Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Department of Mechanical and Industrial Engineering

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Construction performance in case of fire

Analysis of possibilities using ISO 24679-1

Master's thesis in Reliability, Availability, Maintainability and Safety
Supervisor: Jørn Vatn
Co-supervisor: Anne Elise Steen-Hansen
June 2022

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Abstract

There are different ways to design fire safety of the structure. Traditionally, prescriptive requirements set like building codes, building regulations and related standards were popular among fire safety engineers. However, due to increasing the opportunities to innovation, aesthetics and optimization of the spaces in the structure, performance-based design has received more attentions. In addition, this methodology is more user friendly than prescriptive requirements. Several organizations provide performance- based design guidelines such as BSI, ISO, IEFG, SFPE.

Aim of this project is to study provided methodology in ISO 24679-1: Fire safety engineering — Performance of structures in fire — Part1: General, which was considered performance-based design. The topic is defined by the Multiconsult Co. In this regard, the literature review is divided into two parts; investigating performed studies with concentration on assessing the applicability of provided methodology in ISO 24679-1 and investigating of those studies which took inspiration or used a part of related technical reports.

In the following, the first four steps of the methodology are applied to the NOVA spectrum (a steel framed structure of multi-functional arena with 5 main halls) as a case study. Visiting the place revealed this arena in some sections has second floors for office work. This arena with total 46,385 m^2 gross area had 5 halls for events and 3 halls for storage in north wings. Multiconsult Co suggested focusing on the hall B with 7274 m^2 area for further study.

In this regard, fuel load calculation related to accidental condition (in our case fire accident) is performed. The fuel load is identified based on internal content and occupancy type, and it is calculated 118.57 $MJ/_{m^2}$ and 730 $MJ/_{m^2}$ respectively. Then, appropriate equations for calculation of combinational action is extracted and the result is 3,75 $kN/_{m^2}$. All these calculations are performed by having estimation on internal content and permanent and live loads.

To have ideas regarding fire scenarios a qualitative Event Tree is provided. A worst case in fire scenario is selected and fire design calculation is done for this part. In next step, by considering the literature study, a procedure is proposed for implementing the provided methodology in ISO 24679-1.

By working on the case study, a gap regarding fire risk assessment was found. Therefore, a comparison between two fire risk assessments regulation, namely ISO 16732-1 Fire safety engineering — Fire risk assessment — Part 1: General, and NS 3901.E:2012 Requirements for risk assessment of fire in construction works is performed to provide an overview on risk assessment part.

Preface

This project is master's thesis as a part of the two-years' master of science in engineering in Reliability, Availability, Maintainability, and Safety (RAMS) program at Faculty of engineering, Mechanical and Industrial engineering, at the Norwegian University of Science and Technology (NTNU). Here, I would like to thank my main supervisor Professor Jørn Vatn, Department of Mechanical Engineering and Production and co-supervisor Professor Anne Elise Steen-Hansen, Department of Civil- and Environmental Engineering, for their supervision during this study. I really appreciate their patience during this time and all efforts that they spent for this project. Their deep monitoring and guidance in different stages helped me to finalize this project.

This subject had been identified by Multiconsult. I would like to thank Audun Borg, section leader fire safety in Multiconsult for giving me this opportunity to work on this project. I also would like to thank Kristine Woldseth Thorstensen, fire safety engineer in Multiconsult for her time in collaborating in this project.

Finally, I would like to thank my sister and all friends who truly have supported me during these two years and push me forward and help me not to lose my faith.

This thesis was written in memory of my Mom and Dad who taught me Never give up pursuing my dreams.

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List of Abbreviations (or Symbols)

BSI	British Standard Institution
ISO	The International Organization for Standardization
IEFG	International Fire Engineering Guidelines
SFPE	Society of Fire Protection Engineering
NTNU	The Norwegian University of Science and Technology
NS	Norwegian Standard
TR	Technical Report
LHS	Latin Hyper-cubic Simulation
PC	Performance Criteria
2D	2-Dimensional
3D	3-Dimensional
FEM	Finite Element Model
HRR	Heat Release Rate
MW	Mega watt

FDS	Fire Dynamic Simulator
EC	European Code
OAT	One-at-a-Time
RTM	Rebar Temperature Maximum
P_f	Probability of failure
EI	Integrity, Insulation
CFD	Computational Fluid Dynamics
CFast	Consolidated fire and smoke transport
REI	Load-bearing capacity, Integrity, Insulation
MJ	Mega Joules
$q_{f,d}$	Design fuel load
$q_{f,k}$	characteristic fire load density
$\delta_{q,1}$	factor of fire activation risk due to the size of the compartment
$\delta_{q,2}$	factor of fire activation risk due to the type of occupancy
δ_n	factor of the different active fire-fighting measures
$M_{k,i}$	combustible material amount
H_{ui}	net calorific value
u	moisture content of material
PVC	Polyvinylchloride
EQU	Equilibrium of the building
STR	Rupture or loss of Stability
GEO	Deformation of the Ground
FAT	Fatigue
ULS	Ultimate Limit States
SLS	Serviceability Limit States
E_d	Design value of effect of actions
E	Effect of actions
$G_{k,j}$	Characteristic value of permanent action j
P	Relevant representative value of a prestressing action
A_d	Design value of an accidental action
ψ_1	Factor for frequent value of a variable action
ψ_2	Factor for quasi-permanent value of a variable action
$Q_{k,i}$	Characteristic value of the accompanying variable action i
P	Relevant representative value of a prestressing action
FSO	Fire Safety Objective
FR	Functional Requirement
R_d	The design value of the corresponding resistance
$E_{d,dst}$	The design value of the effect of destabilizing actions
$E_{d,stb}$	The design value of the effect of stabilizing actions
ETA	Event Tree Analysis
$\dot{Q}(t)$	Heat Release Rate
α	Fire growth rate
t_0	Smouldering time
t_{gw}	Time of reaching to Max heat release rate
$\dot{Q}_V$	Calculated HRR by ventilation-controlled
A_0	The area of the opening
H_0	The height of opening

m_g	The mass of fuel burned during the growth phase
ΔH_{eff}	The effective heat of combustion of the fuel
m_{tot}	Total fuel mass
t_s	The duration of the steady state burning
t_d	The duration of the decay stage
AOV	The Automatic Opening Vent

1 Introduction

Throughout design, construction, and operation of a building, it is important to consider the fundamental requirements of fire safety. Indeed, fire safety provision is to minimize the loss of life, loss of finance and damage to property, damage to heritages, continuity of operation, and caution to the environment. Therefore, it is important to clarify the fire safety requirements and the acceptable level of fire risk for a building at the first life stages [1], [2],[3].

In addition, the content of fire safety of building can also cover other concepts like how to manage fire, how to control and reduce probability of ignition, how to manage combustible materials, how to limit fire propagation and growth, etc. in designing the construction fire safety policy two approaches can be applied. 'Deemed-to-satisfy' approach simply follows the perspective rules. In other words, this approach tries to satisfy the governments regulation for fire safety or protect the properties based on defined specification by assurance companies. On the other hand, performance-based fire engineering approach is going to address fire containment [1], [2], [3].

performance-based fire engineering is to increase the performance and the safety of a structure by developing engineering solutions. In addition, performance-based fire engineering provides flexibility in design, construction cost reduction and improvement in safety. However, complexity is also imposed throughout the implementation process. Then, it is required to study the fundamental principles of the performance-based fire engineering approach [1], [2], [3].

1.1 Theory and background

Firstly, in 1997 [4], [2] the performance-based codes were nominated as an alternative to prescriptive buildings standards. The changes in requirements and attitudes from one side and flexibility because of engineering from other side have developed buildings. Moreover, by documenting the performance of different solution, the building-related standards are also improved.

However, it is still challenging to document the fire safety performance of a building, why fire safety performance is based on qualitative assessing, and these assessments should show how much designs comply with the regulations. In addition, fire safety engineering is not so that sophisticated to be able to deal with the performance-related complexity like uncontrollable source of energy, interaction between human and building, etc. Nevertheless, this is not an excuse for not documenting fire safety performance.

As mentioned, to document fire safety performance a comprehensive assessment is required. And earlier we need a conceptual framework to implement fire safety objectives. Fire safety is introduced as a "set of practices intended to reduce the destruction caused by fire" [5], and conceptual model for fire prevention in building can be summarized as below:

- Fire safety physics – fire characteristics: study of the start, growth, and effects of fire.

- Structural fire safety engineering – building characteristics: study of the architectural and structural design of the building and its systems related to the occurrence, growth and effects of a fire and the ability to flee from a fire.
- Fire safety Psychonomic – human characteristics: study of the interactions between the surroundings and the behavior of people in these surroundings.
- Fire intervention science – intervention characteristics: study of the intervention in the event of a fire in the form of the response by the fire service and the in-house emergency responders.
- The influence of the environment on fire safety – environmental characteristics: study of the location of the building in relation to fire safety in the building.

Each of these disciplines have mutual effect or interaction with each other. Therefore, working on fire safety field requires a broad knowledge and insight in science and engineering. In this content, a fire safety engineer tries to apply engineering methods to develop or assess the design of built environment through the analysis of specific fire scenarios or through the quantification of risk for a group of fire scenarios. Regulations suggest that the following three safety criteria should be considered for assessing the fire-related design of a building:

- Personal safety for occupant
- Environmental and Social safety
- Material safety

In addition, the following variables should also be evaluated when performance-based design of a building is assessed.

1. Load bearing capacity of structures
2. Limitation of fire and smoke spread
3. Fire spread to other areas
4. Evacuation opportunities of occupants
5. Ensuring safety of rescue teams

In this regard, fire test experiments are applied in two ways [6]:

- Single fire that represented by a standard time- temperature curve
- Isolated elements or assemblies with defined boundary conditions and sizes

These tests are executed under fire standard condition, and real conditions are not taken into consideration. Then, from thermal point of view, real fire load, ventilation systems, thermal features of nearby boundaries, active and passive fire protection, etc. should be considered, and from Mechanical point of view, possible distribution of loads into rest of elements in a building need to be studied due to single element study[6].

Fossli N.G. [2], stated that performance-based standards are too young. It means that, the existing regulations and codes are not necessarily perfect. Nevertheless, with recent progression in fire safety engineering, there are worldwide organizations which are developing performance-based methodologies to assess level of fire safety in new or built structures. For an instance, the SFPE (Society of Fire Protection Engineers) has defined an approach which is called "Performance-based design as an engineering approach to fire protection design based on (1) agreed upon fire safety goals and objectives, (2) deterministic and/or probabilistic analysis of fire scenarios, and (3) quantitative assessment of design alternatives against the fire safety goals and objectives using accepted engineering tools, methodologies, and performance criteria" [7]. Therefore, it is required to study the developing performance-based methodologies deeply. In this way we will find how much the existing regulations and tools are applicable, how much they need to be modified, and even how much the methods have been succeeded to assess the level of safety of buildings.

A well-accomplished series of performance-based methodologies to assess level of fire safety in new or built structures have been developed by the International Organization for Standardization (ISO), like ISO 23932-1 Fire safety engineering — General principles [8], and ISO 24679-1 Fire safety engineering — Performance of structures in fire — Part 1: General. ISO 24679-1 generally provides a methodology for analyzing the performance of structures in the built environment when exposed to a real fire.

1.2 Theory

Throughout this theory it is to introduce the main steps for implementing the ISO 24679-1.

Main steps for applying ISO 24679

Although, the type of structure is effective on safety criteria, quantification of Performance of the structure in fire accident based on ISO 24679-1[6] can be summarized into 8 steps generally.

1. Scope of the project for fire safety of structure
2. Identify objectives, functional requirements, and performance criteria for fire safety of structures
3. Trial design plan for fire safety of structure
4. Design fire scenario and design fires
5. Thermal response of the structure
6. Mechanical response of the structure
7. Assessment against the fire safety objectives
8. Documentation of the design for fire safety of structure

Nevertheless, based on the type of structure, each of these steps are defined, explained, performed, and evaluated differently. In chapter 2, literature study on applicability of ISO 24679-1 is performed. It is described that how these steps are explained in different cases.

1.3 Goals

The overall goal of this thesis is to use of ISO 24679[6] - Fire Safety engineering - Performance of structures in fire. Traditionally, fire technical performance for load-bearing systems were evaluated based on the pre-accepted solutions and tables. ISO 24679 provides the possibility to fulfil the fire technical requirements.

This study is to investigate ISO 24679-1 by considering three perspectives:

1. how much ISO 24679-1 have received attention
2. how the applicability of ISO 24679-1 in assessing the level of fire safety of a building can be evaluated.
3. what are the difficulties in implementing the ISO 24679-1 and how it can be facilitated

Therefore, firstly a literature study on applicability and popularity of ISO 24679-1 is accomplished. Then, a procedure for implementing the standard is proposed accompanying with a case study. In this regard, it has decided to:

- Figure out what have been done regarding ISO 24679-1
- Investigate of all related technical report including ISO/TR 24679-2,3.
- Investigate how to implement and execute ISO 24679-1.
- Investigate a case study which used mentioned ISO.
- Propose a procedure to apply the methodology in ISO 24679-1

The outcome of this master's thesis can be useful in order to assess the performance of built structure.

1.4 Scope and limitations

In this study, in first step a literature review on assessing applicability of the ISO 24679-1 was performed. In this regard, published technical reports have also studied. In general, technical reports are identified as an example of application of ISO 24679-1 and prepared in format of ISO 24679-1. Besides of TRs, some studies which had used a part of this method or related technical reports have been also investigated. A case study which is a steel frame structure spectrum in Lillestrøm, Norway was selected by Multiconsult. Co. to work on first four steps of this methodology. This multi-functional spectrum includes five halls for events and three separated halls used for storage. On top of some halls, second floor had been built for office work. Multiconsult suggested concentrating on just one hall (hall B with 7274 m^2 area) which is one storey. After addressing advantages and disadvantages of this methodology and difficulties in implementation of ISO 24679-1, in next step, a procedure for implementation of mentioned ISO was proposed. To check the feasibility of suggested procedure, Multiconsult was asked to have a review on this procedure. Since, a gap in fire risk assessment was found, in next step, two risk assessment framework including ISO 16732-1 "Fire safety engineering — Fire risk assessment — Part 1: General", NS 3901.E "Requirements for risk assessment of fire in construction" works compared to have an overview on risk assessment stage of ISO 24679-1.

1.5 outline

In this project,

- Chapter 1 is introduction, including background, objectives and project limitation.
- Chapter 2 is about evaluation of suggested methodology in ISO 24679-1.
- Chapter 3 is literature review of studies related to ISO 24679-1.
- Chapter 4 is methodology part which is decided to work on a case study. The first four steps of mentioned ISO are taken into account.
- Chapter 5 is about result of studying the case.
- Chapter 6 is discussion part including advantages and drawbacks of ISO 246791-1, proposed procedure for implementation of ISO 24679-1, a comparison between two risk assessment frameworks namely ISO 16732-1, NS 3901.E.
- Chapter 7 is conclusion and recommendation.

2 Evaluate the methodology of fire performance of building

Behavior of the construction need to be assessed by performance-based standards, guidelines, and tools in fire design rather than perspective requirements[9]. Before, the buildings were designed to be preserved from the fire affects. However, these days by improving the performance-based design codes, fire is considered as a design condition throughout the design process. In addition, instead of experimental results, databases are being developed based on the realistic data for validating the computational models.

This chapter is to discuss the methodologies in evaluating the fire performance of buildings based on ISO 24679-1[6]. These evaluating methodologies may be based on one of the following categories:

- Fire-structural experiments: data of full-scale experiments are applied to validate the predictive models and evaluate the performance of components, connections, etc. of a structure
- Fire-structural modelling: pre-test prediction and post-test validation are conducted to evaluate the performance of predictive models. In addition, data from the ire-thermal-structural models are integrated to improve and develop the tools, guidelines, and codes.
- Reliability and uncertainty analysis: throughout structural response analysis, the effects of uncertainties from fire dynamics modelling on the structural performance is studied. Therefore, resistance factors for design can be updated continuously.

Scientists are applying an evaluating methodology or a combination of them to develop fire performance-based-related codes, tools, and guidelines. First category develops the performance-based methodologies based on accepted criteria and performance metrics. By mean of second category predictive tools can be validated. And third category provides information about range of applicability of a predefined method. Finally, the outcome of these evaluating methodologies show how a comprehensive fire safety approach can be implemented [10]–[13].

2.1 Assessing Definition

Different studies are trying to assess ISO 24679, by making changes in one or some steps of this framework. In this regard, firstly it is required to know how each step of ISO 24679 can be changed. In the following the possible changes in each step of this framework is described separately. For this purpose, according to ISO 23932-1 the guidance is divided into 12-steps fire safety performance-based design systematically [8].

Boundaries definition phase

1. Fire safety engineering scope of the project

   By setting the scope of the project it would be possible to extract the performance-based design-related information, for example, building features, extent of the application, affected neighbors, and external factors. In addition, it would be possible to know if refurbishment, change of use, and new construction of building are involved in design or not.

2. Fire safety objectives

   Fire safety objectives for ISO 24679-1[6] can either be obligatory or optional. However, clarifying the objectives would provide information about the trial design and performance analysis parts. Generally, these goals can be classified as Life safety, Property protection, Continuity of operations, Protection of the environment, and Protection of heritage.

3. Functional requirements

   Functional requirements are mainly defined based on the fire safety objectives. Then, these two steps can also be compacted. Functional requirements specify the required functions of performance-based design to catch the fire safety objectives. In better words, the controllable elements in designing a structure are relevant to functional requirements, for example fire protection systems.

4. Risk analysis approach

   In performance-based design it is required to declare explicitly the tolerable risks in numeric values. Risk analyses enable designers to compare the predicted risk with the tolerable value. In addition, it should also be clarified that in which risk uncertainty the performance-based design is being evaluated. For lowest, intermediate, and higher level of risk treatment, qualitative, deterministic, and probabilistic analysis should be applied respectively.

5. Performance criteria

   Performance criteria are a series of engineering metrics in deterministic or probabilistic form depending on the manner of risk assessment.

Design Phase

6. Fire safety design plan

   The elements of fire safety design should be taken into account to construct the fire safety design plan.

   - Fire initiation and smoke production
   - Spread of fire and smoke
   - Compartmentation and structural stability
   - Detection and suppression
   - Human behavior and evacuation
   - Firefighting response

   These elements should also be considered when the fire safety strategy of the building is prepared.

7. Design scenario

   Design scenario accounts for two types, fire scenario and occupant behavioral scenario. Fire safety design elements, risk analysis approach, and performance criteria are the Prerequisites for developing or studying design scenario. In fact, when one of this three steps is going to be investigated, in following design scenario should also be studied.

8. Engineering methods

   After preparing fire safety design plan and design scenarios, the consistent engineering tools should be applied to clarify how much fire safety objectives are met. For example, a procedure based on performed models, data analysis, and engineering judgment can make fire safety design plan and design scenarios comparable to the fire safety objectives.

9. Design evaluation

   By quantifying fire safety design plan and design scenarios, it is time to analyze the data, deal with uncertainty, and evaluate the fire safety design plan and design scenarios based on performance criteria.

Managing phase

10. Documentation

    All performed calculation, evaluation, analysis, and preparedness, assumption, etc. should be documented.

11. Implementation

    For new building this step makes sure that the construction complies with the design and in the case of a change all the steps should be revied.

12. Executive

    When the project is completed, the implemented management system should be kept alive. Indeed, inspection should be performed periodically within the life of the building and in the case of a change, the life cycle analysis should be applied.

