for quick and safe escape and rescue of people with disabilities. The need for equipment will depend on the particular type of building, and the internal emergency preparedness the building has. Examples are special equipment for giving alarm signal to the occupants in the building, and equipment to facilitate rescue using the stairs. See also §11-12 second and fourth paragraph.



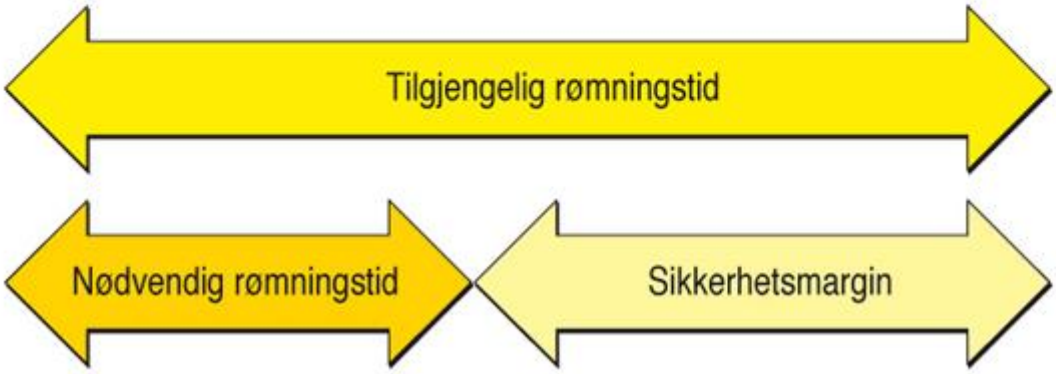
§ 11-11 Figure 1: Escape from a building can be split into three phases
A. Movement within the fire compartment of origin. This is not considered a part of the defined escape path.
B. Movement in a corridor defined as an escape path.
C. Movement in the stairwell which is part of the escape path to the exit of the building"

(2) *The time available for escape shall be greater than the time required to escape from the construction works. An adequate safety margin shall be included.*

Guidance text: "*Available safe egress time (ASET) is the time from a fire starts until the conditions become critical. Required safe egress time (RSET) is time it takes to escape a building.*

Safe escape is based on the condition that ASET is significantly longer than RSET. The difference between ASET and RSET is an expression for the safety level and is termed safety margin, see figure 2.

The figure gives a very simplified view of the relationship between the ASET, RSET and the safety margin. When analyzing evacuation conditions (verification by analysis, see chapter 2.) there are uncertainties in all of the input parameters and variables, and thus also in the calculation of ASET and RSET. When doing calculations, uncertainties shall be considered and documented, both separately and combined. When evaluating the required safety margin, the uncertainties in the calculations must be taken into account.



§ 11-11 Figure 2: The relationship between available safe egress time ("tilgjengelig rømningstid"), required safe egress time ("nødvendig rømningstid") and the safety margin ("sikkerhetsmargin") during evacuation "

(3) *Fire compartments shall be designed and furnished in a way that facilitates speedy and efficient warnings, escape and rescue.*

Guidance text: None

(4) *Escape routes from peoples´ whereabouts to the exits from a fire compartment must be clear and facilitate speedy and efficient escape.*

Guidance text: *"The maximum distance from any location in a fire compartment to the closest exit is defined in §11-13 table 1."*

(5) *During the period of time a fire compartment or escape route shall be used by people escaping, no temperatures, concentrations of smoke gases or other circumstances shall occur that hinder escape.*

Guidance text: *"The purpose of this requirement is that occupants in the building shall be able to escape or be rescued to a safe place without suffering serious injury.*

The calculation of temperature, radiative heat flux, visibility etc. in the escape paths is only applicable when doing verification by analysis. Tenability criteria are located in SN-INSTA/TS 950:2014 Analytical fire safety design – Comparative method for verification for fire safety in building."

(6) Signs, symbols and text showing escape routes and safety equipment must be able to be read and understood while escaping when fire or smoke are developing.

Guidance text: "*Good signage with signs, symbols and text will assist in reducing the required safe egress time. It is the hazard class of the building, the size and the plan layout that decides the need for, and scope of, the signage.*

General principles for visual aid systems with electrical or photoluminescent components are outlined in NS 3926-1:2017 Visual aid systems for escape of buildings – Part 1: Design, construction and control. See also §11-12 third paragraph. For signage of manual extinguishment systems see §11-6 fourth paragraph."

Potential issues identified

Since verification of life safety is arguably one of the most critical and frequent verification tasks in PBFSD, these requirements need to be clear and well understood. The guidance text to the building code requirements are of special value for this section, as they provide additional details on verification.

Sub article 1 states the overall functional requirement for quick and safe evacuation from a building. People with disabilities should also be accounted for in this regard. The guidance text defines this approach in a very specific way, illustrating the concept of evacuation from a fire compartment to an escape route (corridor), and to the exit. While this is in accordance with the functional and performance requirements as they are stated in §11-8 Fire compartments, §11-13 Exit from fire compartment and §11-14 Escape routes, this approach is actually a challenge for modern open-plan building design to comply with, as discussed in chapter in 4.3. If the proposed changes in chapter 4.3 are included, the guidance text in this chapter should be included and updates as well. The guidance text also provides additional details on how to account for people with disabilities, suggesting that evacuation could require special equipment or special organizational emergency routines in the building.

Sub article 2 outlines the concept of available and required time for safe egress. Evaluating life safety is usually performed based on this concept of "Available Safe Egress Time" and "Required Safe Egress time", often referred to as ASET-RSET. ASET-RSET is a well-known and internationally used performance-based design concept for evaluating life safety. It is however potentially a challenging and time-consuming verification task, as it typically requires investigation of both the spread of fire and smoke in a building, and the evacuation of people. These are also two very different fields of engineering, and thus requires a high level of competence to be able to cover both. The concept is defined in the sub article in a simplified form and the importance of the safety margin is pointed out. The guidance text explains the concept further and illustrates the relationship between the available and safe egress time, and the safety margin. No quantified acceptance criteria for life safety are however given.

Sub article 3, 4, 5 and 6 discuss more specific performances linked to fire compartments, escape routes and need for emergency signage and path guidance systems.

The guidance text for sub article 5 is of particular interest, as it suggests a particular source for verification of tenability criteria for life safety analysis; The Inter-Nordic standard/Technical specification SN-INSTA/TS 950:2014 "Analytical fire safety design – Comparative method for verification for fire safety in buildings" [21].

4.7.1. General requirements for ability to escape during a fire in the Swedish building code

The following functional requirements are identified as general requirements for ability to escape during a fire in the Swedish building code, reproduced from [43]. Note that there are many requirements given for "ability to escape during fire" this in the building code, however only those defined in general terms are included here to better compare against the equivalent section in the Norwegian building code. All the functional and operative requirements for ability to escape during a fire in the Swedish building code are however included in the appendix for reference, see chapter 10.

" 5-3: Ability to escape during a fire

5:31 General

Buildings shall be designed to ensure that there is an adequate time for evacuation during a fire. Adequate time for evacuation means that people who evacuate are not exposed to falling structural *elements, high temperatures, high levels of heat radiation, toxic gases or reduced visibility that might impede evacuation to a safe location with sufficient certainty. "*

Summary of the Swedish requirements

The Swedish building code has far fewer general performances for facilitating ability to escape compared to the Norwegian building code. Although the concept of ASET-RSET is not explicitly mentioned in the functional requirement in the Swedish building code, there is little doubt that the functional requirement is referring to this concept for evaluating life safety. No quantified performances are given or referenced in the building code. It should however be pointed out that a method of verification for life safety together with quantified acceptance criteria and relevant input data is given in the Swedish verification method BBRAD.

4.7.2. General requirements for ability to escape during a fire in the New Zealand building code

The following functional requirements are identified for general requirements for ability to escape during a fire, reproduced from [34] C4:

"

C4 – Movement to a place of safety

Functional requirement

C4.1 *Buildings must be provided with:*

(a) effective means of giving warning of fire, and

(b) visibility in escape routes complying with clause F6.

C4.2 *Buildings must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a place of safety and that those occupants will not suffer injury or illness as a result.*

Performance

C4.3 *The evacuation time must allow occupants of a building to move to a place of safety in the event of a fire so that occupants are not exposed to any of the following:*

(a) a fractional effective dose of carbon monoxide greater than 0.3:

(b) a fractional effective dose of thermal effects greater than 0.3:

(c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m2 where visibility may fall to 5 m.

C4.4 *Clause C4.3(b) and (c) do not apply where it is not possible to expose more than 1 000 occupants in a firecell protected with an automatic fire sprinkler system.*

C4.5 *Means of escape to a place of safety in buildings must be designed and constructed with regard to the likelihood and consequence of failure of any fire safety systems. "*

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There are no limits on application specified.

Summary of the New Zealand requirements

The functional requirement in the New Zealand building code for movement to a place of safety has many similarities to the equivalent requirement Norwegian and Swedish building codes, and the approach of estimating ASET-RSET is also required here. The New Zealand building code however also provides quantified performances in the form of acceptance criteria for life safety directly in the building code using the concept of fractional effective dose (FED) for carbon monoxide, thermal effects and visibility.

It should also be pointed out that relevant input data and method of verification for life safety is given in the New Zealand verification method C/VM2.

4.7.3. Suggestions for improvements

As it currently stands, the general functional and operative requirements given for facilitating escape in the Norwegian building code is considered to be reasonably well constructed with respect to the level of PBFSD it allows. The same approach is generally used by Sweden and New Zealand, where New Zealand has taken the step of including quantified performances in the building code itself. The performances linked to verification of life safety are essential to fulfill the functional requirement, and as such the following suggestions for improvement are strongly linked to this:

- The performances with respect to life safety can be improved if tenability criteria are quantified directly in the building code. As it is currently defined, there is a suggestion to use tenability criteria in SN-INSTA/TS 950:2014 [21] in the guidance text.. While the tenability criteria in this standard are generally recognized, it is questionable whether the definition of an acceptable level of life safety for a building code should be given by a third-party standard. It allows for little flexibility for the building authorities to change the criteria, or even add newer ones, if deemed needed. If the tenability criteria in that standard are considered acceptable as they presently are defined, then there should not be an issue to include them in the building code as well. This is essentially what is done in the New Zealand building code. This would define a quantified performance for this section and thus leave no doubt as to what the minimum safety level (for evacuation in a fire) in the Norwegian building code is.

- While the acceptance criteria given in [21] are generally well recognized, they do not suggest tenability criteria for evaluating accumulated toxicity or thermal effects .This can often be necessary in a life safety analysis, especially with a long evacuation time through smoke. To improve on this, the concept of FED (Fractional Effective Dose) should be considered implemented. The use of the FED concept for evaluating tenability linked to toxicity and thermal effects is discussed in detail in the *"SFPE handbook of fire protection engineering"* [56] and in ISO 13571 "*Life-threatening components of fire – Guidelines for estimation of time to compromised tenability in fires"* [57]. The concept was even suggested in the guidance for technical verification by NKB [16]. It can be summarized as concept that expresses tenability as a function of accumulated dosage, based on combined inputs (like oxygen, carbon monoxide and carbon dioxide, or thermal effects). The accumulated dosage at a given times is expressed as a fraction of the end point that would lead to loss of tenability.

- The concept of safety margin and what is a reasonable level must be further discussed. While the approach in the building code where the safety margin is linked to the level of uncertainties is a good suggestion, quantifying all possible uncertainties in an analysis is a major undertaking, and often not even practical possible within a reasonable time frame. While defining explicit safety margins in the building code is perhaps not possible, some additional guidance and examples would be beneficial to reduce subjective interpretations.

- This specific suggestion of improvement is for a more dynamic approach to life safety criteria. It is recognized that this approach would be more suitable to include in a guidance document or a fire safety verification method than in the building code itself. As such, it is only included here as supplemental/informative suggestion.

  In the approach suggested by [21], there is a an approach where tenability criteria for smoke layer and visibility is linked. If the criteria for smoke layer is achieved, visibility does not need to be evaluated. A similar approach for toxicity is also defined, where toxicity does not need to be evaluated if visibility is above > 5 m. If accumulated dosage of toxicity and thermal effects are also included as required life safety criteria, then a similar approach could also be used for this. One possible approach would be to state that if evacuation through smoke (or with proximity to smoke) occurs for more than 3 minutes, then accumulated dosage would need to be evaluated.

  Accumulated dosage as tenability criteria could also be used as an approach for allowing visibility lower than 10 m in large areas, for example to 3-5 m, since a minimum of visibility should be required to maintain ability of orientation. Visibility has been shown to generally limit the available safe egress time much earlier than the other tenability criteria [58]. While visibility is important for orientation during an evacuation, it is not an immediate life-threatening tenability criterion. As such, an argument could be made to adjust the required level of this tenability criteria so that it is more in balance with the other tenability criteria. This change should however require that accumulated dosage of toxicity and thermal effects be considered. A flexible system of increasing complexity in the verification process based on increased risk is suggested. Such a system could be used to differentiate on the amount of verification that is needed based. An example based on smoke exposure to occupants is shown below, proposed values are indicative only.

  <u>First level:</u> Evacuation through smoke is not allowed. The smoke layer interface height should be identified to be at a level where it will not expose occupants of smoke. The minimum layer height should be 2 m, or 1.6*0.1*H

  <u>Second level:</u> Evacuation through smoke is allowed, but smoke concentration or visibility must be maintained at sufficient levels to prevent issues related to toxicity. Visibility must be maintained above 10 m in all relevant evacuation areas.

  <u>Third level:</u> Evacuation through smoke and reduced visibility is allowed. Both instant and accumulated dosage levels of toxicity for occupants must however be verified. The concept of fractional effective dose (FED) may be used to evaluate accumulated dosage, whereas the level must not be above 0.3. A minimum of 3 m visibility should however still be retained to have a minimum coordination ability. Reduced movement velocity of occupants due to reduced visibility conditions must also be considered.

4.7.4. Discussion

This section of the building code is considered to be the section that bests support PBFSD in the Norwegian building code, as the concept of ASET-RSET is widely recognized approach. As previously mentioned, it is also arguably the most frequent verification task in PBFSD. The large variability seen in verification often can be linked to differences of practice in how ASET-RSET is estimated. The given suggestions for improvements are considered to limit some of that variability by clearly identifying what the acceptance criteria for life safety are. This will then also automatically reduce the scope of engineering methods, as the methods must be able to estimate the performance that is given by these criteria.

It is recognized that some of the suggestions are more suitable to include in a guidance document or a fire safety verification method. If this document is under control by the building code, acceptance criteria may be defined outside the actual building code, and the document/method may be referenced by a relevant building code requirement. If such a document/method is not under the control of the building authorities, the main life safety acceptance criteria should be listed in the building code as performances, and a reference to the recognized third-party document/method should be included to provide support on use of relevant engineering methods.

Potential negative impacts of the proposed improvements could be that recognizing such deterministic acceptance criteria for life safety as the acceptable fire safety level could create issues related to the ability of verification of safe escape in certain building designs. Examples of this could be smaller rooms where occupants are sleeping or need assistance in evacuation, like in residential, hotel or health care occupancies. Such occupancies would potentially have an increased evacuation time to a fire event. Current (conservative) deterministic fire and evacuation modelling practices that do not (or only in a limited capacity) account for probabilistic effects would most likely be challenged to show safe escape conditions from such rooms. This issue may however be solved by multiple approaches:

- It may be recognized that the proposed deterministic criteria are unsuitable for use in small rooms, or rooms with a low ceiling height. Such rooms are however often compliant with acceptable solutions anyways, so the problem may not be very predominant.

- The deterministic acceptance criteria can also be supplied with probabilistic acceptance criteria. Such criteria are however challenging to identify and define, especially directly in the building code, as they clearly indicate a certain acceptance for causalities in a fire event. While it is generally recognized that this is implicitly accepted through the prescriptive/acceptable solutions because there are multiple casualties due to fire each year in Norway, expressing it through a defined acceptable probability is more difficult for society to accept. Probabilistic methods and acceptance criteria for risk have been in effect for onshore and offshore industry for many years already however, arguably to good effect. The same approaches should be possible to use for building fire safety design as well. There are ongoing developments and cooperation in the Nordic countries to define suitable method probabilistic criteria through a new inter-Nordic standard, INSTA 951 – "Probabilistic methods for fire safety design" [11].

5. Using fire safety verification methods to support verification

5.1. Introduction

This chapter contains the results of the second main investigation, which is on the use of fire safety verification methods.

Global experience with the practice of verification of PBFSD has revealed that there are some potential issues, as pointed out in chapter 1. One of the main challenges is that the verification of performance-based designs can have a high degree of variability between different designers. This can be seen both in the number of applied engineering methods, in the results of those methods and even the interpretation of those results. This makes it difficult for reviewers and authorities having jurisdiction to decide if the design is considered "safe enough". This is especially true when the building code does not include any performances linked to the functional requirement, and the fire safety level is in practicality defined by the pre-accepted performances. In such cases it is almost impossible to evaluate the PBFSD without also doing a comparative analysis with the pre-accepted performances as the reference fire safety level.

This problem could be argued is a symptom of the high level of freedom that the first versions of performance-based building codes made possible. Some countries that adapted the performance-based approach at an early stage seems to have suffered this to a various degree [1], where going from a purely prescriptive building code with a low degree of design freedom, the pendulum was pushed all the way to the other side to allowing almost full design freedom. A question whether the fire safety engineering field was mature enough for such a level of freedom at that time seems an appropriate one. Multiple sources from various countries [1][2][5][9][13][31][26][59] have pointed to challenges with verification in the practice of PBFSD. While many examples may be considered not harmful and just linked to questions of adequate documentation, there is no denying that PBFSD may be both unintentionally misused and intentionally abused to produce building designs that can have serious hazards for both life- and property safety. Therefore, actions should be taken to adjust the practice so that the probability of this occurring is reduced.

