Exploring Potential Problems Causing the Final Implemented Design to Deviate in a Performance Based Fire Safety Design Approach

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Report 5456, Lund 2014

HOST UNIVERSITY: Lund University

FACULTY: Faculty of Engineering, Lunds Tekniska Högskola (LTH)

DEPARTMENT: Department of Fire Safety Engineering

Academic Year 2013-2014

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Promoter: Henrik Hassel

Master thesis submitted in the Erasmus Mundus Study Programme

International Master of Science in Fire Safety Engineering

Title - Exploring Potential Problems Causing the Final Implemented Design to Deviate in a Performance Based Fire Safety Design Approach

Author – Hanish Arora

Report 5456
ISSN: 1402-3504
ISRN: LUTVDG/TVBB—5456--SE

Number of pages: 67
Illustrations: Hanish Arora

Keywords

Performance Based Fire Protection Engineering Design, Fire Risk Assessment, Fire Safety Design

Abstract

The fire protection engineering is primarily about the design of fire protection systems based on identified fire risks in a building. The design process comprises of three main stages i.e. conceptual design stage, construction/implementation stage and final implemented design which is the end product. Sometimes the final implemented design deviates from either the defined goals and objectives, or conceptual design or fire risk assessment. The literature reviews and interviews conducted for the various Swedish fire safety professionals in this thesis, helped to identify the potential reasons which lead to this deviation. The results from the two methods established that the possible major reasons causing this deviation are disassociation of fire risk assessment in design during different stages, lack of justification in application of assumptions and data, problems in sub-system interactions, lack of expertise in monitoring, problems in verification process etc. A review of the new Swedish building regulation on performance based design approach identified that the new regulation have been able to address some of the identified problems like verification process etc. causing deviation in the final design. But still lot more comprehensive research and guidance is required in the areas of sub-system interactions, monitoring during the design implementation etc.

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Date – 30/04/2014 HANISH ARORA

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A review of the new Swedish building regulation on performance based design approach identified that the new regulation have been able to address some of the identified problems like verification process etc. causing deviation in the final design. But still lot more comprehensive research and guidance is required in the areas of sub-system interactions, monitoring during the design implementation etc.

सार

आग संरक्षण इंजीनियरी मुख्य रूप से किसी भवन में अभिज्ञात आग जोखिमों पर आधारित आग संरक्षण प्रणालियों के डिजाइन के संबंध में है। डिजाइन प्रक्रिया में तीन मुख्य स्तर होते हैं अर्थात अवधारणात्मक डिजाइन स्तर, निर्माण/कार्यान्वयन स्तर और अंतिम कार्यान्वित डिजाइन, जो अन्त्य उत्पाद है। कभी-कभी अंतिम कार्यान्वित डिजाइन या तो परिभाषित उद्देश्यों एवं लक्ष्यों अथवा अवधारणात्मक डिजाइन अथवा आग जोखिम आकलन से हटकर होता है। इस शोध-प्रबंध में विभिन्न स्वीडिश आग सुरक्षा व्यावसायिकों के लिए आयोजित साहित्य समीक्षाओं तथा साक्षात्कारों से संभावित कारणों का पता लगाने में सहायता मिली जो इस परिवर्तन को अग्रसर करता है। इन दो पद्धतियों के परिणाम से यह बात स्थापित हुआ कि इस परिवर्तन के संभावित मुख्य कारण हैं, विभिन्न स्तरों के दौरान डिजाइन में आग जोखिम आकलन का अलग होना, धारणाओं तथा डाटा के अनुप्रयोग में औचित्य का अभाव, उपप्रणाली अंतः क्रिया में समस्याएं, मॉनीटरिंग में विशेषज्ञता का अभाव, सत्यापन प्रक्रियाओं में समस्याएं आदि। कार्यनिष्पादन आधारित डिजाइन दृष्टिकोण पर नए स्वीडिश भवन विनियमों की समीक्षा से यह स्थापित हुआ है कि नए विनियमों से सत्यापन प्रक्रिया आदि जैसी कुछ अभिज्ञात समस्याएं जिससे अंतिम डिजाइन में परिवर्तन होता है, का समाधान हुआ है। किंतु डिजाइन कार्यान्वयन के दौरान उप प्रणाली अंतः क्रिया, मॉनीटरिंग आदि के क्षेत्रों में अभी बहुत अधिक व्यापक अनुसंधान और मार्गदर्शन की आवश्यकता है।

Table of contents

List of abbreviations

1. FRA – Fire Risk Assessment
2. PBFPED – Performance Based Fire Protection Engineering Design
3. LU – Lund University
4. RSYD – Raddningstjansten Syd (Region South Fire and Rescue Service)
5. FSM – Fire Safety Manager
6. FPC – Fire Protection Consultants
7. FPE – Fire Protection Engineer
8. FSS – Fire Safety Strategy
9. ASET – Available Safe Egress Time

List of tables and figures

1. Introduction & Objectives

1.1 Background

The Fire Protection Industry has been growing at a rapid pace since the last 2 decades because of the constant development and increasing industrialization; the subsequent fire hazards have also multi-folded [1]. This has resulted in more exploration and innovation in the fire safety industry. In order to manage and tackle the fire hazards associated with a project; the design of the fire protection systems becomes very important. This design of the fire protection systems is based on either the prescriptive codes or on Performance Based Fire Protection Engineering Design (PBFPED).

The prescriptive code based design implies to follow the guidelines and detailed rules set in the building regulation of the particular country. The provisions in these codes have been empirically derived but perhaps do not have proper technical authentication, which means that the specifications in the prescriptive codes are often lacking technical details. Many countries in the world are still using this method for the design of fire protection systems; the drawback with this method is that it doesn't allow for innovation and restricts the design choice.

With the rapid growth and development, introduction of new complex structures, the use of prescriptive code based design is losing its functionality. Hence most of the developed and developing countries are now shifting towards the PBFPED method [2] which allows for innovative and more flexible design choices. In a PBFPED, the fire protection system is based on the identified fire hazard/risk in the building and understanding of the various factors of a fire which are fire initiation, fire spread, occupant behavior as well as material and structural response to the fire.

Another aspect of this shift from prescriptive code based design to performance based design is the cost efficiency and required level of safety. The prescriptive code based design has been in place in all the countries and the society has accepted it [2]. From a fire safety engineering review it has been observed that these prescriptive code based designs tend to be more conservative than required and are therefore not very cost effective [2]. But the PBFPED allows stakeholders to opt for a more cost effective design with an acceptable level of safety (based on various stakeholders' objectives and goals) [3].

In the PBFPED approach, the design is based upon the design objectives and goals as identified by the stakeholders. The PBFPED approach can be divided into three stages "as reflected in standards like BSI [4], ISO [5], IFEG [6], and SFPE [7]":

1. *Conceptual Design Stage* – In this stage a concept design is made based on the inputs from the different stakeholders and identifying the various risks/hazards associated with a project. This stage involves various assumptions and application of various other data like reliability data, statistical data and other material properties.

2. *Construction/Implementation Stage* – In this stage, the approved concept design goes into implementation during the construction phase of the project.

3. *Final Implemented Design Stage* – In this stage the final design that is implemented during the construction is verified and post all verifications and checks if deemed to be safe, the project goes into operation.

The PBFPED method involves a thorough risk assessment of the associated fire hazards which the building might encounter in its lifetime. This assessment enables the consultants, designers, engineers and stakeholders to understand the fire hazards that their project faces or may face during its operation. The approach used in conducting the fire risk assessment can either be probabilistic, deterministic or both [8].

On the basis of this assessment, fire protection systems are designed to cover the identified fire risks. This is more of a scientific approach which involves experimental data, certain assumptions are made and sometimes statistics are used. To compensate for all these assumptions and uncertainties, safety factors are used based on the experience of the designers and consultants to ascertain an acceptable level of safety in the buildings.

The PBFPED tends to face various challenges like interaction of Fire Risk Assessment (FRA), use of assumptions and data, inclusion of tradeoffs in design, subsystem interactions in the design, verification process etc. [1]. These challenges can lead to a deviation of the final implemented design if not addressed.

The lack of interaction of FRA during the different stages of the PBFPED implementation of the building has been found to be one of the main reasons for the considerable unpredictability of the achieved performance levels of the design [9]. Additionally there has been a consistent lack of quantifiable or verifiable performance requirements and criteria for the PBFPED [10] which results in problems in the verification of the design.

In this study the major challenges as identified in the article by *B.J. Meacham and A. Alvarez* [1] have been analyzed. This analysis will help to understand the potential reasons that lead to a deviation of the final implemented design.

Although the overall aim of this study is to be a generalized study and not particularly focusing on the practices in any one country. Since it is being conducted in Sweden, a major part of the study would be concentrated on the Swedish designs and inputs. Additionally the performance based design regulation in Sweden has been updated recently that provide more specifications and details in comparison to the previous regulation which were more generic [11]. It would be interesting to gain some insights regarding the new regulation and their impact on the identified gaps in this research.

1.2 Aim

The aim of this thesis study is to explore and identify potential reasons and factors that lead to a deviation in the final implemented design. This deviation can results in either non compliance to the design goals and objectives, or non-adherence to fire risk assessment of a design, or underperformance or an over performance of a design.

1.3 Objectives

As this thesis is exploring the problems causing deviation of the final implemented PBFPED for a building project, so the following objectives have been formulated:

- To investigate whether there are deviations in the implemented design and, if this is the case, identify the reasons and factors which lead to this deviation.
    - To investigate the interaction of FRA during the different stages of PBFPED.
    - To check if the final implemented design follows the conceptual design.

- The available literature as described in section 3.3 below, indicates factors like application of assumptions and data, imbalance between cost efficiency and acceptable safety level, justification of sub-system interactions and verification process as the major reasons and factors for the deviation so:

- To understand the application and justification of assumptions and data in design.
- To understand the balance between the cost efficiency and acceptable level of safety of a PBFPED.
- To understand the sub-systems interaction in PBFPED and the problems and challenges faced during the implementation of design.
- To understand the verification process of a PBFPED.

- To analyze the impact of the new Swedish regulation for PBFPED on the above reasons and factors.

1.4 Delimitations

- During this study it was realized that the objectives could be seen as different research areas in themselves and thus constitute vast individual subjects. Hence with reference to this thesis, these have been categorically explored within the subject boundaries and the focus has been restricted to identify the factors and reasons based on the experiences and perceptions of different fire safety professionals.

- This study is restricted to fire protection building design of new buildings and does not apply to the lifetime of a building. During the life of the building the occupancy and operations in the building are subject to change. The PBFPED approach is restricted to the identified occupancy and operation, if there is any deviation; the design needs to be re-worked.

- Another limitation of this study is the scope; this study has been extensively conducted in Sweden by interviewing various professionals of the fire protection industry. Although for the literature review, global papers, articles, journals and books have been referred. Generalizations and extrapolations to other countries should be done cautiously.

2. Methodology Overview

At the start of this thesis research, possible methodologies were explored, which could help in sorting out the subject. Different methods such as document studies, project visits, literature review and interviews with different parties involved in the fire safety design were possible. But after analyzing the time limitation and boundaries of the thesis it was realized that the literature review and interviews would be the best suited methods. The identified factors and reasons are primarily based on the experience and perceptions of the fire protection engineering practitioners. Figure 1 describes the process, and the following sections provide a detailed account of method used.