It is worth saying that the most of studies have focused on the two first phases, boundaries definition and design phases, of this guidance.

2.2 Literature study on assessing the ISO 24679

This part is to discuss the limitation, strength and required improvement in some of systematic steps of ISO 24679 according to performed studies.

A study in performance criteria for performance-based fire design investigated the performance criteria in ISO 24679-1:2019. Van Coile R. et. al. [14] believes although ISO 24679-1:2019 is a practical framework to quantify the performance of structures in fire, the guidance definition on practical criteria is not enough. In following the study shortly described the boundaries definition phase of ISO 24679-1:2019 and then tried to clarify the meaning of practical criteria based on a literature review.

This article mentioned that if an applicable performance criterion is to be specified, it is required to select an appropriate risk analysis approach by considering the whole uncertainties. In other words, specifying the performance criteria is feasible when the probability of unwanted events and consequences of all the scenarios are assessed completely. In addition, the author referred to ISO 23932-1:2018 and concluded that a set of performance criteria can satisfy a corresponding functional requirement. However, performance criteria are still a sufficient requirement for functional requirement not a necessary requirement. According to the risk analysis approach, performance criteria can be deterministic or probabilistic. An important note from this study is that different fire safety objectives can have the mutual functional requirements and different functional requirements can have the mutual performance criteria. Moreover, for evaluating the performance of a building mathematically is not satisfying. In fact, brain storming, analytical interpretation and engineering judgment are required.

Van Coile R. et. al. [14] mentioned that reports do not specify the functional requirements and related performance criteria and tried to categorize the performance criteria based on two facts:

1. 'The effectiveness of the performance criteria in demonstrating compliance with a functional requirement must be evaluated from the perspective of a set of performance criteria'
2. 'The individual relevance of a performance criteria relates to its relative importance as part of a set of performance criteria'

In the following, the two type of definition performance criteria in this study is described.

Performance criteria in worst case approach

Firstly, the author tried to provide a list of performance criteria and associated functional requirements for concrete structure (Table 2-1).

No	**Ref.**	**Performance criteria**	**Functional requirements**
1	ISO/TR 24679-6:2017	Shear capacity check No overall loss of stability	Maintain compartmentation Stability up to burnout
2	RWS (2017) [15]	Concrete critical temperature Reinforcement critical temperature	Repairability post-fire
3	Law et. al. (2011) [16]	Reinforcement critical temperature Deflection limit Strain limit	Stability within rational time
4	Green et. al. (2013) [17]	Fire resistance time (Without loss stability during exposing to fire)	Stability within rational time
5	Lelli et al. (2018) [18]	Without loss of stability	Stability up to burnout
6	Hopkin et al. (2018) [19]	Without loss of stability Utilization time Deflection time	Stability up to burnout

Table 2-1: performance criteria and associated functional requirements in worst case approach [14]

Table 2-2 shows that the provided performance criteria need specified evaluation. For example, for performance criteria in case 3 need to be evaluated in temperature domain, while for cases 5 and 6 the thermal structural assessment is required. For all these evaluation performance criteria is defined to achieve a set fire resistant time based on stability and deflection limit. But we know that for example deflection limit may be different form a standard to another one. Therefore, meeting or not meeting the functional requirement by these performance criteria depends on the definition of deflection limit and stability. So, the author believes these types of conflicts are not described for specifying performance criteria in ISO 24679.

Performance criteria and risk assessment approach

At another part of study Van Coile R. et al. [14] classified the performance criteria based on risk assessment approach. They concluded that mainly performance criteria are specified by considering the probabilities of exceeding a limit, consequence rarely is taken into account.

No.	**Ref.**	**Performance criteria**	**Functional requirements**
1	ISO/CD TR 24679:2020	Achieve fire resistant time with defined reliability	Achieve fire resistant time
2	Phan rt al. (2010) [20]	Capacity check Deflection limit	Be defined by stockholders
3	Lange et al. (2014) [21]	Repair cost and downtime	Be defined by stockholders

Table 2-2: defining performance criteria and functional requirements in risk assessment approach [14]

Fire resistant time is accepted as the functional requirement to satisfy the fire safety objective. However, because of the uncertainty in structural response it is impossible to guarantee fire resistant time. Therefore, performance criteria are defined in a way to specify the threshold probability and remove the ambiguousness.

The study by Phan et a. [20] clearly showed that functional requirements need to be defined by consulting with the stockholders. And deflection limit can also be a performance criterion if associated risk assessment has accomplished. In better word, defining the performance criteria based on a comprehensive risk assessment can guarantee meeting functional requirements better.

Finally, Coile R. et al. [14] concluded that if a succeed fire performance-based design is the target, performance criteria should be specified based on a strong procedure. Why performance criteria or a set of performance criteria are required to meet the functional requirements, and meeting functional requirements means satisfying fire safety objectives. Therefore, performance criteria need to be clarified better than what described in ISO24679-related technical reports or performed studies.

A study investigated how much the uncertainties of input parameters can be tolerated by fire performance-based design framework of ISO 24679. For this purpose, Jovanović B and Van Coile R [22] investigated the special case in ISO/TR 24679-8:2020 ('concrete column subject to a standardized heating regime'). To study the uncertainty of an input parameter, Monte Carlo simulation was utilized to map the maximum axial load distribution in the column (Pmax). The author stated that this type of probabilistic analysis is demonstrated by ISO/TR 24679-8:2020.

Although Qureshi et al. [23] concluded scattered retention factor for the concrete strength, ISO/TR 24679-8:2020 supposes EN 1992-1-2:2004 [24] as the reference and not states a deterministic value in this parameter not only for concrete but also for concrete cover. However, Jovanović B and Van Coile R [22] believe as an important parameter retention factor for concrete cover should also be considered scatter. Therefore, this study updated the list stochastic variables of ISO/TR 24679-8:2020 as shown in Table 2-3.

Parameter	**Distribution**
concrete compressive strength,	------------
Concrete compressive strength retention factor	Logistic
reinforcement yield strength	Lognormal
Steel yield stress retention factor	Logistic
Average eccentricity	Normal
Out of straightness	Normal
Out of plumbness	Normal
Concrete cover	Beta $[\mu \pm 3\sigma]$

Table 2-3: updated list of Stochastic parameters of ISO/TR 24679-8:2020 [22]

In following the author used Latin Hyper-cubic Simulation (LHS) to find the distribution of Pmax. They mentioned that 104sample is taken exactly based on the described procedure in ISO/TR 24679-8:2020. But, contrary to ISO/TR 24679-8:2020, the produced Pmax histogram distribution was not fitted with the lognormal approximation. Jovanović B and Van Coile R [22] found that ISO/TR 24679-8:2020 proves the derivation of safety factors, by applying the approximation from theoretical distributions (Figure 2.1).

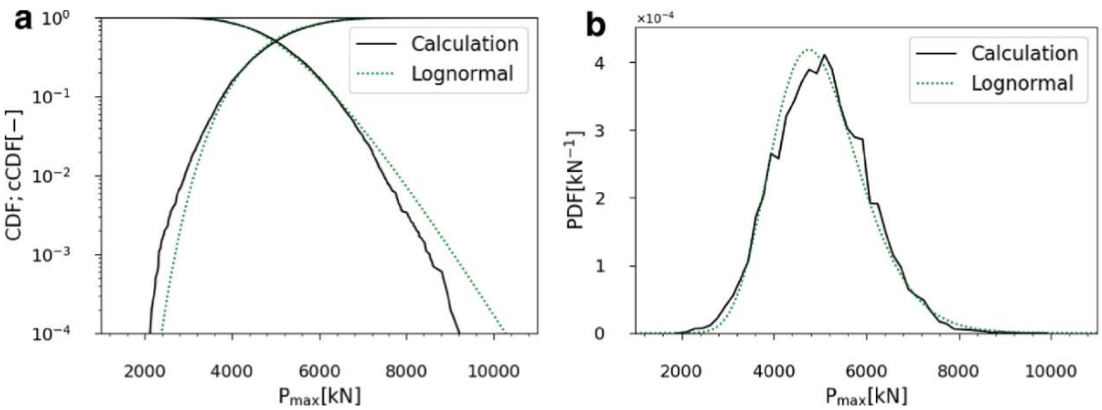


Figure 2.1: cumulative distribution function (left) and probability distribution function (right) diagrams for column load bearing capacity in standard fire (lognormal distribution is provided by ISO/TR 24679-8:2020) [22]**.**

To deal with the mentioned issues, Jovanović B and Van Coile R [22] made efforts to map the distribution for the column load bearing capacity. First, a sensitivity analysis was conducted to find the most effective parameters on Pmax. Then, a mixed lognormal distribution was provided for the column capacity in fire, shown in Figure 2.2 The authors believe that for further development of guidance, these provided information may be helpful.

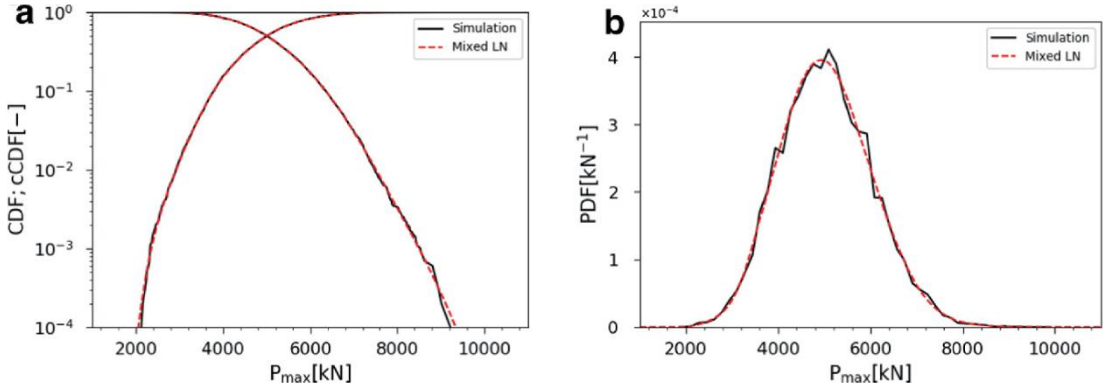


Figure 2.2: cumulative distribution function (left) and probability distribution function (right) diagrams for column load bearing capacity in standard fire (corrected lognormal distribution is provided by the authors) [22]**.**

Finally, the author concluded that by dealing with the input uncertainties and providing an accurate mixed lognormal distribution for column load bearing capacity, it is possible to predict the probability of failure for the column in exposure to fire, though the results need to be generalized in future research.

A well-performed article, namely 'Recommendations for performance-based fire design of composite steel buildings using computational analysis', suggested a systematic guideline for identifying goals, plan scenarios, and analytical methods. Gernay T, Khorasani N [25] believe performance-based fire design approaches have ability enough to provide benefit in terms of safety, sustainability, resilience, and cost-effective for new building. This study performed computational modelling on a case study, 'steel framed buildings with composite floor slabs', to analyze the fire-exposed structure deeply.

Gernay T, Khorasani N [25] firstly identified the performance targets and associated single and multi-component fire scenarios, beside considering fire as the secondary event. And finally, different modelling approaches were utilized to investigate to response of the structure and the change on design. The authors claimed that this approach enable engineers to optimize the fire protection plans and the design of structure based on the defined fire safety objectives.

Gernay T, Khorasani N [25] established their study on the framework of ISO 24679-1:2019, Figure 2.3 Therefore, firstly the authors defined the multiple-fire performance objectives and associated level of hazard by considering the project specification and stockholders' preferences. At the next step, fire plan design was clarified. In this step, fuel load, fire growth, and severity with a range of uncertainty were evaluated. Then by quantifying the thermal exposure condition, the authors needed to assess the thermal-exposed structure. For this purpose, temperature evaluation through thermal analysis and internal force and displacement evaluation through structural analysis had been required. Finally, it was checked if predicted response complies with performance requirements.

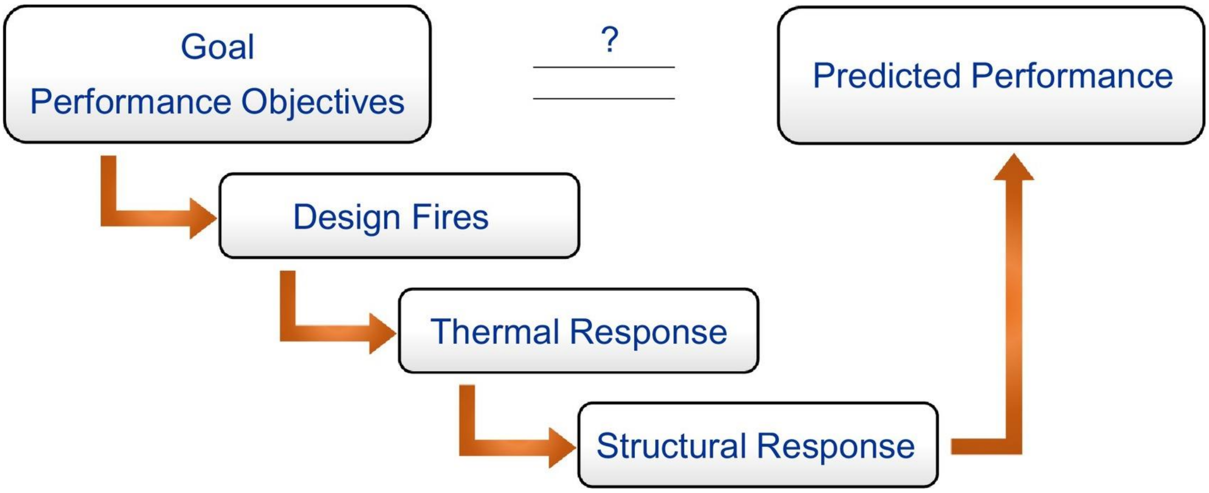


Figure 2.3: procedure of performance-based fire design based on ISO 24679-1:2019 [25]**.**

By considering the worst case, performance objectives and the scenarios were defined as it is shown in Figure 2.4.

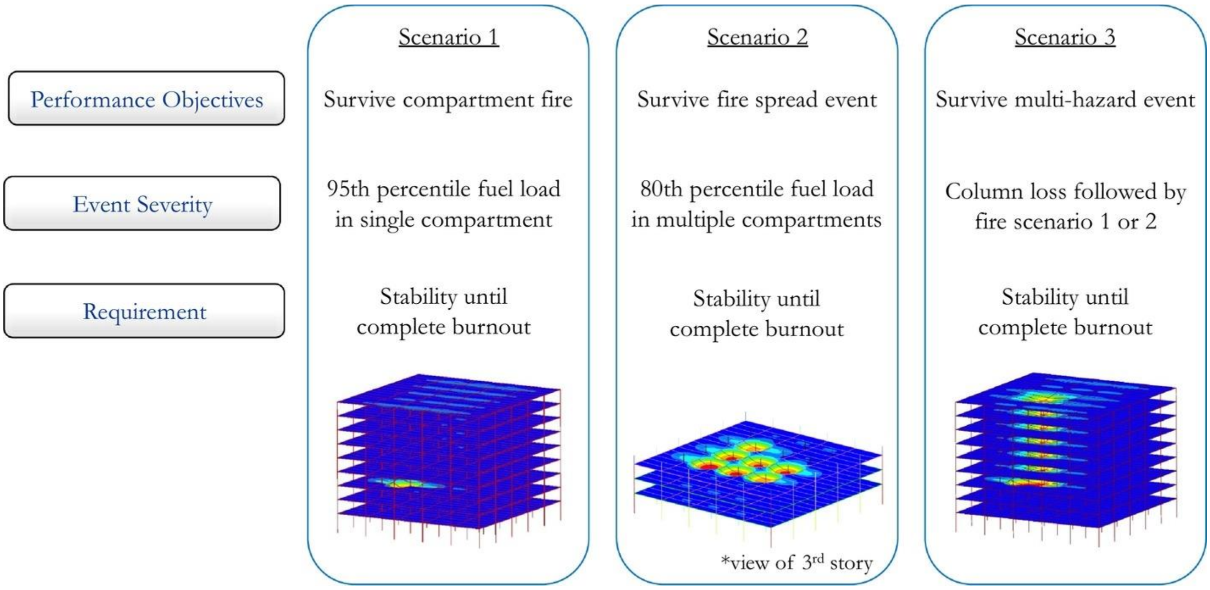


Figure 2.4: defined performance objectives, requirements, and scenarios for performing performance-based fire design on a composite steel building [25]

After performing computational modelling and numerical analysis this study presented the results and showed that this procedure can compare different scenarios and consider multiple objectives with associated more complex hazard scenario. However, the importance of this article is that the weakness of ISO 24679-1 framework for extreme scenarios can be solved. In addition, in the case of resilience objectives, this procedure would be applicable if quantifiable engineering demand parameters are defined correctly [25].

3 Literature review

First edition of ISO/TS 24679:2011 was replaced by ISO 24679-1:2019 [6]. First application of fire safety engineering using abovementioned standard was done on an open car park [26] by the International Organization for Standardization. The authors had tried to prepare a clear analysis by giving important information briefly in first stage including ventilation configuration status, access to fire brigade, non-fully developed fire due to no fire spread, structural analysis of non-insulated steel frame and profiled steel deck slab. All these information will affect next steps.

A 3-storey car park with all opened facades was focused and it had been designed and built according to the French regulation. In order to investigate that a structure will expose to how much thermal and mechanical load two important items was considered namely fuel load and mechanical actions. In this study, for calculation of fuel load the authors used available data from heat release rate of car fires and fire spread between cars according to real fire tests were done at CTICM in European research project [27]. To identify mechanical action, EN 1990 [28] has been used.

$$1{,}0\ G + 0{,}7\ Q$$

Where G is defined as permanent loads and Q is live loads.

The fire safety objective of this study was defined as saving the life of occupants, fire fighters, and who are in nearby. Therefore, a requirement was specified to fulfil this purpose which is no failure of building during the whole time of fire occurrence. As a result, a criterion is required to check if improvement in design led to improvement of safety of lives. To avoid structure failure, the following performance criteria has to be met:

- Maximum deflection of beams regardless type is not over 1/20 of their span,
- Maximum mechanical strain of mesh stays lower than 5 %.

With respect to ISO 24679-1[6], the structural stability was considered for defining PCs, since there is no compartmentation in car park.

One of the purposes of using this method in studies is that to suggest fire safety improvements in design and test that suggested changes in the built structure by different ways. The authors first defined the content of the structure means the full description of steel frame, concrete and specific information size of shear connector, distribution of secondary and primary beams. Then, since steel frame is non-insulated therefore, it was proposed to have:

Redistributing the loads on the floor by having "the Floor system" to act under membrane action. A structural solution is given in the study which includes using steel bars S500 to reinforce the floor [26]. In another strategy, it was suggested to use steel bars S355 which is more fire resistant [26].

In order to have an assessment on proposed design, identifying design fire scenarios is required to test that suggested design. There are different approaches in documents [6], namely list of prescribed scenarios, qualitative methods or semi-quantitative, comprehensive set of scenarios included likelihood and consequences. Fire scenarios in this study had taken from a survey which had been done before in open car park by considering the number of involved cars in fire, in two floors of parking car, different location of parked cars. The authors had tried to use two most intensive fire scenarios to assess behavior of the structure in fire. One was selected in ground floor because of the height of floor in for different position as you can see in Figure 3.1.