This could be achieved in several ways, as pointed out in chapter 1.2. For improving the quality of verification, there is no question that education and competence of the designers are critical elements. That however seems to be taken reasonably seriously in Norway, as a BSc education with strong focus on fire safety engineering and technical safety has existed for over 20 years already. A MSc-level was also recently introduced in 2015 [60]. A curriculum that focuses on the practical application of PBFSD is crucial to produce future fire safety engineers that can perform this practice with a high level of quality.

Another way of improving the quality of verification would be to provide more guidance and specification of the practice, especially when this is done in close connection with quantified performance requirements for fire safety. Certain countries like Sweden and New Zealand have followed this approach and created what is referred to as a fire safety verification method (FSVM). A FSVM is a document that typically details engineering methods, design fire scenarios and relevant input data. If provided by the building authorities it may be stated as a regulatory path of compliance, much like on the same level as the use of acceptable and deemed-to-satisfy solutions. A FSVM may be intended as a full suite for verification of all the relevant building code fire safety requirements (full scope of compliance), or it may only cover certain parts (limited scope of compliance). The exact definition of a verification method is a bit varying in the literature. Lobel et al in [59] p.1 provide the following definition:

"Verification Methods, also known as Fire Safety Design Methods, are prescriptively informed methods for carrying out calculations, modelling and building design."

While IRCC/Meacham [6] p.28 provides the following definition:

" Calculation, simulation or test methods that prescribe one way to comply with the building regulation. Verification methods can include: Calculation methods, using recognizes 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 verifications by test, where compliance with specified numbers, dimensions or locations is required (non-destructive tests, such as pipe pressure tests, are also included). "

For purpose of discussion in this thesis, FSVM will be considered as a recognized path of compliance with the building code, both full and limited. If such a method is not considered a path of compliance, it will be referred to as a "guidance document" instead. While a FSVM is usually administered by the building authorities due to the status as a path of compliance, a guidance document does not necessarily need to be. A guidance document may be a recognized standard or a form of a best practice document owned and maintained by the fire safety engineering community. The content may however be much the same as in the verification method, although not necessarily have the same recognition and status as it would have if it had been developed by the building authorities.

In FSVMs acceptance criteria, engineering methods and input data will typically be given to define a specific fire safety level. It is important to point out that the decision to provide such input data is a critical one, as it invariably will quickly be considered minimum fire safety level. This may even hold true for guidance documents, especially if the document does not state how the content should be used. While this can be a real challenge, providing relevant engineering methods and input parameters are arguably one of the biggest benefits of such a method or document, as it would no longer be a need to assess the very large amount of various methods and input data that are available in the literature. This makes the task of verification a lot less resource-demanding and simplifies quality assurance and (3rd party) design reviews. These benefits are much the same benefits that prescriptive design offers and using a verification method can indeed be thought of as a "prescriptive way of doing PBFSD".

The decision to introduce a FSVM (that is considered a path of compliance for the building code) for fire safety should not be taken lightly. The reason for this is how a FSVM is created and how it defines its relationship to the acceptable solutions, or in the case of Norway, the pre-accepted performances. Should the content of a verification method like design scenarios and input data be based solely on scientific literature and first principles, or should the content be calibrated against the pre-accepted performances? The acceptable solutions/pre-accepted performances will for many countries define the societal acceptable fire safety level, so it makes sense to do a calibration of a FSVM with this as a reference level. If both pre-accepted performances, and alternative performances/solutions verified through the verification method, are deemed to comply with the building code, it stands to reason that the pre-accepted performances should also be able to withstand the rigor of being tested with the verification method. Currently however, that does not always seem to hold true.

The main reason for this is believed to be that current engineering methods and input data are for the most part deterministic and often defined conservative to err on the conservative side to account for the presence of high uncertainty that is normally present in fire safety-related phenomena. This means that there are limited efforts to account for the probabilistic nature of a fire, like if it occurs and how it develops. If there is even a minor risk of a large/fast fire occurring, then that is usually considered the main design scenario. The same also applies for human behavior, where suggestions for detection and reaction times may be several minutes, and do not account for the proximity to the fire. If a large/fast fire in a room is combined with limited ceiling height and occupants with a slow reaction time, it is not difficult to show that no occupant will be able to leave the room before untenable conditions are reached. This is made even more obvious when there are requirements to consider robustness in the design as well, for example consequence of a failure in an automatic extinguishment system or an automatic fire detection and warning system. The pre-accepted performances are for the most part not based on fundamental scientific principles. Since they are at least in part based on previous events, they do account for the probabilistic aspect however. As such, it should not be expected that the pre-accepted performances be able to provide the same level of safety as alternative solutions that have been designed through a purely deterministic verification method. Because of this, a calibration of the content in a verification method with the pre-accepted performances as a reference safety level (and vice versa) should not performed before a solid grasp on the probabilistic aspect of fire safety is achieved.

5.2. Experiences from development of a fire safety verification method in Australia

The recent efforts in Australia pursing a FSVM discussed by Lobel et al in [59] illustrates the particular challenge of creating a such a method. The reason for a desire for a FSVM stems from a struggle where authorities having jurisdiction do not have satisfactory confidence in that buildings with PBFSD can comply with the relevant performance requirements in the building code. Further investigation into this led to the possible options of revising the performance requirements by adding quantification, or to create a verification method. The Australian Building Codes Board (ABCB) created a draft of a fire safety verification method in 2017 and sought out to create a policy-neutral method that would be calibrated against the acceptable solutions. This was to be done through a calibration study consisting of a multiple leading Australian and international fire safety engineering firms. 8 typical building types that represented varying sizes and complexity was chosen and would be designed through current acceptable solutions and then benchmarked with the proposed verification method. The following observations were made through that study, [59] p.2-3:

(i) Once design scenarios and inputs are prescribed, science loses out and the essence of performance-based decision making is lost. Any FSVM should not prevent performance-based design from first principles still being applied as an alternative.

(ii) A FSVM may be appropriate for basic building designs like bulk goods warehouses but is not appropriate for complex building designs when more interconnected variables are at play.

(iii) Although at first glance a FSVM would appear to improve consistency of approach due to prescribed scenarios and inputs, this belies the difficulty in prescribing a consistent or appropriate modelling and analysis methodology and the numerous assumptions and approaches associated with this, which may still significantly affect the result.

(iv) Benchmarking against traditional prescriptive provisions that are not scientifically based is somewhat counter-productive and will always inhibit the application of contemporary science and knowledge. While some stakeholders are concerned about performance-based design, the FSVM calibration project demonstrated that the traditional prescriptive provisions arguably represent building designs which are less safe.

(v) The problems associated with the application of performance-based design are not fundamentally due to the Performance Requirements themselves, but rather:

- *A lack of minimum and consistent competencies to undertake performance-based design and review performance-based designs*
- *A lack of consistent regulatory requirements associated with the appropriate administrative*
- *approach to this task*
- *A lack of guidance regarding involvement of stakeholders, selection of inputs, analysis*
- *methodology, documentation of design results and implementation expectations*
- *There is not always clear buy-in from key stakeholders or a regulatory description of what the fire safety strategy should include or how this should be documented*

This study was also part of a topic presented at "12th International Conference on Performance-Based Codes and Fire Safety Design Methods" and in the presentation, the following was also stated about the results of the calibration study, p.20:

- *General failure of DtS buildings to pass VM across the board*
- *When using VM tenability criteria, ABCB set societal and individual risks criteria were exceeded*
- *Confusion and difficulty agreeing modelling approaches despite VM instructions*
- *It was clear the VM was not policy neutral*

Point (iv) in the paper and the subsequent points made in the presentation, are of particular interest, as it states that benchmarking the deemed-to-satisfy (DtS) solutions is counter-productive, and that the solutions that were benchmarked using the verification method could be considered less safe, i.e. meaning that design based on the acceptable solutions failed with respect to the acceptance criteria defined in the verification method. [59] p.4 also points to the problem of a policy-neutral verification method where calibration against the acceptable solutions without considering the probabilistic aspect is problematic.:

"In this case, to achieve policy neutrality with a DtS design, the fire growth would have to be varied greatly and the pre-movement time significantly reduced, yet each of these values were based on well researched and supported documents that are internationally recognized. This is not necessarily representative of a shortfall in the existing building code, but rather that the building code has been written to consider the statistically likelihood and outcome, i.e. risks, of events rather than being based purely on simplified single-instance fire model. However, it is recognized that without the overlay of probabilistic occurrences of fires the modelling does result in the building code appearing dangerous for occupants. "

Lobel et al [59] p.5 conclude that the main problem of lacking quality in verification in current PBFSD practice is linked to a lack of competency, and that a verification method will not be able to rectify this problem:

"This required evolution of the FSVM reveals the true weakness of current performance-based design practice; namely a lack of competency by some practitioners. No code is sufficient to replace adequate competence in the fire engineering field, and it was FPA Australia and the consortium's opinion that the FSVM itself could not improve the practice of fire safety engineering in Australia. Rather, it requires a reform of how competence is achieved via educational training, tested via certification, and maintained and checked throughout the career of engineers with audits, third party reviews, and continuing professional development."

This paper provides a valuable insight into the process of development of a FSVM and the questions that must be answered in such a process. There are obviously some disagreements in the fire safety engineering community in Australia on how the challenge of variability in verification should be rectified. It is also clear that Australia is heavily influenced by what New Zealand is doing in this aspect.

5.3. Experience with practical use of the Swedish verification method BBRAD

An introduction to BBRAD is given in 2.6.2. In this chapter, more practical experience with using the verification method is summarized, based on data from literature review and interviews.

A paper by Noren et al [61] was presented at the *"9th International Conference on Performance-Based Codes and Fire Safety Design Methods"* in 2012, documenting a study performed on using BBRAD. They stated that the design fire scenarios and the suggested input parameters in BBRAD for verification of life safety were not derived from scientific data, and not deemed conservative when compared against the typical design fires and input data that would be used in the practice before BBRAD was made available. The conclusion of that study was that following the guidelines in the verification method could potentially lead to an increase in the societal risk level, but that it was difficult to quantify the actual impact due to the low frequency of the large fires typically used in PBFSD. The importance of a doing a consequence analysis to properly assess the impact of such a verification method before it is implemented in the building regulation, was underlined. The problem with fixed input parameters was also pointed out, which could potentially lead to a design that could be both over- and under dimensioned depending on the layout of the building in question. Some major benefits were however also recognized, among them better consistency and transparency between designs from different fire safety engineers and simpler design review and control. The fact that the verification method also heavily relies on use of automatic extinguishment system as a safety measure by allowing less conservative input data when this fire safety measure is used, will drive the use of such systems up in alternative solutions. Such systems have a very large impact on the fire safety level, both in a realistic environment and in theoretical fire modelling environment.

It is noted that this study was performed in the same year as BBRAD was published, and thus limited experience with the method may have influenced the results. In addition, the design fires and input data they compared the values in BBRAD against, could also be questioned, as this data was chosen based on a Delphi study involving 4 major fire safety engineering firms in Sweden. Even though this may be considered a reasonable average of the practice before BBRAD, it does not necessarily reflect the minimum acceptable safety level. Never the less, the concluding points are still considered noteworthy with respect to introducing a major change like a verification method in the building regulation.

5.3.1. Interviews with practitioners of PBFSD

Two live interviews with fire safety engineers experienced with the practice of PBFSD in Sweden and the development and use of BBRAD have been conducted, see 10.5 and 10.6 for written summaries. The purpose of these interviews was to get an impression on the practice of PBFSD in Sweden before and after the introduction of BBRAD, and their experience with practical use of the verification method. A compressed summary of their responses is given below.

- There is a general agreement that both prescriptive and performance-based design are necessary to be able to support the Swedish building development. Each approach has their strengths and weaknesses and complement each other well.

- The practice of PBFSD in time before BBRAD could generally be considered more varied and inconsistent. In addition, the building code between 1994-2012 also seems to have allowed deviation even from the mandatory building code requirements without a need for a special application to the building authorities, if a comparative safety level (if the building code requirements had been followed) could be documented.

- The major revision of the building code in 2012 arguably pushed the pendulum of building design freedom toward the more prescriptive/specified side, with mandatory performances for sprinkler systems in hospitals and certain healthcare buildings, and requirement for refuge areas for public buildings. The introduction of the verification method BBRAD, published together with this revision, may also be seen as part of this increased need for specification. This is usually how building code revisions are performed; the level of design freedom will typically vary between revisions where measures are taken to adjust the faults observed with previous practice.

- The present quality of PBFSD is deemed high. although exceptions can always be found. This high quality is credited to the availability of high-quality fire safety engineering education, and a more defined building regulation.

- BBRAD is voluntary to use, as it is considered a part of the general recommendations. Alternative solutions may be used in lieu of the general recommendations so an alternative to BBRAD is also possible. The experience is however that few dares to step outside the recommendations given in BBRAD, as they are typically considered the minimum acceptable level at this point.

- If the specific area is covered by BBRAD, the experience is that it is usually used when doing analytical design. The most used areas are probably life safety assessments and fire spread between buildings, as these areas have the most guidance. The chapter about documentation and control is obviously also used extensively.

- No measurable increase in the application of PBFSD has been noticed since the introduction of BBRAD. Generally, it is just now performed more structured and defined, especially for the approach using qualitative assessments. Before BBRAD, qualitative documentation could be on the level of "considered satisfactory because of sprinklers". Now, the qualitative verification is more structured and follows the approach outlined in BBRAD.

- On the topic of benefits and drawbacks with using BBRAD, the major benefits seem to be consistency in the verification between different designers and easier 3rd party review. There is less discussion about what appropriate input parameters and design fire scenarios are. The major drawbacks are that even though you feel the input parameters in BBRAD are not ideal for a specific project and you have the possibility to choose something else, you often still end up using it anyways. 3rd party review does not really question the values in BBRAD, so it is an easy way to avoid disagreements.

- Both interview subjects agreed that overall level of quality in verification has increased since the introduction of BBRAD. There is no desire to remove it without having anything better in its place. Certain parts of it may be improved or expanded upon, such as how to choose the method (level) of verification. In addition, more specification and guidance are probably needed to get more designers to consider using method 3, quantitative risk analysis, as very few designs currently use this approach.

5.4. Experience with practical use of the New Zealand verification method C/VM2

The background and introduction to C/VM2 is detailed further in 2.7.2. In this chapter, more practical experience with using the verification method is summarized, based on data from literature review and interviews.

An insight into the practical experience from using C/VM2 over a period of 4 years by James [31] was presented at the "SFPE 12th Conference on Performance-Based Codes and Fire Safety Design Methods" in 2016. The following is a summary of the challenges and benefits presented.

The main drawbacks were considered to be:

- An immediate problem related to alterations of existing buildings surfaced right after the introduction of the FSVM, as there was a requirement that if an acceptable solution design was chosen, the acceptable solution had to comply fully. Any deviation from it would require the use of either the FSVM or treat the design as an alternative solution. As existing buildings would often have deviations from the current acceptable solutions, this resulted in many of these buildings requiring verification, a work load that was not able to be met by the fire safety engineer work force at the time.

- FSVMs may lead to a stifle in design creativity

- The FSVM can lead to over design and under design, for example small rooms are not able to support the large fires proposed in the method, and there are options for reducing the fire size (other than implementing fire safety measures like extinguishment systems).

- There are situations where the FSVM is not able to provide sufficient guidance, like vertical smoke spread throughout a high-rise building. This is a problem when the verification method is a complete path of compliance.

- The use of alternative solutions has almost been made non-existent due to a more perceived complex and uncertain verification process. This can be considered to limit creativity and design freedom.

While the main benefits were:

- Reduced the use of "sound engineering judgement", a practice that was used to try to estimate the performance or an outcome of a design given a fire scenario without doing any actual verification through engineering analysis.

- Provided a consistent framework for analysis, and in turn has provided consistency for comparing design for similar buildings, eventually leading to a sense of common knowledge on how buildings would perform when tested with the design fire scenarios in the FSVM.

- Increased certainty in the design process and reduced the amount of disagreements with respect to input data. This time saving has then been used to improve the design process.

Of special note in the paper is a mention that the ministry of business, innovation and employment (MBIE) are in the process of undertaking a complete review of C/VM2. One of the views is that the FSVM should have been implemented more as a guidance document instead of a verification method considered a path of compliance.

James concludes with a statement, p. "*the verification method is considered a diamond in the rough*".

While the process of going through the implementation of the verification method seems to have been challenging for New Zealand, the effort seems to be considered to have been worth the trouble at this point by some of the practitioners. The quality in the verification has been raised, and the verification method has created a benchmark for what can be considered good design.

Duncan provided an overview of the evolution of the New Zealand building code at the "SFPE 12th Conference on Performance-Based Codes and Fire Safety Design Methods" in May 2018 [29]. p.41 provides the following summary of the pros and cons based on multiple years of experience with C/VM2:

Pros were considered to be:

"

• *Prescribed Method of Demonstrating Performance*

• *Standardisation of design*

• *Removal of approvals risk and regulatory uncertainty*

• *Aligned to the quantification at code level – standardisation*

While cons were:

• *Intended to be used as a framework, however taken as absolute*

• *Limitations for Tall Buildings and buildings with staged evacuation*

• *Not a comprehensive review of all performance requirements without the need for consultation and the fire engineering brief process.* "

The pros are what one would expect a FSVM would be able to do, so not very surprising. It is however good to see that it brought the level of standardization that was sought. The cons are more surprising, as these are effects that probably were more unforeseen. The example with limitations for tall buildings and staged evacuation is a good example of how challenging it is to keep a FSVM up-to-date as building designs evolve.