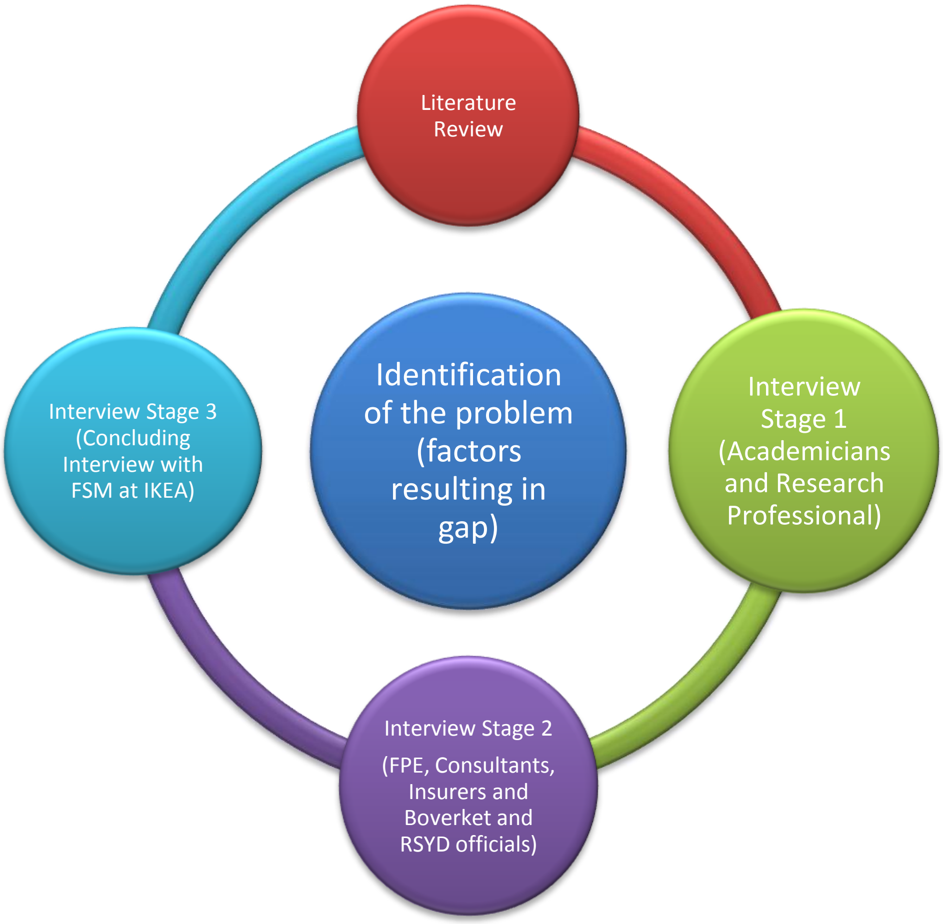

Figure 1 Methodology Flowchart

2.1 Literature Review

In this method, a review of the literature like books, articles from journals (Journal of Fire Protection Engineering) and scientific papers, and search words like fire safety design etc. were conducted. As this thesis focuses on the complete PBFPED approach, so various associated literature were referred for understanding the concept of different stages and processes involved in this approach. This literature was found to be very important in identifying that there are various challenges and problems in the implemented design because of different reasons. Hence the review of literature led in establishing the concrete foundation of this thesis that is to explore the reasons and factors which lead to the deviation in the implementation of the final design. The literature enabled to achieve an understanding of the various concepts associated with the objectives of this thesis study. The literature review helped to get a deeper knowledge and insights on the fire safety engineering and different aspects associated to it. From the literature review it was identified that there are many factors like lack of interaction of FRA, sub-system interactions, and balance between cost efficiency and safety level, absence of a robust verification process that leads to this disparity. A brief summary of the associated important concepts of these literatures that were relevant for this study has been given in the section 3 below.

The findings of the literature review i.e. the various factors causing the deviation in the final implemented design; were used to formulate the questions for the interviews. These factors were structured as interview questions, to identify and investigate their effect on the final implemented design.

2.2 Interviews

After realizing the theoretical background of various process and regulation associated with the PBFPED approach and other related problems; the next method of conducting interviews with different parties associated to the design was adopted. To meet the objectives of this thesis, interviews were conducted for various professionals/parties associated with the fire safety design of a building.

These interviews as shown in the Figure 1, enabled to prove and establish that the factors as identified from the literature reviews tend to cause a deviation in the final implemented design. The further details of the interviews have been described in the separate section of Interview Process.

3. Theoretical Points of Departure

This chapter explains the key concepts associated with this study. It describes the various concepts used in FRA and PBFPED approach. Various papers, articles and books which were referred and used in assimilating the different opinions and aspects associated with the gaps between the FRA and implementation of PBFPED have been discussed below.

3.1 Fire Safety Design Process

The fire safety design is the design of the fire safety systems (active and passive) for a particular building or project. This design is primarily aimed at life safety. One of the main components of the fire safety design is the building regulation of the state or country [9].

Nowadays there are two types of fire safety design processes in most of the countries. The first process is the prescriptive code based fire safety design process which was introduced many years ago. The regulatory provisions of the prescriptive design were empirically derived and lacked technical fundamentals but are still accepted widely. The prescriptive requirements in building regulation reflect the low levels of technology previously available for design of fire safety and protection in buildings [9].

This prescriptive design process has resulted in the achievement of fire safety and protection that is accepted by society. It has been observed that this process neither results in the most cost efficient design nor maintains a reliable safety level [9]. Additionally the prescriptive design process restricts the design choices and innovation.

The second process, i.e. PBFPED process, was developed using scientific understanding of various aspects of fire safety, e.g. responses of materials, the building and its occupants to fire etc. This process enables greater flexibility in the design choices and more cost efficient designs.

Advantages of PBFPED over prescriptive code based design:

The following advantages of PBFPED over prescriptive code based design are suggested by the SFPE Guidelines [7].

- The PBFPED approach caters for the unique aspects or uses of a building.

- The PBFPED approach provides an option for selecting and developing an alternate fire protection solution depending on the type of project and its requirements.
- The PBFPED approach allows for the comparison of safety levels of various alternate design options and hence enables to determine the desired safety levels and corresponding costs.
- The PBFPED approach results in more innovative design options because it requires the designer to use different tools in analysis thus an increased engineering approach.
- The PBFPED approach enables the design of various fire protection systems in integration rather than being designed in isolation. This enables the designer to accomplish a proper fire protection strategy for a project.

Detailed description of PBFPED:

The PBFPED approach is distributed into three stages as described in the figure below and further explained in the following section. The process flowchart has been adapted from the SFPE guideline; further changes have been made for better description and explanation [5], [6], [7].

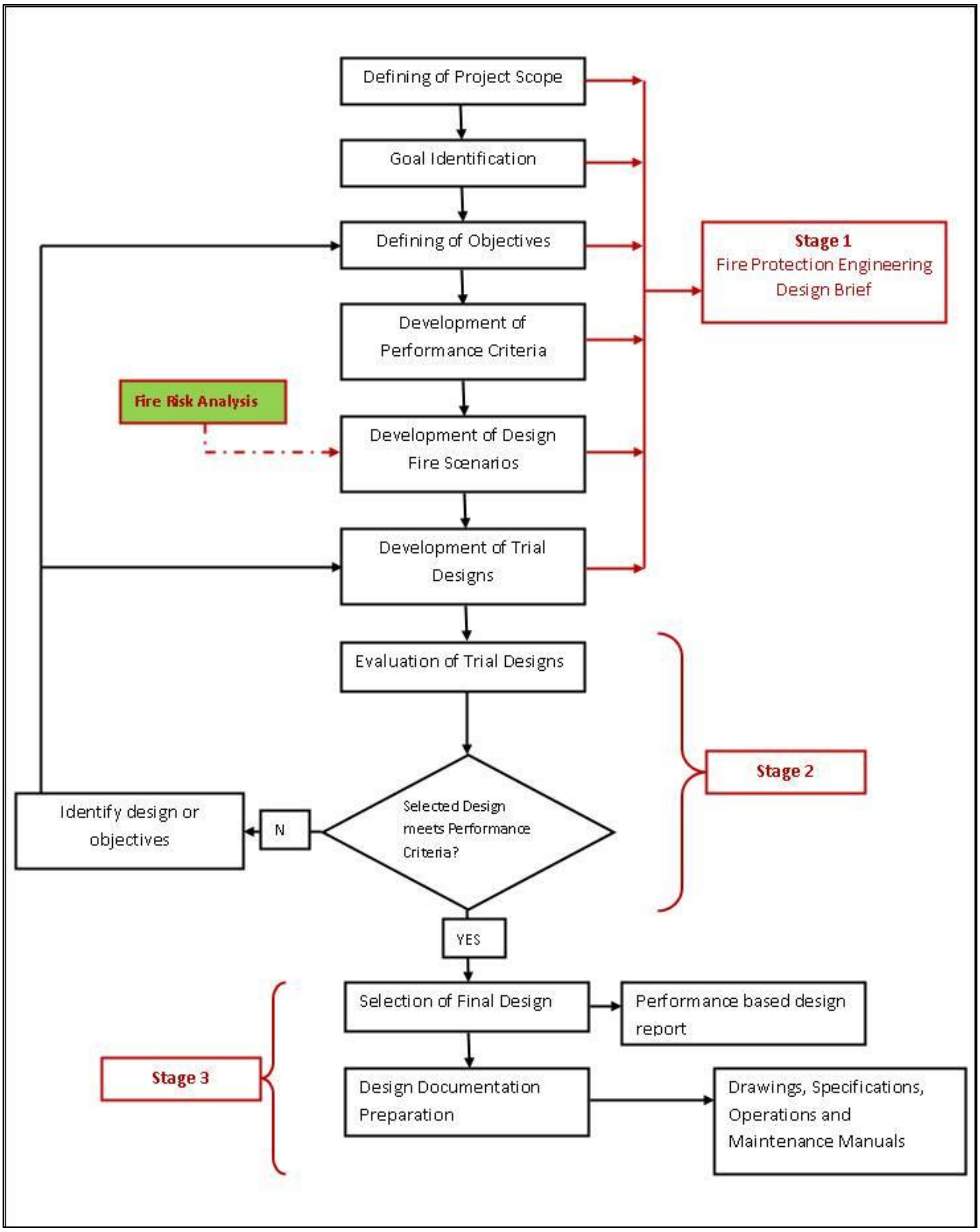

Figure 2: Performance Based Design Process Flowchart

Stage 1

(Fire Protection Engineering Design Brief):

In this stage, the major aspects are the realization of a project, defining a project scope, goal identification, defining of design objectives, development of performance criteria, development of design fire scenarios and establishing trial designs.

Defining of Project Scope:

This step of performance based design consists of identifying the constraints on design and project, various stakeholders and parties to be associated with the project. Various other preliminary aspects like proposed building construction, features, characteristics of occupants and buildings, building use, applicable codes and project management methods are identified.