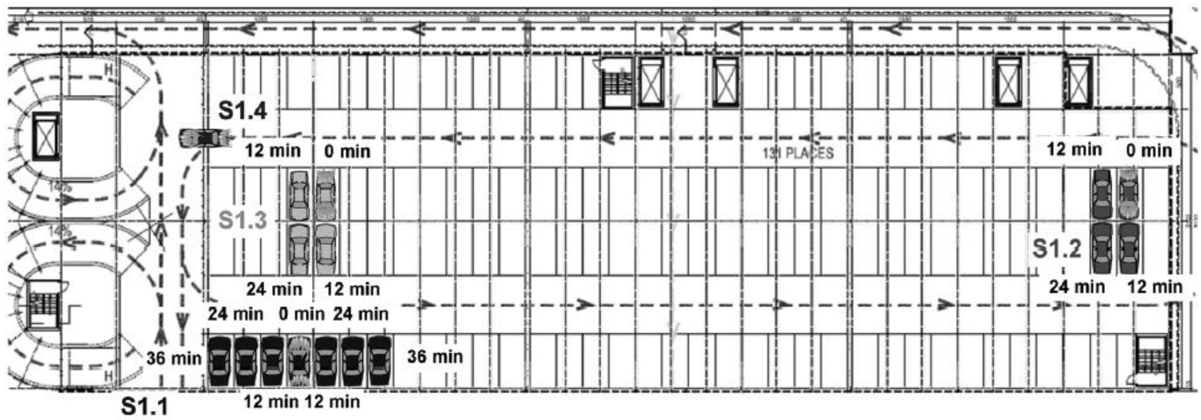


Figure 3.1: Possible fire scenario in first floor considered in ISO 24679-3[26]

Another design fire scenario was focused on second floor by considering some other locations, as you can see in Figure 3.2. Since, there were three different types of cars in each scenario, first heat release rate of them studied and then heat release rate of them under different scenarios were considered.

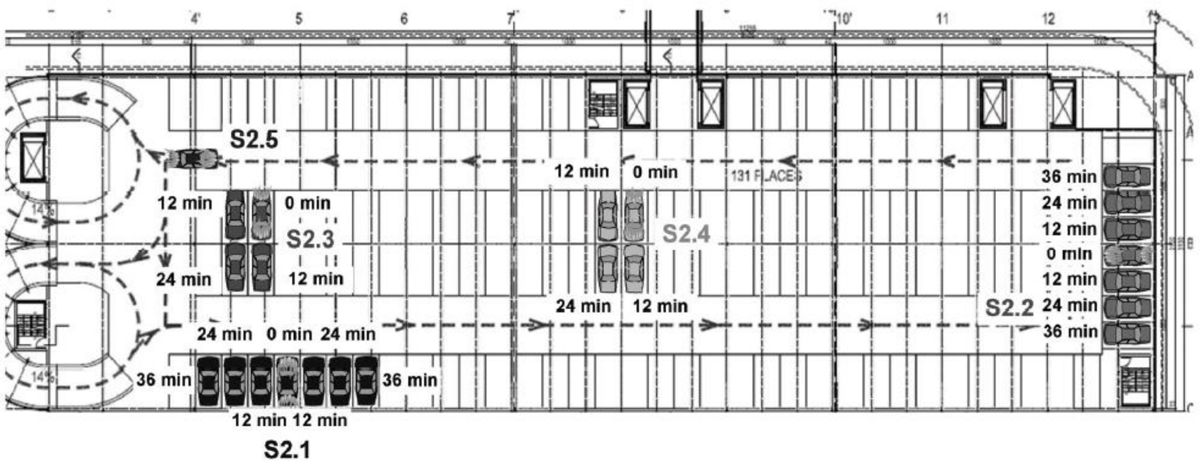


Figure 3.2: Possible fire scenario in second floor considered in ISO 24679-3[26]

Thermal actions from fire flames which expose to the structural members in nearby of burning cars were estimated by an analytical formula in EC1991 [29] called Hasemi's method. On the other hand, the effect of hot smoke layer on structural members far from fire was estimated by a numerical calculation named two-zone model[30]. By using this method, users can predict the heating that structural members receive.

It showed by passing almost 40 minutes of heat receiving was reduced due to full open facade of car park. For thermal response of the structure, the calculation of heat transfer in elements which exposed directly or indirectly to the fire were taken into account. In this study, 2-Dimensional modelling was used to conduct a heat transfer analysis on exposed and unexposed side of four principle structural members. Their study showed that primary and secondary beam are the most endanger elements in fire in this study. Since, the heated structural elements may cause expansion or contraction or totally deformation, the mechanical response of the elements are taken into account.

According to reference [6] the global structural analysis approach was done with respect of advanced calculation modelling. A 3-Dimentional Finite Element Model is used. A coarse definition of FEM is a method to solve numerically differential equations in engineering field and mathematical modelling. Specified areas of interest include the traditional fields of structural analysis, heat transfer, fluid flow, mass transport. To solve a problem by FEM, a large system is subdivided into smaller parts called finite elements [31]. In this study, three different types of finite elements are used namely 3-D nonlinear line element, 3-D nonlinear multi-layer shell element, 3-D linear line element. The difference was not mentioned.

The results revealed that the floor faced large deflection and maximum elongation of reinforced steel grid is 2,2%. The result for first floor showed that the tension of reinforcing steel mesh concrete slab is 2,0%. The authors concluded that the maximum value of tensile strain does not exceed 3% but some modifications were suggested.

In another study, Mohd Zahirasri et al. [32] tried to take idea from previous version of ISO 24679-1[6] to do quantitative risk analysis and define a suitable fire scenario for car parking building. So, a part of step four in ISO 24679-1[6] was considered. According to literature, which was provided shortly in this study, number of fire accident in car part was increased. In this regard, the authors did same study subject as previous study. The life safety of occupants, fire fighters was introduced as the main motivation for finding appropriate fire scenarios in structural design. Therefore, this work tried to have a larger risk-based research project where the first step is to create design scenarios which will be used for further analysis. In this regard, it is necessary to consider the approximate number, layout and type of vehicles that could be present in a parking building, the likelihood of multiple vehicles that could burn simultaneously and the potential total energy that could be released by the burning vehicles. Due to limitless of parking configuration, first a generic approach for scenario was defined. In this regard, the number of parking spaces n and x as number of vehicles considered. Figure 3.3 depicted this generic scenario approach.

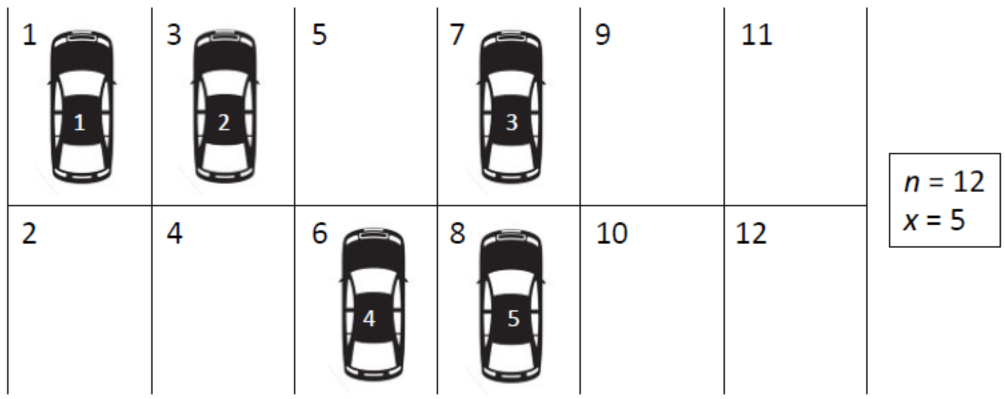


Figure 3.3: Generic scenario

Main purpose of this paper is to identify the likelihood and magnitude of multiple fire risk analysis which is usable to identify the impact of having a range of different vehicle fire scenarios in parking buildings. A quantitative approach was done in this study to establishes a dimensionless measurement for comparison. Since risk is a combination of likelihood and consequence of an accident therefore, the consequence is considered as the severity of the fire and is represented by the vehicle heat release rate and probability depends on different factors which were included in this study.

This paper established a probabilistic risk analysis approach by means of simple vehicle parking model, statistical data on vehicle fleets, measurements of passenger vehicle heat release and vehicle fire incident data. In this study, key variables are "vehicle parking distribution probability and how vehicles form clusters of neighbors, vehicle classification, vehicle fire involvement probability, and the severity of vehicle fires". Since this study provides a numerical assessment, all of important variables are quantitatively defined for each scenario. First item which was the vehicle parking probability key is used to identify the relative location of parked vehicles at a given time.

The author used Monte Carlo distribution for finding car parking distribution. As car parking and space between them will be influenced by different items like human behavior, a random distribution method cannot perfectly predict a good car distribution. Therefore, a parking tendency factor introduced. This parking tendency factor is controlled by a user-defined weighting method which cares about the probability of vehicles being parked at in different locations. The authors provided 80% weighting as an example in Figure 3.4. Regarding second factor which is vehicle classification, just private road passenger vehicle considered. In this study, the American National Standards Institute classification of road passenger vehicles based on mass of the vehicle is considered. For vehicle involvement probability, the authors took historical data in fire car parking into account.

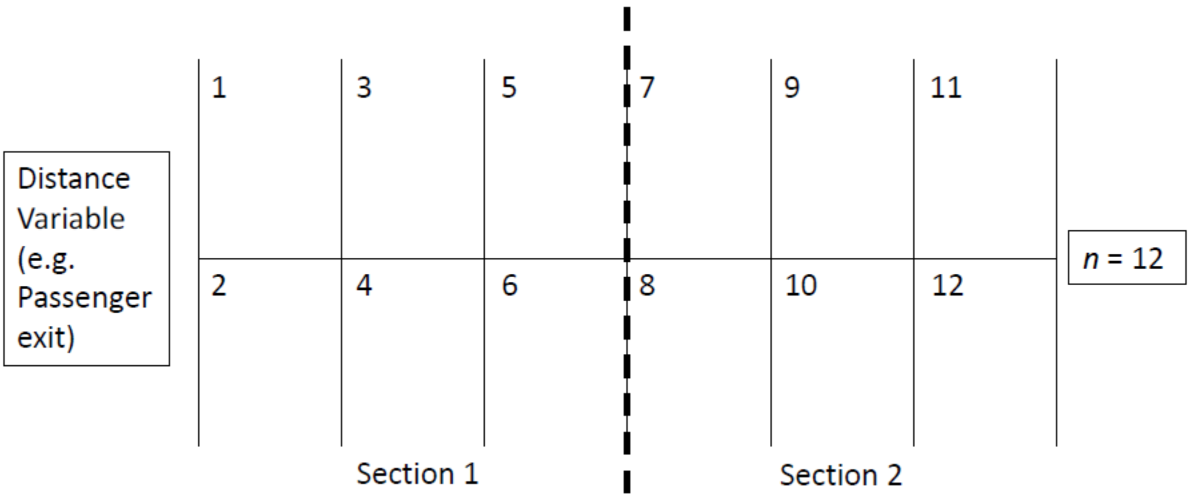


Figure 3.4: Generic car parking scenario for 12 spaces with tendency factor

To conduct severity study, heat release was considered. Tohir had another study in distribution analysis for the fire severity characteristics of single passenger road vehicles using published heat release rate data. Therefore, they borrowed some data for consequence calculation. This work got information of full-scale laboratory experiment data from 41 single passenger road vehicles in the terms of heat release rate, the time to peak rate of heat release and total heat released. Although in that work only four classes were analyzed namely Passenger Car: Mini, Light, Compact and Medium.

In this study any structural design did not perform, and it was about finding the most probable scenario. In this regard, an example for fire scenario in car parking proposed by a single row of parking spaces to understand better and easier of the process where the case includes of 5 parking spaces with 3 vehicles as it is visualized in Figure 3.5. All of the possible parking distribution scenarios for this case was considered. Whit considering three different assumptions, two methods for analysis proposed. As a result, in the method1 more vehicles involved, and the highest fire risk is for a single vehicle at $4{,}9 \times 10^{-4}$ fire risk level for a $75\,\%$ occupancy.

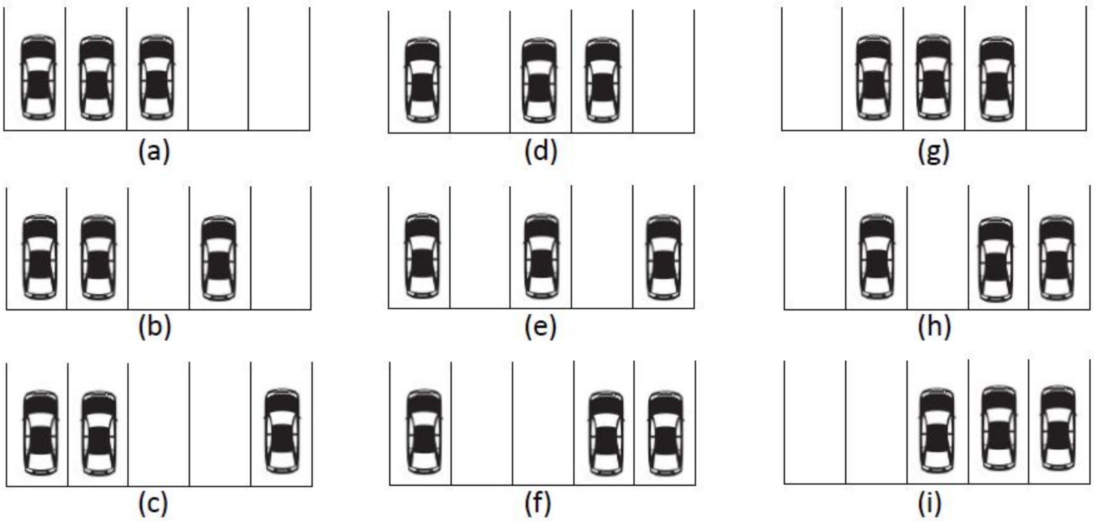


Figure 3.5: Possible scenarios with 5 parking spaces with 3 vehicles

Another work is a study of fire resistance assessment of airport terminal structure according to ISO 24679-1 [6]which had been done by the International Organization for Standardization. This two floors' airport terminal is in China so, some requirement regarding fire scenarios planning borrowed from Chinese building regulation.

A full description of effective information was first given like provided fire system in the structure, type of structural elements in both floors and main functional usage of the structure and so on. The object of this study was defined as calculation of mechanical performance of steel elements in the time of fire if proposed plan to the structure is practical.

For fuel load analysis, information was taken from a survey which had been don on this airport terminal and includes of fuel loads in different locations of the terminal like shopping area, check in hall and so on and so forth. This survey revealed the information which is mentioned in table. As, it shows in Table 3-1 baggage ware house and shopping include most fuel density 670 and 470 $MJ/_{m^2}$respectively.

No	**Location**		**Fuel load density $MJ/_{m^2}$**
1	Shopping area		470,0
2	Offices		439,0
3	Departure hall		93,0
4	Baggage sorting area	National	104,0
		International	93,0
		Baggage warehouse	670,0

5	Security check area	81,0
6	Frontier inspection and the customs	31,0
7	Check-in-hall	64,0

Table 3-1: Fuel load density

Since fire is considered as an accidental action, the probability of occurring more than one accidental action is low. Therefore, it will be considered with combination of permanent and live load. To calculate the combination of actions the following formula was provided in CECS 200 [33]:

$$S_m = \gamma_0 \left(S_{Gk} + S_{Tk} + \psi_f S_{Qk}\right) \quad (3.1)$$

$$S_m = \gamma_0 \left(S_{Gk} + S_{Tk} + \psi_q S_{Qk} + 0{,}4 S_{Wk}\right) \quad (3.2)$$

Where:

- S_m = the design value of combination of action.
- S_{Gk} = nominal value of permanent load.
- S_{Tk} = temperature effect of fire on the structure.
- S_{Qk} = nominal value of live load.
- S_{Wk} = nominal value of wind load.
- ψ_f = frequent coefficient of live load.

γ is partial factor associated with the uncertainty of the actions which is 1.15 for class A building. It was explained since that the roof is arch-shaped, according to Chinese regulation[34] the wind load in just opposite of other loads. As a result, Eq 3.1 was found suitable for this study.

The authors determined all objectives, functional requirement and performance criteria in respect of related codes in China. The fire safety objectives of this study were about life safety of people who are using the terminal and fire fighters and continuity of operations and conservativity of property. Functional requirement of the steel structure was defined as no destructive damage to the structure or any collapse in fire time.

The authors defined the performance criteria with respect of CECS 200[35]:

- $R_d \geq S_m$ while R_d is load-bearing capacity of the structure and S_m is design value of combination of actions. By meeting these two conditionals of statics:
  - ✓ "The maximum permitted *deflection* for the steel beam *shall not* be larger than $L/400$" where L is the length of steel beam in second floor.
  - ✓ "The maximum stress of the structure under fire condition *shall not* be larger than yield strength of steel at elevated temperature.
- No lower fire resistance of the steel structure (t_d) than fire resistance rating (t_m)
- $T_d \geq T_m$ while T_d is considered as critical temperature which structure faced failure and T_m is maximum temperature of the structure.

To design a trial plan, second floor is considered for rest of study because columns and roof made of steel. The authors explained in detail about two types of portal steel frames in second floors earlier in the study, as it is showed in Figure 3.6. This information will be effective on trial design. It was indicated that all these sizes for preliminary design of the steel structure were done according to a document "Code of design of steel structure" [36].

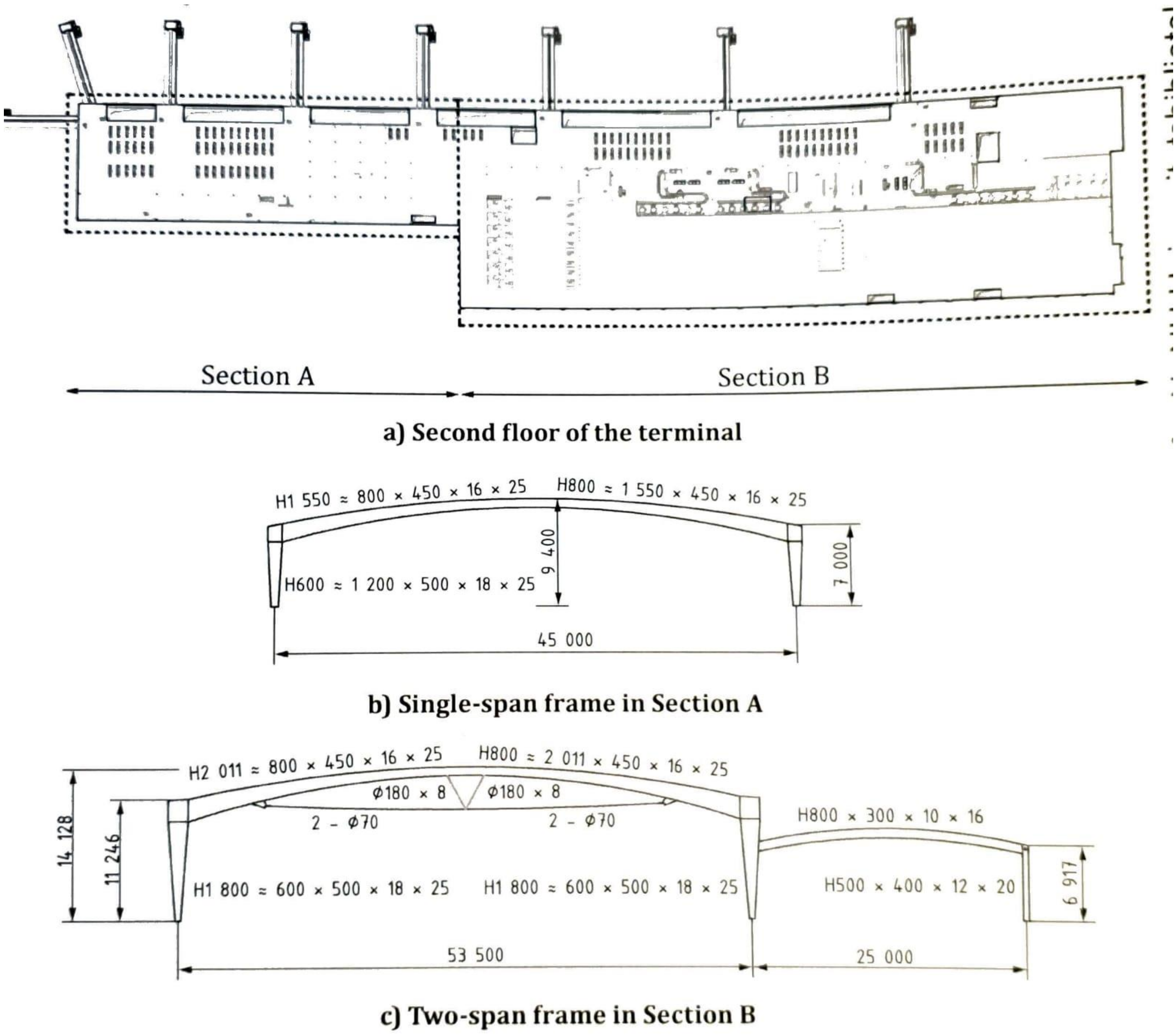


Figure 3.6: Two types of steel frames in the terminal

Referring to code for fire protection design of building document, it was revealed this airport terminal is in Class B, the authors did not mention what is class in that document. For trial design plan, it was suggested to protect second floor by thick fire coating with fire resistance rating not lower than 2.5 h according to GB 50016 [37].