Because of these experiences, C/VM2 might be reorganized in the near future, [29] p.42 provides the following outline of possible approaches for changing it:

C/VM2 Compliance Pathway Options

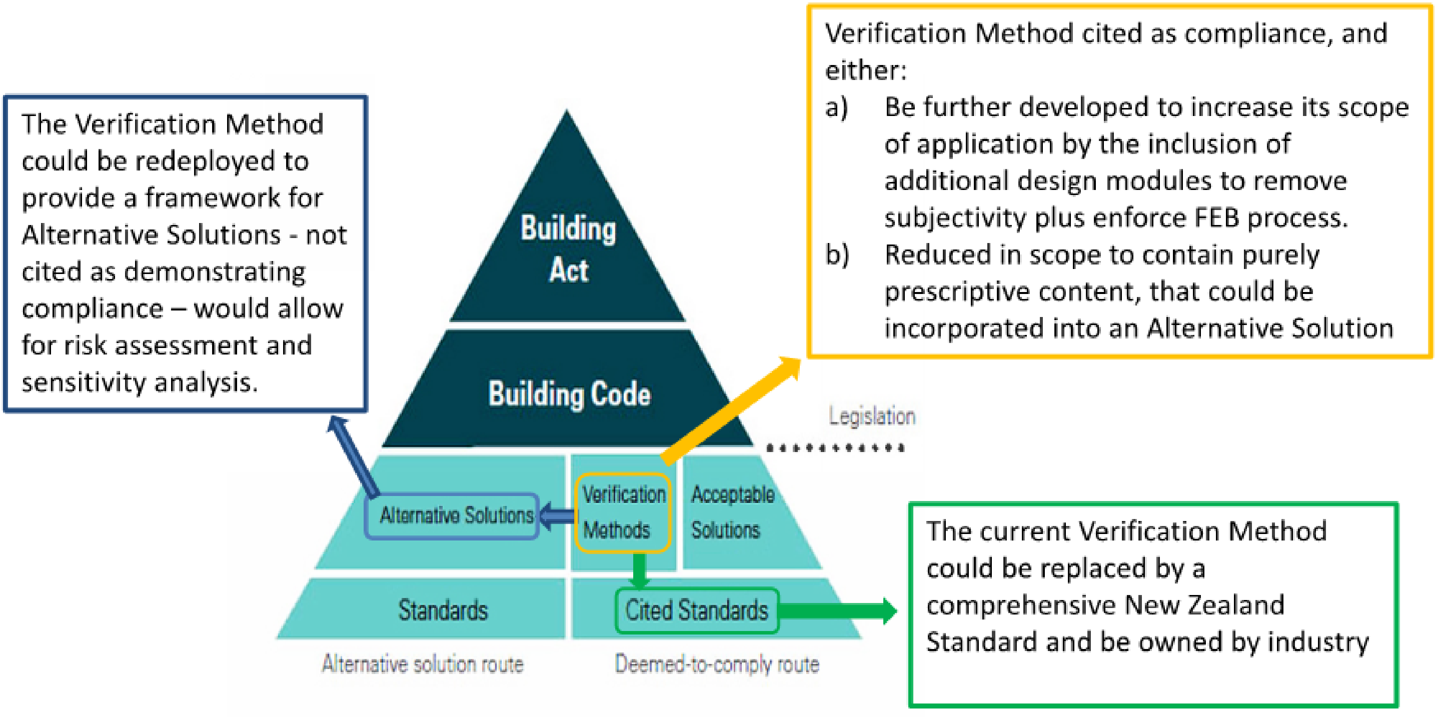

Figure 5-1 Possible options for changing C/VM2

As illustrated, four potential paths of change are considered:

1) Remove C/VM2 from the deemed-to-comply/prescriptive path and method of compliance, and redeploy it as a framework for alternative solutions (this was how it was originally intended to work)

2) Keep C/VM2 as a compliance path, but:

A) develop the scope further to fix issues relating to "missing content"

B) reduce the scope to purely prescriptive content, allowing it to be viable for alternative solutions as well (in effect move more towards the approach used by the Swedish BBRAD)

3) Replace C/VM2 with a standard owned by the industry

What new path New Zealand chooses to follow for C/VM2 remains to be seen.

5.4.1. Interviews with practitioners of PBFSD

Four long-distance interviews (questionnaires) with fire safety engineers experienced with the practice of PBFSD in New Zealand and the use of C/VM2 have been conducted, see 10.7-10.10 for written summaries. The purpose of these interviews was to get an impression on the practice of PBFSD in New Zealand before and after the introduction of C/VM2, and their experience with practical use of the verification method. A compressed summary of their responses is given below.

- On the topic of how the option of prescriptive and analytical design approaches are considered, there is a consensus that both approaches are necessary, as prescriptive design can be used for simpler buildings and performance-based design for the more complex which falls outside the acceptable solutions. It is also pointed out that using the acceptable solutions should not require engineers, and that technicians should be sufficient to use.

- The current trend in the building regulation seems to be to provide more specification and streamlining certain areas in the acceptable solutions and the C/VM2. At an overall level, these documents cover the main aspects of fire safety. There are however, large gaps in certain areas, like for example specification of construction details in interfaces between walls and ceilings, and external cladding, where either acceptable solutions or C/VM2 are not able to provide sufficient guidance, and therefore left entirely to the interpretation of the fire safety engineer. There are also multiple examples of where the documents are poorly worded or poorly compiled.

- There is a minimum level of quality in verification enforced in New Zealand due to AHJ requiring independent peer review when using C/VM2 or alternative solutions. The AHJ are also reasonably competent, as they usually have a background in fire safety engineering. The fire services (Fire and Emergency New Zealand) also have their own design review team. The level of quality in verification documentation prior to the introduction of C/VM2 could be considered weaker, with a less defined structure and limited analysis. This has been improved with the more robust documentation requirements in the C/VM2. To further improve the quality, documentation requirements for fire modelling should be included as well, as different designers provide different ways of presenting results in the verification documentation.

  The design peer review process however can be time-consuming and requires additional project resources. In addition, it is lacking a consistent high-level. This could be improved by having a common template for design review, for example for fire modelling input.

- C/VM2 is voluntary to use, as it is considered a part of the acceptable solutions (prescriptive design). Alternative solutions may be used in lieu of the acceptable solutions. Alternative solutions have however become very rare, and usually employ the same structure that is defined in C/VM2 for verification documentation.

- Since C/VM2 is written with the aim of being a "full scope of compliance document" the verification method is generally used when performance-based design is needed. There are however exceptions to that it is not able to cover, and for those exceptions alternative solutions must be used.

- Whether C/VM2 has led to an increase in PBFSD depends on the definition, since C/VM2 is considered a part of the prescriptive path. Any deviation from the acceptable solutions require the use of C/VM2 unless alternative solution is used. Before C/VM2 alternative solutions were used to address limited deviations from the acceptable solutions. That practice has likely reduced and is now covered by C/VM2 instead. Doing full performance-based design of an entire building has however likely increased because of the introduction of the C/VM2, since the method was created with this in mind.

- The benefit of the C/VM2 is that there is no need to verify sources or references. The drawback is that it is still very prescriptive, using it still leads to delays in the peer review process and it is restricted to charted engineers. The fact that it is not applicable for all buildings is also a problem.

  C/VM2 also has a lack of minimum levels for certain constructions, such as for door widths, ceiling heights, door hardware etc. These performances must then be defined using other sources.

- There is a general agreement that the overall level of quality in verification has increased since the introduction of C/VM2 and the verification method is implemented correctly in the building regulation. There is no desire to remove it, but there are certainly areas that can be changed and improved, like adding clarifications and a template or check-list for design review.

  One specific change that should be considered is that the method should not replace all aspects of the acceptable solutions design, as it is not able to provide all the detailed design performances by itself. Converting the verification method into something similar of a "fire safety engineering guideline" instead could remedy this.

- There is a general impression that the building authorities are not able to keep up with updating the verification method as new experience are acquired through time, and that they depended on feedback form peer reviewers and fire service reviewers for the technical aspects of it. C/VM2 is not updated on the same frequency as the acceptable solutions, this creates gaps and loopholes in a C/VM2 design compared to an acceptable solutions design. This is a problem when C/VM2 is considered to be a full scope of compliance FSVM.

5.5. Discussion

Introducing a FSVM that is considered a path of compliance in Norway will have a major impact on the practice of PBFSD and is a decision that should not be taken lightly. Evidence of issues in quality linked to variability in verification between different building designs suggest however that there is a need for additional guidance and specification of the practice of PBFSD. Sweden and New Zealand have experienced much of the same symptoms that have been observed in verification through many years in Norway and are still very much present in the current practice. These countries made the decision that a FSVM would be worth pursuing. The question of whether Norway should do the same is therefore relevant. The cumulative experience from the practical use of FSVM since their introduction in 2012 seems to indicate that they can, at least in part, fulfill some of the goals they set out to achieve. There is a general impression of a more level playing field, and a sense of minimum acceptable quality level that the verification should deliver. This simplifies the job of design review and acceptance from authorities having jurisdiction. Even when deviating from the verification methods, the defined structure and methods given in these verification methods are often reused in the alternative approach, so quality is to certain degree maintained in this verification as well. This seems to underscore that a verification method definitively can be used to limit the large range of variability seen in verification and be used to better define a minimum acceptable fire safety level and thus reign in some of the potential misuse and abuse of PBFSD that could lead to unsafe design.

The drawbacks of a FSVM should however not be understated. The most critical drawback seems to be that it is counter-productive to the critical process of building-specific risk evaluation. The core of principle of PBFSD is that the fire safety design is better tailored for the specific building in question, and this is in large part based on evaluating and accounting for the actual risk expected in that specific building. If this important step is ignored when using a "cook book" approach in a FSVM, there is a risk of both under- and over dimensioning, depending on the scope and amount of specification given in the method.

How such a method should be created and implemented are therefore important questions which must be answered before considering implementing it. The most fundamental consideration seems to be to what extent the FSVM should cover in the building code. The following terms are introduced for the two main categories of FSVM that have been identified:

I. Full scope of compliance FSVM

II. Limited scope of compliance FSVM

The difference between these two lies in the scope of what they are intended to cover. The full scope of compliance approach is comparable to what is currently used by New Zealand through C/VM2. The FSVM is intended to cover all the building code requirements related to fire safety. All parts of the verification method must be followed if a decision to use it is made, and by following the method the building design will be in compliance with the building code. In effect, a full scope of compliance FSVM is intended to be a fully independent design approach, comparable to the acceptable solutions. This approach will clearly define the expectation of verification when a design outside the scope of the acceptable solutions is desired. It will allow the building authorities effective control over the acceptable fire safety level in designs where fire safety engineering is used as a tool to verify the fire safety level in the building design instead of the acceptable solutions. There is however a critical responsibility to keep such a method relevant and up-to-date, as it would require the same follow-up and care as the acceptable solutions. Creating and supporting a verification method that is considered a full scope of compliance for the building code will thus likely place a substantial resource burden on the building authorities.

A limited scope of compliance approach is more comparable to what Sweden has done with BBRAD. Only the specific areas identified in the FSVM are considered covered. For areas not covered by the verification method, the designer would need to use prescriptive/acceptable solutions or do a full analytical verification without the support of the FSVM.

Based on the accumulated experiences with use of C/VM2 through multiple years and the fact that they are now considering a revised usage of it due to issues, a full scope of compliance verification method is not recommended by the author. The initial efforts and troubles of creating a such a verification method in Australia also underscores that this approach is a large undertaking, especially when the acceptable fire safety level is only implicitly defined through the collective pre-accepted performances such as in Norway. The Norwegian building authority has also communicated that this is something they currently do not want to do, they are more interested and willing to pursue such guidance through collaboration efforts, such as inter-Nordic standardization (see Ch 10.3). A justification for a full scope of compliance verification method could be made if there was unquestionable evidence that performance-based design buildings had a fire safety level that was consistently lower compared to buildings designed with the pre-accepted performances. The verification method would then be able to reign in such malpractice very quickly and effectively. Currently in Norway, while there are indicators that point to challenges with verification and documentation in PBFSD, there are however no large warning lights that the design approach is producing buildings that are more unsafe than that designed with the pre-accepted performances. An approach with a full scope of compliance FSVM is therefore not considered to be needed.

A limited scope of compliance FSVM may however be a reasonable pursuit. Such an approach bypasses the main issue of having building authorities to take responsibility of creating a verification method that must cover every building code requirement related to fire safety. The use of the FSVM may be limited to just certain areas or conditions of fire safety in a building, and the applicability of the method could ultimately have to be considered by the designer. This approach seems to strike a reasonable balance between the involvement and burden placed on the building authorities and provides a common platform of verification practice for designers that does not strongly limit the freedom of design. A limited scope of compliance FSVM is therefore considered to be a potential effective approach.

The fundamental issue with FSVMs identified in the beginning of this chapter however would still be present in both approaches. Identifying the actual fire risk in the building design should be a mandatory process in any PBFSD building. A potential more optimal path could therefore be to have a recognized and unified fire safety engineering guidance document instead of a FSVM. The guidance document must however also be able to suggest suitable engineering methods, design scenarios and relevant input data linked to specific occupancies for it to be of practical use This could be owned and maintained by a third party (or multiple parties) in the fire safety community. The previously mentioned inter-Nordic standardization committee seems to be a natural candidate for such an effort. An argument can be made that this already to some extent has started through the creation of INSTA 950:2014. While it is recognized that this standard does provide some guidance, it is still considered lacking. A few examples of this are:

-Multiple t^2 fire growth rates are given, but they do not state what typical fire or building they are representative for.

-Soot yields are defined for wood and plastics, but no guidance is given to what is considered a reasonable mix between the two. No guidance on what mix should be used in different occupancies.

- Maximum fire sizes are defined by amount of available ventilation. Such fires are however often not suitable for life safety verifications, and more challenging to estimate with reasonable accuracy in available engineering tools due to the increased complexity of combustion in under-ventilated fires.

- Some acceptance criteria for life safety are given, but accumulated toxicity due to exposure of smoke during evacuation is accounted for. There is also little guidance on how to best estimate these metrics, which could lead to very different conclusions on when acceptance criteria for life safety is met in the design.

Providing additional guidance to this standard would go a long way to create the practical guidance that is needed. As such, there is necessarily not a need to create an entirely new and separate guidance document. Existing standards can be amended or supplied to provide what is needed. As an example of this, INSTA 950 has a national appendix where the involved countries may remove or add to the suggested values given by the standard. In the Norwegian appendix no such changes are however given.

Norway also has a national standard for fire risk analysis through NS 3901. The current version, NS3901:2012, provides no practical guidance on verification or engineering methods however. It provides a general structure to create a documentation for a fire risk analysis and gives some recommendations to what design fire scenarios should be considered. The previous version of NS3901, NS3901:1998, in comparison had a large accompanying guidance part that provided extensive guidance on verification. No such guidance part has however yet been made for the newer 2012 version. If a similar guidance part was to be created for the 2012-version, this could also fulfill the required need.

If the path of a fire safety engineering guidance document is pursued, it is still recommended that the building authorities be part of the editorial team of such a document, at least in an observatory capacity. One of the big benefits of verification methods administered by the building authorities is their involvement lends to the credibility of the process, and that there is a sense of adequate and defined level of reasonable quality when it is used. This notion could also be achieved with a guidance document, if the building authorities involve themselves to a reasonable extent. It is difficult to avoid that that such a guidance document does not become the de facto recognized standard for fire safety engineering, as it may be argued that this is implicitly one the goals that are pursued. Measures should however be taken to avoid the problem where it becomes the minimum acceptable standard, and where it is next to practical impossible to use other alternatives. This must be specified in the document. It should be a guidance document that is voluntarily to use, created in such a fashion that it promotes the use of analytical design as long as it can be deemed applicable by the designer. The idea would then be to reward the designer by supplying a "fast-lane" for analytical design that does not require extensive research into the literature to acquire suitable engineering methods and relevant input data and reduces disagreements with 3rd party design review

6.Discussion

This chapter contains additional discussion based on findings in the theoretical background study that were not deemed part of the topics covered in chapter 4 and 5. Discussion on the topics related to chapter 4 and 5 are included at the end the subchapter in those chapters in order to ensure discussion followed the analysis and results.

6.1.The acceptable fire safety level in the Norwegian building code

How the acceptable fire safety level should be defined in a performance-based building code using performances derived from the functional requirements is illustrated with the 8-tier IRCC model in chapter 2.1. How this was defined in "TEK97" with "pre-accepted performances" based on prescriptive requirements from a previous building code is explained in chapter 2.4. This approach remains much the same with the current version of the building code "TEK17". There is still a lack of operative requirements with fundamental performance metrics linked to the functional requirements.

A comparison of the approach used in the Norwegian building code with the 8-tier IRCC model (see Figure 2-2 and Figure 2-3) reveals some noticeable differences. It is however important to remember that there is a time gap between the two models, as the current Norwegian regulation system was put into effect in 1997, while the 8-tier IRCC was originally developed in 1998, and then modified by Meacham in the following years. Some differences must therefore be expected as the IRCC model for a performance-based building code was refined further after Norway introduced "TEK97". The comparison is included in this discussion to show that there might still be room for additional optimization in the Norwegian building code.