Goal Identification:

After the definition of the project scope the next step is the identification of the fire safety goals of various stakeholders associated with the project. These goals can be life safety, property protection, business continuity, historical preservation and environmental protection.

Defining of Objectives:

After all the stakeholders agree on certain goals for a project, the next step is to define the objectives. These objectives are technical definitions of the agreed goals of the stakeholders. These could be defined in terms of loss of life, financial losses, maximum allowable conditions etc.

Development of Performance Criteria:

Once the design objectives are defined, these objectives are quantified to develop the performance criteria to be met by the design. The performance criteria are used to compare the performance of various identified trial designs. The performance criteria for a design can be the threshold values of materials, gas temperatures, or thermal exposure levels for human beings.

Development of Design Fire Scenarios:

After the performance criteria are established, various design alternatives are developed and analyzed to meet the established performance criteria. In this step initially the possible fire scenarios are identified; these fire scenarios are possible fire events in the building. These are developed based on the fire risk identification and assessment (detailed in section 3.2) of the project. After the identification of possible fire scenarios, they are then sorted out into a set of design fire scenarios.

Development of Trial Designs:

After the development of design fire scenarios, the next step is to establish initial designs that are planned to meet the performance criteria. These initial designs are the trial designs that consist of various fire safety systems and other building features that might be required to meet the performance criteria. Apart from developing the trial designs, the method of evaluation of these designs that should be agreed upon by all stakeholders is also identified in this step.

Stage 2

Evaluation of Trial Designs:

In this step, the trial designs evaluation is conducted using the design fire scenarios to verify whether or not the trial designs meet the established performance criteria. The trial design which is successful in the evaluation can then be considered as the proposed final design.

If none of the trial designs meet the performance criteria, then the designer needs to go back in the process and re-design the objectives or re-develop the trial designs and perform another evaluation for the new trial designs.

Stage 3

Final Design Concept Selection:

Once a trial design is successfully evaluated for the performance criteria, it can be considered as the final design. If there is more than one successful trial design, further analysis is required. In this analysis there could be various influencing factors like timelines, financial considerations, maintenance and other factors.

Design Documentation:

After the final design has been identified, the next step is to prepare the design documentation. This documentation is important to make all the stakeholders understand about the various aspects of the design like, design implementation, operation and maintenance etc. This documentation comprises of design brief, design report, detailed specifications and drawings, and operations and maintenance manuals.

3.2 Fire Risk Assessment (FRA) [12], [13]

FRA is a process of assessing the identified risks to the people and property as a result of unwanted fires. In a FRA possible undesired fire scenarios are considered with their probabilities of occurrence explicitly in a probabilistic approach or implicitly in a deterministic approach as well as their consequences. These fire scenarios are basically fire events that are laid out chronologically, which are linked together by the success and failure of fire protection measures. Few fire events that have been identified as the major events which should occur before a fire causes harm to occupants are as follows:

I. Fire ignition
II. Fire Growth
III. Smoke Spread
IV. Failure of occupants to evacuate
V. Failure of the fire department to respond.

Fire protection measures are used to prevent the occurrence of each of the above events. The probability of a fire scenario relies on combined probability of failure of all fire protection measures. The risk to occupants relies upon the probability of fire scenario and consequence of a fire scenario i.e. level of damage to the occupants.

As stated in section 1.1 the PBFPED method involves a FRA to identify the associated fire hazards in a project. The approach used can be either a probabilistic or deterministic and can even be both, depending upon the choice of the clients and FPE.

A probabilistic approach is a quantitative approach which includes probabilities of fire scenarios and their respective consequences. In a probabilistic approach consequences of each scenario are analyzed and then weighted by their probabilities of occurrence. A deterministic approach on the other hand, is a more qualitative approach (quantitative in general) which does not estimate the probabilities of fire scenarios explicitly. Instead it considers the consequences associated with the worst credible fire scenarios. In a deterministic approach, scenarios that are expected to occur with a probability above some threshold value are analyzed to determine their consequences [13].

There has been a lot of debate on the use of these two approaches and research is still ongoing to identify which is best suited for the fire safety design [8]. The use of any of the two approaches tends to induce an uncertainty in the resulting design.

Generally a FRA in a project is conducted based on the fundamental approach. This approach involves three steps:

1. Development of all possible fire scenarios that a fire may initiate.
2. Development of each fire scenario in a sequence of fire events that may lead to actual fire development. These fire events include fire growth, smoke spread, occupant evacuation etc.
3. Modeling of the various fire events to forecast the outcome of occupant fatalities and property loss.

3.3 Challenges for Performance Based Fire Protection Engineering Design (PBFPED)

The PBFPED approach has been in place for slightly more than 2 decades now. A lot of countries like Sweden, Denmark, Australia, New Zealand, etc. have adopted this approach in their regulation and the other countries have started accepting this approach. Even though this approach is being accepted widely but there are a few problems/challenges faced in this approach. A few major challenges have been identified in the article by *B.J. Meacham and A. Alvarez* from Journal of Fire Protection Engineering [1].

- The PBFPED approach in most of the countries is currently dependent on guidelines and standards which are more generic and process oriented with no specification of the critical components such as performance criteria, quantified design fires, design verification etc.
- Limited knowledge of the subject for different stakeholders – few shortcomings have been identified in the Fire Engineering Brief as the stakeholders are unaware of the design methodology and are risk averse [14].
- Another problem in the PBFPED approach is limitations in the data availability and use of computational tools required for the evaluation.
- Since the guidelines are generic, this can result in different designs for the same project each with different levels of risk to occupants, building etc. The

reason for this is that there is no well defined guideline on selection of acceptance criteria and design fire scenarios.

- A few technical issues have been identified in the calculation methods and appropriateness of the data used for justification of trial design acceptability.
- Few uncertainties have been observed in the areas of consideration of human behavior, risk perception and other specific areas of the PBFPED approach.
- The level of safety is not acknowledged and this leads to an imbalance in the safety level and cost.
- Lack of guidance on the application of the generic values for the critical components of the PBFPED such as performance criteria etc.
- Even though the regulatory bodies and authorities have tried to define and quantify the performance criteria and design fire scenarios in their respective countries, the intent and reasoning behind these quantifications is being lost. The regulation prescribes more detail on the specification of scenarios or on how to calculate scenario consequences. This does not necessarily mean that they are applicable to specific requirements of the project.
- Another phenomenon related to human behavior aspect of the PBFPED a stampede is not accounted for when assessing the life safety performance associated with fires in buildings. A stampede is a reason for an increased number of casualties in case of a fire.
- Determination of the most influential factors affecting the evaluation of trial designs is another challenge that is faced in the PBFPED approach. During evaluation process various factors like sensitivity of subsystem output to design objectives cost benefit analysis, uncertainty management etc. are either not clearly assessed or not always considered.
- The assessment of the PBFPED by comparing the design with a prescriptive solution is another challenge. It is a common approach used globally to check whether the engineering design is safe or not, but there is no proper justification in the comparison. The details and knowledge behind a prescriptive solution are limited and the quantifications are based on good practice and partial empirical evidences. In a PBFPED approach, this rationale is not applicable and demands more transparency.

- Another challenge is to foresee the future use, occupancy and management of the building. In a project there are various stakeholders and parties involved and often each party or company is responsible for a limited part of the building project. Often minor changes may be done without checking for the consequences. This results in the prerequisites of the Fire Safety Strategy report (FSS) being overlooked and not being taken care of. Generally the project in-charge should manage these interconnections, but it does not necessarily happen in relation to fire safety design [15].
- The PBFPED approach demands an integrated approach to building fire performance and all the different system interactions have to be considered. Whereas during modeling of the scenarios to analyze the life safety objectives, many factors such as fire and evacuation interactions are not well addressed (factors like counter flows of fire fighters, door opening and closing by evacuees are not considered). This leads to a challenge to define the reliability of the design.

The PBFPED design approach faces these challenges in practice and application. The literature review shows that the identified challenges have resulted in possible deviations and shortcomings in understanding, application and implementation of the PBFPED process, and inconsistency in the performance levels of the design.

3.4 New Regulation on Fire Safety Engineering (PBFPED) in Sweden [11]

Background on the new regulation [16]***:***

It has been nearly two decades, since the introduction of the PBFPED approach. In 1994, Sweden went from prescriptive building requirement to performance based building regulation. The revised fire safety guidelines were implemented on 1st of January 2012 [16]. The main objective of the new regulation is to create fire safety requirements with well defined performance levels and purposes. The review of the previous regulation revealed that there were uncertainties regarding the acceptable level of safety. The factors responsible for the uncertainties were [17]:

1. No national guidance for fire safety engineering
2. No legal framework to perform the design

3. The regulation was function based with limited details about the performance levels or acceptable solutions.

The different consultants and designers undertaking a performance based design, made their own assessment and created design parameters like heat release rate etc. This led to inconsistency and variance in the market as there were options of different designs with different levels of safety for a project. There was no definition for the acceptable level of safety.

The new guidelines give general recommendations on the acceptable level of safety by either quantitative criteria (some cases) or by deemed to satisfy solutions (most cases). The recommendations on performance based design as per the new regulation have been able to:

1. Provide a legal framework for PBFPED
2. Provide specific guidance on acceptable level of safety

The effect of new regulation on fire safety engineering:

The *BBR 19* regulation [22] specifies how the analyses should be done and recommends input data and acceptance criteria. The scientific description and background for the data values in the regulation is ambiguous. The required fire scenarios and design fires as described in the regulation are neither based on scientific data nor conservatively chosen [11].

The new regulation has resulted in prescribed design conditions for certain design situations. In the new regulation, the design fires recommended are smaller than those that were being used previously which will result in an increase in ASET (Available Safe Egress Time) when developing designs. Another benefit is that the clients will get more consistent recommendations independent of the choice of fire engineer, which means there will be a lot more consistency in the designs. The new regulation have simplified the control by the authorities and made the whole process more transparent [11].

The new regulation show more influence of the fire protection systems on the designs, this would result in increased use and application of these systems. Also the regulation has introduced robustness checks for different fire protection sub-systems of a building; to check for the inter-dependency and reliability of different systems.

With the introduction of recommended values and scenarios etc. in the new regulation, a minimum acceptable level of safety has been defined. The need of verification of the design i.e. verification of the final implemented design to the conceptual design and to design goals and objectives is addressed. This approach can be used to determine what verification methods can be used and whether a robustness assessment is needed or not.

3.5 Summary of Points of Departure

The literature review reveals that there are various challenges and problems that the performance based design approach faces. These problems give rise to potential deviations in the performance of a final implemented design from the conceptual design. The major problems and challenges that have been identified are as follows:

1. Absence of national guidelines or regulation for performance based design approach in different countries. The present guidelines are more generic and global which leads to an individual interpretation of the requirements and guidelines by various FPE's. This further result in huge variance in the designs.
2. There is no legal framework defining the process of developing a performance based design which results in different Fire Protection Consultants (FPC) and FPE performing the design in different approaches. This introduces a lot of inconsistency in the design.
3. The safety levels are not well defined and often it is difficult to estimate what is safe for the client.
4. There is no clarity upon the verification process, what methods need to be used and how the process needs to be conducted.
5. There is limited knowledge and understanding on the different sub-system interactions in the design; all the different systems are designed in isolation. A standard explaining how to deal with the, establishing of sub-system interactions and their complexities is required.
6. There is a problem of awareness, knowledge and communication about the performance based design among various people associated with the project.
7. The understanding about the balance between the cost factor and an acceptable level of safety is another concern. The client/customer is focused on the cost and expenditure factor and in a scenario with no clarity of the acceptable safety levels, this leads to an imbalance between the two aspects. This imbalance can sometimes result in under-estimation of the risks.