It should be mentioned that steel columns in second floor are the main load bearing elements. These are most likely affected by fire. Therefore, the authors had decided to continue with this part of building. Also, since the steel roof of terminal is high enough therefore the roof left without any protection.

In case of fire scenarios, a description of all effective things is necessary including fire ignition, growth, and extinction of fire with also considering fire spread routes under identified condition. On the other hand, by using information from fuel load density and type of combustibles, fire ignition location and worst cases toward structural stability, three fire zones are designed.

First fire scenario named A is about that fire can affect directly increase in column's temperature (effectiveness of fire ignition). Second named B and third ones named C is that fire will happen directly under main and secondary span frame (effectiveness of worst cases in structural stability). Figure 3.7 depicts fire origins in second floor and cross-sectional views of them as well. The authors divided fire suppression system into automatic fire extinguishing system and smoke extraction system. Therefore, there will be totally 6 fire scenarios, 2 in each location.

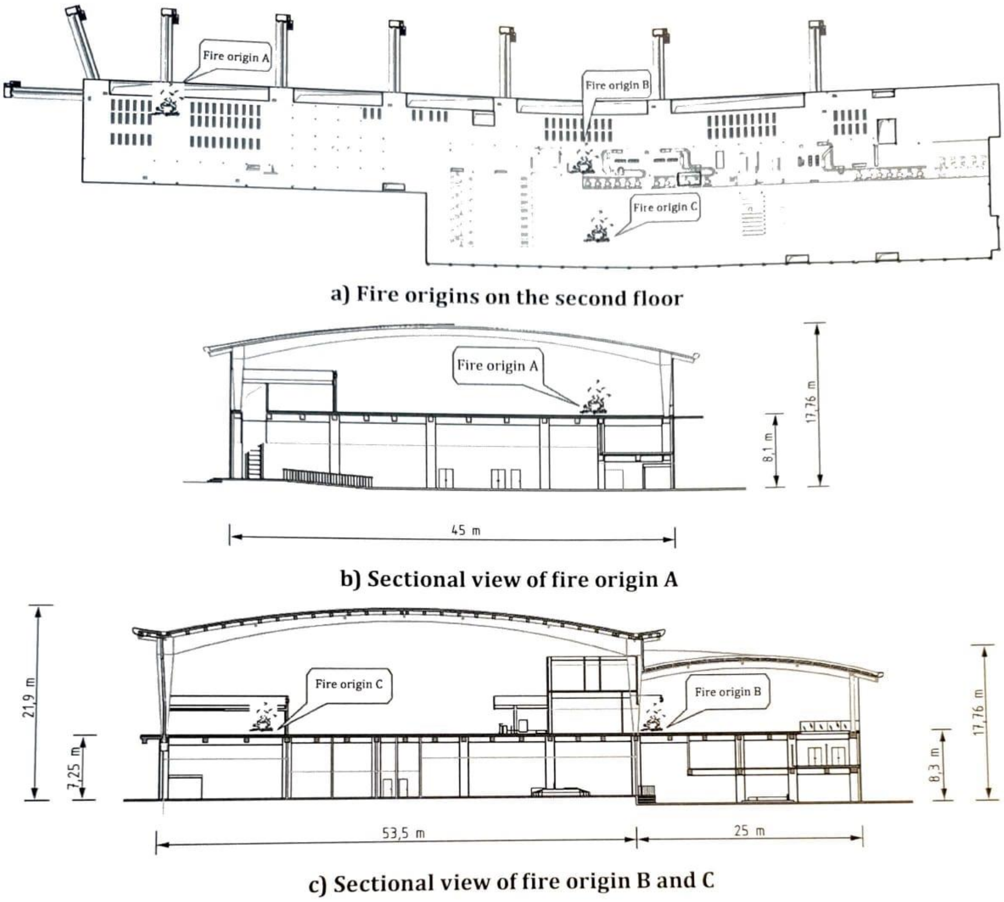


Figure 3.7: Fire origins of A, B, C

In case of thermal actions, the authors divided their study into four parts namely, fire growth rate, shop fire, defining of heat release rate and Numerical fire simulation. For fire growth rate an HRR-time relationship was suggested:

$$\dot{Q} = \alpha(t - t_0)^2 \quad (3.3)$$

Where:

- $\dot{Q}$ = Heat Release Rate of resource fire (kW)
- α = the fire growth rate $\left({kW}/{s^2}\right)$
- t = the burning time
- t_0= the smouldering time (s).

Since, smoldering time shows little effect on fire distribution, t_0 is considered equal to 0. Then, the equation turns to

$$\dot{Q} = \alpha t^2 \quad (3.4)$$

Four different types of fires are tabled according to required time that HRR reach to $1\,MW$ namely slow, medium, fast, ultra-fast. As, it is depicted in table by increasing α the slope of curve increases. For further studies and calculation of α, shop store and its content investigated to estimate nearest and most possible α for worst case study.

Categories of fire	**Typical combustibles**	**Fire growth factor**	**Time for HRR to reach 1 MW**
Slow	Hardwood furniture	0,00293	600
Medium	Cotton or polyester cushion	0,01172	300
Fast	Mail bags full of letters, wood pallet racks, plastic foam	0,04689	150
Ultra-fast	Pool fire, fast burning decorations, sheer curtain	0,1875	75

Table 3-2: Fire growth factor

The authors took information from a previous study which simulated clothing shop fires, one a rack of jeans with specified conditions and one pile of mixed textile clothes. In that study, $20\,kg$ rack of jeans exposed directly to a burner which was $150\,mm$ under the clothes. After measuring HRR curve and fire growth rate, as it was depicted in Figure 3.8, fire after $50\,s$ grows faster than fast-fire which was indicated in Table 3-2 as α (0.04689).

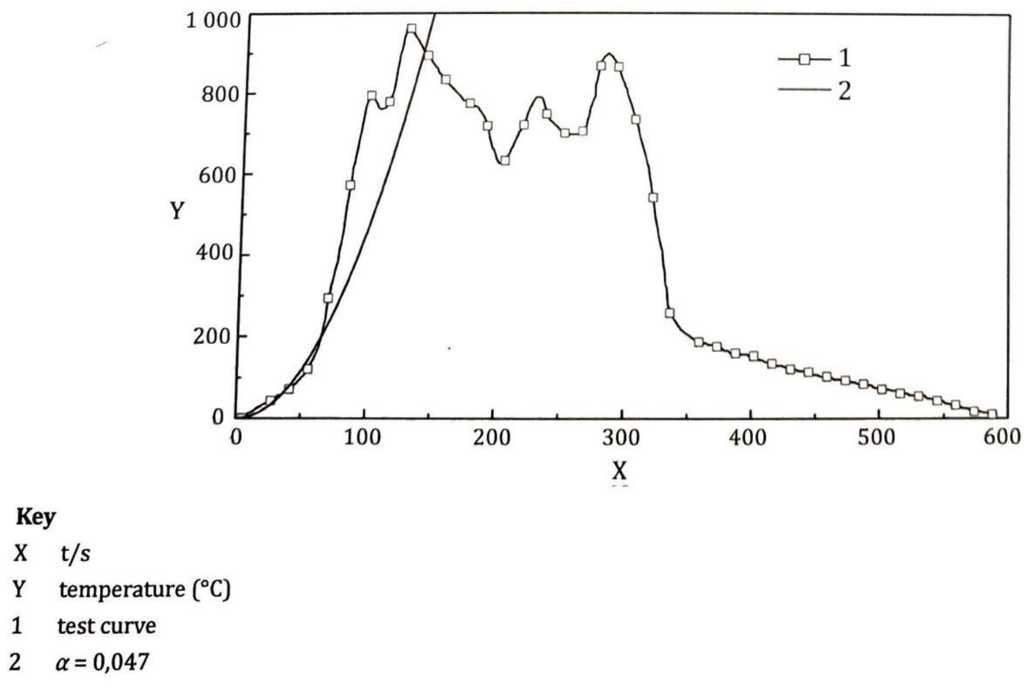
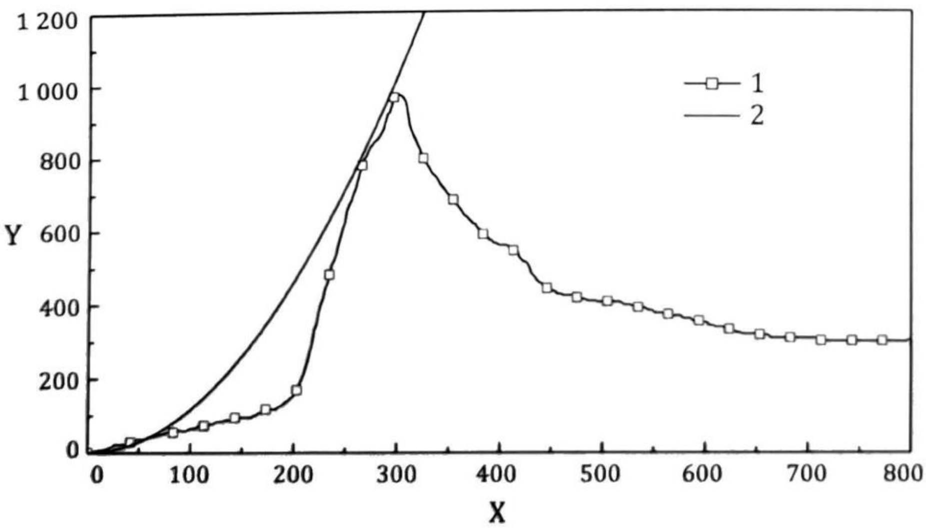


Figure 3.8: HRR curves for rack of jeans as a function of time

In another test on pile of mixed textile clothes which was put on a steel counter, was exposed to a burner $150\,mm$ below. The HRR rate curve in Figure 3.9 showed that fire in this case grows slower than medium fire which was indicated in table as α (0,02).



Key
X t/s
Y temperature (°C)
1 test curve
2 $\alpha = 0,02$

Figure 3.9: HRR curve for pile of mixed textile clothes as a function of time

Therefore, fire growth rate in the airport was considered fast fire rate considering this fact that other shops involve fewer combustible materials. To have worst case scenario to identify the heat release rate, fire suppression system was not activated but intervention of fire brigade is considered. By considering some condition the effective burning time is defined by:

$$t = t_j + t_c + t_l + t_z \quad (3.5)$$

Where:

- t = the effective burning time
- t_j = alarm time considered 3 minutes include 1 minute for recognizing fire and 2 minutes for confirmation of signal and sending fire alarm to main fire station.
- t_c = time for fire bridge to respond and start leaving fire station considered 1 minute.
- t_l = travel time of fire brigade considered 2 minutes.
- t_z = preparation for firefighting considered 2 minutes. All these measures are defined according to conservative consideration.

Calculation showed that 8 minutes is the effective burning time. To keep the safe side, the authors consider this factor equal to 10 minutes. Therefore, shape fire is defined as:

$Q = \alpha t^2 = 0{,}04689\, t^2 = 0{,}04689 \times 600^2 = 16880\ (kW)$ or equal to $16.9\ MW$.

To simulate the effect of fire and smoke spread on the elements a Fire Dynamics Simulator (FDS) was applied. With respect of cost of simulation and effect of accuracy, non-uniform mesh division was selected. The mesh sizes were defined as $0{,}25\ m \times 0{,}25\ m \times 0{,}25\ m$ near the source and $0{,}5\,m \times 0{,}5\,m \times 0{,}5\,m$ for rest of spaces. Afterwards, a sensitive study was done to validate the accuracy of the study.

In order to investigate the thermal response of elements when exposing to smoke, the gas temperature curves from FDS in previous part was used to assess the temperature profile of steel structure. The result show that in waiting hall that part of steel column which will expose to direct fire and at height $5\,m$ will reach 310̊© and at height $6\,m$ will reach 250̊©. Therefore, it was suggested to stakeholders that part of column under $8\,m$ shall be protected by fire coating with no fire resistance lower $2{,}5\,h$.

Two recommended formulas according to CECS 200 [35] was given in the document to calculate the temperature of that unprotected part of column when exposed to hot smoke. Since thermal conductivity of steel is quite high and steel temperature increase fast. The authors explained that steel temperature is assumed same temperature of smoke close to the element. As a result, the maximum temperature of smoke is considered as temperature of steel element and since steel is not thick ($25mm$) therefore, temperature profile is evenly distributed.

To see how the element will react in case of fire, mechanical response is studied. In this study, only steel frame which expose to direct fire was considered. From deformation analysis of the main frame in fire scenario zone C while have worst case scenario, it was concluded that the maximum mid-span deformation was 0,086 and the deflection of the structure was $L/662$ which compared to required PC which was $L/400$ is quite lower.

From deformation analysis of the secondary frame in fire scenario zone B while have worst case scenario, it was concluded that the maximum mid-span deformation was $0{,}081\,m$ and the deflection of the structure was 0,023 m which compared to PC is not exceeded. The strength analysis revealed that the maximum tensile and compressive stress was not exceeded over the required design strength even in maximum enhanced temperature. The maximum temperature of the main frame and secondary steel frame will reach 140 © and 240 © which is lower than design value (300 ©). According to provided results, the proposed method is approved and is feasible.

Mohammad Heidari et al [38] tried to propose a probabilistic approach to identify the reliability of a structural element when expose to fire when it designed according to Eurocode 1991-1-2 [29]. Their attempt was to determine the most important items which is needed to take into consideration in fire safety engineering design. They studied a reinforced concrete slab with 180 mm thickness and a standard load bearing fire resistance of 90 minutes. The slab was supposed to be in 420 m^2 office with 4 m height. Their assumption was uniform temperature and burning condition. A summary of what the authors have done is:

- To find a "reference case" fire scenario several fire scenarios concerning fuel load, ventilation size, contribution of fire suppression system, material properties etc. conditions were considered.
- Collect some temperature time curves with respect of EC1 [29]parametric fire method with assumption of uniformly burning fire in fire compartment.
- Heat transfer analysis on "reference case" fire scenario was done to have sensitivity analysis.

The authors provided an analytical Eq 3.6 which was given in reference EC1 [29] to calculate the fire temperature and it is valid for compartments with floor areas up to 500 m^2 and 4 m height:

$$T_g = 1325\ [1 - 0.324 \exp(-0.2t^*) - 0.204 \exp(-1.7t^*) - 0.472 \exp(-19t^*)]\ ℃ \quad (3.6)$$

The Eq 3.6 is a reference of finding fuel load. After defining fire temperature, a sensitivity analysis on the main items in EC1 [29] and heat transfer had been performed. It is mentioned that the heat transfer was solved by use of one-dimensional finite difference method for all conductive, convective, and radiative heat transfer.

The sensitivity analysis in this study was using One-at-a-Time method. In a simple word, it works by changing one input at a time, keeping others at their baseline, and calculating the variation in the output. All defining inputs were tested and result were compared to check which parameters are the most effective ones on the result. In this study, OAT method used to identify most effective parameters for further study of uncertainty by Monte Carlo simulation. Monte Carlo study had been done to assess reliability of concrete slab by means of the failure probability.

In more details, the authors gave description of sample for their study and took the calculation method from Eurocode 1992 to assess its performance. Fire was exposed to the slab from below therefore, the performance of slab was defined the temperature of the rebar in the tension zone.

The important parameter for defining failure of the slab was considered tension of a reinforced slab and critical temperature. For calculation of this critical temperature a reduction factor equals to 0.6 for combination loads was introduced. It was defined that by considering safety factor and other loads, failure of this reinforced slab will occur if reduction factor is $0{,}52$.

To define the duration and severity of fire, ventilation condition, amount, and distribution of fuels in the building is effective. It was mentioned different factors influence ventilation condition. Due to the matter of fact of uncertainty regarding ventilation, the authors had studied both fuel-controlled and ventilation-controlled design fires. As a result, a set of temperature time curves were provided with influencing opening factor 0.02 to 0.2 m1/2 and most effective reference case was that one with 0.097 m1/2.

The sensitivity analysis was performed regarding the most challenging parameters to check how inputs affect the maximum rebar temperature. Input items are including:

Fire load density which revealed that RTM (rebar temperature maximum) increased with respect to fuel load both with/out considering parameters in EC1. Other factors were fire-fighting measure index, axis distance of reinforcement with special effect on RTM, opening factor with no special consideration on RTM, concrete density and so on.

The OAT study specified parameters which does not affect the rebar temperature. As a result, less simulation number in Monte Carlo a probabilistic assessment is needed. Following abovementioned study revealed that six parameters for probabilistic assessment including fuel load, fire-fighting measure, opening factor, thermal inertia, coefficient in Γ, coefficient in t_{max} play vital roles. The Monte Carlo simulation were run in 1500 runs. In next step, the probability of failure P_f was defined the ratio between the number of simulations in which the structure failed and the number of times the simulation was performed, as following:

$$P_f = {}^{n_f}/_{n} \quad (3.6)$$

While n_f was considered as the number of failed simulations, and n is the total number of simulations. Therefore, the reliability of the system will be:

$$R = 1 - P_f \qquad (3.7)$$

Considering this reliability result, an Event tree was concluded to study quantitatively the effect of fire-fighting measure with regards of EC1 information. Mohammad et al showed in the Figure 3.10 that where all fire-fighting devices were available in the building, the P_f of slab was 0.3%, Unavailability of sprinkler systems, ended in a 1% P_f. When both sprinkler system and detection and alarm systems were not available in the building, the probability of failure was 8%. Consequently, the higher the firefighting measure index, the higher the design fire load density and the higher the probability of failure.