Compared to the previous NKB model, the 8-tier IRCC model split the performances from the operative requirements. This is important to point out considering previous discussion about performance metrics typically located under operative requirements. Performances are now on separate tiers below the operative requirements tier. In this regard, the operative requirements should be interpreted as requirements that interprets and the details the functional requirements further, mainly qualitative. Performances are thus given on the subsequent tiers. The functional requirements in the Norwegian building code are considered to fulfill tier 1 and 2 to a reasonably well degree. The pre-accepted performances however try to fulfill tier 3,4, 5 and 7A in a "single package" which makes the structure and approach used by the Norwegian building code a bit difficult to understand when compared against the 8-tier model IRCC. Tier 6[2] is also considered currently lacking, at least when considering that the tier seems to indicate fundamental performance criteria, and not the large collection of specific performances and technical solutions given by the pre-accepted performances. Tier 7B is also lacking as there are no currently recognized FSVMs created by the building authorities[2].

The Norwegian building regulation does have something that is referred to as "pre-accepted solutions" as well. These are however mainly technical solutions/provisions on how to construct elements (such as walls and floors) with adequate fire resistance. These are typically given by third parties but are acceptable to use without the need for new or additional documentation. These "pre-accepted solutions" may be considered to fulfill parts of tier 7, but as illustrated in the example of the IRCC model in Figure 2-2 tier 7 typically references acceptable solutions and performance-based solutions. These are not considered to be the equal of the Norwegian "pre-accepted solutions".

[2] The building authorities published a guidance document for the design of smoke ventilation systems, "Melding HO-3/2000 Røykventilasjon. Temaveiledning. " in 2000, which would qualify as a verification method and even contained performance metrics and acceptance criteria for life and property safety. That guidance document is however now considered outdated and may only be used in an informative way.

It is important to point out that the Norwegian building code tries to define the performance tier in the IRCC model through the "pre-accepted performances". These however seem more comparable to what are referred to as acceptable solutions in the IRCC model, especially when considering that these performances for the most part are based on building requirements from a previous prescriptive building code (which are typically also recognized as acceptable solutions). This is also backed up by how the IRCC model defines acceptable solutions and how countries such as New Zealand defines the functional requirements, performances and acceptable solutions. IRCC/Meacham [6], p.26 defines acceptable solutions as follows:

"Acceptable Solution (Approved Document, Deemed-to-Comply): A solution that has been determined by the authority having jurisdiction (AHJ) to comply with the societal goals, functional objectives and performance requirements stated within a performance-based regulation. These may be specific prescribed/specified solutions, provided in or referenced by the regulation, or performance-based solutions derived using verification methods provided in or referenced by the regulation."

In New Zealand the acceptable solutions are typically very identical to what you find in the Norwegian pre-accepted performances, example below given for intermediate floors, from [62] C/AS3, p. 36:

Acceptable Solution C/AS3

Intermediate floors

3.4.3 On *intermediate floors* (see Figure 3.8) the *open path* length, for compliance with Table 3.2, shall be taken as 1.5 times the measured length. However, the measured length as determined in Paragraph 3.4.2 c) may be used if the *intermediate floor* is a *smokecell* and an *escape route* is available from the *intermediate floor* without passing through any lower space in the same *firecell*.

Comment:
People on an *intermediate floor* may be exposed to smoke at an earlier stage than people on a full floor. Reduced *open path travel distances* mean reduced exposure time to smoke from the *fire*.

Stairs and ladders

3.4.4 Stairs and ladders occurring in an *open path* (see Figure 3.9) shall have their *open path* length taken as:

a) **For straight and curved stairs**: the plan length measured on the stair centreline multiplied by 1.2, plus the plan length of each landing

b) **For spiral stairs**: twice the vertical height, and

c) **For ladders**: three times the vertical height.

Comment:
It is acceptable to use two spiral stairs as part of the *escape routes* from such situations as an *intermediate floor* down to the *firecell* floor. Likewise, where ladders are permitted to serve such situations as the fly-tower of a *theatre*, two ladders may be used as the *escape routes*.

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3.4.6 THIS PARAGRAPH DELIBERATELY LEFT BLANK

Figure 3.8 Intermediate floor open path length
Paragraph 3.4.3

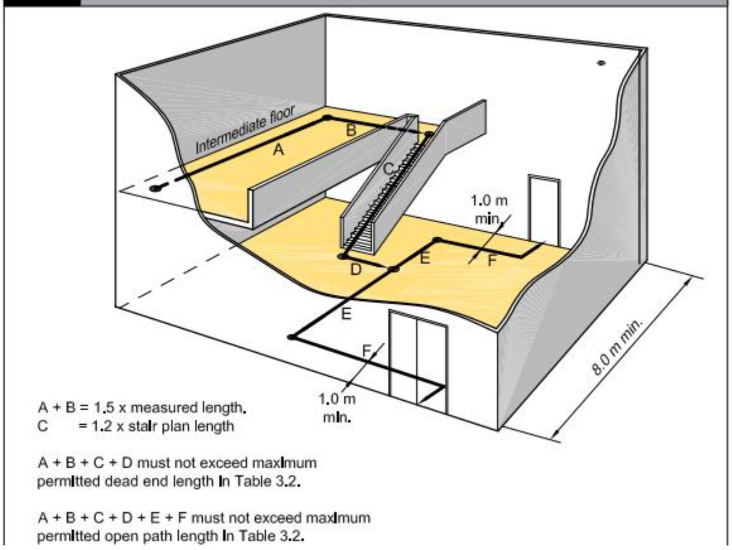

Figure 6-1 Example of acceptable solution in New Zealand C/AS3

The New Zealand performances are however given in the building code as operative mandatory requirements, not by the acceptable solutions, as shown in the figures below, [34] C.4:

FUNCTIONAL REQUIREMENT

C4.1 *Buildings* must be provided with:

(a) effective means of giving warning of *fire*, and

(b) visibility in *escape routes* complying with clause F6.

C4.2 *Buildings* must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a *place of safety* and that those occupants will not suffer injury or illness as a result.

Figure 6-3 Functional requirement in the New Zealand Building code

PERFORMANCE

C4.3 The *evacuation time* must allow occupants of a building to move to a *place of safety* in the event of a fire so that occupants are not exposed to any of the following:

(a) a *fractional effective dose* of carbon monoxide greater than 0.3:

(b) a *fractional effective dose* of thermal effects greater than 0.3:

(c) conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m^2 where visibility may fall to 5 m.

C4.4 Clause C4.3(b) and (c) do not apply where it is not possible to expose more than 1 000 occupants in a *firecell* protected with an automatic *fire* sprinkler system.

C4.5 Means of escape to a *place of safety* in *buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety systems*.

Figure 6-2 Performances in the New Zealand Building code

From this it may be surmised that acceptable solutions in the IRCC model are not considered to be at the "performance level", or define the performance requirements, they are pre-approved solutions used to fulfill the performances. In the Norwegian building code however, the "pre-accepted performances" do both the task of the performance-tier and the acceptable solutions-tier. The goal behind this approach seems to have been to provide some level of performance without creating new performances derived from the functional requirements and thus running the risk of changing the current acceptable fire safety level. This approach does not however seem to follow the structure suggested by the IRCC model where the performances are derived from the functional and operative requirements and are considered separate from the acceptable solutions. This makes the practice of PBFSD and use of alternative design more difficult, because the fire safety level is unclearly and only implicitly defined.

There is an option where the building designer and relevant stakeholders can create "alternative" performances" however. Since performances have been shown to be what should define the acceptable fire safety level, this is comparable to allow the designer to set the acceptable fire safety level by themselves. This is considerably challenging task, and sensitive to subjective interpretation. The argument for considering this acceptable, is that this approach requires a high level of competence. Currently any fire safety design that does not use the pre-accepted performances requires an education at civil engineering/MSc level and a minimum of 8 years of relevant experience in Norway as given by the regulations relating to building applications "SAK10" [63]. While putting the role responsibility for defining the acceptable fire safety level through alternative performances on a competent building designer in theory may sound reasonable, practical experiences show potential issues related to a high variability between different design. The reasons for this can be summarized by the fact that there are different possible performance metrics, varying acceptance criteria linked to those metrics, and a large range of different engineering methods used to estimate those metrics. How the engineering methods are applied by each user can even have a great impact on the results, and thus subsequently influence whether a specific design is considered to comply with a defined fire safety level.

An alternative to this system would be to have the building code or equivalent recognized document (such as a FSVM) to able to define the acceptable fire safety level independently. This is comparable to what is suggested previously in the IRCC model. To be able to achieve this there is a need for well-defined functional requirements and sufficiently quantified operative requirements. These operative requirements would typically need to further define quantitative performance metrics and recognized acceptance criteria, which would then be used as means to measure if compliance is met when doing verification of alternative solutions.

Such a system would arguably be in a good position to clearly define the acceptable fire safety level without requiring support and use of the pre-accepted performances. The major benefits would be to "even the playing field", by defining a common fire safety level through relevant performance metrics and recognized engineering methods that would be used by all designers so that the practice of verification and expected minimum level of quality between different building designs would be recognizable.

The primary concern with this approach is that building code developers would be faced with the same challenge as the building designers are faced with when trying to define the acceptable fire safety level. Covering all the different available performance metrics, their respective acceptance criteria and wide range of possible engineering methods would be a very large and challenging undertaking. To realistically cope with this, certain choices would have to be done which would limit the number of possible ways to verify an alternative solution, and thus also reduce some of the flexibility and design freedom given in the performance-based design approach. This consequence is likely not avoidable, but the impact may be reduced by making sure that the most used and recognized methods in the fire safety community are supported. It would also be possible to allow for the option to use other performance metrics, acceptance criteria and engineering methods not listed by the building code. It could be emphasized that this would require the designer to provide additional documentation that supports the use of these alternatives. This would promote a fast-track if a recognized metric and an engineering method was chosen, but not prevent use of others if they may be properly documented.

6.2. The relationship between the Norwegian building code and the "guidance to the building code" document

Understanding the full scope and intent of the various building code requirements for fire safety does not seem to be practically possible without the input from the accompanying guidance text. This is however not uncommon, as providing the full explanatory background and intent of a requirement in the actual building code requirement would quickly make the building code difficult and complex to use. The accompanying guidance text to the building code requirements is however located in the guidance document. This is the same document that also contains the pre-accepted performances. This document is not considered a legally binding document for building design, only the building code itself has this status. This creates a potential issue when the accompanying guidance text not only provides additional details on the background and intent on the building code requirement, but also defines further what should be considered in a verification. The guidance text for the building code requirements and the guidance text for the pre-accepted performances are even sometimes intermixed in the same paragraph, complicating things even further. Whether the interpretation of the building code requirement in the guidance text is legally binding or not thus becomes unclear.

The following is an example of this for §11-6 "Measures to prevent the spread of fire between construction works", reproduced from [38] and [41]:

Building code requirement:

"(1) *Fires shall be prevented from spreading between construction works:*
a) in order to maintain the safety of people and domestic animals; and
b) so that a fire does not cause unreasonably large financial losses or societal consequences. "

Accompanying guidance text:

"The first section describes the intention with the requirements in §11-6.
Fire spread between construction works can be prevented by:

a. establish satisfactory distance between the construction works so that heat flux, flame impingement and falling burning construction works do not ignite the neighboring construction works

b. use fire-rated separating construction works with adequate fire resistance, load-bearing capacity and stability"

This example raises some potential questions:

- Is there a legally binding requirement for verification of fire spread linked to heat flux, flame impingement and falling burning constructions when using safety distance less than 8 m as a design option?

- Are the two design options of safety distance and fire-rated separating construction works the only options that may be (legally) used to prevent fire spread between construction works?

The proposed solution for this issue is to include all guidance text related to the building code requirements in the actual building code. To prevent cluttering of the building code requirements it is suggested to include this guidance text as an appendix, which could easily be linked to the relevant requirements. This would remove any confusion as to whether the interpretation in the guidance text would be considered legally binding, as it would be in the building code. It also seems that some of the guidance text to the building code requirement may even considered to be operative requirements. Converting relevant guidance text operative requirements would strengthen the intent and performance of the functional requirement even further.

7.Conclusion

The goal of this thesis was to investigate the status of PBFSD for buildings in Norway. The status seems to be that the practice is working, but there are issues in the verification process that lead to a high degree of variability in the level of quality. These are typically questions related to what method/tool to use, what input data to use, what is the appropriate fire safety level and what is considered "good enough" documentation. These issues are not specific for just Norway, similar issues are also seen in other countries where PBFSD is practiced as well.

The structure of the Norwegian building regulation model and certain section for fire safety in the Norwegian performance-based building code has been analyzed. The following suggestions for improvements are suggested:

- Harmonize the current Norwegian building regulation system more towards what is proposed in the 8-tier IRCC model. Currently it would seem that the Norwegian building code is using acceptable solutions (referred to as "pre-accepted performances") from a previous building code to define the performances in the building code. This defines the acceptable fire safety level implicitly and is not considered ideal for the application of PBFSD. Performances should be derived from fundamental principles from the functional and operative requirements, and where possible, give quantified metrics.

- Guidance related to the understanding of functional and operative requirements in the building code, should be in the building code itself or in an equivalent recognized document.

- The functional requirements in §11-8, §11-13 and §11-4 should be rewritten to avoid referring to specific use of fire safety measures. Currently they refer to use of fire compartments, and that exits from fire compartments must lead to escape routes that also are separate fire compartments. This is considered to be limiting design freedom and practice of PBFSD.

- The definition of fire and risk classes in §11-2 and §11-3 may be improved by expanding on the current system and provide more practical examples of known occupancies. Implementing additional sub classes for the risk classes, and more quantified risk profiles for the fire classes will create a classification system that is better able to tailor the necessary safety to the actual risk.

- The term "sufficient time needed for rescue" in §11-4 should be better defined to be able to account for it in verification. A suggested solution is to estimate time needed for rescue as a safety factor based on time required for escape. Additional engineering methods for verification of the complete fire duration are also needed. It is suggested to investigate creating a new guidance document for this.

- Adding quantitative performance requirements to §11-6 is considered possible, as the main mechanisms of fire spread between buildings are known. It is however necessary to provide more detail on to what extent fire spread due to embers/burning construction works transported by wind must be accounted for.

- The functional requirements for relating to escape and rescue in §11-11 support PBFSD reasonably well. The variability in verification may however be improved by defining performance requirements and acceptance criteria in the building code, or a recognized guidance document/fire safety verification method. This would also help to better define what is the acceptable fire safety level with respect to life safety in the building code.

The question of whether Norway should pursue a FSVM in order to improve quality in verification in PBFSD has also investigated. The following conclusion is given:

- A full scope of compliance FSVM such as the current New Zealand C/VM2 is not recommended due to the complexity and large resources needed to create and maintain such a method.

- A limited scope of compliance FSVM such as the current Swedish BBRAD may be a reasonable approach to fix many of the issues related the variability in verification, and to provide a fast-track for application of PBFSD without requiring extensive resources.

- The optimal approach however is deemed to be a recognized "fire safety engineering guideline" created and maintained by a third party such as the fire safety engineering community. It is encouraged to pursue this as a collaboration effort, like the Inter-Nordic standardization committee (INSTA). This also seems to harmonize well with the current direction of the Norwegian building authorities.

8. Further work

Two major areas of PBFSD, the performance-based building code and the use of fire safety verification methods, were the focus of this thesis. There are however other areas that can have a big impact on the practice as well. Education, certification, quality assurance and design review are important elements that can have a big influence on the quality of the practice. It is recommended to also evaluate these aspects as well when considering how to best improve PBFSD.

Benefits and drawbacks have been weighed on the suggested improvements to the fire safety section of the building code. Changing building code requirements are however a complicated procedure, and changes should be thoroughly considered by multiple parties before implemented. As such, further review and a proper consequence analysis of the suggested changes are necessary steps to fully investigate the impact they may have.

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10. Appendices

10.1. Swedish building code Section 5-3 Ability to escape in case of fire

The following requirements for the ability to escape a fire is given in the Swedish building code, reproduced from [43], p.

" 5:3 Ability to escape in case of fire

5:31 General

Buildings shall be designed to ensure that there is an adequate time for evacuation during a fire. Adequate time for evacuation means that people who evacuate are not exposed to falling structural elements, high temperatures, high levels of heat radiation, toxic gases or reduced visibility that might impede evacuation to a safe location with sufficient certainty. (BFS 2011:26).

5:32 Access to escape route

5:321 General

Unless otherwise specified in Section 5:322, spaces where people are present other than occasionally shall be designed with access to at least two independent escape routes. If the dwelling or premises have more than one floor, at least one escape route shall be provided on each floor. However, a small mezzanine floor may be designed without an exit to an escape route from the mezzanine floor provided that evacuation can still take place in a satisfactory manner. (BFS 2011:26)

In a building of more than eight but not more than sixteen storeys, each dwelling and premises shall be designed to have access to at least one Tr2 stairway. In a building with more than sixteen storeys, each dwelling and premises shall be designed to have access to at least one Tr1 stairway. (BFS 2011:26).

5:322 Access to only one escape route

Doors directly to a secure location may be the only escape route from spaces on the ground floor for 1. spaces in occupancy class 1 if the means to escape may be considered satisfactory and where only a limited number of people are expected to be present. 2. smaller premises and dwellings in occupancy classes 2A, 3 4 and 5B, that are easily surveyable where a limited number of people are expected to be present. (BFS 2014:3).