The implication of the new Swedish regulation on these challenges was verified in this study and it was realized that the new regulation has been able to provide solutions to a certain extent:

1. The new regulation forms a part of the national building regulation, with some recommendations about the various design aspects that were previously generic.
2. The regulation has provided a legal framework for the FPE to develop the performance based design, with a defined structure.
3. The regulation also provides a set of recommendations that can be interpreted as the minimum acceptable level of safety to be satisfied by the different designs.
4. The verification process has been defined in the new regulation, describing what methods to be adopted and what all needs to be verified.

To verify the challenges and the effect of the new Swedish regulation in practice; interviews were conducted for the various fire safety professionals involved in this design approach with different roles to play. The detailed description about the interviews has been further given in the Section 4 below.

4. Interview Process

The interviews are the most important part of this study, which were aimed at exploring and identifying the gaps between FRA and PBFPED implementation. Research interviews for various organizations/people involved during these two processes of a project were conducted. For setting up the interview process, seven stages of an interview investigation, as described by *Steinar Kvale* [18], were used.

Thematizing - (defining of the objectives/purpose of the thesis and the associated concepts): The theme of the interviews corresponds to the objectives and various theoretical points of departure as detailed in previous sections.

Designing - (planning of the design of the study and the whole process from identifying the objectives to reporting of the interview results): In this study the objectives were defined during the set up of the research subject and the corresponding structure was established.

Interviewing - (interviews were conducted for the various groups/professionals with a reflective approach to the knowledge sought): Interviews were conducted for various groups or professionals associated with the fire safety design of a building, to understand the problems and how they are being dealt with.

Transcribing - (interview transcriptions): During the process of conducting interviews transcripts were prepared from oral speech and written text.

Analyzing – (analysis of interviews): The various interview transcripts were analyzed to set up a correlation with the objectives of thesis. The analysis has been further described in the section Results & Discussion (Interview Analysis).

Verifying – (verification of analyzed transcripts): After analyzing the interview transcripts they were summarized. These were then shared with different interviewees for their verification and review. This verification was conducted to ensure the reliability and validity of the interview results.

Reporting: once the interview analyses were successfully verified, the individual interview analyses were categorized into different groups which are presented in the results.

4.1 Interview Set-up

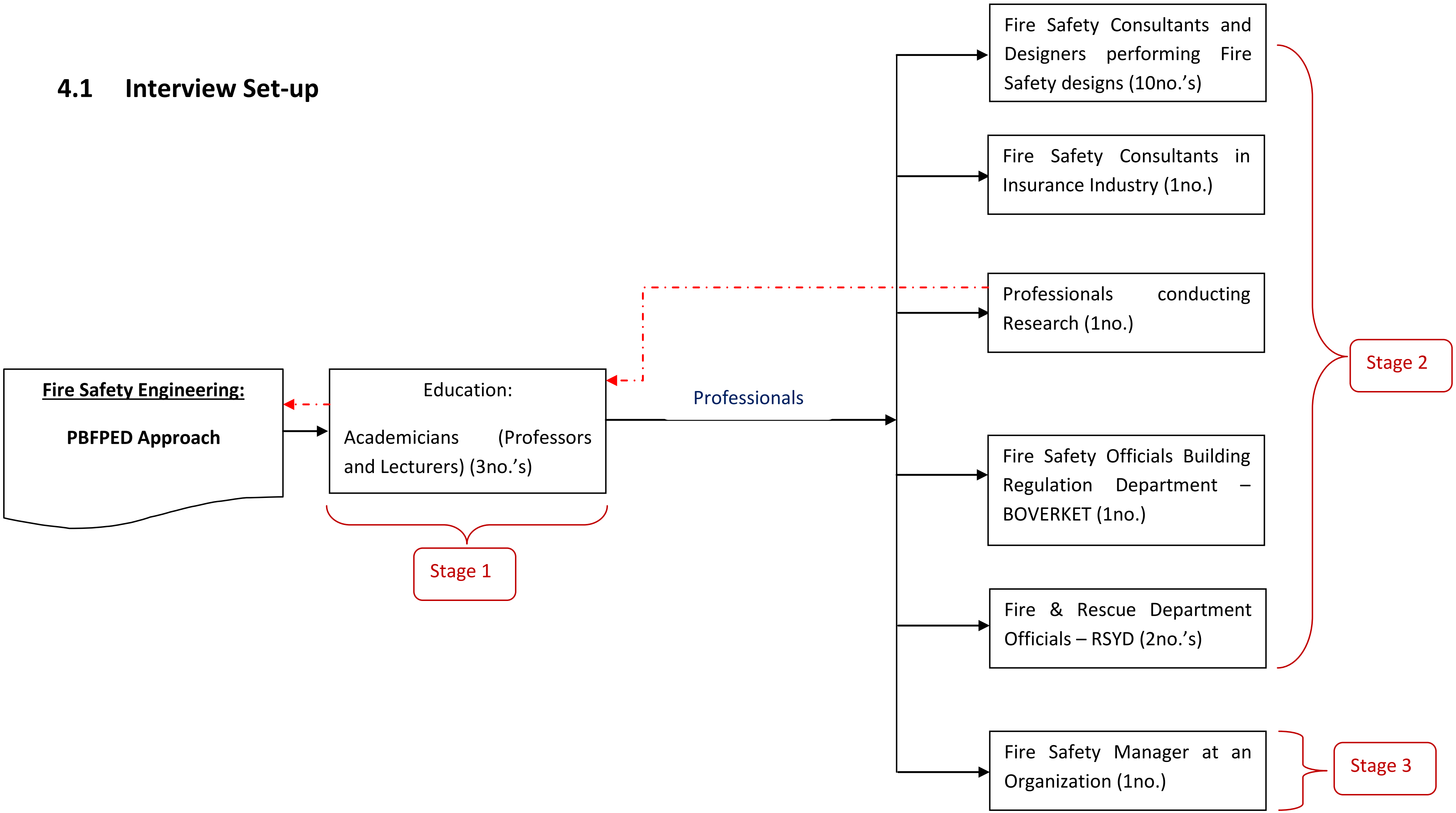

Figure 3 Interview Process Flow

The interviews were set-up to cover up different professionals associated with the PBFPED approach. These interviews as described in the Figure 3; have been classified in three stages:

***Stage 1*:**

The first stage was the pilot interviews which were conducted for different professors and lecturers at the Department of Fire & Safety at Lund University. These pilot interviews were conducted to understand their opinion about the whole process. An academician's job is to educate and train students who will become fire safety professionals. It was therefore necessary to understand what aspects are being taught to the students. The pilot interviews gave a chance to verify the co-relation of the interview questions with the objectives of the thesis.

Another interview of the first stage was the interview with a professional at the SP research institute, who is involved in conducting research on various subjects associated with the fire safety engineering. During the meeting it was realized that he is associated with a research subject which's objective is to identify various problems in the application of PBFPED approach in Sweden and to see through different stages of a project. This interview helped to get a more complete understanding of the problem.

In total four interviews were conducted at this stage three academicians and one for the research professional.

***Stage 2*:**

The second stage focused on identifying and exploring the problem as perceived by professionals associated with the PBFPED. In this stage, the interviews were conducted for experienced fire safety professionals such as consultants, designers, engineers, associates and officials working in various fire safety engineering companies, insurance companies, building regulation department, fire and rescue department and research organizations.

These interviews helped to understand the various challenges that are faced during the designing process. They also helped in realizing other problems associated with the PBFPED approach in different stages of the project. An understanding of the various aspects concerning the application of the statistical data and assumptions during the designing of a fire protection system and also how a balance between the cost efficiency and acceptable safety level for a particular project is maintained was achieved. The literature review showed that these are the major challenges in the

PBFPED approach and may result in the deviation of an implemented design from a concept.

The interview with an associate from the insurance company, gave further insights on the challenges and problems during a whole project. This interview also addressed the problems at the stakeholder's level and the challenges in important aspects like verification of the design etc. which often lead to deviation in the performance of a PBFPED [1].

Another set of interviews was conducted with officials working at the building regulation department – Boverket and officials from fire and rescue services – RSYD. These interviews were conducted to analyze the impact of the new Swedish regulation on the above reasons and factors. The interviews with the fire & rescue service officials helped in understanding their perspective of the problem and their thoughts about the PBFPED approach.

***Stage 3*:**

The last interview was conducted for the Fire Safety Manager (FSM) at IKEA. It helped to understand the stakeholder's point of view. The interview allowed, exploring the various other reasons behind the problem and how these problems are tackled and managed without compromising on the goals and objectives.

4.2 Interview Questions

The interview questions were formulated after associating each, with the objectives of this study. The description of the questions and corresponding thesis objective are shown below.

Objective 1: Investigation of interactions between FRA and fire protection system design; and conceptual design to final design.

1. How do you see the interaction between fire risk assessment and fire protection design implementation during the various stages of a project; and implementation of a concept design?

2. If there are problems or deviations in the interactions of the above two processes, then what are the possible reasons and factors for this deviation?

Objective 2: To understand the application and justification of assumptions and data in design

3. In performance based design various assumptions and statistical data are used to determine the different aspects like performance criteria, material properties etc. of a project. But with the rapid development all around the hazards and risks associated with a project are changing and becoming more and more complex. So how do you justify the application of data and assumptions which come from the past?

Objective 3: To understand the balance between the cost efficiency and acceptable level of safety of a performance based fire protection system design.

4. It is said that PBFPED approach is two pronged – choosing most cost efficient design and retaining an acceptable level of safety. So how do you tend to address this situation in your work and manage the balance?

5. In order to maintain the balance between the two aspects of cost efficiency and acceptable safety level, how do you determine that the proposed safety levels are non-compromising or safe enough and at the same time cost effective?

Objective 4: To understand the sub-system interactions in PBFPED and the problems and challenges faced during the implementation of the design.

6. As fire safety engineering is about interaction of various subsystems so during the designing process what are the problems faced in this regard? How are these challenges coped up?

Objective 5: To understand the verification process of a PBFPED.

7. Verification of a performance based fire protection design is another major aspect of the design. So what are the challenges faced in the verification process of the design? (Two types of verification – verification of conceptual design with the FRA and verification of implemented design with the conceptual)

Objective 6: To understand the effect of the new Swedish regulation on the identified reasons and factors.

8. With the new Swedish performance based design regulation in place, how do you see the impact of the new prescribed specifications of critical components like fire size, growth rate, design factors etc. on the design and its implementation? Do they restrict the scope of innovation and judgment in

design, in comparison to the other global regulation which are more generic and offer consultants engineers a wide variety of options to explore?