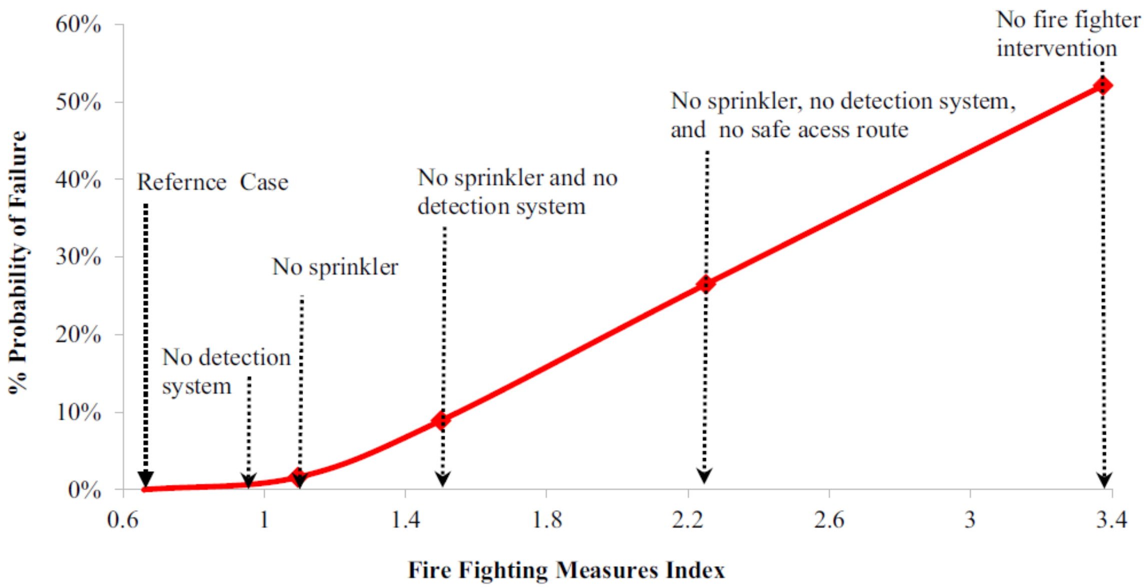


Figure 3.10: Probability of failure for a range of active fire fighting

By increasing the importance on probabilistic analysis in fire engineering, Jovanović B. et al. [39] tried to propose a consolidated probabilistic load model through a study, namely "Review of Current Practice in Probabilistic Structural Fire Engineering: Permanent and Live Load Modelling". In this article, the authors try to also investigate the applicability of presented model in ISO 24679.

This study [39] states that although experience-based approaches are efficient and rational especially when the performance is revised continuously, for innovative design solutions a full probabilistic approach should be applied to demonstrate the consistency of the design [40]. After an extended literature review on popular load models and describing the necessity for probabilistic approach for contemporary design, the authors showed that the proposed model can comply with the reliable regulation. Then, three model, including Model A (proposed by Guo Q, Jeffers A [41]), model B (proposed by Van Coile R. et al. [42]) and model C (proposed by the Authors [39]), were compared in different cases. One of these cases were studied concrete column in ISO 24679-6:2017.

The authors tried to compare the models based on failure probability of concrete column. A 4 m height column with dimensions of 500×500 mm^2. Column was made of concrete C30/ 37 and was reinforced with siliceous aggregates and 12 longitudinal rebars. The 20 mm rebars were covered with 42 mm of concrete. To compare the models, two parameters were selected:

I. strength retention factor
II. beta distribution

results showed that higher probability of failure is produced by Model A. Figure 3.11 shows that the probability distribution function for all three models and column concrete capacity.

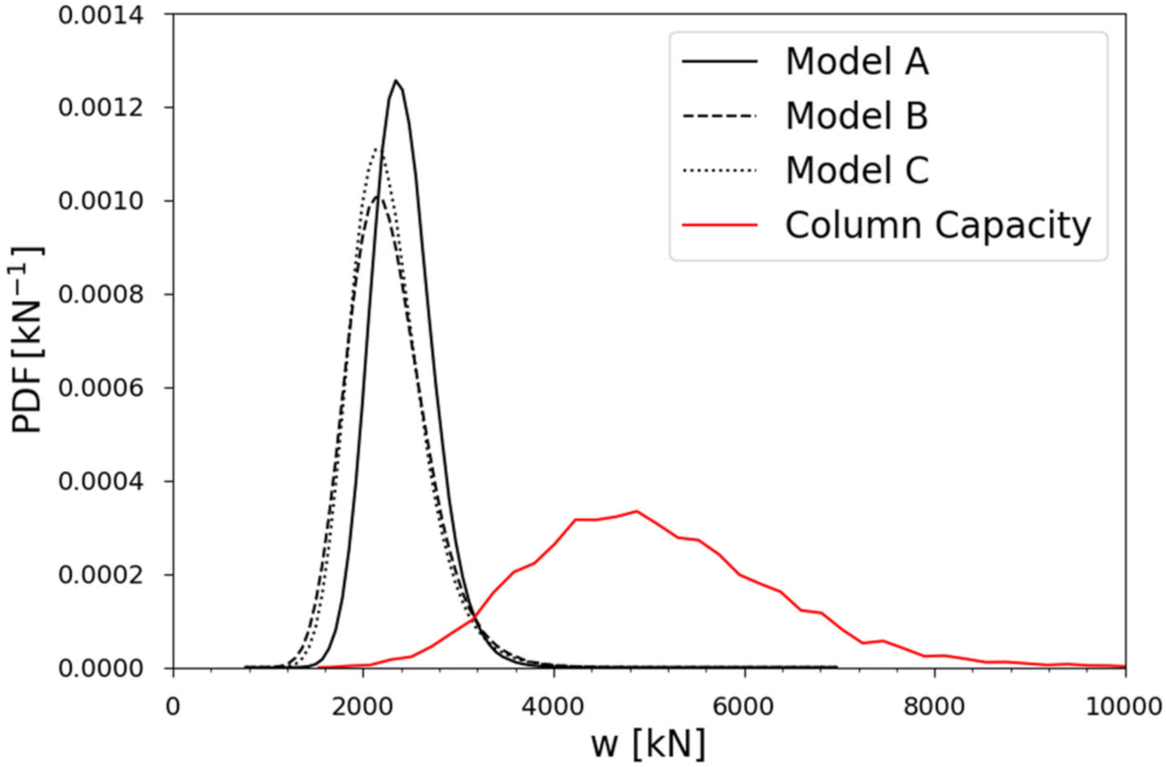


Figure 3.11: probability distribution function for three load models A, B, and C and load capacity of concrete column [39]**.**

Finally, the authors concluded that proposed model can be applied for performance-based fire design to study mechanical load, why this model provides better accuracy and comparability [39].

By focusing on ISO 24679-6 [43], Possidente L. et al. [44] investigated that two worst fire scenarios for a 15-story steel structure. The authors believed that investigation of different fire scenarios is required for a comprehensive application of performance-based fire design. In addition, this study nominated the ISO 16732-1[45] ("Fire safety engineering — Fire risk assessment — Part 1: General") as the approach for quantitative fire risk analysis.

The case study building was reported by ISO 24679-6, a 68.5 m steel structure building with 8236 m^2 gross floor area. Designers applied EI 60 fire-rated partitions to prevent fire from spreading fire. All other characteristics of the building and application are completely described by the authors [44]. Because of higher ration of column application, Possidente L. et al. [44] selected the second floor of the building and investigated the scenarios which affected on one floor at one time. The authors considered number of the involved column in s fire scenario and try to establish a event tree analysis, then based on the developed event tree the two worst case fire scenarios were selected (Figure 3.12).

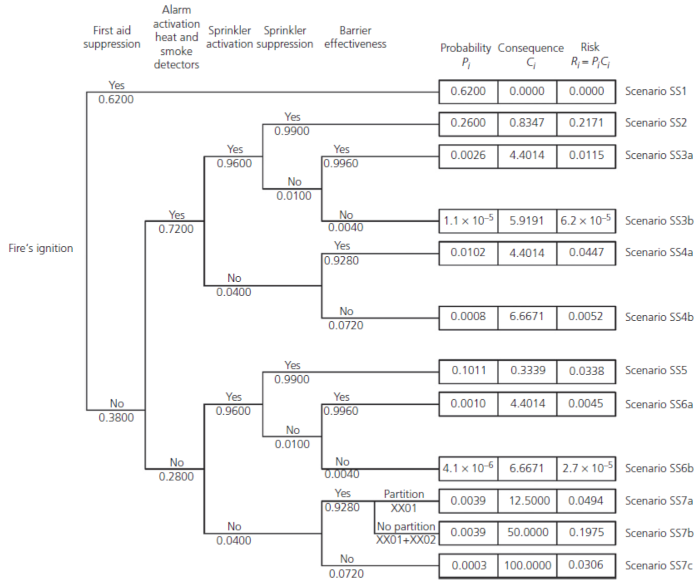


Figure 3.12: event tree analysis for studying the different fire scenarios [44]

Based on this risk assessment, the authors selected scenarios SS7a and SS7b. scenario SS7a is when fire was started from office XX01 (see Figure 3.13) and there was a wall between office XX01 and office XX02. SS7b scenario refers to the situation that fire is in XX01+XX02 (see Figure 3.13) and separating fire is not fire resistant. In the following Possidente L. et al. [44] applied rate of heat release to calculate the severity of the scenarios quantitatively. By calculating fuel load density of $511^{MJ}/_{m^2}$, and floor area of 87.5 m^2, maximum power of 21.9 MW is available for the fire scenario SS7a. however, for the fire scenario SS7b, all the compartment and floor area is equal to 362.5 m^2 and available power would be 90.6 MW. By this consideration the paper provided Figure 3.14 as the rate of heat release diagram for two scenarios.

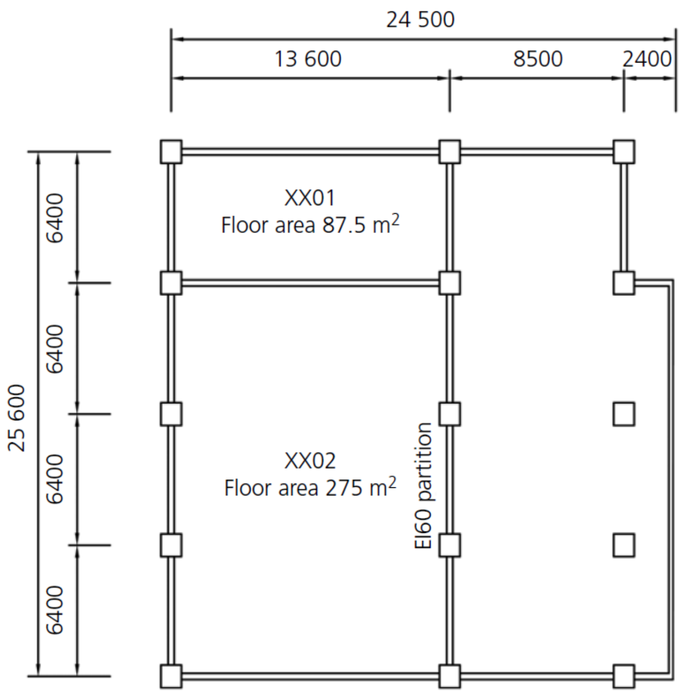


Figure 3.13: schematic diagram of second floor and layout of the offices [44].

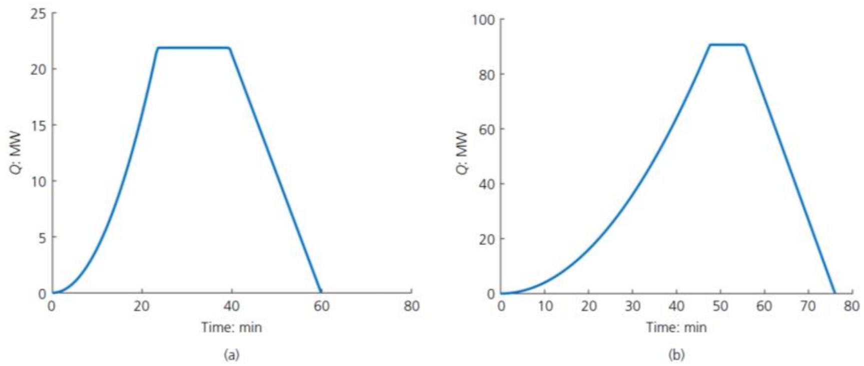


Figure 3.14: Rate of Heat Release for (a) scenario SS7a and (b) scenario SS7b

The authors [44] studied the fire development by applying computational and numerical simulation. Ozone model was applied to investigate the evolution of high temperature gas, to predict the thermal environment, CFast model was implemented, and computational fluid dynamics helped Possidente L. et al. [44] to know about type of fire and fire properties, and one-dimensional thermal analysis of beams and column were performed applying fire dynamic simulation.

The fascinating results of this article show that, in the case of SS7a scenario, probably composite slab would experience the failure. And in the case of SS7b scenario, after 40-45 min, internal beam G1-3 would face failure. These results are indeed obtained by analyzing zone temperature, highest temperature, hot zone temperature, and temperature profile of structure resulted from the fire dynamic simulations.

Finally, Possidente L. et al. [44] concluded that, CFAst, OZone, and FDS provide reliable results in predicting average temperature, and for anticipating peak temperature and temperature distribution, the author suggested FDS. In the case of analyzing effect of fire on the structure, the paper found the CFD as the best alternative. the authors also believe that for a successful fire risk assessment in performance-based fire design, knowing the fire exposed behavior of structures is required.

4 Methodology: Case study

In this part, we are going to work on first four parts of application of ISO 24679-1[6] in a spectrum located in Lillestrøm. A visit of the place of case study was done. It revealed that the building includes 5 different halls and a hallway with glass façade (see Figure 4.1) in one side which connect these five halls to each other. Although, all of the halls are in use for different events, depending on what kind of event happens inside one hall, there is possibility of not using adjacent hall. Also, on top of some halls second floor was built but they were not for using in events. To see more picture of the building please check Figure A.6,Figure A.7.

Figure 4.1: Facade view of NOVA spectrum

Fire Safety engineering- Performance of structure in fire- Case Study: Example of a steel framed spectrum

4.1 Design strategy for fire safety of structure

The built environment is an arena for trade fair exhibitions, congresses, conferences, concerts and events and all related business. Nova Spektrum arranges both trade fairs and audience fairs [46]. This arena has been provided with fire suppression system and alarm system as well. See Figure A.1 for fire system layout in first floor. According to the provided fire plan for both floors, there are enough emergency exits in first floor to the outdoors by considering the capacity of each hall. By considering the multi-function of spectrum, lots of different combustible stuffs in all halls are expected. The halls are separated by fire resistant walls therefore fire localized in the location of initiation. Load-bearing elements are mainly non-insulated steel. Fire Doors are used.

Closest fire stations to the spectrum are Fet Fire station and Lørenskog Fire station with 6,6 km/ 7 min and 4,8 km/ 6 min distance respectively. So, fire brigade intervention benefit was not taken into account in this study.

Qualification of the performance of structures in fire

4.1.1 Step1: Scope of the project for the fire safety of structures

Built environment characteristic

This built environment is one-storey (two-storey in some sections) steel frame spectrum with 5 halls for events and 3 halls in North which is used for storage, two in west (A, B), three in east (C, D, E) and one hallway which connect all west and east wings to each other. Except hallway (glass facade) which creates connection between halls A and B to C and D and E, all wings are separated by free space as you can see in Figure 4.2. The gross floor area is about 46,385 m^2 and the first-floor height is 20 m. See Figure A.2, Figure A.3 for more building drawing. According to regulation, this spectrum is Hazard class 5 and fire class 4[47].

This area has been provided with different type of passive and active fire protection systems like escape exits, marker light indicating the direction of escape ways to the outdoors, escape zone, escape corridor, manual fire alarm, fire hose, trigger for smoke hatch, fire alarm control panel and fire-resistant walls with characterization of REI 120, EI 30, EI 60. See Figure A.4, Figure A.5 for full description of fire protection system in both floors.

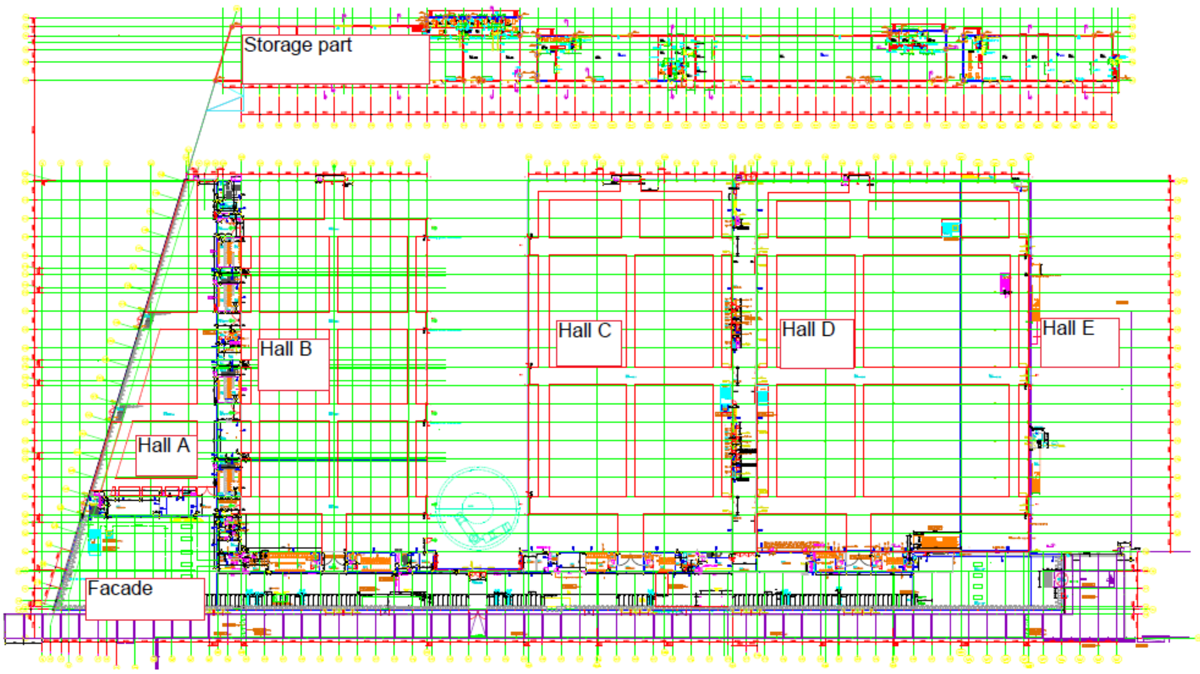


Figure 4.2: Building drawing first floor

Fuel load

General speaking, in calculation of fuel load or fire load density all combustible materials which were used in structure should be taken into account. That part of material which is not included char in fire time does not need to be considered [29]. Fuel load densities are described by the type of combustible materials (which is used in building or attached into), their amount and their location. These are usually determined using existing databases or from investigation and surveys [6]. The fire load which is applied in calculation should be design value [29], there are two ways to identify design fuel load, according to national classification of occupancies and measurements which specifically had done for projects [29]. For current study, there was not any survey or study regarding fuel load. In this regard, calculation is provided as the following [29]:

$$q_{f,d} = q_{f,k} \,.\, m \,.\, \delta_{q1} \,.\, \delta_{q2} \,.\, \delta_n \qquad (4.1)$$

While m is defined as combustible factor, δ_{q1} is a factor of fire activation risk due to the size of the compartment, δ_{q2} is a factor of fire activation risk due to the type of occupancy. For δ_{q1}, δ_{q2} Table 4-1 can be used:

Compartment floor area A_f (m²)	**Fire Activation Factor δ_{q1} concerning compartment**	**Type of occupancy**	**Fire Activation Factor δ_{q2} concerning occupancy**
25	1,10	Art gallery, museum, swimming pool	0,78
250	1,50	offices, residence, hotel, paper industry	1,00
2500	1,90	manufactory for machinery & engines	1,22
5000	2,00	chemical laboratory, painting workshop	1,44
10,000	2,13	manufactory of fireworks or paints	1,66

Table 4-1: Factors δ_{q1}, δ_{q2}

$\delta_n = \sum_{i=1}^{10} \delta_{ni}$ is a factor of the different active fire-fighting measures i (sprinkler, detection, automatic alarm transmission, firemen, etc). Table 4-2 shows suggested values for $\delta_{n,i}$.