If the conditions for satisfactory evacuation are met, a stairway Tr1 may be the only escape route from dwellings in occupancy class 3 and from premises in occupancy class 1. If the conditions for satisfactory evacuation are in place, stairway Tr2 must be the only escape route in the premises in occupancy class 1 in buildings with a maximum of eight storeys and from dwellings in occupancy class 3 in buildings with a maximum of sixteen storeys. (BFS 2011:26).

5:3221 Ability to escape from spaces where people are only temporarily present

Spaces where people are only temporarily present shall be designed with access to at least one escape route. (BFS 2014:3).

5:323 Escape through windows

Windows for escape shall be designed to ensure that the escape can be conducted in a satisfactory manner. (BFS 2011:26).

In spaces in occupancy class 1, schools in occupancy class 2A and dwellings in occupancy class 3, one of the escape routes may be replaced by access to a window. The window's lower edge must be positioned no higher than 2.0 meters above the ground outside and the opportunity to escape must otherwise be provided in a satisfactory manner. Evacuation from dwellings in occupancy class 3 in buildings Br2 and Br3 may also be in accordance with Section 5:353. (BFS 2011:26).

Escape from windows with the help of the rescue services may be taken into account as one of the escape routes for buildings in occupancy classes 1 or 3, provided that no more than 15 people evacuate this way from the fire compartment. This requires that the rescue services have a sufficiently fast response time and capacity. Parking bays designed for the fire service equipment shall be provided. (BFS 2011:26).

5:33 Design of escape routes

5:332 Walking distances in an escape route

Escape routes shall be designed to ensure that the risk of people being trapped by fire and smoke is restricted. (BFS 2011:26).

5:334 Design of escape routes

In premises designed for a large number of people, measures shall be taken to avoid a high occupant load at the exit and long waiting times. (BFS 2011:26).

5:335 Doors

Doors to be used for evacuation shall open outwards in the escape direction and be readily identifiable as exits. Inward opening doors may only be used if queues are not expected to occur in front of the door. Other variations of doors may be used if they can provide an equivalent level of safety as sidehung doors. (BFS 2011:26)

Doors to be used for evacuation shall be easy to open and pass through. Exemptions are allowed for spaces in occupancy class 5D. (BFS 2011:26).

Doors to be used for evacuation that can only be opened with a key, may be used in spaces in occupancy classes 1 and 3 if the doors serve a small number of people likely to have access to the key. (BFS 2011:26).

5:336 Evacuation place

Public buildings that shall be accessible and usable in accordance with Section 3:1 for people with limited mobility or orientation capacity shall be provided with at least two independent evacuation places. If the premises have more than one floor, at least one evacuation site shall be provided on each floor. If the premises specified in Section 5:322 only have a single escape route, the premises may be designed with only one evacuation site. The evacuation site shall be located in an adjacent fire compartment and be adjacent to, or in, the escape route. An evacuation site shall accommodate at least one small outdoor wheelchair. An escape route that is accessible and usable, and that leads horizontally to a secure location does not require any evacuation place. Public buildings that are fitted with an automatic fire suppression system do not require an evacuation place. Additional requirements are specified in Section 5:352. (BFS 2014:3).

5:34 Fire safety installations

5:341 Exit signs

Exit signs refer to signs or similar that in the event of an evacuation provide guidance to ensure the evacuation is not hindered by difficulty navigating the building. Exit signs shall be installed in areas that are difficult to navigate. Requirements exit signs are also contained in Sections 5:351, 5:352, 5:354 and 5:357. Where there are requirements for exit signs, lighting or backlighting of the exit signs shall have a guaranteed power supply equivalent to the emergency lighting specified in Section 5:343. For those areas where requirements for exit signs apply, the signs or equivalent shall be fitted adjacent to the doors and windows that are intended for evacuation. Signs shall be designed as green discs with clear white symbols and shall be easily noticed. (BFS 2011:26).

5:342 General lighting

Escape routes shall be provided with general lighting that work with satisfactory functionality. (BFS 2011:26).

5:343 Emergency lighting

The building or part of the building where emergency lighting is stipulated, the lighting shall enable evacuation even in the event of power outages. In case of fire, the emergency lighting shall fulfil its role in the parts of the building that are not in the immediate vicinity of the fire. In the event of power outages the emergency lighting shall provide the intended illumination for not less than 60 minutes. Emergency lighting shall also be provided in all stairways which are used as escape routes in buildings of more than eight storeys. Requirements for emergency lighting are also contained in Sections 5:352, 5:353, 5:354, 5:355 5:356 and 5:357. (BFS 2016:6).

5:35 Specific requirements for the various occupancy classes

5:351 Occupancy class 2A

Premises in occupancy class 2A shall be provided with exit signs. Smaller premises that are easily surveyable may be designed without the need for exit signs. (BFS 2011:26).

5:352 Occupancy classes 2B and 2C

Escape routes from places of assembly shall be designed for the maximum number of people who are permitted to be present in the premises. (BFS 2011:26).

It shall be possible to open doors in, or to the escape route by pushing the door or using an easily operated handle. (BFS 2011:26).

Places of assembly shall be provided with devices for warning in case of fire and where necessary devices for early detection of fire. (BFS 2011:26).

Places of assembly shall be provided with exit signs for evacuation. Places of assembly shall be provided with general lighting and emergency lighting. Escape routes from places of assembly shall be fitted with emergency lighting. Emergency lighting shall be provided outside adjacent to the exits. External escape routes from places of assembly shall be lit and provided with emergency lighting along their entire length. (BFS 2011:26).

5:353 Occupancy class 3

Dwellings in occupancy class 3 shall be fitted with devices for early detection and warning in case of fire. It shall be possible to perceive the signal where people are present other than occasionally. Path to an escape route in common spaces in occupancy class 3B shall be provided with emergency lighting. (BFS 2014:3)

Habitable rooms in occupancy class 3 that are present in buildings in building classes Br2 or Br3 shall be able to be evacuated without assistance from the rescue services. (BFS 2011:26).

5:354Occupancy class 4

Spaces in occupancy class 4 shall be fitted with devices for early detection and warning in case of fire. (BFS 2011:26).

Spaces in occupancy class 4 shall be provided with exit signs for evacuation. Escape routes shall be fitted with emergency lighting. An evacuation plan shall be posted in every guest room. (BFS 2011:26).

5:355 Occupancy class 5A

Spaces in occupancy class 5A shall be fitted with devices for early detection and warning in case of fire. Escape routes and spaces in occupancy class 5A intended to be used during night time shall be provided with emergency lighting. (BFS 2016:6).

5:356 Occupancy class 5B

Spaces in occupancy class 5B shall be fitted with devices for early detection and warning in case of fire. Escape routes from spaces in occupancy class 5B shall be provided with emergency lighting. (BFS 2011:26).

5:357 Occupancy class 5C

Spaces in occupancy class 5C shall be fitted with devices for early detection in case of fire. Paths to escape routes may pass through adjacent fire compartments. Passage between fire compartments shall be made without the smoke spreading to the section not exposed to the fire. Escape routes from spaces in occupancy class 5C shall be provided with emergency lighting. Guidance marking shall be in place in buildings in occupancy class 5C. (BFS 2011:26).
"

10.2. Interview-guide Vidar Stenstad (DiBK - Building authorities, Norway)

Interview-guide

Interview subject: Vidar Stenstad

Preparation for interview by Jon Arild Westlund, 2018-10-11.

The interview topic will be on performance-based fire safety design in Norway, and on the potential introduction and use of a verification method.

Purpose

The purpose of this guide is to have an overall structure in place ahead of the interview.

This guide is given ahead of the interview to the interview subject to allow for some insight into the questions that will be asked. Some minor changes to the questions might occur during the course of the interview based on responses.

Legalities

1: Are you comfortable with having your full name included in the report? (yes / no) please sign if yes

2: Are you comfortable with having the interview recorded? (yes / no) please sign if yes

If you are uncomfortable answering any of the questions in the interview you can just state that you do not want to answer the question, and I will move on to the next.

A written transcript that will be included as an appendix in the report can be sent before completion of the report so that you may suggest corrections. All information not included in the report will be handled discretely and accessible only by me.

Introduction of thesis

The working title of the thesis is "Status quo of performance-based fire safety design in Norway". The goal of the thesis is to investigate possible areas of the performance-based fire safety design process for buildings in Norway that can be improved. Experience from two other countries, Sweden and New Zealand will be used to see if there is any value to be learnt.

The two major areas that will be covered are:

- The functional requirements given in the Norwegian building code, and how usable they are for the purpose of verification in performance-based fire safety design

- The role of verification methods and if Norway should pursue this path further to increase quality

Interview subject presentation

Please give a brief summary of your education and work-related experience to the topic of this interview.

On performance-based fire safety design in general

1: What is your view on the performance-based design approach?

2: What is your view on the prescriptive design approach, and how do you think this approach fits in as we move towards more performance-based design?

On building regulation in Norway

1: What is your knowledge of the development and introduction of the first version of performance-based code (TEK97)?

1B: Could you comment on the process where the previous prescriptive requirements from BF87 was converted to prescriptive solutions, and then matched together with the new functional requirements?

1C: How was the process or consideration to whether the prescriptive solutions would fulfill the new functional requirements handled?

1D: Was there any type of "calibration or harmonization" involved?

2: What is your opinion on whether the introduction of the performance-based code for fire safety was introduced at the right time?

3: What is your opinion on the topic of whether the overall fire safety level should be identified by the functional requirements (and any performance requirements) in the building code, or should it be identified by the prescriptive solutions?

3B: If you think the fire safety level should be identified by the building code requirements, do you think the current code requirements have sufficient quantified performance metrics and defined acceptance criteria to be able to produce verification that only uses the code requirements as a benchmark (ie. no comparative analysis using the prescriptive solutions as benchmark) ?

4: Do you think the functional requirements as they are defined in the current version of the building code (TEK17) are working optimal?

5a: What is your current view on the overall quality of performance-based fire safety design in Norway?

5b: Do you think is it used to create designs that we for the most part consider safe, or is it being misused or abused to create potentially dangerous designs?

5c: What is your current view on the overall quality of <u>verification</u> (of performance-based fire safety design) in Norway?

5d: If quality is considered insufficient, what measures do you think should be implemented to improve it?

6: Are there any plans to do (major) changes to the building code, and if so what are they?

7: Can you provide any comments to the ongoing project "Funksjonskrav – veien videre"

On the use of verification methods to increase quality

8: What is your opinion on the available guidance on the practice of performance-based fire safety design in Norway today, do you think it is adequate?

9: What is your opinion on a verification method equal to what Sweden or New Zealand currently have, a verification method published and supported by the building authorities as a path of compliance?

10: How you think we should calibrate the content of such a verification method against the overall fire safety level in the prescriptive solutions?

11: Does the Norwegian building authority currently have the resources to create and support a verification method, and are they sufficient?

12: What is your opinion on the idea and possibility of creating an unified "fire safety engineering guidance" document that would be created and maintained by the industry itself, but involved the building authorities in such a way that the method could be adequately "recognized"? This would not be considered a "full compliance path" for the building code, and responsibility would still reside with the designer with respect to using it in a justifiable way.

Thank you very much for taking the time to help me with my thesis!
Jon Arild Westlund-Storm, 2018-10-11

Jon Arild Westlund-Storm

10.3. Summary of interview with Vidar Stenstad, DiBK

This is a translated written summary based on live interview. The summary is written by the author. Some parts may be limited or compressed compared to the original interview.

Interview subject presentation

VS: I am civil engineer in building technology, with education from the Norwegian University of Science and Technology in Trondheim (NTH) in 1978. I completed my doctoral at the same location in 1983, on the topic of fire safety in older Norwegian brick built houses. I have worked at the Norwegian Institute of Wood Technology from 1982 to 1985, in parallel to my doctoral thesis. I also worked for 10 years in the consultant industry, at Dr. tech. Kristoffer Apeland AS, doing technical consultancy on building and fire engineering and design. From 1995 to 2005 I worked at the Norwegian Building Research Institute (Byggforsk), doing among other things fire safety design and fire safety briefs, and writing design guides in "Byggforskerien", a series of best-practice documents and industry-recognized methods for the building sector. From 2005 to current I have worked at the Norwegian Building Authority (BE/DiBK). Here I work with a lot of different things, building regulation in general as well as fire safety in particular. I was very involved with the building code of TEK10 and TEK17, was also the project leader of TEK17 and worked with the different fields. I have also been attending many international fire safety conferences with the topic of performance-based fire safety design, and have presented Norwegian views and experiences. I also participate in an international forum, IRCC, which is a collaborative group for countries that work on development of performance-based codes.

On PBFSD in general

1: What is your view on the performance-based design approach?

VS: My opinion is that we do not really have an alternative. I started doing fire safety design in the mid-80s and the practice was then to present the fire safety strategy at the local fire department, discuss what was possible and what was not possible to directly comply with, and then in the end hope for approval. In certain cases, a dispensation from the building code had to be submitted and the local building authorities had to get involved to consider if it was acceptable. This is a process that is not very functional, and unclear with respect to the role of responsibility of the local authorities. The competence level in the various local building authorities is varying with some bigger cities having very good competence, and then smaller cities almost no competence at all. Placing the responsibility at the designers is therefore the best and right approach. The advantage of a performance-based (functional-based) building codes are many, it allows for innovation and development of technology, and since the requirements are more broadly defined they require less maintenance and updates, and in principal do not require any dispensation from the requirements. The functional requirements are for the most part international recognized, and that may simplify the process of allowing free flow of services between countries. Functional requirements are also able to support existing buildings. There are many benefits with the performance-based (functional-based) building code, and there really isn’t an option to go back to how it was before. Another good point is that the building authorities do not have the necessary required resources to be ahead of the curve and produce suitable prescriptive requirements for innovative and new buildings. A good example is the new trend with high-rise wooden structures and "Mjøstårnet", it would not be reasonable and possible to create prescriptive requirements for such buildings. The competence must be located at those who design the buildings, and the responsibility of documenting adequate safety and compliance to the building code should be carried by these people. Prescriptive requirements do not promote critical thinking with respect to the risk of the specific building, and if you want to promote this way of thinking and this way of design, then it must be done through a performance-based (functional-based) building code, it really is the only viable path.

This design approach is however sometimes misused or intentionally abused with more simpler buildings like office buildings and housing dwellings. In normal situations it should not be a need to do any alternative solutions/analytical design on such buildings, however the experience is that deviations from the pre-accepted performances are still performed, perhaps too often. It may be considered a wrong use of competence and resources to do analytical design on such simple housing dwellings for example. Analytical design is best suited for the more complex and innovative buildings.

2: What is your view on the prescriptive design approach, and how do you think this approach fits in as we move towards more performance-based design?

VS: We need to keep the pre-accepted performances as well, as there must be a simplified way to design the more simpler buildings that are typically in project class 1 and 2. There should not be a need to use resources for analytical design on simple buildings. It is a requirement to support simplified design, but also as a way to continue to define the safety level when it is not defined by alternative means, as the pre-accepted performances are able to define the acceptable safety level, at least implicitly.

On building regulation in Norway

1: What is your knowledge of the development and introduction of the first version of performance-based code (TEK97)?

VS: I was not directly involved at least on the technical part of it. At the time of the introduction of TEK97 I was working at Byggforsk. Through RIF I was however involved on the part concerning 3rd party review. As you mentioned, the functional requirements in TEK97 are almost directly extracted from the NKB publication in 1994. We were the only country that took those requirements directly into the building code. The Nordic model of a function-based code became the template for how the functional requirements in TEK97 was designed.

1B: Could you comment on the process where the previous prescriptive requirements from BF87 was converted to pre-accepted performances, and then matched together with the new functional requirements?
1C: How was the process or consideration to whether the pre-accepted performances would fulfill the new functional requirements handled?
1D: Was there any type of "calibration or harmonization" involved?

VS: Yes, to a certain degree. The main point of consideration in the transition from BF87 to TEK97 was that the safety level was to be maintained. Since the safety level was defined implicitly through the prescriptive requirements in BF87, and that those were requirements were to be reused as new pre-accepted performances, these new pre-accepted performances would be used to define the safety level of TEK97 as well so that the safety level from the previous building code was maintained.

2: What is your opinion on whether the introduction of the performance-based code for fire safety was introduced at the right time?

VS: That may of course always be a topic of discussion. The thought at the time was that the time had come to take the leap, so to speak. A large amount of preparatory work had already been done at the time. You can always wait and try to make things better, but there is also value in starting to use it to get more real-life practice and experience. It was also considered to be a non-critical issue since most of the requirements from the previous building from 1987 was converted in to new pre-accepted performances for TEK97. This made it possible to use prescriptive design for the most part as before, but also slowly opening up for performance-based fire safety design as well. Basically, all the fire safety requirements were considered to be possible to verify using performance-based fire safety design, but obviously we lacked some tools and methods to be able to do this.

3: What is your opinion on the topic of whether the overall fire safety level should be identified by the functional requirements (and any performance requirements) in the building code, or should it be identified by the pre-accepted performances?