9. Do you see the adoption of this new regulation as a positive step ahead in the fire protection engineering or is it more inclined towards the traditional prescriptive design approach?

To conclude the interviews the next question was formulated to find out possible solutions for the identified problems.

10. What are the possible ways to cover up the identified deviation factors and ensure the implemented design follows the fire risk assessment and meets the stakeholder's goals and objectives?

These interviews were conducted by making an individual appointment with each of the participant. Since the thesis subject is diverse and general, hence the structure of the interviews was semi-structured i.e. open ended interview, which allowed for new ideas and general discussions during the interview [19]. The interviews were recorded to ensure that no information from the interview is lost. Upon the completion of the interviews, the formulated transcriptions were re-sent to all the participants for review and revisions if required.

5. Results & Discussion (Interview Analysis)

After the transcript reviews from various participants, the summaries were compiled together in different professional groups as shown in Figure 3. The results from the interview questions were segregated based on the thesis objectives. In order to identify the best suited method for the analysis of interviews, a book by *Steinar Kvale* was used, which describes five different approaches to Interview Analysis [18]:

1. *Condensation*: synopsis of meanings expressed by interviewees into shorter formulations. This approach involves a reduction of large interview texts into a more concise summary.
2. *Categorization*: implies that interviews are coded into categories. Statements are reduced to simple categories indicating occurrence and non-occurrence of a phenomenon.
3. *Narrative Structuring*: is a continuation of the information by the interviewee. It entails the sequential and social organization of a text to bring out its meaning. This analysis method focuses on the information given during the interview and works out their structure and their plots.
4. *Interpretation*: goes beyond a structuring of the apparent meanings of a text to deeper and more or less tentative interpretation of information.
5. *Ad-hoc*: establishing analysis through ad-hoc methods is a diverse approach. Various different common approaches, sophisticated textual or quantitative methods can be used to bring out the analysis.

In this study the *Condensation and Interpretations* approach has been used to analyze the interviews. This method was found to be the most appropriate for this study because it enabled concise summaries for the different interview questions in correlation to the objectives. With the use of this approach, an attempt was made to read the interviewee’s answers without prejudice and present the statements as understood in own language.

Since there were different groups of professionals working with different roles and capacities in a project, the results of the interviews varied between the different groups. The results and interpretation for each of the thesis objective are presented in separate sub-sections below. Each sub-section includes the individual interpretation (discussions) made out from the various interview summaries and literature review. It has been found that there are various reasons that lead to deviation in the final implemented design. The various interviewees confirmed that few challenges and problems as identified by *Meacham and Alvarez* in their article [1] like the problems in sub-system interactions, concerns in verification process, lack of FRA interaction etc. do tend to cause a deviation in the final implemented design. Additional problems were also identified from the interviews concerned with the project phase i.e. after the conceptual design and final design. These problems are lack of communication, lack of involvement of FPEs' and, lack of expertise on monitoring etc. Additionally recommendations to tackle the identified problems are given in this section.

5.1 Interactions between FRA and fire protection system design; and conceptual design to final design

5.1.1 Results

Academicians:

At an institute imparting education, it's like an idealistic world. The knowledge being taught is restricted to the conceptual designing of a project and doesn't necessarily consider the implementation of the design during different stages of a project. From the academicians' perspective, the design implementation is considered to be just following a conceptual design and the FRA is a tool to ensure the design performs according to the needs and requirements.

In the whole process of a PBFPED approach a few problems have been identified particularly in the interactions between the two designs (conceptual and final implemented design) like lack of expertise and guidance about verification process, limited tools and in some cases no tools available for verification.

Another problem is that the available standards and guide books don't have much detailing beyond the conceptual design. This means that guidance on the monitoring of a design during the construction phase/implementation is lacked and this can lead to deviation in the final design.

Research Professional:

The risk identification process is considered as the preliminary step to establish a conceptual design, to be aware of the associated hazards and risks. The two aspects are connected from start to finish but if not well connected then the problem arises. Hence it is very important to do a FRA before the start to establish possible risk mitigation and understanding of the overall fire safety concept.

During the design implementation, economic pressure is a problem, sometimes the deviation may happen due to economic constraints. For example, sometimes during the construction phase of the project small modifications like change in material etc. can be made. This can result in a deviation of the final design.

Monitoring or following up fire safety is another problem in this regard – we don't have good data on how well we comply with fire safety regulation or concepts in design, construction and the operational phase of the building.

Insurance Professional:

In a new building it's hard to make a fire risk assessment for e.g.: if building a shopping centre, by the time things get into construction phase, the things get changed because of various reasons. The problem is in adhering to risk assessment, because the understanding about risks between different stakeholders is limited and this may result in negligence's.

FRA is basically used to develop cost effective solutions, because the builder often wants to opt for a cheaper solution. The choice of design option depends upon the cost of the solution and safety levels, and there is a smaller safety margin due to optimization.

Another problem in this regard, is the unawareness of the future use and operations during the planning phase and this limited knowledge causes the problem in the design. The end user might have different interest whereas the people actually constructing see the risks in their own way. This can also lead to a deviation in the performance of a final design.

Time and cost factor are also a major concern. Time relates to the tenure of the project, because sometimes the project phase is long and some modifications or changes are made during the construction phase. Every time when there is a modification, the design needs to be re-visited and modified which doesn't necessarily happen.

Also while working on a project, adhering to timelines is a constraint as FRA takes extensive time. A detailed FRA means it would end up in higher costs for the project phase, but it may result in more cost effective solutions in the end.

Fire Safety Consultants and Engineers:

In practice FRA is not being conducted in detail, the focus is mainly on the design of the building, evacuation, structural stability etc. But for a complex project like a mental prison etc., FRA is conducted to see for different aspects that need to be assessed in case of a fire. FRA is sometimes applied only for certain aspect of the building rather than the whole building design.

The associated hazards/risks with the building project are dependent on the type of building and instead of conducting a FRA often references from previous projects and other reference books are used to identify the hazards. The requirement of FRA also depends upon the needs of the client and what objectives does he/she may have for the particular project.

The problem is to adhere to the risk assessment through the project, as people involved are not well versed with the risks and also because all the stakeholders are not aware of the risks.

The dilemma is sometimes the use of the project as defined by the client at the start of designing tend to change by the time it gets operational. As a designer need to be flexible in defining the design scenarios; to account for new changes that may come in by time. Also communication is a problem here; often the interpretation of the objectives and goals of the clients is not very clear.

Lack of education is another problem; since people have different backgrounds and this sometimes lead to problems in the interpretation of the design in the absence of FPE, as in some cases the FPE is not involved in the whole length of the project. Involvement of FPE depends upon the client, who is the client if it's an architect then involvement is from the beginning whereas if the client is a project manager then the design is already in place and have to live with the project constraints.

One of the interviewees working at a renowned fire safety consultancy firm quoted – "Fire Safety is seen just as an obligation in the building process as often the client just see it as an additional cost".

Fire & Rescue Services (RSYD) Official:

The FRA depends upon the different consultants, who tend to base their design on their individual assessment and experience, but there is no standard or guideline on this aspect. In practice a design comes first and then the risks are identified. FRA is just to make sure that the design works. There is a lack of knowledge in this regard and the expertise as well.

At the start of the designing of the project consultants, often do not conduct a FRA, the designing of scenarios is based on the past experiences and knowledge from the previous projects. So there is a possibility that the risks or hazards are being under-estimated or overestimated. If Fire and Rescue Services are involved at the earlier stage of the designing, then they can support in proper risk identification and designing by sharing previous fire experiences.

Monitoring process during the construction stage is another problem in this regard, as there is lack of competency or awareness about this, often the expertise is lacked in this area and sometimes the designers are also not involved.

Boverket Official:

The risk assessment is conducted only in few complex projects, in most cases; the approach is more of a prescriptive, where the inputs etc. are defined as in the regulation. The problem is in describing the FRA in the regulation. Also the area of FRA lacks knowledge and experience; there is a deficiency of proper guidelines or standards from the authorities or regulation.

The control and involvement of the building authorities in the building projects is too limited. In Sweden the authorities don't have the liability of the design, the building authorities are not involved in the design brief and other processes of the projects, this situation could lead to a scenario where certain hazards may go unattended.

From a Boverket official's perspective an increase of involvement of the building authorities in the design stage could help in concluding on the number of risks and hazards associated with any design.

Fire Safety Manager, IKEA:

It's very important that the FRA is conducted before performing a design. At IKEA, a pre-assessment study was conducted to identify the inputs for design. So the risks or inputs are already pre-defined. But in case of any complex building or new geographical location, a detailed FRA is conducted. It's a challenge to follow the identified FRA at the start of the project and during the whole project process, so it's important to have milestones in the project to verify for the FRA at regular times.

A major problem in the PBFPED implementation is the Monitoring process during the construction phase/implementation. There is a lack of competency and awareness about this aspect.

Communication among the various stakeholders is another problem that often leads to a deviation. The different people involved in the project have different understanding about the risks and during implementation this can result in small modifications or changes.

From the perspective of a FPE performing the fire safety designs the reasons behind these deviations are the lack of education and expertise in the estimation of the risks. Different stakeholders see and understand risks with their own perspectives and this can lead to negligence in fire safety standards. In certain cases the involvement of FPE is not for the whole project, this often results in misinterpretation of the fire safety design and can cause deviations in the performance of the design.

As IKEA, the problem faced is the comparison of the design to different countries legal requirements.

5.1.2 Discussions

The results show that there are problems in the two interactions between the FRA to the fire safety design and conceptual design to the final design. It has been identified that the FRA is not considered as an individual phenomenon, it is part of the PBFPED process. The FPEs' who are responsible for making the designs are not concerned with performing detailed risk/hazard identification. They focus on the design and ensure ways to bring out cheaper solutions based on the regulation or as identified from a similar project in the past. This situation may be interpreted as either under- or overestimating the risk. The problem is lack of guidance and expertise in the area of FRA. The regulation and standards on PBFPED approach do not describe this aspect of fire safety engineering. The design fire scenarios are based on the previous experiences.

Another problem is the limitation in knowledge and expertise beyond the conceptual designing phase of a project. The guidelines and other standards prescribe information and expertise which is limited to the conceptual designing stage. There is no standard or guidelines on the implementation of the design and monitoring process. There is no reliable data on how well we comply with fire safety regulation or concepts in design. From the interviews with the FPE's it has been realized that their involvement is sometimes restricted to the conceptual stage which means that during the implementation stage (monitoring), there is no professional expertise.

The communication between the different stakeholders and parties involved in the project is another problem. It begins with the different understanding about risks and fire safety. A lack of awareness and casualness often leads to modifications during the course of project such as change in the building use or occupancy etc. All these modifications tend to modify the design and result in a deviation in the final design and under-performance of the design.