$\delta_{n,i}$ function of Activation of fire-fighting measures											
Automatic fire suppression				**Automatic fire detection**			**Manual fire suppression**				
Automatic Water Extinguishing System	Independent Water Supplies			Automatic fire detection & Alarm		Automatic alarm transmission to fire brigade	Work fire brigade	Off-site fire brigade	Safe access routes	Fire-fighting devices	Smoke exhaust system
	0	**1**	**2**	By heat	By smoke						
δ_{n1}	δ_{n2}			δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}
0.61	1	0.87	0.7	0.87	0.73	0.87	0.61 or 0.78		0.9 or 1 or 1.5	1.0 or 1.5	1.0 or 1.5

Table 4-2: Factors δ_{ni}

For mainly cellulosic materials, the combustion factor may be assumed as $m = 0{,}8$.

$q_{f,k}$ is the characteristic fire load density per unit floor area $\left[{}^{MJ}/_{m^2}\right]$. Since, there is no previous study in this case, the author needed to calculate an estimated amount for that. In this regard, two items need to be taken into consideration: first, content of material inside and second, type of occupancies[29]. For calculating characteristic fire load results from combustible values inside the building the Eq 4.2 [29] are used:

$$Q_{fi,k} = \sum M_{k,i} \, . H_{ui} . \Psi_i = \sum Q_{fi,k,i} \qquad [MJ] \quad (4.2)$$

While $M_{k,i}$ is combustible material amount in Kg and it is calculable by defining permanent fuel load and variable fuel load.

H_{ui} is net calorific value in ${}^{MJ}/_{kg}$.

Ψ_i is considered as an optional factor in assessing protected fire loads. Regarding this factor, there are two options [29]:

- In case fire loads (meaning values inside the structure) are designed to tolerate exposing the fire, there is no need to consider this optional factor.
- In case fire loads (meaning values inside the structure) have no specific fire design but they can still survive from fire accident, optional factor can consider as the following:
  - The largest fire load but at least 10% of the protected fire loads is associated with $\psi_i = 1{,}0$.
  - Some fuel loads are protected, some of them are unprotected but it is not large enough to add heat to have constant fire, then for those protected fuel loads $\psi_i = 0{,}0$.
  - Out of mentioned conditions, ψ_i needs to be assessed individually.

For calculation of H_u Eq 4.3 is usable:

$$H_u = H_{u0}\,(1 - 0.1u) - 0{,}025u \qquad \left[{}^{MJ}/_{Kg}\right] \quad (4.3)$$

While u is defined as moisture content and H_{u0} is the net calorific value of dry materials.

In case you do not have moisture content of material (u) and/or H_{u0}, Table 4-3 depicts net calorific values of some solids/ gases/ liquids which had provided by EC1 [29] as the following:

Solids	
Wood	17,5
Other cellulosic materials • Clothes • Cork • Cotton • Paper, cardboard • Silk • Straw • Wool	20
Carbon • Anthracite • Charcoal • Coal	30

Chemicals	
Paraffin series • Methane • Ethane • Propane • Butane	50
Olefin series • Ethylene • Propylen • Butene	45
Aromatic series • Benzene • Toluene	40
Alcohols • Methanol • Ethanol • Ethyl alcohol	30
Fuels • Gasoline, petroleum • Diesel	45
Pure hydrocarbons plastics • Polyethylene • Polystyrene • Polypropylene	40
Other products	
ABS (plastic)	35
Polyester (plastic)	30
Polyisocyanerat and polyurethane (plastics)	25
Polyvinylchloride, PVC (plastic)	20
Leather	20

Table 4-3: Net calorific values H_u $\left[{}^{MJ}/_{kg}\right]$ of combustible materials for calculation of fire loads[29]

Therefore, fire load density $q_{f,k}$ per unit area will be:

$$q_{f,k} = \frac{Q_{fi,k}}{A} \quad (4.4)$$

While A is floor area of the fire compartment or reference space, or inner surface area of the fire compartment.

To have fire load from the occupancies Table 4-4 are suggested by EC1 [29]:

Occupancy	**Average**	**80% fractile**

Dwelling	780	948
Hospital (room)	230	280
Hotel (room)	310	377
Library	1500	1824
Office	420	511
Classroom of a school	285	347
Shopping centre	600	730
Theatre (cinema)	300	365
Transport (public space)	100	122
Note: Gumbel distribution is assumed for the 80 % fractile.		

Table 4-4: Fire load densities $q_{f,k}$ $[MJ / m^2]$ for different occupancies

the provided values in Table 4-4 are applicable when the following conditions are valid; first, δ_{q2} is equal to 1,0 and, Second, they are applicable when for ordinary compartments of occupancies. In case of special compartment which is not included in the above table try to use previous equation for characteristic fire loads in Eq 4.1.

Finally, after considering fire load from occupancies it should be added to fire load from building.

Mechanical actions

Since, fire occurrence is an accidental action (something that occupants do not wait for that), the likelihood of combined load meaning fire and extreme mechanical load at the same time is quite low[6]. On the other hand, other accidental actions need to take into consideration like seismic risks, damage to separating elements, damage to suppression system due to an earthquake and so on[6]. All these elements are effective on designing fire scenarios and further calculation in defining heat release rate.

As, it was mentioned earlier in literature review part, loads on structure can be defined as "dead load or permanent actions" and "live load or imposed actions". First one refers to those loads that are always present and self-weight of building materials. Second one refers to those that may be present in the building or may not including human occupancy loads, non-human occupancy, snow and wind load and so on [48].

To determine mechanical actions EC1990 was considered[26]. Mechanical actions are combination of permanent and live loads. According to EC0 actions are classified into permanent actions (G), variable actions (Q), accidental actions (A) [28].

According EC0[28], relevant design situation shall be considered, and it is classified like:

- *Persistent design situations* which is normal usage of the structure.
- *Transient design situations* which it means it is temporary to the structure like repair time.
- *Accidental design situation* which as it was abovementioned no one in the structure expect to face this situation like fire, explosion and localized failure.
- *Seismic design situations* which it refers to seismic events[28].

In this study third situation is considered. It should be explained that there are two different limit states [28] namely Ultimate and Serviceability limit states to calculate combination of loads (mechanical actions). Ultimate limits define states related to collapse or similar conditions of structure failure and it concerns to the safety of people and/or safety of structure. In this regard, limits in the following shall be verified where-ever they are relevant.

- Loss of equilibrium of the building (EQU)
- Failure caused by deformation, rupture or loss of stability (STR)
- Failure or deformation of the ground (GEO)
- Failure caused by fatigue or other time related effects (FAT)

Serviceability limits refer to those of service requirements in case of structure and structural members which are not met anymore. It concerns to the structural functioning in normal condition, comfortability of people inside and the structure appearance. In this regard, three different types of verification shall be done[28]:

- Deformation related to irreversible limits
- Vibrations related reversible limits
- Damage to the structure related to long-term effects

In other words, concerns of the ultimate or strength limits are preventing from collapse or failure structure while, serviceability limits concern about deflection and vibration which may affect the provided service of the structure. Those loads which might happen more frequently during life span of building are related to serviceability states. Structural design in case of fire is about considering ultimate limit states (ULS) since, the vital point in fire accident is about strength of the structure and safety of the occupants rather than appearance of the structure or comfort of people[48]

Regarding calculation of ultimate limit states (ULS), there are three different equations for:

- persistent and transient design situation
- accidental design situation.
- seismic design situation.

Since, this study is about occurring fire in a structure therefore, calculation for accidental situation will be considered. The general Eq 4.5 shows the accidental situation:

$$E_d = E\left\{G_{k,j}; P;\ A_d;\ \left(\psi_{1,1}\ or\ \psi_{2,1}\right) Q_{k,1};\ \psi_{2,i} Q_{k,i}\right\} \quad j \geq 1; i > 1 \qquad (4.5)$$

In mathematical way:

$$\textstyle\sum_{j\geq 1} G_{k,j}\text{"+"P"+"}A_d\text{" + "}\left(\psi_{1,1} or\ \psi_{2,1}\right) Q_{k,1}\text{" + "}\sum_{i>1} \psi_{2,i} Q_{k,i} \qquad (4.6)$$

while,

A_d Design value of an accidental action

E_d Design value of effect of actions

E Effect of actions

$G_{k,j}$ Characteristic value of permanent action j

P Relevant representative value of a prestressing action

$Q_{k,1}$ Characteristic value of the leading variable action 1

$Q_{k,i}$ Characteristic value of the accompanying variable action i

ψ_1 Factor for frequent value of a variable action

ψ_2 Factor for quasi-permanent value of a variable action

Characteristic values of actions

By considering Eq 4.6 there are elements that should be clarified as the following:

- The permanent action shall be analyzed as:
  - Small variability in G can be result in a single value of G_k
  - Not small variability in G can be result in considering two different values, upper value $G_{k,sup}$ and a lower value $G_{k,inf}$
- The prestressing (P) should be considered as a permanent action which created by controlled forces and/or controlled deformation to a structure.
- The design value A_d of accidental actions should be defined for each project.
- The variable actions shall be involved
  - Upper or lower value
  - Nominal value where statistical distribution is not known[28]
- Regarding characterization of ψ according to table A1.3 in EC0[28] is selected as frequent value, $\psi_1 Q_k$, used for verification of ULS including accidental actions.

Design situation	**Permanent actions**		**Leading accidental action**	**Accompanying variable actions**	
	Unfavorable	**Favorable**		**Main (if any)**	**Others**
Accidental	$G_{kj,sup}$	$G_{kj,inf}$	A_d	ψ_{11} or $\psi_{21} Q_{k1}$	$\psi_{2,i} Q_{k,i}$
"In the case of accidental design situations, the main variable action may be taken with its frequent value" Important cautious: by mentioning frequent value, selecting ψ_1 will be given as hint. For more information, readers can check out section 4 part 1.3 in EC0 [28]. Attached to EC0 [28], there is Norwegian National Annex. It is useful to check all variable that you choose. In this part, same variables for ψ were offered.					

Table 4-5: Design values of actions for accidental actions

By considering Table 4-5, Eq 4.6 will be shortened into:

$$G_{kj,sup} + \psi_{11} Q_k \quad (4.7)$$

Values of ψ_0, ψ_1, ψ_2 are accordingly by using European code 1990 [28] will be found in Table 4-6:

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category			
Category A: domestic, residential areas	0,7	0,5	0,3
Category B: office areas	0,7	0,5	0,3
Category C: congregation areas	0,7	0,7	0,6
Category D: shopping areas	0,7	0,7	0,6
Category E: storage areas	1,0	0,9	0,8
Category F: traffic area, vehicle weight≤30KN	0,7	0,7	0,6
Category G: traffic area, 30KN< vehicle weight≤160KN	0,7	0,5	0,6
Category H: roofs	0	0	0
Snow loads on buildings			

Finland, Iceland, Norway, Sweden Reminder of CEN Member States, for sites located at altitude H >1000 m a.s.l Reminder of CEN Member States, for sites located at altitude H≤1000 m a.s.l	0,7 0,7 0,5	0,5 0,5 0,2	0,2 0,2 0
Wind loads on buildings	0,6	0,2	0
Temperature (non-fire) in buildings	0,6	0,5	0
Note that ψ values may be set by the National annex.			

Table 4-6: Recommended values of ψ factors for buildings

Note: Same values for ψ are presented in National annex at the end of EC0 [28]. It means Norwegian authorities choose same values for partial factors.

Therefore, in this study to calculate the combination actions, Eq 4.8 is concluded:

$$E_d = G_k + 0{,}5\, Q_k \qquad (4.8)$$

Structural analysis means calculating load flows, dead and live load on the structural elements can be calculated for simple structures If member sizes are known. For more complicated structures computer programs are widely used [48]. General speaking, load calculation on beam, column and slab can be calculated as the following [49]:

Load on column = Self weight of the column* Number of floors

Load on beams = Self weight per running meter

Total Load on Slab = Dead Load + Live Load +Wind Load + Self-Weight

In order to calculate self-weight of an element, it is needed to have dimensions and information about the component of material included. Most likely, this information is given to you by the designer of the structure or stockholders.

4.2 Step 2: Identify objectives, functional requirements, and performance criteria for fire safety of structure

4.2.1 Fire safety objective

Fire safety objectives are mostly concerned about life safety, keeping safe the property, no intervention in the operation, protection of heritage and environment [50]. In this regard, the following Fire Safety Objectives are considered:

Object 1: Health and Life safety

Sub-object 1.1: protection of occupants

FSO1: The fire safety design shall be like which fire related injuries or illness to occupants kept minimizing [8].

Sub-object 1.2: protection of fire fighters

FSO2: The fire safety design shall be like which fire brigade have enough time to operate properly and have safe evacuation[6] , [8].

Sub-object 1.3: protection of third parties (outside of the structure)

FSO3: The fire safety design shall be like which people in nearby face no fire related dangers.

Object 2: Environmental protection in order to prevent from long- lasting consequence on the environment. [50]

Sub-object 2.1: water and ground protection

FSO4: The fire safety design shall be like which “Nitelva river” water quality included transparency of water stay same before fire accident.

FSO5: The fire safety design shall be like which fire-fighting water shall not create water underground pollution.

Object 3: Property protection

Sub-object 3.1: Moveable properties inside the structure

FSO6: The fire safety design shall be like which movable priceless properties inside the building keep safe without degradation in their quality.

Sub-object 3.2: Continuity of operations

FSO7: The fire safety design shall be like which no long-lasing interruption of current process inside the building especially for super crucial business which interruption may lead more loss that fire accident.

Sub-object 3.3: Preservation of heritage

FSO8: The fire safety design shall be like which to minimize the probability of occurrence fire in either nearby of historical or cultural building or inside.

4.2.2 Functional requirement

As it was mentioned before, functional requirements are described related to compartmentation and stability of building [6].

FR1: FSO1 and FSO3 is fulfilled while occupants are not exposed to sudden changes in conditions regarding to increasement of temperature on unexposed surfaces (Insulation), radiation, spread of toxic/hot gases, irritant species and/or flames (Integrity) and resistance of building toward collapse (stability) in entire time of fire.

FR2: FSO2 is reached if neither the load-bearing (walls) structures building nor non-load-bearing elements (partitions, doors, windows) do not collapse in evacuating time.

FR3: FSO4 is fulfilled if burned material from structure or particles and ashes does not spread easily to endanger species in the river and vicinity.

FR 4: FSO5 is fulfilled if not large amount of waste extinguishment water spread into ground water.

FR5: FSO6 is fulfilled if damages restricted to the room/ compartment of fire origin.

After setting functional requirements, it is time to select a risk analysis approach. The idea behind of risk analysis approach is that after all fire safety calculation, you need to compare results with tolerable level of risk in your study. The means of this comparison is named as performance criteria.

Depending on the level of treatment of uncertainty in the study, risk analysis approaches are categorized as qualitative, deterministic, and probabilistic analysis. While the level of uncertainty treatment increases respectively. In this study, an approach between qualitative and deterministic approach which may know as semi quantitative risk analysis was selected. The purpose of deterministic analysis is to design by assuming worse than average exposure. This approach sometimes known as consequence analysis [8]. Since, there was not access to appropriate and required information, the author had to have qualitative assumption in some parts of study. Therefore, applying fully deterministic analysis was not applicable.

4.2.3 Performance criteria

In order to define effective performance criteria for fire safety in current study, it is necessary to know how steel structure behave when its temperature increase (the building is assumed as a steel frame structure). Parameters which will be helpful in checking process of steel structure behavior[51],[48].

- Enhanced temperatures in steel elements
- Applied loads on the structure
- Mechanical properties of steel considering yield strength, modulus of elasticity
- Thermal properties of steel considering thermal elongation, specific heat and thermal conductivity

According to ISO 24679-1[6], to minimize the damages to the considered objectives, it is possible to consider the performance criteria into two main classifications:

1) Minimize fire spread through the building with considering compartmentation category
2) Minimize failure in structural stability with considering partial or total collapsing

Studies show that for both structural stability and compartmentation performance criteria, thermal and mechanical properties are most related features [28].

Performance Criteria to limit fire spread (compartmentation)

- All vertical compartments included load-bearing and non-load- bearing do not transmit extreme heat which can increase the possibility of ignition of combustibles in other side of compartment. It is measurable by heat flux or increase in temperature of opposite side (Insulation parameter).
- All vertical compartments included load-bearing and non- load- bearing do not penetrate flame or hot gases which can increase the possibility of ignition in other side (Integrity parameter).

Performance Criteria to limit structural damage (structural stability)

Regarding mechanical properties, according to EC0 [28], where-ever it is required, it should be verified that limit states are not exceeded relevant *design situation*. Therefore, ultimate limit states should be checked. As it was mentioned earlier, ultimate limit states shall be verified where-ever the following limits are relevant to your study: In EQU, STR, GEO, FAT limits.

- When a limit state of static equilibrium of the structure EQU is related, the following criteria shall be verified:
  $E_{d,dst} \leq E_{d,stb}$
  Where $E_{d,dst}$ is the design value of the effect of destabilizing actions and $E_{d,stb}$ is the design value of the effect of stabilizing actions.
- When a limit state of internal deformation or excessive deformation of a section, member or connection (STR and/or GEO) is related, the following criteria shall be verified:

$E_d \leq R_d$

Where E_d is the design value of the effect actions like internal force, moment and R_d is the design value of the corresponding resistance. In this study, limit states related to deformation are relevant. Therefore, we select last criteria as performance criteria in this study.

- The (permitted) maximum deflection of all steel beams shall not be larger than $L/_{250}$ of their spans. This value is considered according to literatures.

Note1: General speaking, all type of structures (building, bridge, etc) consist of different components like beams, columns, slabs etc. All efforts here in this study is about to ensure the loading can be reached to the ground safely. One of the factors which shows that elements in the structure is able to fulfil the intended role is deflection. Deflection is considered as failure criteria in fire resistance testing[48]. In case of beams (columns), the maximum deflection is measured by the beam's span length divided by 250: $L/_{250}$. So, it is required to calculate numerically the deflection on the element and compare that amount with allowable value [52].

Regarding thermal properties, we will have:

- The critical temperature (T_d) for deformation of steel columns should not be less than the maximum temperature (T_m) of steel columns $T_m \leq T_d$

Note: The critical temperature is a temperature which structural failure will happen [34]. In our case, T_d for steel is defined equal to 400̊© according to Figure 4.3 EC 1993-1-2[51].