VS: In situations where you have a prescriptive reference building, comparative analysis is the most used method from what I have understood. In those situations, the fire safety level is implicitly defined by the pre-accepted performances. For buildings that don't have a prescriptive reference building, typically buildings in fire class 4, it is up to the designer to define the acceptance criteria together with the building stakeholders. The designer thus has the responsibility to decide on what the fire safety level should be. One might consider having probabilistic acceptance criteria for loss of life due to a fire in a building code, but no building authorities have done this so far, due to political considerations. Our statistical data however expresses a certain probability of loss life that accepted by society, at least implicitly. In conclusion, the responsibility resides with the designer, which has confirmed that he/she has the necessary knowledge and competence to do performance-based fire safety design. The designer must define the acceptance criteria together with the building stakeholders. It is a system based on mutual trust. In this aspect, the obligatory requirement for 3rd party review also helps to make sure that fire safety level in the performance-based designs are acceptable.

3B: If you think the fire safety level should be identified by the building code requirements, do you think the current code requirements have sufficient quantified performance metrics and defined acceptance criteria to be able to produce verification that only uses the code requirements as a benchmark (i.e.. no comparative analysis using the pre-accepted performances as benchmark)?

VS: It is not certain that it is possible to define "universal" quantified requirements that are applicable for all buildings, especially for the traditional buildings. The building code requirements (now pre-accepted performances) the have been developed through hundreds of years and combined together in package they define the acceptable fire safety level implicitly. Using modern quantitative tools and methods to try to measure this fire safety level is demanding, you have to take the fire safety level for what is. It is based on history, tradition and experience of previous events. The level is what is today, and it is considered appropriate by our politicians. If you set quantified criteria in the building code itself, you also have to specify the applicable methods as well, and there are wide range of different methods that may be used. To make that approach work you have to limit the freedom to use just certain methods that are considered acceptable. It is not necessary ideal to lock down the practice in this way, in effect reducing the possible methods that a designer may use. There are drawbacks and benefits with most methods, but the current available methods in Norway by using NS3901 in combination with INSTA 950, Byggforsk or equivalent documents, should be sufficient. If we could make everyone on board using these methods, then we would jump lightyears ahead in terms of quality.

4: Do you think the functional requirements as they are defined in the current version of the building code (TEK17) are working optimal?

VS: There are always areas that can be improved. We did some fine-tuning now for the TEK17, but for the most part the requirements seem to be working well. The challenge is to define functional requirements that is not possible to abuse, and some fundamental principles must be maintained. Safe escape routes are among these fundamental principles we have to make sure are still part of a building where performance-based design is used.

5A: What is your current view on the overall quality of PBFSD in Norway?

VS: Probably the same as the level of quality in verification, it seems to be highly variable.

5b: Do you think is it used to create designs that we for the most part consider safe, or is it being misused or abused to create potentially dangerous designs?

VS: We don't really know much about that since we don't often go into the specific details of the design of buildings. In those special cases where we choose to do investigation into major fires, performance-based design has not been identified as a particular culprit.

5c: What is your current view on the overall quality of <u>verification </u>(of PBFSD) in Norway?

VS: We don't really have an opinion on that as we don't evaluate the quality of verification. Sometimes verifications are sent to us to get our opinion on whether it is good or bad, but we do not provide that. We do however talk to various parties in the fire safety community, and from what we can understand there is a high degree of variability. We do however think that the quality has been improved in the recent years, particularly after we introduced obligatory 3rd party review. From what we can hear this has had a certain effect on increasing the quality.

5d: If quality is considered insufficient, what measures do you think should be implemented to improve it?

VS: If we could make everyone on board using the available methods then we would jump lightyears ahead in terms of quality.

6: Are there any plans to do (major) changes to the building code, and if so what are they?

VS: No

7: Can you provide any comments to the ongoing project "Funksjonskrav – veien videre"

VS: Report to be finalized in December 2018.

On the use of verification methods to increase quality

1: What is your opinion on the available guidance on the practice of PBFSD in Norway today, do you think it is adequate?

VS: The combination of the national and Nordic standards and specifications should be adequate to support the practice.

2: What is your opinion on a verification method equal to what Sweden or New Zealand currently have, a verification method published and supported by the building authorities as a path of compliance?

VS: That particular approach may limit the freedom of available methods to just a few select few, which may not be ideal in the long run, and may be challenging for the building authorities to properly maintain.

3: How you think we should calibrate the content of such a verification method against the overall fire safety level in the pre-accepted performances?

The interview subject did not provide an answer to the question

4: Does the Norwegian building authority currently have the resources to create and support a verification method, and are they sufficient?

VS: We think that the further development of verification methods should be done in Nordic and European cooperation.

5: What is your opinion on the idea and possibility of creating an unified "fire safety engineering guidance" document that would be created and maintained by the industry itself, but involved the building authorities in such a way that the method could be adequately "recognized"? This would not be considered a "full compliance path" for the building code, and responsibility would still reside with the designer with respect to using it in a justifiable way.

VS: This is something that we are positive to.

[END OF INTERVIEW]

10.4. Interview-guide Sweden and New Zealand

The following template was used as an interview-guide to the individuals that were interviewed on the topic of PBFSD and verification methods in Sweden and New Zealand.

Interview-guide

Interview subject:

Preparation for interview by Jon Arild Westlund, 2018-08-27.

The interview topic will be performance-based fire safety design in Sweden/New Zealand and the use of verification method BBRAD/C/VM2.

Purpose

The purpose of this guide to have a structure in place ahead of the interview.

This guide is given ahead of the interview to the interview subject to allow for some insight into the questions that will be asked. Some minor changes to the questions might occur during the course of the interview based on responses.

Legalities

1: Are you comfortable with having your full name included in the report? (yes / no) please sign if yes

2: Are you comfortable with having the interview recorded? (yes / no) please sign if yes

If you are uncomfortable answering any of the questions in the interview you can just state that you do not want to answer the question, and I will move on to the next.

A written transcript that will be included as an appendix in the report can be sent before completion of the report so that you may suggest corrections. All information not included in the report will be handled discretely and accessible only by me.

Introduction of thesis

The title of the thesis is "Status quo of performance-based fire safety design in Norway and proposals for improvement". The goal of the thesis is to investigate possible areas of the performance-based fire safety design process that can be improved. Experience from two other countries, Sweden and New Zealand will be used to see if there is any value to be learnt.

The two major areas that will be covered are:

- The functional requirements given in the Norwegian building code, and how usable they are for the purpose of verification
- The role of verification methods

Interview subject presentation

Please give a brief summary of your education and work-related experience to the topic of this interview.

Performance-based fire safety design

The main topic of this interview is performance-based fire safety design.

1: What is your general view on this particular design approach in general?

2: What is your opinion on the prescriptive approach, and how do you think this approach fits in as we move towards more performance-based design ?

Building regulation system in Sweden/New Zealand.

1,2, 3: What is your impression of the first edition allowing the performance-based approach, what is your impression of the current version, and how do you think they compare to each other?

4: What measures have been taken through the years to improve it (or make it worse).

5: Do you perhaps know what measures the building authorities have planned to develop it further?

6: If applicable, what measures do you think need to be made?

Performance-based fire safety design in Sweden/New Zealand

1: What is your general impression of the level of quality on the practice?
2: If any, what areas need to be improved or changed to increase the level of quality?

On the topic of verification methods - BBRAD/C/VM2

1: BBRAD/ C/VM2 is considered as voluntary to use, have I understood that correct?

2: Have you used BBRAD/ C/VM2 in your work?

3: If so; how often do you typically use it?

4: For what types of analytical design do you use it for the most?

5: What is your impression on how often it is generally used in performance-based fire safety design in Sweden?

6: Do you think it has lead to an increase in the use of performance-based fire safety design?

7: What are the benefits and drawbacks of using such a method from a purely practicing engineering point of view? Do you perhaps know some practical examples that illustrate this?

8: Do you think it has improved the overall level of quality of analytical design in Sweden since its introduction?

9: Regulation-wise, do you think it is implemented correctly as it is currently now? (ie. voluntarily/mandatory path of alternative design)

10: Do you feel that the authorities are able to keep up with updating the recommendations as the years go by and new experience and knowledge is acquired?

11: If applicable, given the choice, would you chose to change BBRAD/ C/VM2 or remove it completely?

12: If you want to change it, what types of changes would you do?

13: Any other concerns regarding BBRAD/ C/VM2 you want to communicate?

Other views and matters

Are there any other views or matters concerning the practice of performance-based fire safety design that you want to express?

Thank you very much for taking the time to help me with my thesis!

Jon Arild Westlund-Storm
2018-08-27

Jon Arild Westlund-Storm

10.5. Transcript of interview with Daniel Rosberg, WSP

This is a translated written summary based on live interview. The summary is written by the author. Some parts may be limited or compressed compared to the original interview.

Interview subject presentation

DS: I have an *education as a fire safety engineer from "Lunds Tekniska Högskola - LTH". After my exam I did some research on under ventilated fires and on the backdraft phenomena, both computer modeling and experimental work. I however quit the research quite early since I got a proposal to work as a teacher and started teaching the subject "Enclosure Fire Dynamics", "Fire chemistry" and "Fire risk assessment", all subjects relevant for PBFSD. Taught these subjects at LTH for some years until for about 15 years ago I started to work as a consultant and have been involved in different building projects designing fire safety protection. For about 4-5 years ago I was made "Technical responsible" at the Stockholm subway, and as such have been working most of the last years under ground rather than above. Currently I am now working at WSP as a consultant, but also have responsibilities for development and collaboration efforts.*

I have also done some work for Boverket, with the revision of the requirement for constructions in the EKS, more specifically the revision for EKS 10. I helped them with some investigations regarding the localized fire approach, how to define it, the size of the fire etc . We also looked at the risk of flashover, what methods to estimate when that occurs and what conditions are necessary for it to occur.

I have done some work for the Swedish Government regarding the harmonization of the building regulations, both in general and specific for fire safety, against the regulations of the other European countries. I have also been a consultant for the Danish authorities and their building regulations, specifically for their requirements for high-storage buildings.

PBFSD

1: What is your view on this particular design approach in general?

DS: I am quite positive to the PBFSD. I think it is a good design approach to promote innovation, and to avoid getting locked down to specific technical solutions. The regulation must support and promote a certain amount of innovation. If you put performance-based design in the hands of capable fire safety engineer, you generally end up with a good fire protection level that is tailored specifically for the building.

2: What is your opinion on the prescriptive approach, and how do you think this approach fits in as we move towards more performance-based design?

DS: While I think performance-based design is a good approach, I do think prescriptive design still have an important role to fill. Housing buildings and family dwellings is a good example where we rarely use performance-based design, perhaps with the exception for ventilation systems. Generally though for such buildings the prescriptive requirements fulfill a good role. Performance-based design is for the most part used for large public assembly buildings where there is a specific need for it. For the most part though, simplified design is used.

Generally, if you have two similar buildings then you would for the most part would expect the same level of fire safety design as well, and the prescriptive approach certainly promotes that. It also provides some level of expectancy for the building owner and the building developer with respect to what is required for fire safety.

Building regulation system in Sweden.

1, 2 &3: What is your impression of the first edition allowing the performance-based approach, and the current version? How do you think they compare to each other?

DS: *I did not practice fire safety design that far back in time. I started around year 2000. I do however have some insight into the development. The earlier versions had arguably a higher level of freedom, and the later versions have limited that freedom in certain aspects. There is one particular aspect that was changed in BBR19 which was released in 2012, 2012 was a year where the code changed drastically, and you can generally divide the building code versions in two parts, before and after this period in time. BBR18 is then the version before this time, and in this version, there was a chapter 5:11 called "Alternative design". This chapter generally stated that you are allowed to design the fire safety in other ways than described in this chapter (chapter 5) as long as you can show through verification that the total fire safety level in the alternative design is not worse than would have been achieved if the design was based on all the requirements in this chapter. So, as you probably know, the code is divided into functional requirements, sometimes mandatory provisions and general recommendations. Prescriptive design is by following the general recommendations. What chapter 5:11 allowed through alternative design however was to not even consider the functional requirements or mandatory provisions. So, this is very unclear in terms of what verification must be performed, and it is very strange to have a performance-based code and then have a requirement that allows you to not fulfill the functional requirements. So, when I state that the older versions of the building code had a high degree of freedom, this is basically what I am referencing.*

In newer versions we still have the option to apply the authorities having jurisdiction (AHJ) for a "Minor deviations" from the building code. The AHJ can in certain situations accept minor deviations from the code, the conditions being that there is a particular reason, and it is still possible to show that the building can be designed to be technical reasonable. This is however not something that the designer can accept or do by themselves, the decisions of accepting this is on the AHJ. To the best of my knowledge this option has not been judicially challenged in terms of which party has the responsibilities should the need for that arise due some fault in the building later on.

The major difference is that the possible ways of showing compliance has been made much clearer. There is now the path of general recommendations (prescriptive) or alternative design, which now must fulfill the functional requirements as well. Some might consider that the current version has constrained the level of freedom, but it might also just be that they have made the original intention clearer.

4: What measures have been taken through the years to improve it (or make it worse).

DS: In general, multiples steps have been made to adjust the regulations through Nordic harmonization, so that they harmonize better against other the regulation in other countries in the Nordic region.

Other worthy mentions are some changes in the building code implemented in the major revision in 2012. These are mandatory provisions/performances.

- *hospitals shall have a sprinkler system, and even certain types of healthcare buildings for senior citizen.*
- *public assembly buildings shall have means of refuge area if it is not possible for occupants with disability to exit the building without using stairs This area should be big enough to accommodate wheelchairs and should have means for communication. However, who is to be at the receiving end this communication is not really stated, and thus unclear.*

So, the building code of 2012 has adjusted the safety level a bit higher, and at the same time also reduced the flexibility some due to these changes being mandatory, i.e.. not part of the general recommendations.

New requirements like these do however need some time to mature and develop as practitioners get used to them, so we need to see how this develops further. I know a lot of colleagues of mine are frustrated with these requirements.

There are also some examples of where requirements have been reduced, among exterior façade materials that are allowed to have droplets when exposed to fire. These requirements were reduced to harmonize with the Danish building regulations.

5, 6: Do you perhaps know what measures Boverket have planned to develop it further? If applicable, what measures do you think need to be made?

DS: I do not really know much on what they are currently working on, with the except of load-bearing constructions exposed to the local fire, and how that should be designed. As it currently is practiced, it would seem that certain buildings are allowed to be designed by just using the local fire, as long as it can be verified that flashover does not occur with a reasonable probability. I know that they are considering implementing a specified fire size to check whether flashover occurs, like a big fire of 20-30 MW, and if flashover does not occur in this scenario, you are allowed to just use the local fire. In this scenario they are also considering adjusting the size of the local fire a bit up as well. As you know, the area with respect to heat release rate pr. area is very important to estimate the heat exposure in a local fire so they are considering including more details for how to approach this.

PBFSD in Sweden

1: What is your general impression of the level of quality on the practice of PBFSD?

DS: This is best viewed if can split the time before and after 2012, with the introduction of BBRAD. Before that, there was arguably a higher level of variability with respect to how engineers chose to verify their designs.

Now however, my impression is that the level of quality is pretty high. We have a pretty good education for fire safety engineering in Sweden, and a building regulation that has become more clearly defined. There are however of course always some variations between the different designers.

2: If any, what areas need to be improved or changed to increase the level of quality?

DS: Not necessarily linked to BBRAD, but as mentioned earlier, design of load-bearing constructions using a natural fire seems to an area where there is a reduced level of knowledge. There is also perhaps currently too much variation in the designs.

On the topic of verification method BBRAD

1: BBRAD is voluntarily to use, have I understood that correctly?

DS: Yes, that is correct. You can see that all the text given in BBRAD is under paragraphs named "General recommendations". Since alternative solutions may be used instead of the general recommendations, an alternative to BBRAD may also be used. My experience is however that very few dares to step outside the general recommendations given in BBRAD.

The general recommendations are typically recognized as a minimum acceptable level. The values given are however sometimes deemed too conservative for a specific building. Take the example of a bathhouse for example, which is a public assembly building. A 10 MW fire for that feels fairly conservative. Measures like sprinklers are almost always needed to be able to use a lower fire size in those configurations.

2: Have you used BBRAD in your work?

DS: Yes, I have used it.

3: If so; how often do you typically use it?

DS: At the moment not so much since I am working mostly in tunnel projects. Earlier however I used it almost always in building projects where we did analytical design.

4: For what types of analytical design do you use it for the most?

DS: Life safety, with escape and occupant movement velocity, and the fire sizes and fire growths. I also use the chapter about preventing fire spread between buildings, where we typically calculate the radiative heat flux. These are the two chapters where BBRAD also have the most complete guidance.

I also use the chapter about ventilation systems, where we use the suggestions for pressure buildup of 1500 Pa and smoke temperatures. The chapter about documentation and control is of course also much used.

5: What is your impression on how often it is generally used in PBFSD in Sweden?

DS: I think it is used quite extensively, it is generally considered the way we do it.

6: Do you think it has led to an increase in the use of PBFSD?

DS: No, actually I don't think that there has been an increase in use, it is about the same. It is just done in a more structured and defined approach now. It is done with better level of quality.

7: What are the benefits and drawbacks of using such a method from a purely practicing engineering point of view? Do you perhaps know some practical examples that illustrate this?

DS: My first reaction when BBRAD was published was that I did not care much for it. I thought it was a bit sad since I considered myself a competent engineer that reviewed scientific research and could extract the information like heat release rates that I needed to do analytical design. I knew where to look, and what to read to do the job, and did not need BBRAD to tell me this. I generally thought the creative freedom I had was more limited.

However, now that I have been practicing BBRAD a few years, in a broader perspective, I think the level of quality has generally been improved, since more are doing verification on an improved level due to BBRAD. At certain times I still think it is a bit sad that it is these values in BBRAD that I need to use when my sense is telling something else should be used. It is, as you have pointed out earlier, that I don't really need to use it, but still I usually end up using it. That is a bit unfortunate.