Another important aspect is the involvement of the authorities. It has been verified that the building regulation department is responsible to establish guidelines and regulation; whereas the municipalities are responsible for according approval and giving permissions to start a project. After this the responsibility and liability is of the owner of the building to ensure a safe design, which when completed is checked by the fire and rescue department officials. The problem is that in between after getting permission to start constructing and finishing, practically there is no involvement of the authorities. This can lead to a situation where the parties involved in the project may get complacent of the fire safety and things can change, that may lead to a deviation in the design or performance. There is a need of more involvement of the authorities' through-out the project in all different phases to ensure that the implemented design adheres to the FRA and concept design. One of the recommendations is that the authorities become involved in the design brief, which could lead to a better understanding of the risks and exposure from their practical experiences, based on their actual fire fighting and investigations.

5.2 Use of Assumptions and Statistical Data in the designing process

5.2.1 Results

Academicians:

As academicians' and actively involved in the research, it has been well established that there are considerable limitations in the data which is used either for modeling (fire modeling and evacuation modeling) or making other assumptions.

A major problem is that a lot of uncertainties are introduced during the quantification process in the design and to handle them a well detailed uncertainty analysis is required. There is a lack of expertise on how to deal with the uncertainty.

Often in practice the FPE tend to make use of the safety margins/factors but there are limitations on the choices of the safety factors/margins because of the induced uncertainty.

The use of assumptions by the FPE in practice also tends to bring in a considerable uncertainty in the design. These assumptions are made based upon the past experiences and engineering judgments of the individual FPE.

In order to ensure justification in the application of data and assumptions in design the companies performing design need to establish good quality assurance program that could check for the uncertainty management and sensitivity of the design.

Research Professional:

Use of statistical data in the designing phase is quite common, even if it is lacking in quality or scope. It is necessary to understand the application of these data and use of other assumptions during the designing, hence the knowledge about the application of data and assumption is very important, but sometimes this aspect is missing. It is important to be well focused and versed in collecting data on new materials and new situations.

It is very important to ensure the management of uncertainties in design, which is not necessarily being taken care off. The problem behind this challenge is the lack of expertise on how to deal with the uncertainty introduced. People in practice tend to use the data without much validation from different sources where the main problem is lack of better data that is valid for the problem in question.

A lot more research in the following aspects – gathering and applying data, ways of dealing with uncertainty, knowledge on safety margins and consistent application is required.

Insurance Professional:

The hazards are increasing with so many developments, and there is no relevant data about these new hazards, hence assumptions are made and cannot just rely on statistical data. There is a problem with the quantification which is made and often during practice the designers miss on the uncertainty introduced when quantifying the data in the design.

With the introduction of the new regulation, in Sweden, the use of statistical data has been limited as the necessary inputs are pre-defined. But the use of assumptions is still a major problem, as the control function (established guidelines) is not good enough, which restricts the verification and assessment of the assumptions. There is a need to have a legal framework to control the important input variables to make it safe from a legal perspective

Another problem is, in practice there is an overuse of the data and assumptions by the FPE's during the design process. Even the models used during the design are too complicated. It has been realized that there is an extensive dependence upon these models, data and assumptions instead of simple calculations etc. which result in uncertainties in the design. Also sometimes the model is used outside its boundaries.

The problem is also the lack of expertise on how to deal with the uncertainty introduced because of the errors. Safety margins are being determined based on the reference building comparison. Sometimes it seems that designers miss the fact that individual buildings have unique safety levels which together makes up an acceptable safety level on average in the society. Hence comparing with the worst possible building accepted by prescriptive rules will result in lowering the safety margins.

Fire Safety Consultants and Engineers:

The quantified numbers are extensively used without much verification and detailing about the used numbers in design. Even the computer models used to simulate real life conditions are also not well detailed and the individual judgments made by the designers are relying only on the experience without any proper guidance. All these tend to bring in uncertainty in design.

Since there is not much expertise on the uncertainty management, the safety margins are used which are determined based on the reference building comparison.

Fire & Rescue Services (RSYD) Official:

The Fire and Rescue Services officials do not go in details to check the various modeling and other areas where some data or assumptions have been applied. The problem is the designers tend to have too much reliability on the modeling. There is a problem in the application of the statistical data since there is no guidance from the regulators or authorities. The justification to the application of the various reliability data etc. can be done only by properly verifying the various other conditions that would have an influence on the system.

It would be good to have some kind of guidelines or prescription from the building authorities describing the safety margins etc. Quality control and uncertainty management is very important in the designing process, it's very important to have quality checks throughout the project.

Boverket Official:

The situation is, whatever data is available has to be used, since there is a shortage of data, so it is very important for better management of these quantified numbers. There is no definition of the safety margins in Sweden, but here the approach is to use the worst credible case and conservative numbers and then verify whether the design is suitable by analyzing it to a required level. As an analyst it's important to verify the statistical data and numbers.

There is a problem in the application of the statistical data since there is limited guidance from the regulators or authorities. The problem is also the lack of expertise on how to deal with the uncertainty introduced because of the errors. It would be good to have some more guidelines or prescriptions describing the safety margins etc. Uncertainty management is very important in the designing process, it's very important to have quality checks throughout the project.

Fire Safety Manager, IKEA:

IKEA's culture is often to use the data which is developed in Sweden, and at the university level through research. Quality control and uncertainty management is very important in the designing process. During designing, the worst case scenarios are opted to take account for the uncertainties that are introduced due to the models and other data.

There are pre-defined safety margins at the organization levels; it all depends upon the different country legal requirements for PBFPED. The application of safety margins is done in input values rather than in output values, hence it means designing more conservatively. But the problem is the lack of expertise on how to deal with the uncertainty introduced because of the errors.

The most important aspect is the third party reviews, to challenge the input values and safety levels. At IKEA, in cases which are complex and where the in house expertise is limited, these third party reviews are used, to verify the assumptions and data used in the design.

5.2.2 Discussion

The PBFPED approach is a relatively young engineering approach, so there is not much data (statistical, reliability etc) available to be used in the designing. All the different groups of professionals in fire safety engineering have said that there are considerable limitations in the application of data i.e. used for modeling and other applications in the designing phase. Even the different models used during the designing are too complicated and have considerable limitations. There is an extensive use of assumptions and engineering judgments made in the modeling phase. Each assumption made in the models introduces an uncertainty. The problem is the lack of expertise on how to deal with this uncertainty.

The safety factors assumed or adopted are not prescribed and hence not reliable and they don't scale in real world. The problem is the absence of generic guidelines or a structure describing how to justify the application of data being used and how to manage the uncertainties of the design. The practitioners are using their own judgments based on the past experiences and knowledge. This situation is not consistent and can result in uncertainties that could lead to a deviation in the performance of the final design.

There is a great need of continuous research and standardization in this aspect of the fire safety engineering; this has also been recommended by BJ Meacham and Alvarez in their article. The national regulation should establish some guidelines, describing on how to select the appropriate tools and data and consequently how to manage the uncertainties. The FPE performing the design should ensure proper validation and justification of the data and assumptions in the design, and there should be a mechanism established by the authorities to check for the same. Another important aspect is guidance on safety factors or margins in the design. At the organizational level, it is important to have mandatory quality checks, to verify the quality of the data and assumptions used in design.

5.3 PBFPED a two pronged process – cost efficient design and retaining acceptable level of safety

5.3.1 Results

Academicians:

At the university, the primary role is to teach how to attain safe solutions and then try to make it a cost efficient design. It is difficult to understand and determine what is safe enough. The safety levels are generally given by the codes, or by clients in certain cases.

The problem in PBFPED approach is that there is an unavailability of methods to determine the balance between the cost and acceptable safety levels. It is very important to verify the robustness of the different systems to ensure the cost benefit principle.

There is a need to have more tools about to ensure the balance between these two aspects of PBFPED. Also another important step could be to enhance upon the understanding to be imparted to students to determine the cost effectiveness and benefits of design.

Research Professional:

Generally cost efficiency is a driving force but simultaneously acceptable level of safety is also vital. It is very important to define the whole process, like performance criteria etc., and how the uncertainties are managed to achieve an acceptable safety level. In Sweden the practice is - safety margins are not being applied extensively in the end of the analysis, rather safety margins are added by using conservative input data or assumptions.

The challenge is to establish an acceptable level of safety. This situation resulted in more variance in designs with different levels of safety and different costs. Before the new regulation came into effect, the determination of acceptable safety levels was dependent on the client, stakeholders and all others involved in the specific project. But the new Swedish regulation has more basic recommendations which define some level of safety as a reference. The PBFPED approach is a relatively young engineering approach, so we need more data and understanding on whether the safety levels designed for are actually safe or not. Hence this area of safety level is still a question and to determine the same is another challenge.

The lack of knowledge and experience in this regard is one of the major problems that can cause the final implemented design to deviate.

Insurance Professional:

In the insurance industry, the job is to advise the client on loss prevention. The client decides on how and what levels of safety is too be designed for.

The factor that if the design is cost efficient or not depends upon the priorities of the client. The acceptable safety levels are often limited to the legal requirements and also on the demands of insurance companies and in some cases the risk appetite.

So the acceptable safety level is the balance between the demands of various stakeholders. It cannot be isolated to one certain perspective and depends on what type of industry it is. There is no detailed understanding about the cost and risk levels of the design. To understand this aspect one approach could be to have more involvement of the authorities and research in this aspect to have a legal framework for quantifications.

The building codes need more of cost benefit analysis and understanding about the balance between the two aspects of cost and acceptable safety level.

Fire Safety Consultants and Engineers:

The cost efficiency is not necessarily a major aspect; in fact PBFPED approach is often used when the prescriptive solution approach can't be used in certain buildings. The problem is that the fires – design fires happen too less and so there is a very limited experience on the real fires. This result in a limited knowledge on what the acceptable level of safety is. Often the FPE in practice make a design to cater for the worst probable fire and also for other small aspects like false alarm, small fires etc.

The regulation asks to design for the worst credible case and sometimes this also leads to an over-estimation of the risk and cost, so in such cases the design is not necessarily cost efficient and probably implies to high safety levels.

The regulation and authorities are focused on the safety levels whereas the client is equally keen on to look at the cost efficiency of the PBFPED. Earlier as there were no recommendations on the safety levels, so the determination of the safety levels was a major challenge.

The involvement of the FPE is another factor, as sometimes the FPE is involved in the initial phase till conceptual stage. Later when the contractor is involved, the things sometimes change like the occupancy or use etc. which results in deviation in the safety levels to compensate for the cost.

There is an unavailability of methods to determine the balance between cost and safety levels. The determination of whether a solution is cost effective or not depends upon the client what levels of safety he/she demands. From the perspective of a FPE in practice, the detailed understanding about the cost and risk levels of the design is not available.

Fire & Rescue Services (RSYD) Official:

As Fire and Rescue Services, the responsibility is not to manage the balance but actually to see the impact of the imbalance in certain cases. The RSYD is focused on verifying the acceptable level of safety whereas for the building owners the focus is more towards cost efficiency part. But then flexibility of the design also varies, if the design only adheres to the minimum requirements of the code then design tends to be inflexible.

There is an unavailability of methods to establish the balance between cost and safety levels. The challenge is to establish what a safe level is. So there is an application of safety margins or factors, which are also not well defined. These safety margins are often based on the engineering judgments of the designers, as there are no guidelines on this as well.

It is important to have some basic legal guidelines about the acceptable safety levels and cost efficiency of the designs.