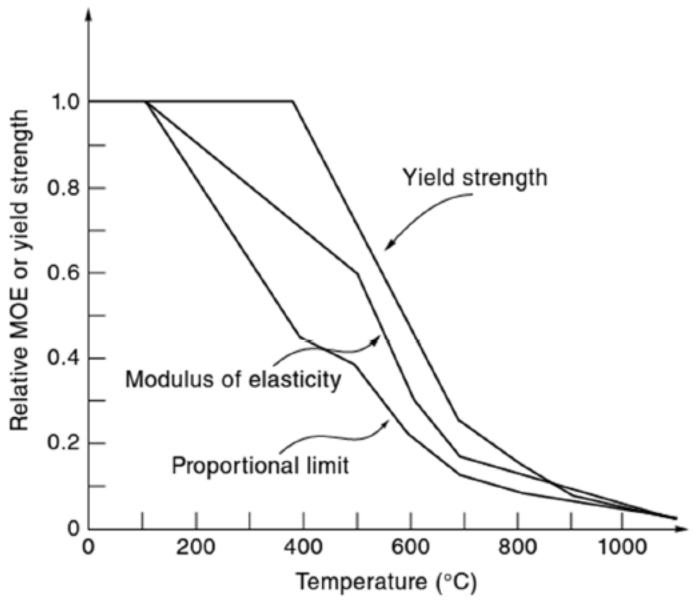


Figure 4.3: Reduction factors for the stress-strain relationship of steel at elevated temperatures

4.3 Step 3: Trial design plan for fire safety of structure

The preliminary design of this building at room temperature was carried out according to TEK97 (Forskrift om krav til byggverk) [53].

In this part, it is needed to have a full description of grade or type of load-bearing structural steel elements in order to suggest improvement to the design or in other word protection system. In general, there are eight different ways to increase resistance of steel structure when exposed to the fire namely: Concrete encasement, board system, spray on- system, intumescent paint, protection with timber, concrete filling, water filling and flame shields [48]. In literatures mostly concrete encasement, spray on-system and concrete filling was used.

In this study, by considering the grade of structural steel and its yield strength (which is not provided), an important issue should be taken into consideration. Since the heating of unprotected steel members to more than 700̊© will be vital in the fire resistance condition, the ceiling should not be without any protection[26].

Two strategy is recommended. First, regarding hall B, columns in east wing of hall and east primary beams will be concrete encased. Other columns in building do not endanger the building to the failure like that addressed column and beam in the beginning because they are connected to the walls which are fire rated. In another strategy, it is possible to use softwood board to protect abovementioned columns and beams to enhance their fire resistance 60 min[48].

4.4 Design fire scenario and design fire

This section is an important part in assessment of structure performance because the designing a fire scenario make all analysis more sensible.

4.4.1 Design fire scenarios

Design fire scenario is defined as comprehensive qualitative description of a fire development[54]. It is considered as fundamental of fire safety engineering assessment since by using these scenarios, the sufficiency of proposed trial safety design will be assessable. In reality, there are lots of different fire scenarios regarding built environment but investigation of all of them is impossible. So, it is important to decrease them to reasonable numbers and consider more sensible and possible scenarios[54]. In scenario planning, risk of fire is studied. Risk is a combination of probability and consequence. As a matter of fact, very low consequence and high likelihood or very low probability and high consequence can end up high or low risk depending on which one is more dominant. Therefore, it is possible to skip these kinds of risks with providing logical reasons [54]. Fire scenarios include things that might help ignition, development of fire, smoke and fire spread through the building, the effect of smoke and fire on people, property and environment to define the consequence of fire.

In ISO 16733-1 [54] a description of fire scenario characterizations is provided. Two parameters which influence defining fire scenarios are "the nature of the structure and consequently the sources of fire". Important items in each categories are as the following:

Regarding the condition of the structure:

- All information about ventilation condition which it specifies information about accessibility of oxygen/ air during fire period
- The layout or connection between compartments which it specifies information about smoke or fire spread into the structure
- All information about fire suppression system which it specifies information about protection layer in the structure, activation status
- All information about used material in compartment and size of them which it specified information about starting of fire and its development
- All information about detecting system includes fire and smoke

Regarding the source of fires:

- Location of fire ignition
- The type of fire starts up (smoldering or flaming)
- Combustion environment which means how much fuel for developing fire is available

By considering all abovementioned items, there are three approaches to identify fire scenarios [54]:

- Using already prepared lists of fire scenarios which may be accessible by national codes or regulations. This approach is easy but some scenarios in built environment might not be considered. For this approach, users need to consider relevant regulatory documents.
- Using qualitative or semi-quantitative systematic approach.
- Using fully quantitative approach especially when have access to likelihood and consequence. In this regard, it is needed to have access to historical data related to the built environment or other statistical data from similar business. Users referred to ISO 16732-1 [45].

In this study, second approach was selected to concentrate on. Regarding systematic approach these following steps [54] should be kept in mind:

- Identification of safety challenges:
  - ✓ Identifying the uses of the built environment especially multi-functional structure, e. trade fair, congress, concerts. In this study, it was tried to focus more on trade fair because mostly includes combustible materials.
  - ✓ Identification of targets that need to be protected: all groups which may use or get involved in fire accident.
  - ✓ Identification of targets' features: it can be included of the amount of people awareness of the egress routes, evacuation procedures, building layout, manual fire alarms usage.
- Identification of fire location
  - ✓ This step includes specification of that space which fire begins and also exact location which might be found by fire statistics like using same situation in a building with same condition. If this information is not accessible, an assessment based on the presence of heat sources, fuel package and occupants might be helpful.
- Identification of type of fire
  - ✓ This step includes different stages like ignition, fire growth, full development, decay and extinction. To identify the initial ignition situation risk analysis can be useful using methods like fault tree analysis, engineering judgement or tests.

Our assumption in this study:

- Fire grows and decay until all combustible materials burnout. There is no fire spread to adjacent halls because of fire-cell limiting walls that mostly used which have common wall with hall B.
- Each hall can be an origin of fire but in this study, the author was suggested to focus on hall B.
- Initial state of fire is flaming not smoldering but by continuation of fire and considering type of combustible material inside the hall lead to fast development of smoke through the hall.
- No effectiveness of smoke detector is considered in order to have worst case scenarios first but later on fire curve need to utilize.

In order to have fire scenario planning, we used a qualitative Event Tree to see what exactly happen if all layer of protection in hall B failed consequently. Afterwards, it will be needed to analyze that the building what thermal and mechanical behavior will show after applying the suggested design.

4.4.2 Design fires (thermal action)

Design fire is defined as a quantitative description of suggested fire scenario [55].

Design fire plays a crucial role in fire safety engineering. Therefore, an appropriate selection of safety objectives and consequently performance criteria then fire scenarios are important steps in order to have suitable input data for the rest of engineering method. There are different analysis methods for fire design like computational fluid dynamics, zone models and simple hand calculation [55].

Totally, design fire is characterized by one or more coming variables with respect to the time including heat release rate (HRR), combustion product species generation rate, smoke production rate, flame height/ volume, burning area and temperature/heat flux [55], [8]. Most famous and useful parameter in design fire is heat release rate. There are different ways to develop a design fire curve such as time with respect to heat release rate.

In order to have a suitable design fire, it is better to know different stages in fire period. The following stages are considered as fire growth phases:

- Incipient stage is considered as smoldering fire [55]. In this stage heat release rate is quite low but smoke rate is pretty much and it ends up to toxic species per unit of mass burned. It has potential to transform into flaming fires. Therefore, the presence of air can affect this part. The main issue in smoldering stage is the production of CO.
- Growth stage is considered as flaming fire [55]. The parameters are characterized to this stage like nature of combustibles and burning properties, geometry of fuel, size and geometry of enclosure, ignitability of the fuel, ventilation, external heat flux, exposed surface area, the power and features of ignition source. There are some items which can affect this stage like sprinkler activation, manual fire suppression, fuel exhaustion, changes in ventilation, flaming remnant[55]. To predict rate of fire growth, there are fire models which can be used under defined conditions. Experimental data are also considered for specific fuels.
- Flashover stage is also flaming fire and it happens when all combustible materials are involved in the fire event. It is mostly happening in small or medium enclosures. It means in huge compartments flashover will not happen.
- Fully developed stage happens after previous stage and is the maximum heat release rate. The duration of fully developed fire depends on how much fuel is available. The factors can affect fire during developing phase are namely suppression system, intervention by fire service, changes in ventilation, compartment effects, combustible construction materials.
- Extinction and decay phase will happen either when the most part of combustible burned or before reaching flash over spread to other places, therefore the rate of combustion decreased.

Depending on type of fire and the built environment some of abovementioned stages are presented in a design fire curve. By using the following steps, the design fire curve will be concluded.

Step 1: Try to extract related and effective information from design fire scenario like dimension of room, size of openings, etc.

Step 2: Try to determine heat release rate by using data for special fuel package from experimental or using some mathematical calculation for fire growth.

Step 3: Try to figure out when flashover will happen (in this study there is no flashover because of large area)

Step 4: Try to define maximum heat release rate by considering ventilation of the structure and configuration of fuel.

Step 5: Try to find the duration of burning from the beginning till decay.

Step 6: Try to find the decay duration

As, it was mentioned in the beginning of this chapter, first four steps were studied. Later studies can focus on next steps including thermal and mechanical response of the structure in fire event.

5 Results

When a steel structure expose to fire, directly or non-directly, the temperature increases while the stiffness and the strength of element decrease which can lead to deformation and failure in the structure. There are different methods to improve the steel structure behavior in case of fire. In order to check if the fire resistance exceeds the design fire severity, three items can be used namely time domain, temperature domain and strength domain [48]. Since most of steel elements need to be protected, fire resistance checking of protected elements is also necessary. Values of fire resistance are accessible by tests, calculations or expert judgement which are provided as lists in various documents maintained or by testing authorities, code authorities or manufacturers [48]. Those fire resistance lists are divided into three classifications generic ratings, proprietary ratings or by calculation will be used. Generic ratings or 'tabulated ratings' refer to those methods which determine a time for resisting of material when faced fire. Mostly it is accessible from national codes or trade organization. Most used suggestion for steel elements protection is encasement in concrete with providing the minimum thickness. Proprietary rating is same generic rating which is provided by some manufactures. On the other hand, calculation methods are divided into simple and advanced methods [48]. In this study, it was tried to use simple calculation in applying fire safety performance engineering.

The methodology that was presented in previous chapter was applied to a one-storey steel frame spectrum by using suggested methodology in ISO 24679-1 [6]. In this chapter, the results based on all concluded calculation and explanation in previous chapter (methodology part) are presented. For the sake of simplicity, it was tried to have some general assumption here and more specific ones in the following in each step:

- Hall B was suggested to focus on for the rest of study.
- All emergency exits are usable and not blocked.
- The trade fair is considered as happening inside the hall B for all calculations and scenarios planning.
- Hall B does not include any fire compartmentation inside or any columns in middle of hall. See Figure A.8.
- our assumption was considering exhibition inside the hall B like shopping centre.

As it was mentioned earlier in Eq 4.1, required factors are as the following:

To calculate δ_{q1} according to Table 4-1 and by considering the area of hall B which is $7274m^2$, since there was not exact number to hall's area in the table therefore, the author had to use the interpolation formula between numbers is Table 4-1 accordingly:

$$\frac{A-B}{B-C} = \frac{D-x}{x-E} \quad (5.1)$$

Eq 5.1 shows interpolation formula while A, B, C, D, E are known and x is unknown.

By considering Eq 5.1 and values in Table 4-1, we have:

$$\frac{5000-7274}{7274-10000} = \frac{2-\delta_{q1}}{\delta_{q1}-2.13}$$

And $\delta_{q1} = 2.06$.

According to EC1 [29], the author assumes $\delta_{q2} = 1{,}0$ to be able to use values in Table 4-4 for fire loads of occupancy.

For finding associated values of δ_{ni}, the author used Table 4-2. Those active or passive measurement effects are considerable in this part. The following results are received accordingly:

δ_{n1} is sprinkler which in list of fire system mentioned while it did not show in fire drawing. Therefore, according to EC1 [29], it is considered equal 1,5.

δ_{n2} is independent water supplies which the author considered it as fire hose and its dependency equals to 1. Therefore, it is equal to 0,87.

Automatic smoke detection & alarm is δ_{n4} and it is equal 0,73.

Off-site fire brigade means those are not located in the place of building and identified as δ_{n7} and it is 0.78. The bigger number was selected because fire brigades are far away to the location.

Safe access route is δ_{n8} and it is considered equal to 0,9 for this study.

By considering implemented fire extinguishers in different places, δ_{n9} is 1.

Trigger for smoke vents was considered as smoke exhaust system and it is equal to 1.

$$\delta_{ni} = \sum_{i=1}^{10} \delta_i = 1{,}5 + 0{,}87 + 0{,}73 + 0{,}78 + 0{,}9 + 1 + 1 = 6{,}78$$

As it was mentioned earlier, the combustion factor is considered as 0.8, therefore $m = 0{,}8$.

In order to estimate the characteristic fuel load $q_{f,k}$, for the amount of combustible material inside hall B, M_K, we assumed to have almost suggested following amount of each type of material in Table 5-1.

By considering Eq 4.2, ψ_i is considered equal to 1 by assumption of the largest fire load, but at least 10 % of the protected fire loads [29].

Type of material	Weight(kg)
Clothes (silk, wool, Cotton)	5000
Paper, cardboard	8000
wood	15000
straw	500
leather	2000
Polyester (plastic)	1000
ABS	1000
Polyisocyanerat and polyurethane	1000
PVC	10000

Table 5-1: Assumed combustible material amount in hall B

Table 4-3 is used to have associated values of net calorific values of H_u [29]. Therefore, characterized fuel load will be:

$$Q_f = \sum (5000 \times 20) + (8000 \times 20) + (15000 \times 17{,}5) + (500 \times 20) + (2000 \times 20) + (1000 \times 30) + (1000 \times 35) + (1000 \times 25) + (10000 \times 20) = 862500 \quad \text{MJ}$$

According provided information, the area of hall B is equal to $7274\,m^2$ therefore, the characteristic fire load density per unit of area $q_{f,k}$ according to Eq 4.4 is:

$$q_{f,k} = \frac{862500}{7274} = 118.57 \quad {}^{MJ}/_{m^2}$$

On the other side, fire load density $q_{f,k}$ of occupancy according to Table 4-4 will be selected as $q_{f,k} = 730 \left[{}^{MJ}/_{m^2}\right]$ same value for shopping center because we assumed that there is trade fair like what is included in shopping center.

Therefore, total fire load density is:

$$q_{f,k} = 118.57 + 730 = 848.57$$

After all, with respect of Eq 4.1 the design value of the fire load $q_{f,d}$ will be:

$$q_{f,d} = 848.57 \times 0.8 \times 2.06 \times 1.0 \times 6.78 \approx 9481 \quad {}^{MJ}/_{m^2}$$

To calculate mechanical action as we have Eq 4.8. Exact amount of live and load in a structure should be provided by designer or third party who may get benefit from the fire safety study according to ISO 24679-1 [6]. In this study, due the lack of appropriate information, values in Table 5-2 are estimated according to some literatures.

Load name	Amount	Unit
Dead load	3	${}^{KN}/_{m^2}$
Live/ variable load	1,5	${}^{KN}/_{m^2}$

Table 5-2: permanent and live loads to the Nova spectrum

By considering Eq 4.8 to calculate design value of mechanical action:

$$E_d = 3 \times 1 + 1{,}5 \times 0{,}5 = 3{,}75$$

By considering this assumption which trade fair is occurring in the place, the following fire safety is considered for the rest of study:

- Life safety of all people inside and in surrounding
- Life safety of fire fighters to have safe rescue process

The rest of fire safety objectives which were explained in methodology part, was put away due to un-accessibility to enough information.

Abovementioned fire safety objectives will fulfil if occupants are not exposed to sudden changes in conditions regarding to increasement of temperature on unexposed surfaces (Insulation), radiation, spread of toxic/hot gases, irritant species and/or flames (Integrity) and resistance of building toward collapse (stability) in entire time of fire.

In this study, performance criteria were just limited to structural stability since there is no compartmentation inside the hall B. Also, concerning hall A and a hallway which have common wall with hall B it should be mentioned they have fire rated wall including EI 60 A2-s1, d0 which by EI 60 it means both insulation and integrity are fulfilled in a test duration 60 minutes. Therefore, performance criteria regrading compartmentation is fulfilled already or is not related to this study.

Figure 5.1 depicted a qualitative event tree in the current study. It showed possible fire accident by considering failure of layer of protection.

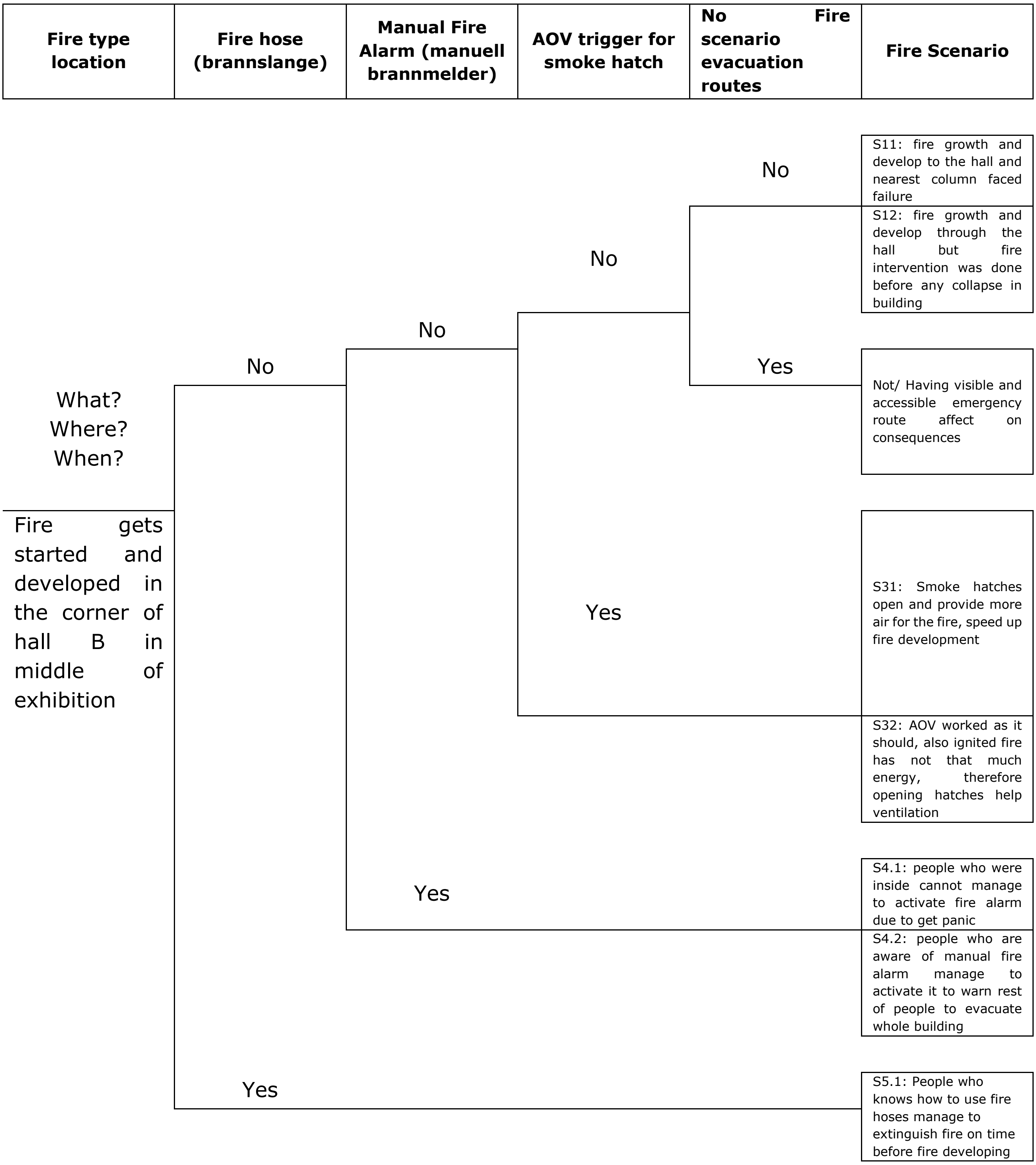


Figure 5.1: Qualitative event tree

By considering all mentioned items, the worst-case scenario in this study will be fire in hall B in the right corner where we have two primary beams and a column while due fast fire development in the hall fire flames almost block those two nearest exit emergencies. People do not use these emergency doors automatically. They would show panic behavior and do not tend to use closet emergency exits to the fire.