There is less discussion about appropriate input parameters now, as you can just confirm that those values from BBRAD have been used. As such, even 3rd party reviewers don't question if values from BBRAD is used. That is a bit unfortunate.

8: Do you think it has improved the overall level of quality of analytical design in Sweden since its introduction?

DS: Yes, I think the level of quality has increased since the introduction of BBRAD.

9: Regulation-wise, do you think it is implemented correctly as it is currently now? (ie. voluntarily/mandatory path of alternative design)

DS: Yes, regulation-wise it seems appropriate the way it is currently done in Sweden.

10: Do you feel that the authorities are able to keep up with updating the recommendations as the years go by and new experience and knowledge is acquired?

DS: No bigger revisions of BBRAD have been done during the six years it has been available now, so it is a bit difficult to say. Either no more applicable knowledge has been gained in these years, or they have not been able to keep it updated. My personal belief is that there hasn't really been that much development on the technical material included in BBRAD so that is explanation. I have great faith in Boverket and the people working there, so if new knowledge should surface I think they will act fast to update it. My impression is that BRRAD is document that is "alive" and will be updated when needed.

11: If applicable, given the choice, would you choose to change BBRAD or remove it completely?

DS: I think it is a good document, and do not want to remove it.

12: If you want to change it, what types of changes would you do?
DS: Maybe on the process of deciding what method of verification to use could be improved on, because the interpretations can become quite subjective. It isn't really described in the text when each method should be used.

Secondly, in the years I have used BBRAD I have generally mostly seen method 1 qualitative assessments and method 2 scenario analysis. I think I have only seen one or two examples of method 3 - quantitative risk analysis. That is a bit unfortunate since I think it is a powerful method. To take BBRAD to the next level, I think we need to do more work on this area. If we could have a table of reliability data for fire safety measures like doors and fire alarm for example and more guidance given on using this data in an analysis, then that would help to promote the use of this method. We have a lot of guidance for deterministic analysis, so the same type of guidance for probabilistic analysis would be beneficial, especially for acceptance criteria. We need to find the key for how to do this.

13: Any other concerns regarding BBRAD you want to communicate?

DS: Perhaps not so very important, but we talked previously about the Eurocode when discussing load-bearing constructions. In chapter 4 of BBRAD where protection against the spread of fire and smoke throughout a building is discussed, the same Eurocode (SS-EN 1991-1-12) is referenced for calculation. This method is almost never used due to its limitations, and no alternatives are given. I would like that something else was suggested in this chapter, like suggesting a different calculation method or give more guidance.

Other views and matters

Are there any other views or matters concerning the practice of PBFSD that you want to express?

DS: We`ve had quite a long discussion now so I think and hope we have covered the most important stuff.

[END OF INTERVIEW]

10.6. Transcript of interview with Anders Johansson, Boverket, Sweden

This is a translated written summary based on live interview. The summary is written by the author. Some parts may be limited or compressed compared to the original interview.

Interview subject presentation

AJ: I currently work with the building regulations in Sweden, "Boverkets byggregler - BBR", equivalent to the Norwegian "bygningsreglementet". Before this I worked in Brandkonsulten for a couple of years. I started working at Boverket in 1998, so I have been involved there for quite a while.

PBFSD

1: What is your view on this particular design approach in general?

AJ: I think it is necessary to have option of analytical design. From our standpoint it is not possible to provide detailed requirements for every type of a building design, so the analytical approach is needed. It is also natural to have this option for modern building design. Fire safety is an engineering discipline that has grown and has been developed lot the last 30 years so it feels natural to have this design option.

2: What is your opinion on the prescriptive approach, and how do you think this approach fits in as we move towards more performance-based design?

AJ: It has its uses, in part since many buildings you do not need to do any particular analysis, like small dwellings and similar buildings. Also, in part as a reference level when doing comparative analysis as part of an analytical design. It can be difficult to find the right goals and performances for all the different situations, so then it is good to be able to compare against the general recommendations in these cases.

From our standpoint, we think these two design approaches will be needed and used for the near future.

Building regulation system in Sweden

1,2, 3: What is your impression of the first edition allowing the performance-based approach, what is your impression of the current version, and how do you think they compare to each other?

AJ: The "pendulum" is moving a bit back and forth with the various revisions of the building code. Typically, you give some freedom, and then some think that there is too high freedom leading unacceptable variations. Then the building authorities try to amend that, and perhaps adjust the pendulum a bit the other way again. For the fire safety regulations, there was a major revision in 2012. One of the bigger changes that was made was the removal a "magical provision" that essentially allowed you to deviate from the mandatory provisions, as long as you could document your design was of equal quality, this option was called "alternative design". This option was removed and replaced with the options of simplified and analytical design. Simplified design follows the general recommendation which you can deviate from by using analytical design. You are however not allowed anymore to deviate from the mandatory code requirements. So, this change was to limit the scope of what was allowed to do, and then the introduction of BBRAD also provided some guidance on how to do it. So there definitely have been some changes over time here.

4: What measures have been taken through the years to improve it (or make it worse).

(Answer in previous response)

5: Do you perhaps know what measures Boverket have planned to develop it further?

AJ: Just now we are in a quiet period, as the committee appointed by the government to review the complete building code is on the last year of this 3-year commitment. So, at the moment we really don't know the direction this review will be heading, and therefore have not yet made any big plans for changes. In general however, not necessarily linked to the fire safety regulations, there is focus on digitalization of the building regulation and how they can be digitally traced, used in BIM systems etc.

6: If applicable, what measures do you think need to be made?

AJ: I can`t think of much more than previously discussed, in general we need to develop the structure and content further. The question of legality and the rule of law is of course always difficult as it is based on code requirements that are considered safe. We shall have to see whether that will drive the requirements to be made more simple and clearer.

PBFSD in Sweden

1: What is your general impression of the level of quality on the practice?

AJ: Generally speaking, this engineering discipline and market area have grown considerably, but at the same time also have a good level of competency. However, the variation is still considered fairly high, there are bottoms and tops with respect to competency, sot it is not possible to say that everyone are considered good in that aspect. There are economic reasons for both consultants and building owners to take shortcuts and not put in the necessary resources that should be required.

2: If any, what areas need to be improved or changed to increase the level of quality?

AJ: We don't have too much certification in Sweden, but we do have something that is called "expert engineer" through our SAK3. That is something that can be used when the building authorities need an extra level of independent design review. These persons are however also often used by building owners as part of a 3rd party design review to verify the level of quality in the project. The follow-up and review of these persons is however unclear, I do not of any of these experts that have lost their certification. It might be a need to be a bit tougher on the follow-up of these experts from the supervising authorities. That is one of the ways that could be considered to increase the level of quality.

BBRAD

1: BBRAD is voluntarily to use, have I understood that correctly?

AJ: In Sweden, the building code is mandatory to follow. We also have the general recommendations, which if you follow these then you have also fulfilled the code. Because of this there is always a safety for the building owner to follow the general recommendations, because then you know you have complied with code and the supervising building authorities cannot say that the design or building is wrong or unsafe. So, the general recommendations are binding also for the supervising building authorities, if these are followed then you have done what is required. So, reversing that, you cannot not follow the general recommendations without doing some that is of equal safety, and be able to verify that. BBRAD is fairly strict in detailing how to do the analysis for the areas that it covers like life safety, load-bearing constructions, facilitating for the fire service etc. so you don't forget to these aspects in your analysis. So, methods are given, but input data is also provided, like what design fire and what walking speed to use in the analysis. This can be both an advantage and a drawback, because there can be extreme cases where the design fire should be even *bigger than what is prescribed in BBRAD. This could be something the designer would normally consider when evaluating the risks, but still in the end feel obligated to choose the design value given in BBRAD. This could be because if something (more conservative) is chosen the building owner could chose a different consultant on future projects. So that is perhaps the biggest drawback. The advantage is that design become more comparable to each other, and you have a defined level for everyone to adjust after. There are some of these input parameters that can have a great effect on the results in the analysis, like the soot yield used in CFD calculations. Such values can be adjusted to calibrate the design to show the results that you want to show.*

2: Have you used BBRAD in your work?

AJ: Very limited, it was published right around the time I stopped working as a consultant. So quite limited. I don't think I can say I have used.

3: If so; how often do you typically use it?

AJ: Not very often.

4: For what types of analytical design do you use it for the most?

AJ: I did not do much work with BBRAD since it was not published when I worked. However, I didn't do much analytical design when I was a consultant either, smoke filling calculations and similar stuff like this was typically done by my colleagues. In Sweden we also do a lot of calculations for ventilation systems. I mainly did calculations for radiative heat flux between windows and buildings.

5: What is your impression on how often it is generally used in PBFSD in Sweden?

AJ: In limited areas it is used fairly often, but often then limited to the method of qualitative assessment, where the steps to identify what areas of the building is affected by the alternative design. Larger verifications are however not uncommon either, for example ASET/RSET calculations is often used in shopping centers and sports halls and similar occupancies. The design fire scenarios in BBRAD is then typically used in the verification process.

6: Do you think it has led to an increase in the use of PBFSD?

AJ: No, I think we did a fair amount of analytical design before BBRAD as well. BBRAD has mainly just changed how that verification in analytical design should be performed. It might be that the process of qualitative assessments is more rigidly documented now, previously that may have been just verified by simple statements like "sprinklers will account for the deviation".

7: What are the benefits and drawbacks of using such a method from a purely practicing engineering point of view? Do you perhaps know some practical examples that illustrate this?

AJ: As I mentioned in questions 1, the advantage is a more comparable and fair playing field, you are not in competition with other consultants in how you do the analysis. The drawback is you may miss important considerations as to what should be the design scenario, even though you are still expected to consider this. It was never the intention that the prescribed design fire scenarios in BBRAD should be used for all possible scenarios. The provided design fire sizes for example should be limited to analysis with respect to evacuation design. It may be that other fire sizes are required when evaluating other parts of the building fire safety, for example load-bearing capacity and fire spread.

8: Do you think it has improved the overall level of quality of analytical design in Sweden since its introduction?

AJ: That is certainly our hope, but we have not done any official investigation in to this. There is no scientific report that can state this, but we do hope this is the case. There is an older investigation that was published in 2005, before the introduction of BBRAD, a doctoral thesis by Johan Lundin, "Safety in case of fire – effect of change in building regulations". That thesis looked into what happened after the building code change in 1994 and how this affected the fire safety level in buildings in the following years. This was performed before the building code was changed in 2012 and was part of the reason why it was deemed necessary to adjust the practice a bit.

9: Regulation-wise, do you think it is implemented correctly as it is currently now? (ie. voluntarily/mandatory path of alternative design)

AJ: We think it fits well in the current Swedish system There is of course a possible consideration that BBRAD could be made part of the same document where the building code requirements (BBR) and the general recommendations are given, to have everything in the same location. BBR however mainly outlines the requirements for the actual building components, and if we allow other content in like how to do analysis, how to do design review and so on, it will be less clear what the specific building requirements are. So, the different benefits and drawback of this is certainly up for discussion. If BBRAD was part of the building code document, it would be easier to reference it for certain verifications for example. In general however, we are pretty satisfied with how it is currently structured.

10: Do you feel that the authorities are able to keep up with updating the recommendations as the years go by and new experience and knowledge is acquired?

AJ: You will have to ask others for a proper response to this question. We try to keep it updated to the best of our ability, and follow the international development of the field, through SFPE and similar organizations for any new developments.

11, 12: If applicable, given the choice, would you choose to change BBRAD or remove it completely? If you want to change it, what types of changes would you do?

AJ: In the grand perspective we should probably create some more guidance to the chapter about load-bearing capacity and the connection to BBRAD in that specific area. Also, the chapter on fire spread between buildings is also fairly limited. So, there are definitively areas of improvements. On the aspect of removing it completely, we would not do that unless we had something similar to point to instead. If we do not have something of our own, we would point to something international that could be used instead. We do not want to just drop it completely and go back to the time before BBRAD.

13: Any other concerns regarding BBRAD you want to communicate?
AJ: It might be that if you have the time and resources you could interview other consultants on this topic as well.

Other views and matters

Are there any other views or matters concerning the practice of PBFSD that you want to express?

AJ: Perhaps the dilemma of dealing with safety and at the same time always working with limited resources and trying to get the most cost-efficient design. If I am to be a bit critical of Swedish fire consultants it would be this drive for economic consideration in the design, especially when it is considered a part of the vision for the consultant company. Views like "everything not stated as *forbidden in the building code is allowed" for example is not optimal, designers should consider the intent of the building code requirement and why it exists. Designers should use their knowledge as to how to get a good fire protection instead of intentionally misinterpreting definitions in the building code, for example "this area is not considered a storage area, it is a parking location for bikes". I am a bit skeptical to that type of design and documentation, and that it occurs a bit too often. That some designers don't think as reasonable engineers, but twist and adapt the definitions to fit their agenda, is problematic.*

[END OF INTERVIEW]

10.7. Transcript of interview with Devin Glennie, New Zealand

Interview subject presentation – Devin Glennie

DG: I am Senior Fire Engineer working with a fire engineering company in Christchurch, New Zealand. I have been working in the New Zealand construction environment for two years. Prior to my time in New Zealand, I worked in Canada and dealt with the National Building Code of Canada, Alberta Building Code, and NFPA standards. I have worked on a variety of acceptable solution and alternative solution (or performance-based designs) in Canada, New Zealand, and Australia.

PBFSD in general

1: What is your view on this particular design approach in general?

DG: It provides a useful compliance pathway for complicated buildings and buildings that fall outside of prescriptive requirements.

Very rarely does it provide significant cost savings to a project (when considering total construction cost for a project) except for the largest of buildings. In most cases, performance based design adds extra time to the design process and headaches for the design team. It is always a cost-benefit sales pitch on a job to justify the use of a performance based design.

2: What is your opinion on the prescriptive approach, and how do you think this approach fits in as we move towards more performance-based design?

DG: Not every building requires a performance based design. In many aspects, the prescriptive approach provides a useful pathway for simple designs (single level buildings, simple fit-outs, residential or office towers with limited podium spaces, etc.).

Building regulation system in New Zealand

1: What is your view on the first edition of the building (1992) allowing the performance-based approach?

DG: The building code legislation comprises several different components including the Building Regulations 1992, the Building Act 2004, and then Protection from Fire compliance documents C/AS1,2,3,4,5,6,7 and C/VM2. The primary documents used everyday are the Acceptable Solutions C/ASx and performance design document C/VM2. These are constantly updated and amended. I do not have enough historical experience in New Zealand to comment on the first editions of these documents.

2,: What is your impression of the current version of the code?

DG: I will speak mostly about the compliance documents C/ASx and C/VM2 in comparison to other building codes I have worked with. In general, there is a heavy reliance on the reliability and functioning of sprinklers and smoke detection in New Zealand fire designs. Means of escape and fire resistance ratings are much less rigorously implemented in buildings in New Zealand because of this. At a high level, these documents cover the main aspects of fire safety. However, there are specific sections that are poorly worded or and the documents are poorly compiled. There are plenty of sections that contain 'gaps' in the code that do not address specific situations or are silent on certain requirements. These are left to the knowledge and skill of the fire engineer to fill in the gaps and produce fire designs that are appropriate for the building. Other codes I've worked with that have extension prescriptive text along with extension commentary and intent sections.

3: How do you think the two versions compare to each other, what measures have been taken through the years to improve it (or make it worse)?

DG: There has been a trend to make the acceptable solutions and C/VM2 documents more specific or streamlined in some areas. But, the approach is not consistent and has failed in some aspects.

5: Do you perhaps know what measures MBIE have planned to develop the code further?

DG: MBIE releases regularly updates on code developments. Acceptable solution documents C/AS1,2,3,4,5,6,7 are being re-combined into 1 document (To be called C/AS1) which will likely result in headaches as it will likely contain errors.

6: If applicable, what measures do you think need to be made to develop the building code further?

DG: Specific guidance on external cladding will need to be implemented in the building code. Further development is required for specific construction details and how these should be approached (ie. interfaces between walls and ceiling and fire rated and non-fire rated construction).

There are big gaps in the product approvals and testing regime in New Zealand but that is not the result of the building code.

PBFSD in New Zealand

1: What is your general impression of the level of quality on the practice of PBFSD?

DG: There is a minimum level of quality enforced in New Zealand due to AHJs requiring independent peer reviewers to review design documents for C/VM2 or alternative solution designs. Additionally, the AHJs generally have a background in fire engineering and Fire and Emergency New Zealand has their own design review team. The level of quality is not maintained by the building codes themselves but by the design review process.

The level of quality differs mainly in the construction of the buildings and there are vastly different levels of experience in the monitoring of construction and ensuring that a building is built correctly to meet the performance based guidelines. Overall, the quality of construction is rather low and contractors and architects defer to fire engineers to pick up their mistakes.

Additionally, the historical fire reports I've reviewed prior to the implementation of C/VM2 often were weak on details for performance based design. There was limited structure to the design and limited analysis done to ensure they were implemented. The implementation of C/VM2 has required more robust documentation requirements for fire engineering reports.

2: If any, what areas need do you think need to be improved or changed to increase the level of quality?

DG: There are no formal documentation requirements for fire modelling of challenging fires. So, different consultants will provide different levels of results (from simple screen shots to print offs of code, etc).

Verification method C/VM2

1: Have you used C/VM2 in your work?