Boverket Official:

This situation is more dependent upon who the client is? As quoted by the interviewee – "*If the client is a building contractor then the focus is to achieve a cost effective solution and retaining a safety level by just fulfilling the requirements of the code, whereas if the client is the owner or architect then attaining a considerable safety level is equally important as the cost effectiveness*."

There is an unavailability of methods to establish the balance between cost and safety levels. A comparison with the prescriptive code design is made to determine if the PBFPED is safe or not.

There is no detailed understanding about the cost and risk levels of the design. This area of PBFPED is still a major challenge and lot research and study in this aspect to establish the balance between cost and safety levels is required.

Fire Safety Manager, IKEA:

At IKEA, the cost effective approach is not necessary, it is more to meet the pre-defined safety levels.

At the organization level, the acceptable level of safety is pre-defined and in most of the cases, they meet the minimum legal requirements of the countries. The general understanding about cost estimation of the designs and numbers is not good. So it can be interpreted that the cost verification of the design alternatives and solutions is missing, so it is hard to analyze how cost efficient the design is.

There is an unavailability of methods to establish the balance between cost and safety levels. To identify what is safe and what not; often a comparison of design is made with the prescriptive code design. But practically very hard to identify what is safe enough or what is the acceptable level of safety.

There is no detailed understanding about the cost and risk levels of the design. This area of PBFPED needs more exploration and guidance from the regulation about the two aspects of cost efficiency and acceptable safety levels.

5.3.2 Discussion

From the interview results, it is established that the two aspects – cost efficiency and retaining an acceptable safety level in a PBFPED are dependent upon the client's requirement. The regulation has defined the level of safety in the form of the performance criteria but they are not sufficient to determine the acceptable level of safety. It is very difficult to identify what the acceptable level of safety is; as there is not much data and understanding on whether the defined safety levels are actually safe or not. Hence this area of determining an acceptable safety level is a problem.

In order to attain an acceptable level of safety, often the FPEs use safety factors or margins to cover for possible uncertainties/errors in the design. These are based upon engineering judgments of the individual engineer. There is no guidance on these by the regulation.

The cost estimation of the designs and numbers lacks understanding and knowledge. Hence it is often difficult to analyze how cost efficient the design is. In their article, *B.J. Meacham* and *A. Alvarez* have described this problem as a political challenge in the PBFPED process.

The regulation in Sweden asks to design for the worst credible case and sometimes this leads to an over-estimation of the risk and cost. There is an unavailability of methods to establish the balance between cost and safety levels. Even though a lot of research is ongoing, this area needs to be explored further.

To understand this aspect one approach could be to have more guidance from the authorities. Specific guidance on safety levels should be given by establishing minimum acceptance criteria for various different fire risks/hazards in different types of buildings. It is important that the national guidelines describe the management of balancing cost efficient design and an acceptable level of safety. *P. Johnson* [20] has also concluded in his article that "*it is essential that the building codes and legislation recognize the balance of risk and cost*."

5.4 Sub-systems interactions in PBFPED

5.4.1 Results

Academicians:

This is an important area in the PBFPED that tends to brings up various problems and concerns, like interactions between occupants and fire during evacuation. It is very important to realize the sequence of actions and systems as to what comes first and how the system works. Designing of different systems need to be in parallel like different modeling viz. fire and evacuation need to be conducted in parallel to ensure that both the designs coincide and work in tandem.

The fire protection systems need to be looked upon like a global system to ensure that all the different systems work in tandem. The final design tends to becomes too complex because of the various sub-systems that can result in many technical problems.

In order to ensure that the final design doesn't deviate; the coordination between different people involved in the project is very important. Also it is important to know what action or system is relevant in a particular project and the sequential designing of the same. A lot of research is still required in this area even though considerable research is going on.

Research Professional:

The sub-system interactions in PBFPED are a challenge. It is very important to look at the concept of buildings, how the system should interact with each other in the building. Also it is necessary to realize what how the whole fire protection system works and their chronology. The problem is that different systems are looked upon in isolation but need to be viewed as a global picture. The designing of different systems need to be in parallel.

The robustness checks of the different systems are another important aspect to verify the sub-system interactions. There is a lack of data and knowledge in this field of PBFPED.

Insurance Professional:

Sub-systems in the design are like a technical tree and keeps becoming complex with every new system being added to it. The PBFPED approach may lead to technical complications. It is very important to have enough knowledge to put all the systems in theory and practice like when we need to combine the sprinkler system with smoke ventilation system, so need to know that they can affect each other. Hence it is important to understand the associated limitations and sequence.

This is a major problem in the lifetime of the building, because there are too many systems and the operations and maintenance of all these different systems and management of subsequent interactions is a major challenge for the end user.

The problem is that while designing, the various systems are designed individually in isolation. When the interactions are required to be established there are no detailed guidelines or standard describing how to get all different system work together in a global system. Another aspect here is that the robustness of these systems is checked in a more qualitative manner as there is no quantified approach. And most often all this is dependent on the engineering judgment which tends to be different for different individuals and to establish which one is most plausible is a challenge.

Fire Safety Consultants and Engineers:

An interviewee from the fire protection consultancy quoted that the "Sub-systems in the performance based design are like a technical Christmas tree with various branches (systems) each connected to the other and keeps becoming complex with every new system being added to it and their consequent interactions."

The presence of different sub-systems in the fire protection design makes the final design too complex and whenever any new system is added in the design, the complexity increases because of the increase in the various interactions.

This area of PBFPED is not very well addressed, because of limited knowledge and complexity. There is not much understanding about the human interactions with the different aspects of fire.

The problem is different systems are looked upon in isolation and hence the expertise about how they work together is still limited. At present different systems are assessed in isolation and then robustness is checked in a more qualitative manner as there is no quantified approach. Most often all this is dependent on the engineering judgment.

This area of sub-system interactions also causes problem in the testing of the design. The industry requires a lot more expertise and research to take care of this aspect of PBFPED.

Fire & Rescue Services (RSYD) Official:

In this aspect of PBFPED, there is no guideline on how the different sub-systems in the fire protection design should work together. This aspect is not very well addressed, because of the limited knowledge and complexity. The challenge is to know the interaction of different systems in the design and then accounting for them in the modeling and real application.

The only option available is the testing or physical check of the various systems before the start of the building. A design guide defining the interactions of various systems in a project is required which shows the entire process.

Boverket Official:

The building regulation have given some recommendations on what kind of standards to be used for the various sub-systems, but there is no global system on how all these systems should work together. The different systems are designed in isolation. There is a lack of models to analyze the various systems working together.

It is important for the designer to regularly verify during the design stage in order to ensure that the different systems work together and in a proper sequence. Often the knowledge about the interactions is limited and it is very important for the user to understand what are the important parameters and the sequences and the related uncertainties when using them together.

Verification of these different Sub-system interactions is also a major problem in the lifetime of the building, because there are too many systems and various interactions. Also the operation and maintenance of all these interactions and different systems is another concern. These issues tend to be taken care of separately in the designing phase. The most important aspect in sub-system interactions is prioritizing which system works first and how and then how the next system reacts and operates.

Fire Safety Manager, IKEA:

Sub-system interaction is also a major problem in the lifetime of the building, because there are too many systems and various interactions involved. The problem is all these different sub-systems are looked upon and designed for in isolation and the concerning issues also tend to be taken care of separately. The most important aspect in sub-system interactions is to determine the proper chronology. Often, the final design does not have a proper chronology and this result in a deviation.

Testing of these sub-systems is also another concern, because all these sub-system interactions are too complex and often hard to test in the chronological order.

At IKEA the pre-defined aspects and different other fire safety design principles developed at the organizational level, help to some extent, in this area. This area of PBFPED often results in unpredictability of the design performance, so it is very important to take proper care during the designing.

5.4.2 Discussion

The sub-system interactions have been identified as one of the major challenges in the PBFPED approach. This has been verified from the reviewed literature and the interviews.

The challenge is to know the interaction of sub-systems and accounting for them in the modeling and real application.

The interviews show that the limited expertise and knowledge about sub-system interactions in a PBFPED may result in a deviation of the final design from the conceptual design because of unknown factors such as human interactions and response of various systems during the emergency. During the implementation of the design, modifications tend to be made which could affect the sequence of these sub-systems. The above mentioned aspects are unknown and hidden during the design and future use of the building tends to change.

There is a necessity for guidance in this area which enables to see the fire safety system as a global system and identifying how these sub-systems work together. The present regulation provides some recommendations on standards to be used to design the various sub-systems. Better knowledge and expertise on the selection of the scenarios and their development would help in seeing through the various sub-system interactions. It is necessary to understand the desired sequence of the various sub-systems during the development and selection of the scenarios. The testing of various interactions during different stages of the project would help in seeing through and maintaining the functionality of the different sub-systems during the different project phases.

5.5 Verification Process

5.5.1 Results

Academicians:

There is no well defined verification process to verify the final implemented design. The problem is to find a structured method to see verification as not just following the risk analysis but also to check for the quality of conducted risk analysis. Sometimes the competence to conduct verification is also a problem. A proper verification is necessary throughout the different stages of the project and at the end.

Another important aspect in verification is to conduct a proper sensitivity analysis to check for the variability of the solution. The verification process needs more standardization for consistent solutions/designs. More involvement of the Fire & Rescue Services is required in this process to ensure that the designs are implemented as designed for.

Research Professional:

The risk in a project is that it's very hard to make changes in the design at a later stage; hence the design needs to be verified continuously and it should be an ongoing process. But the problem is that there is no well defined verification process for the different phases of design and construction.

In certain cases FPE's are not involved in the design implementation, which means that there is no physical verification during the implementation stage and this might lead to a deviation. A proper verification is necessary throughout the different stages of the project and at the end.

There is a requirement for detailed robust guidelines from the regulation in this aspect, as this part is often the responsibility of the designer or the client, so it can be considered as it is being compromised for.

Insurance Professional:

It is very important to document the pre-requisites like assumptions etc. for the PBFPED and if something does change in them the design does need to be revaluated. Sometimes for the small issues, the re-evaluation is not done.

Mostly the changes during the design phase are accounted for whereas the major problems happen after the design is constructed or implemented and last minute architectural tweaks etc. or end users adjustment lead to deviation in the performance of the design. The involvement of the FPE is very important in this regard, which tends to depend on the size of the project. The problem happens either when the FPE is not involved for the whole of the project to check on regular basis and some change like the use or some other feature is added which might cause the problem.

Another important aspect is the different subsystem interactions in the fire safety design, which is another major challenge in the verification process. It is often hard to see different interactions of various sub-systems in case of an emergency. So it's very important to have better flexibility at the initial stage to prevent problems later in the process.

The problem is, there is no proper guidance in this aspect of fire safety engineering. The regulation need to define the method for assessment in a bit more clear manner and more involvement of the authorities would be good.

Fire Safety Consultants and Engineers:

Verification is often done to check whether the safety margins applied in the design will be good, to take account for the small modifications and uncertainties in data and statistics. As there is no clear guidance on how FRA should be carried out so more often past experiences and engineering judgments are used; hence in the verification it is sometimes a challenge because better understanding is required about it. The third party reviews becomes very important and need to see through the user influence on the design, as there tend to be much reliability on the engineering judgments.

In the verification of implemented design, the challenge is – lot of fire safety aspect is hidden for example how many layer of gypsum is used in the construction etc. and instead of checking we tend to rely upon the certification by the contractor. The challenge here is also the limited knowledge about various details of different fire safety materials.

One of the major problems in the verification process is the involvement of the FPE. It is important that the FPE should see through the design during the whole project and verify at the end. But it necessarily doesn't happen as in certain cases, the FPEs' are not involved in the design implementation, so it leads to a deviation.

Fire & Rescue Services (RSYD) Official:

Verification is a major problem; it is often done in various stages, but the RSYD is often restricted to second verification, only in complex projects the verification of conceptual design is also made. One of the major problems in verification is the actual verification of various sub-system interactions as they are too complex to understand and be verified.

More involvement of the authorities is required in this process to ensure that the designs are implemented as designed for.

Boverket Official:

The local authorities as per the regulation have to verify the building control plans or the conceptual plans and then authorities or the certified engineer has to conduct the final verification based on the physical checks and testing's at the end. There are some general recommendations on how to check the design by verifying the 5 different aspects like fire spread between buildings, evacuation times etc. as detailed in the regulation. As per the regulation it is important to check for the robustness of various sub-systems for the 5 aspects during the design stage.

But the problem is the actual physical verification process is not well detailed. The liability of the design and the responsibility of ensuring that the design should be safe; is of the builders and owners of the building, hence the verification is also a part of their responsibility. In certain cases, where the design might be complex or for some other reason, the authorities may demand some other certified engineer to control the verification (3rd party control).

There is a need to have more standardized guidelines and regulation in this aspect of PBFPED.

Fire Safety Manager, IKEA:

Prior to the new regulation, the verification was a major problem; there was a lack of expertise and knowledge in this aspect. There is a demand of a global structure or guidelines to give some description about this aspect, as the organization is expanding more on a global platform.

Often in the newer areas, whereas there is a lack of knowledge about the surroundings of the project and other aspects that are not known before, a third party verification is conducted to ensure for the design inputs and parameters.

In the conceptual design verification, the challenges are - to find proper method of Verification; and to make various other people involved understand about the analysis of the design. It is to identify what aspects of fire safety that are influenced or affected and other challenges in the modeling stage like human errors etc.

It's important to have more involvement of the building regulation and Fire & Rescue Services in this process to ensure that the all aspects of the conceptual designs are being implemented.

5.5.2 Discussion

The verification process confirms that the design meets the design objectives and goals; it meets the risk assessment and meets all the other designed parameters. This process compares the final implemented design to the conceptual design. After conducting interviews for all the different fire safety professionals, it is identified that this aspect of the design is also one of the main problems. But the new regulation BBR 19 has helped to curtail down the problem with the recommendations on the verification methods. In the conceptual design, the major verification challenge is to find a proper method of verification; and to make various other people involved understand about the analysis of the design. In the verification of design implementation the challenge is that a lot of fire safety aspects are hidden; i.e. the number of layers of material is used in the construction etc. In practice, instead of physical inspection the engineer tends to rely upon the certification by the contractor. It is important to make spot checks since it's not possible to check all the materials. Supervision during the implementation stage is vital to ensure that material quality and quantity as expected.

Another challenge is the verification of sub-system interactions in the fire safety design. It is often difficult to see different interactions of various sub-systems in case of an emergency. So it's very important to have better flexibility at the initial stage to prevent problems in verification.

The liability and responsibility for the occupant safety is of the owner of the building, who is dependent on the FPE's. The verification of the design is also the responsibility of the owner except for some complex cases. Often, the fire safety consultancy firm performing the design of the project is responsible for the verification of the design. This leads to a rather uncertain situation, because if the same firm performing the design also conducts the verification, there might be instances where some errors or uncertainties may remain unnoticed. However if different firm gets the verification task, they are not aware of the conceptual design to the same extent and may therefore miss things. This area remains a problem in the PBFPED process.

Prior to the introduction of the new regulation BBR 19, the absence of a well defined verification process in the regulation was a problem. This resulted in different consultants adopting different measures to verify the design. Hence the national regulation needed to make the verification process more standardized for consistent solutions/designs.

Another solution could be the involvement of fire and rescue services in the verification process of the designs, as this would mean no complacency or leniency in the uncertainties or errors if identified. Also this would result in a more justified verification, as this would ensure identification of certain concerns and errors that may remain un-noticed because of the lack of real fire exposure and experience with the FPEs' performing the design.

5.6 Effect of the new Swedish regulation

5.6.1 Results

The results of this section matched for several interviewee groups; hence the results have been combined for the groups where it matched.

Academicians, Insurance Professional, Fire Safety Consultants and Engineers and Fire Safety Manager, IKEA:

Earlier different consultants had very different designs for same project. So it is very important to have a framework to perform a design and the new regulation is therefore required. The new regulation has provided some sort of performance levels for the society. The regulators have a possibility to adjust the safety levels.

To summarize it is considered that the new regulation are a positive step in the PBFPED, as a framework within which the design is performed has been recommended, which would lead to more reliable and consistent designs. Also the new Swedish regulation has been able to create a minimum safety level which means less variance in designs and consistency.

Research Professional:

The review and control system is very important. The recommended numbers and values in the new regulation have been established based on the experience of the various fire safety experts in Sweden and through benchmarking with what's found in international literature and codes. This quantification has enabled to define some levels of safety more clearly. Earlier in Sweden, the system was; designer himself was making choices of values and assumptions for the fire scenarios and input data which was causing a major problem in the verification process. Hence these new regulation were introduced which give a legal basic and more coherent structure.

As a research professional perspective, the new regulation are not imposing major restrictions on the FPE's, while there is some restrictions on choices there is still a large flexibility. The new regulation can be considered as a positive step ahead which gives a clear structure and, defined verification which would help to bring consistency in the market and resulting designs. The new Swedish regulation have been able to create a minimum safety level that result in less variance in designs and ensured consistency.

Fire & Rescue Services (RSYD) Official and Boverket Official:

Earlier in Sweden, the practice was that different FPEs' designed very different designs for a same project. So it was necessary to establish a basic legal structure to perform a design and the new regulation are exactly that were required. The new regulation has provided some sort of performance levels for the society. The new regulation helps the reviewer in verifying the design and hence the new regulation is good for society. The new regulation in some cases is making an engineer more accountable on his/her work. The quantified numbers are based on some references and prescriptive. The interviewee from the Boverket quoted – "In certain cases the new regulation have resulted in making a fire safety engineer accountable for his/her work/design, which was not the situation before."

The new regulation has been developed to ensure reliable and consistent fire safety designs. The new regulation have also been able to establish a common understanding about the fire risk levels among the different parties involved in a PBFPED. These new Swedish regulation has been able to create a minimum safety level which means less variance in designs and more consistency.

5.6.2 Discussion

All professionals assess the new Swedish regulation as a positive step in the PBFPED approach. Before the new regulation was introduced in Sweden, there was too much variance and inconsistency in the fire safety designs. The new regulation has been able to bring down this variance and inconsistency by introducing a legal structured framework for the FPEs' to perform the PBFPED.

The new Swedish regulation has provided recommended design fire scenarios which have resulted in the consistency. Previously, FPEs' could establish their own design fire scenarios based on their expertise and experience.

Before the introduction of the new regulation there was a major problem in establishing a minimum acceptable level of safety. The new regulation introduced recommendations that define an acceptable level of safety except for a few complex buildings. Previously there was no defined verification process in the regulation. The new regulation has identified the need for verification and state three different verification methods that can be used by the FPEs'. These methods are as follows:

1. Qualitative Assessment – compares the design to acceptable solutions.
2. Scenario Analysis – evaluate the solution for the established performance criteria, design scenarios and other conditions
3. Quantitative Risk Analysis – comparative analysis based on the acceptable solutions.

Another improvement that the new regulation brings is that they introduced robustness checks for performance levels in case one system fails, which was not required as per the previous regulation.

It was identified that there are also a few points of concern connected to the new regulation. The main concern was the unavailability of an explanation about the quantified recommended values in the regulation. Some of the interviewees feel that the new regulation restricts the scope of innovation and engineering judgment in design.

It can be said that the new Swedish regulation, are definitely a positive step ahead in the PBFPED approach. The new regulation has been able to cut down some of the problems and reasons that were causing the final design to deviate from the conceptual design, but still more efforts are required to develop a comprehensive and complete solution to take care of all the identified problems and challenges.

6. Conclusions

It has been observed that the final implemented Performance Based Fire Protection Engineering Design (PBFPED) does tend to deviate in performance because of the various identified problems. The main problems for the deviation are the lack of expertise, knowledge and understanding in the key aspects like FRA, sub-system interactions, verification process, and lack of expertise in monitoring of the design implementation. Another area of concern is that the national and international guidelines on the PBFPED approach are restricted to the conceptual designing, and there is no guidance on the design implementation.

The new Swedish Building Regulation on PBFPED approach however; address some of the identified problems by guidance on the verification process, recommendations on the design fire scenarios etc. But still a lot more explanation and guidance is required on important aspects such as the FRA, background and understanding about the recommended quantifications and scenarios, application of assumptions and statistical data.

The involvement of fire and rescue services in the design process to ensure proper detailed fire risks identification and defining of various important aspects about the fire size, location of fire based on their experiences can yield more improvements. Also the involvement of the authorities would help ensuring that the design adheres to the FRA, throughout the different stages of a project.

There is a need for intensive research in the PBFPED approach for the various identified problems, as this approach is being accepted and adapted all across the globe rapidly.

6.1.1 Future Research Recommendations

Based on the interview results following future research topics are recommended.

i. Development of relevant statistical data at national level to be used in the design.

ii. Application of safety factors and margins in the PBFPED approach.

iii. In the area of Sub-system interactions in PBFPED to see for how different subsystems of the design work together.

iv. Development of guidance on the fire safety design implementation process - Monitoring.

7. Acknowledgment

Foremost, I would like to express my sincere gratitude to my supervisor Prof. Henrik Hassel, for the continuous guidance and support. His guidance helped me a great deal throughout the time of research and writing of this thesis. Besides my supervisor, I would like to thank the following interviewees, for sharing their knowledge and experience on the subject:

- Daniel Nilsson – Lund University
- Patrick van hees – Lund University
- Hakan Frantzich – Lund University
- Michael Stromgren – SP Fire Technology
- Daniel Rosberg - WSP
- Johan Noren – Briab
- David Tonegran - Tyrens
- Karl Harrysson – Brandskyddslaget
- Fredrik Nystedt – WUZ
- Tobias Jansson – P&B
- Ulf Goransson – FSD
- Ulf Johansson – Bengtdahlgren
- Anders Johansson – Boverket
- Fredric Hermansson – RSYD
- Henrik Greiff - RSYD
- Jan Lagerblad - IKEA

A special thanks to the IMFSE family i.e. the management and faculty members who provided valuable insights and assistance during this course. I would also like to thank all my batch-mates for their support during these 2 years and for making this experience a memorable one.

Finally, I would also like to thank my family and friends for the absolute support, they provided throughout my life, especially my sister who motivated me to take up this course.

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