DG: Yes, I have worked on several large buildings and several small buildings that required C/VM2.

2: If so; how often do you typically use it?

DG: My work focus in New Zealand has been with C/VM2 projects so I've been consistently using it for two years. Across all projects I've seen, the use is limited (maybe 10 to 25% of projects).

3: For what types of analytical design do you use it for the most?

DG: There are a variety of buildings that fall outside the scope of the acceptable solutions. The main areas are buildings with atriums, buildings with multiple mezzanines, delayed evacuation strategies, or large or tall buildings. Often it is used for warehouses where sprinklers are not desired.

There are two specific aspects of C/VM2 that are permitted to be used by fire engineers for acceptable solution designs. This is the assessment of horizontal fire spread (radiation calculations) and fire severity (specifying the minimum equivalent fire resistance ratings). The radiation calculations are frequently used because the assessment method in the acceptable solutions is rather dumb and overly conservative.

4: What is your impression on how often it is generally used in PBFSD in New Zealand?

DG: Basically all performance based designs in New Zealand fall under C/VM2. Alternative solutions will generally incorporate the design process or analysis regime of a C/VM2.

5: Do you think it has lead to an increase in the use of PBFSD?

DG: Performance based design of an entire building has likely increased. There has likely been a decrease in alternative solutions that address only one specific aspect of a building. This is usually mandated by the AHJs. If the building does not meet the requirements for an acceptable solution, it will be assessed under C/VM2.

6: What are the benefits and drawbacks of using such a method from a purely practicing engineering point of view? Do you perhaps know some practical examples that illustrate this?

DG: C/VM2 does not contain any defined minimum levels for features such as door widths, ceiling heights, door hardware, etc. Often, C/VM2 reports are silent on these details and merely address the design scenarios. Not all aspects of a building need performance based solutions (such as what type of hardware should be permitted on a door) but these features need to be captured somewhere.

7: Do you think it has improved the overall level of quality of analytical design in New Zealand since its introduction?

DG: Yes as discussed previously.

8: Regulation-wise, do you think it is implemented correctly as it is currently now? (ie. voluntarily/mandatory path of alternative design)

DG: Yes. Though the fire engineering brief process has become rather complicated. There is generally more trouble getting an FEB approved than getting a fire engineering report approved from various stakeholders. There is an expectation from a variety of stakeholders that the FEB present preliminary design for the building where it should really just de-risk the consenting process and agree to common inputs and design scenarios.

9: Do you feel that the authorities are able to keep up with updating the recommendations as the years go by and new experience and knowledge is acquired?

DG: No. The conversations I have had with the authorities does not appear that they are consistently informed of all updates to all documents and methods of analysis. They rely on the peer review and fire service reviews for a lot of technical aspects.

10: If applicable, given the choice, would you chose to change C/VM2 or remove it completely?

DG: Change it.

11: If applicable, If you want to change it, what types of changes would you do?

DG: The fire modelling rules and design scenarios form a good backbone for conducting analysis but shouldn't replace all aspects of acceptable solution designs. As previously discussed, there is no specification in C/VM2 for minimum widths of doors or door hardware or fire stopping or other aspects.

My preferred version of the document would be similar to the Singapore "Fire Safety Engineering Guidelines" in both format and content. The Singapore document outlines:

- *The applicable design fire scenarios to be considered along with sensitivity checks that need to be included*
- *How the fire safety engineering report should document FDS modelling results including the location of slice files, output quantities, and time intervals*
- *Required drawings to be submitted for building consents*
- *Details to be included in an operations and maintenance manual*

12: Any other concerns regarding C/VM2 you want to express?

DG: It is not updated at the same frequency as the acceptable solution designs or at the same time as commentary documents. So, changes to items like cladding requirements, are not picked up at the same time and this can leave to gaps and loopholes in a C/VM2 design that would not exist in an acceptable solution design.

[END OF INTERVIEW]

10.8. Transcript of interview with Tony De Bruin, New Zealand

Interview subject presentation

TB: BSc Engineering (Civil). No formal fire engineering study. Fire engineering learned on the job only, since January 2006. Carried out about 10 C/VM2 designs. Warehouses, aged care accommodation, commercial office with atrium, hotel with atrium, student union building with atrium, stadium extensions to seating. Modelling using FDS, except the warehouses where B-RISK was used for modelling. Used egress modelling package Pathfinder for hotel. Peer reviewed 3 designs, 1 where B-RISK was used, and 2 where FDS was used. 1 where Pathfinder was used.

PBFSD in general

1: What is your view on this particular design approach in general?

TB: In general, C/VM2 provides a little additional decision making from the engineer (when compared with the C/AS). It is convenient in that the factor of safety is built in by extra conservatism rather than by additional scenarios. It is also convenient that all the literature has been referenced to produce this document, avoiding the user from additional literature research. A full alternative solutions pathway is permitted, but full literature safety factors are required. This provides a path for very complex buildings.

2: What is your opinion on the prescriptive approach, and how do you think this approach fits in as we move towards more performance-based design?

TB: Prescriptive does not require engineers for application. Design can be done by technicians, and should be, but isn`t. C/VM2 is also prescriptive, but allows some engineering judgement and serves a good platform for exploring more complex designs for engineers.

Building regulation system in New Zealand

1: What is your view on the first edition of the building (1992) allowing the performance-based approach?

TB: I have no experience in using the first edition.

2,: What is your impression of the current version of the code?

TB: It is useful for providing a base for interpretation of vague or ambiguous clauses in the compliance documents.

3: How do you think the two versions compare to each other, what measures have been taken through the years to improve it (or make it worse)?

TB:I don't have an opinion.

5: Do you perhaps know what measures MBIE have planned to develop the code further?

TB: No, the code is a slow moving document.

6: If applicable, what measures do you think need to be made to develop the building code further?

TB: The code is fine. It`s the processes that are required to demonstrate compliance that increases the approval time.

PBFSD in New Zealand

1: What is your general impression of the level of quality on the practice of PBFSD?

TB: It lacks a consistent set of high level checking systems, i.e designers, peer reviewers and authorities should have a single template for checking inputs to modelling.

2: If any, what areas need do you think need to be improved or changed to increase the level of quality?

TB: The calculations and verifications should have a methodology that is a "best practice" flow that is driven by the regulatory authority so that review can easily be done. Sketches should contain information that is standardized across all designers. There is too much variation (due to freedom to put as little or as much as the designer likes). This impairs the understanding/reading of drawings. Symbols, colour schemes etc. should be standardized and enforced.

Verification method C/VM2

1: Have you used C/VM2 in your work?

TB: Yes

2: If so; how often do you typically use it?

TB: Seldom.

3: For what types of analytical design do you use it for the most?

TB: Where the building is outside the scope of C/AS

4: What is your impression on how often it is generally used in PBFSD in New Zealand?

TB: For speed of processing the simplest approach should be used, ie. C/AS. This is simple, but conservative. For less conservative (and cheaper) designs more science can be used leading to C/VM2 and ultimately alternative solutions. Most clients want cheap design, but simple and quick processing.

5: Do you think it has led to an increase in the use of PBFSD?

TB: Our code is performance-based therefore all designs are performance-based. IF you mean C/AS instead of C/VM2 then no. Our previous C/AS had options to use specific design for parts that didn't strictly fit. Now it all in one or the other, not bits.

6: What are the benefits and drawbacks of using such a method from a purely practicing engineering point of view? Do you perhaps know some practical examples that illustrate this?

TB: Benefits: Integrated reliable sources, no need to verify sources. Drawbacks: It is still very prescriptive, has delays during the peer review process, restricted to chartered engineers. I have no examples.

7: Do you think it has improved the overall level of quality of analytical design in New Zealand since its introduction?

TB: Yes

8: Regulation-wise, do you think it is implemented correctly as it is currently now? (ie. voluntarily/mandatory path of alternative design)

TB: Yes, but too few projects qualify and can justify the costs of design and peer review with C/VM2

9: Do you feel that the authorities are able to keep up with updating the recommendations as the years go by and new experience and knowledge is acquired?

TB: No

10: If applicable, given the choice, would you choose to change C/VM2 or remove it completely?

TB: Not change nor remove.

11: If applicable, if you want to change it, what types of changes would you do?

TB: No changes other than some clarifications, add checking system, templates for use.

12: Any other concerns regarding C/VM2 you want to express?

The interview subject did not provide an answer to the question.

[END OF INTERVIEW]

10.9. Transcript of interview with Anonymous, New Zealand

Interview subject presentation

A: BE (cilvil), PGDip Fire, MEngSt, PMSFPE. Fire engineer with over 16 years of experience design to NZBC and NFPA codes.

PBFSD in general

1: What is your view on this particular design approach in general?

A: Gives the opportunity to the engineer to apply engineer science to building design to meet the architect and client vision.

2: What is your opinion on the prescriptive approach, and how do you think this approach fits in as we move towards more performance-based design?

A: Prescriptive approach is fit for conventional type buildings where the designer can use as a guide to design a building to a deemed to comply set of requirements. The set of deemed to comply requirements then to be updated based on real fire event experience following risk assessment.

Building regulation system in New Zealand

1: What is your view on the first edition of the building (1992) allowing the performance-based approach?

A: Good approach.

2,: What is your impression of the current version of the code?

A: Updates of the deemed to comply C/ASx requirements to cover the current conventional type buildings is not done. This is in comparison with other international standards.

3: How do you think the two versions compare to each other, what measures have been taken through the years to improve it (or make it worse)?

A :The set of the requirements have not changed. Dividing the document into 7 parts made the simple approach complicated with the end result being the same.

5: Do you perhaps know what measures MBIE have planned to develop the code further?

A: No. It is not obvious what the MBIE approach is.

6: If applicable, what measures do you think need to be made to develop the building code further?

A: Look at other international standards e.g. NFPA, defined the acceptable level of risk in NZ and update accordingly.

PBFSD in New Zealand

1: What is your general impression of the level of quality on the practice of PBFSD?

A: To much emphasis on modelling and less on the overall building design, occupant behavior.

2: If any, what areas need do you think need to be improved or changed to increase the level of quality?

A: The interview subject did not answer the question.

Verification method C/VM2

The interview subject did not answer these questions.

[END OF INTERVIEW]

10.10. Transcript of interview with Benjamin Vallat, New Zealand

Interview subject presentation

Interview subject did not provide feedback on this.

PBFSD in general

1: What is your view on this particular design approach in general?

BV: This approach fits well complex or landmark projects, allowing both creativity and effectiveness. However, I believe this should require a higher level of attention, training, and Quality assurance process. Performance based designs should only be performed by experienced and qualified engineers. The cons are mostly the upfront costs for the client (engineering phase rather than construction), and often a lengthy process which requires multiple stakeholders (client, Authority Having Jurisdiction, Fire service, Peer Reviewer, etc.) to buy in the strategy / design

2: What is your opinion on the prescriptive approach, and how do you think this approach fits in as we move towards more performance-based design?

BV: A prescriptive approach fits in where the projects are simple enough and do not necessarily require a high level of engineering or understanding of the underlying principles to the relevant engineering discipline (here fire engineering). The other benefit is that potentially the nature of a prescriptive approach allows 'anyone' to use it. The cons is really that a prescriptive approach should be conservative and have a limited scope of application. This can also alleviate the process making it faster, but will in general result in a more costly construction (i.e. you might need sprinkler protection and a higher fire rating than you could demonstrate if a performance based approach was undertaken).

Building regulation system in New Zealand

1: What is your view on the first edition of the building (1992) allowing the performance-based approach?

BV: I have not had the chance to work with the 1992 version of the Building Code.

2: What is your impression of the current version of the code?

BV: The current NZBC works well for simple projects, but there are currently some gaps (i.e. performance requirements for Cladding systems) with where the Fire Industry specifically.

3: How do you think the two versions compare to each other, what measures have been taken through the years to improve it (or make it worse)?

BV: As I said, I have not had the chance to compare both Building Code editions.

5: Do you perhaps know what measures MBIE have planned to develop the code further?

BV: Currently the Building Code has a set of guidance documents as follows:

Acceptable Solutions – Prescriptive (7 docs) → Simple building and limited scope (i.e. no atrium, no more than 20 storeys, etc.)

Verification Method – semi prescriptive → Allows for buildings outside of Acceptable Solutions scope, but has recently excluded buildings over 20storeys or with staged/managed evacuation from the scope

Alternative Solution – performance based → MBIE release the guidance (LINK) relatively recently (Mid-2018).

Other measures which I am currently aware of are that MBIE intends to:

A) Amalgamate the acceptable solutions into two documents instead of 7 (one for small residential such as single homes, detached dwellings, etc, and one for all other risk groups). However, I am not sure what restrictions will be placed on the scope of these documents.

B) Cladding – I understand that post Grenfell tower disaster MBIE has been working on a guidance document and a position statement with respect to the design and performance requirements for Cladding systems in NZ. I am not sure however when this will be published

6: If applicable, what measures do you think need to be made to develop the building code further?

BV: Let see once they have addressed A and B what is still missing.

PBFSD in New Zealand

1: What is your general impression of the level of quality on the practice of PBFSD?

BV: It is difficult to say as I have no view on what is performed by most other fire engineering practices and moreover, the recent changes in the guidance documents will require a little bit of time for everybody to get used to it. However, the overall impression I have at the moment is that the quality of the proposed design varies significantly between practices, and also between projects even within the same practices.

2: If any, what areas need do you think need to be improved or changed to increase the level of quality?

BV: In my opinion, a high level of quality on a project relies on two things:

1. Everybody talking the same language (i.e. with the same or similar level of competence), and the engineering being explicitly clear and transparent on the strategy proposed to be adopted for the design, including the modelling inputs and pass / fail criteria.

2. The quality / simplicity of the information fed back to the rest of the design team.

However, there are some challenges in achieving the above. For example, in New Zealand, the AHJ is the Council, and not all councils have resources with the same level of competences in the field of fire engineering available. This may sometimes resulting in misunderstanding between the different parties, which may make the process lengthy and frustrating.

Verification method C/VM2

1: Have you used C/VM2 in your work?

BV: Yes

2: If so; how often do you typically use it?

BV: I have done approximately 175 projects from the single residential house to tall buildings. I have only used C/VM2 in less than 10% of the cases, and a performance based approach for 5 projects.

3: For what types of analytical design do you use it for the most?

BV: C/VM2 is to be used in its entirety. In NZ you are not permitted to mix C/VM2 and acceptable Solutions. However, when doing an alternative solution design (performance based), nothing precludes to use either the acceptable solutions or verification methods inputs as long as they can be justified.

4: What is your impression on how often it is generally used in PBFSD in New Zealand?

BV: Aspects of C/VM2 are used pretty much every time (i.e. to refer to modelling inputs, fire load energy densities, etc.). This generally refers to aspects of C/VM2 which are not typical from those buildings, and sometimes a safety margin or a safety factor may be applied.

5: Do you think it has lead to an increase in the use of PBFSD?

BV: C/VM2 is not a performance based approach strictly speaking. I see it as semi-prescriptive, where you are allowed to use some inputs to justify your design and subsequently the outputs can only vary so much. However, since late 2017 and the latest revision of C/VM2 (amendment 5) some buildings (i.e. tall buildings, or having a staged evacuation) have been specifically excluded from its scope. This has and will continue to result in performance based fire strategy increasingly being used.

6: What are the benefits and drawbacks of using such a method from a purely practicing engineering point of view? Do you perhaps know some practical examples that illustrate this?

BV: The benefits of using C/VM2 is that this sets some level of guidance which are not arguable elements of discussion since they are published by MBIE (Government) and therefore facilitates the process whilst providing some flexibility. The drawback is that most engineers rely way too much on this without considering the context of their project and the limits of the research. Another interesting point is that it a semi prescriptive approach has to be revised frequently in order to keep up to date with current modelling techniques, available softwares, and research based knowledge. In the case of an alternative solution design (performance based), the engineer has to go through the process of demonstrating that the design he has developed is in line with the most recent research or demonstrate why the research is specifically not applicable to the project.

7: Do you think it has improved the overall level of quality of analytical design in New Zealand since its introduction?

BV: It is difficult to ascertain whether the overall level of quality of the design in NZ has improved due to the introduction of a semi prescriptive approach or performance based since the techniques of design / construction, softwares and modelling have also rapidly evolved and improved over the same time.

8: Regulation-wise, do you think it is implemented correctly as it is currently now? (ie. voluntarily/mandatory path of alternative design)

BV: Yes. It has to be voluntary process, but regulated so that complex designs are thought through rather than just ticking the box in a prescriptive framework.

9: Do you feel that the authorities are able to keep up with updating the recommendations as the years go by and new experience and knowledge is acquired?

BV: It is very difficult to keep up to date the regulations with the ever evolving field of engineering and research development so there will always be a time lag between the time the outcome of a research is made public and the time it is finally adopted in the regulations. A performance based approach bridges some of these gaps where possible, but within the limit of what is societally acceptable and within the Building Code.

10: If applicable, given the choice, would you chose to change C/VM2 or remove it completely?

BV: I believe C/VM2 as a semi-prescriptive approach has some benefits so I would not remove it. However, some work is required to address/clarify the applicability or range of applicability of some of the parameters called within it.

11: If applicable, If you want to change it, what types of changes would you do?

BV: Refer 10 above. The applicability and basis of the criteria developed / used within it needs to be clarified.

12: Any other concerns regarding C/VM2 you want to express?

BV: NO

Other views and matters

Are there any other views or matters concerning the practice of performance-based fire safety design that you want to express not covered in the questions?

BV: N/A

[END OF INTERVIEW]