General speaking, the fire ignites, and it goes through fully- developed stage and finally is distinguished or decayed. Four main stages in fire development are incipient stage, growth stage, fully development stage and decay stage. Figure 5.2 depicts four main stages.

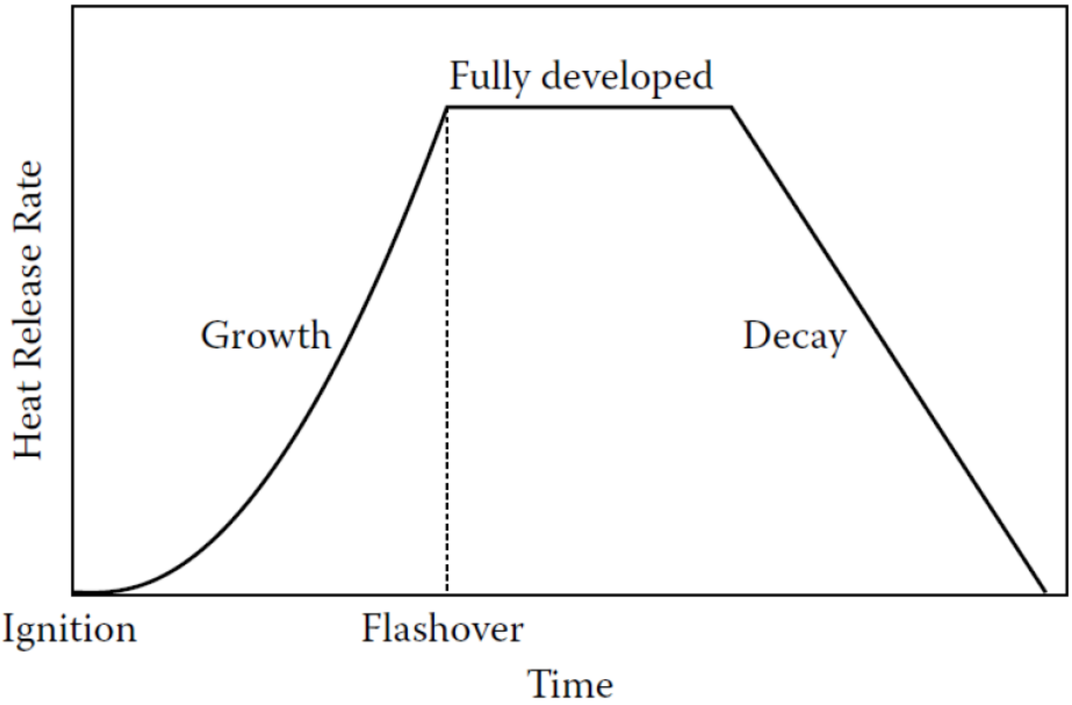


Figure 5.2: Sample design fire curve

Although, the heat release characteristics for some fuel packages are provided in literatures since, fuel package are most likely to change and exceed during the design life of the built environment therefore, simple method to approximate the fire growth was used. The power law design fire curve is used when there is no exact information regarding fuels inside the building [55]. Eq 5.2 shows the power law design:

$$\dot{Q}(t) = \alpha t^2 \text{ while } 0 \leq t < t_{gw} \quad (5.2)$$

Where

- α is the fire growth coefficient $kW/_{s^2}$
- t is the time s
- t_{gw} is the time of reaching to Max heat release rate s
- $\dot{Q}(t)$ is the heat release rate kW

In order to find α, there are four categories including ultrafast, fast, medium, slow fire as the following in Table 5-3.

Fuel type examples	Fire growth category	Fire growth rate $kW/_{s^2}$
Upholstered furniture or stacked furniture against combustible linings; lightweight furnishings; packing materials in piles; non-FR retarded plastic foam storage; cardboard or plastic boxes in stored vertically	Ultrafast	0.19

Bedding; displays and padded workstation partitioning	Fast	0.047
Office furniture; shop counters	Medium	0.012
Floor coverings	Slow	0.003

Table 5-3: Typical fire growth categories of various fuel types[55]

Note: Remember in some cases if you have previous tests results on your study, it is possible to combine abovementioned information and results from experiments like what the authors did in ISO 24679-2[34]. In this study, there is no information regarding previous study on same materials therefore we assume fire developed ultrafast by considering the content inside the building and therefore $\alpha = 0.19$.

This typical fire assumed fire reach to the maximum heat release from the fuel within the enclosure. Therefore, the maximum value for heat release rate $\dot{Q}$ is limited by $\dot{Q_{max}}$ which is calculated either by ventilation-controlled or fuel-bed-controlled [55]. To calculate upper value of t or in another word t_{gw}, first we need to find the maximum heat release by considering ventilation-controlled approach by using following Eq 5.3 [55]:

$$\dot{Q_V} = 1500\, A_0 \sqrt{H_0} \qquad (5.3)$$

While

- $\dot{Q_V}$ is the ventilation-controlled heat release rate kW
- A_0 is the area of the opening m^2
- H_0 is the height of opening m

Totally, hall B includes 10 emergency exits, which some of them were fire doors and some of them were regular automatic doors. In this study, nearest exit doors to the fire-place do not use because of being too close to flame in fire scenario. Therefore, it is just used to calculate air flow into the hall. Visiting the place revealed that nearest door to the fire flame is an automatic door which works using battery and not electricity. The characteristics of door was assumed as 10 in height and 6 in width. Therefore, according to Eq 5.3 the maximum heat release is:

$$\dot{Q_{max}} = 1500 \times (10 \times 6) \times \sqrt{10} = 284605 \quad kW$$

There are some smoke hatches in the hall, but at first, they were not taken into consideration. In further study, it is required to utilize the primary fire curve.

In order to find the maximum time in fire growth, two Eq 5.2 and Eq 5.3 need to be equal. Therefore, the amount of heat release is found equal to the following:

$$\dot{Q(t)} = \dot{Q_{max}}$$

$$0.19 \times t_{gw}^2 = 284605$$

$$t_{gw} = 1224\, s \approx 21\, min$$

It means after 21 min if all emergency fire doors are closed, no fire suppression system activated, no smoke hatches became opens during fire events, fire energy reaches to 284605 kW. It is necessary to notice that abovementioned ventilation-controlled heat release rate is calculated just for one opening. Consequently, if other emergency exits open or smoke hatches open, $\dot{Q_{max}}$ will increase due to direct relation it has with the area A and as a result it takes more time to reach fire development stage.

In order to find the duration of steady burning stage the following Eq 5.4 is used by ISO 16733-2 [55]:

$$m_g = \frac{\alpha t_{gw}^3}{(3\Delta H_{eff})} \quad (5.4)$$

Where m_g is the mass of fuel burned during the fire growth phase, ΔH_{eff} is defined as the effective heat of combustion of the fuel $\left({kJ}/{kg}\right)$. The author assumed that the most effective material inside the hall which leads to ultrafast fire in our scenario is "paper" type material. This material mostly consists of Cellulose with chemical formula $C_6H_{10}O_5$. To calculate heat of combustion of $C_6H_{10}O_5$ the following steps need to follow:

$$C_6H_{10}O_5 + 3O_2 \rightarrow 3CO_2 + 5H_2O$$

$$\Delta H_c = \Delta H_{F,products} - \Delta H_{F,reactants}$$

$$\Delta H_c(C_6H_{10}O_5) = 3\Delta H_F(CO_2) + 5\Delta H_F(H_2O) - \Delta H_F(C_6H_{10}O_5) - \Delta H_F(O_2)$$

According to literature $\Delta H_F(C_6H_{10}O_5) = -1{,}019\ {kJ}/{mol}$, $\Delta H_F(CO_2) = -393.5\ {kJ}/{mol}$, $\Delta H_F(H_2O) = -241.8\ {kJ}/{mol}$, $\Delta H_F(O_2) = 0$ therefore, we will have:

$$\Delta H_c(C_6H_{10}O_5) = 3 \times (-393.5) + 5 \times (-241.8) - (-1{,}019) = -1{,}370.5\ {kJ}/{mol}$$

$$-1{,}370.5\ {kJ}/{mol} \times \frac{1}{162.1406}\ {mol}/{gr} \times \frac{1}{10^{-3}}\ {gr}/{kg} = -8{,}452.54\ {kJ}/{kg}$$

Finally, the result of Eq 5.4 is:

$$m_g = \frac{0.19 \times (1224^3)}{3 \times (8{,}452.54)} \cong 13{,}740$$

Total fuel mass is reachable from the design fire load $q_{f,d}$ and floor area A_{fl} from the following Eq 5.5:

$$m_{tot} = \frac{A_{fl} q_{f,d}}{\Delta H_{eff}}\ (kg) \quad (5.5)$$

$$m_{tot} = \frac{7472 \times 9481 \times 10^3}{8{,}452.54} = 8{,}381.15 \times 10^3\ kg$$

The duration of the steady state burning will be found by using the following equation:

$$t_s = \frac{0{,}8 m_{tot} - m_g}{\dot{Q}_{max}/\Delta H_{eff}} \quad (5.6)$$

$$t_s = \frac{(0{,}8 \times 8{,}381.15 \times 10^3) - 13740}{284605/8{,}452.54} = \frac{4{,}176{,}836.56}{33.67} = 124{,}052.17\ s \approx 2067\ min$$

Assuming linear rate of decay from $\dot{Q}_{max}$ to zero, the duration of the decay stage can be found by the following formula:

$$t_d = \frac{0{,}4 m_{tot} \Delta H_{eff}}{\dot{Q}_{max}} \quad (5.7)$$

$$t_d = \frac{0{,}4 \times 8{,}381.15 \times 10^3 \times 8452.54}{284605} = 99565.37\ s \approx 1659\ min$$

By using abovementioned results, the following Figure 5.3 fire curve was concluded:

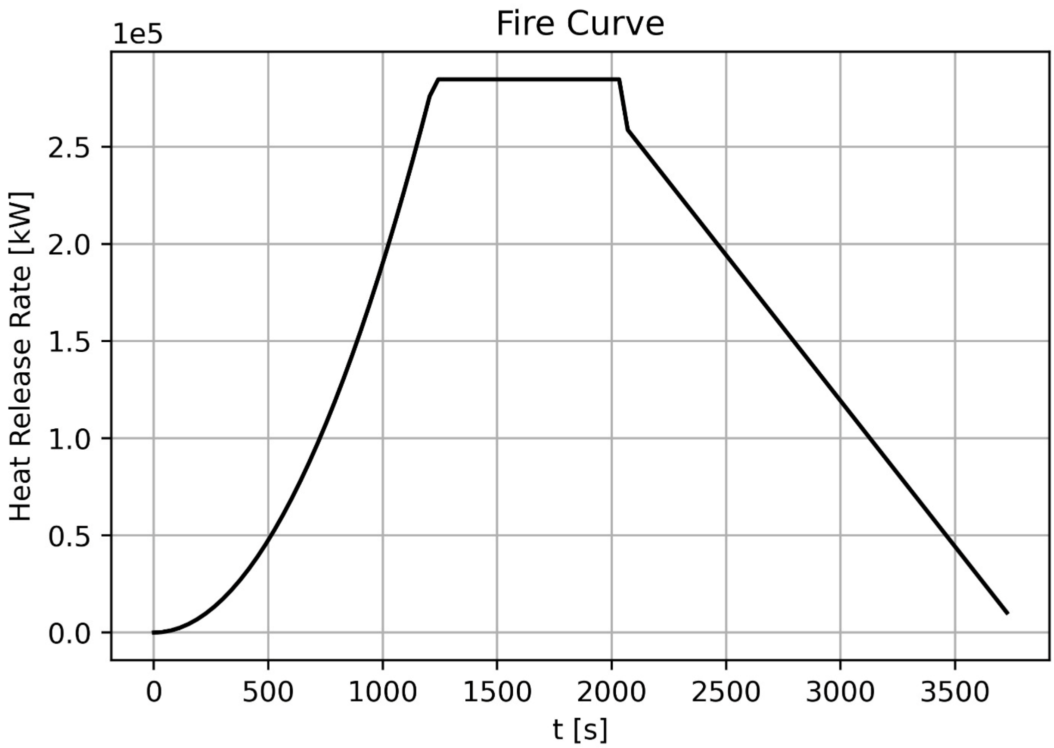


Figure 5.3: Fire curve from calculation

6 Discussion

In this project, the first four steps of provided methodology in ISO 24679-1 [6] were performed. By studying related technical reports which had been studied by the International Organization for Standardization and on the other hand, by working on a case study which was suggested by MultiConsult Co, the following drawbacks and benefits were found respectively:

Disadvantages

- There was no specific study which have been worked on the implementation of ISO 24679-1 [6] (including all steps) except technical reports. On the other hand, mentioned ISO by itself was generic with less provided explanation in different steps. By considering this fact, technical reports were found very general. Due to the matter of fact, the study team who worked on application of ISO/ TR 24679 in different locations, but in several steps, it did not mention specifically why and/ or how used calculation or engineering methods had been chosen for that study. Therefore, it can be quite confusing specially if team has not fire safety or structural engineering background in team. They have to spend a lot of time on studying the ISO and TRs and understand how to utilize steps into their study and at the same time keep eyes on several standards.
- Although, in introduction of ISO 24679-1[6], it was mentioned it is standard form part of compliance with ISO 23932-1 [8], but different part of suggested steps in ISO 23932-1 [8]were skipped in TRs or even if it was used it was not clearly mentioned that how it was applied into the study. For example, risk analysis part was mentioned as an important section in ISO 23932-1 [8]but it was un-clear how to analyse the fire risks in technical reports.
- In different parts of ISO 24679-1, for implementation of subclauses, readers were referred to other standards like in subclause FSOs and FRs it was mentioned that readers can use ISO/ TR 16576 "Fire safety engineering — Examples of fire safety objectives, functional requirements and safety criteria" [50] while first it seems this ISO suggested prescriptive performance criteria and secondly those examples are for three countries in France, New Zealand and Japan which cannot be applicable in other European countries. There was several non-compliance between suggested standards and ISO 24679-1[6] which make using this ISO more complicated and confusing.

Advantages

- It seems this framework is not strict in different ways so study team can utilize, shape or even skip some parts of the frame according to their application.
- It is possible to apply some or just one step/part of ISO 24679-1 [6] into your study.

6.1 Procedure on implementation of ISO 24679-1 in the structure

Regarding abovementioned shortcomings and benefits, the following procedure has been proposed to investigate the performance of the structure in case of fire using ISO 24679-1 [6]. It does not mean that this procedure is applicable in all kinds of structures with different application. In different cases, study team may need to modify some steps according to their study objective. Investigation of performance of structure in fire event should be done using the following steps:

All first four step are effective in last part of implementation study:

Step 1 – identify the scope and limitation of the study which helps fire safety analyst to know how much s/he need to investigate the details. In this step, the following information should be provided by stakeholders or those ones who receive benefits from this study:

I. The purpose and application of the structure and all included parts e.g. offices, shopping center, dormitory etc. Also, the capacity of the whole and each part should be identified.

Note1: This information will influence the characteristics of people inside the building and how much they are able to evacuate the building in the fire event. It also affects later steps including defining safety objectives, functional requirement, performance criteria, designing fire scenarios. When you identify the capacity of each part of the building, it will affect live loads estimation.

II. Complete and exact information about geometry of the structure included number of floors, location of primary/ secondary beams, columns, openings (including type of opening for example being fire rated or regular ones) and their dimensions.

Note2: Number of floors has impact on defining load bearing capacity and permanent (dead) loads. All other information will be effective in designing fire scenarios and designing fire step.

III. A complete information regarding all fire suppression system type (active & passive), their layout in the structure, this information may include the activation process, required time for activation, failure probability and so on.

Note3: It will impress fuel loads calculation, fire scenarios, design fire scenario, design fire step.

IV. Dead loads include loads that are always present in the structure and self-weight of building. Live loads include those loads which are not permanent in life span structure including crowd and equipment.

Note4: Effective on mechanical actions. In this regard, According EC1990[28], relevant design situation shall be considered. There are four types of design situation namely *Persistent design situations, Transient design situations, Accidental design situation, Seismic design situations.* Select one design situation related to your study. Given that fact this procedure is provided for accidental situation, therefore it influences the rest of the study. Also, keep this fact in mind that coincident occurrence of accidental actions is not necessary.

It should be explained that there are two different limit states [28] namely Ultimate and Serviceability limit states to calculate combination of loads (mechanical actions).

Ultimate limits define states related collapse or similar condition of structure failure and it concerns to the safety of people and/or safety of structure. In this regard, limits in the following shall be verified where-ever they are relevant:

- Loss of equilibrium of the building (EQU)
- Failure caused by deformation, rupture or loss of stability (STR)
- Failure or deformation of the ground (GEO)
- Failure caused by fatigue or other time related effects (FAT)

Serviceability limits refer to those of service requirements in case of structure and structural member which are not met anymore, and it concerns to the structural functioning in normal condition, comfortability of people inside and the structure appearance. In this regard, three different types of verification shall be done[28]:

- Deformation related to irreversible limits
- Vibrations related reversible limits
- Damage to the structure related to long-term effects

In other words, concerns of the ultimate or strength limits are preventing from collapse or failure structure while, serviceability limits is more about deflection and vibration which may affect the provided service of the structure. Those loads which might happen more frequently during life span of building are related to serviceability states. Structural design in case of fire is about considering ultimate limit states since the vital point in fire accident time is about strength of the structure and safety of the contents rather than appearance or comfort of people[48]

Regarding calculation of ultimate limit states (ULS), there are three different equations for persistent and transient design situation, accidental design situation and finally seismic design situation. This procedure is about occurring fire in a structure therefore, calculation for accidental situation will be considered. The general Eq 6.1 that shows the accidental situation is:

$$E_d = E\left\{G_{k,j}; P;\ A_d;\ \left(\psi_{1,1}\ or\ \psi_{2,1}\right) Q_{k,1};\ \psi_{2,i} Q_{k,i}\right\} \quad j \geq 1; i > 1 \quad (6.1)$$

In mathematical way:

$$\sum_{j\geq 1} G_{k,j} \text{"+"} \text{"P"} \text{"+"} A_d \text{" + "} \left(\psi_{1,1} or\ \psi_{2,1}\right) Q_{k,1} \text{" + "} \sum_{i>1} \psi_{2,i} Q_{k,i} \quad (6.2)$$

while,

A_d Design value of an accidental action

E_d Design value of effect of actions

E Effect of actions

$G_{k,j}$ Characteristic value of permanent action j

P Relevant representative value of a prestressing action

$Q_{k,1}$ Characteristic value of the leading variable action 1

$Q_{k,i}$ Characteristic value of the accompanying variable action i

ψ_1 Factor for frequent value of a variable action

ψ_2 Factor for quasi-permanent value of a variable action

Characteristic values of actions are as follow:

By considering Eq 6.2 there are elements that should be clarified as the following:

- The permanent action shall be analyzed as:
- – Small variability in G can be result in a single value of G_k
- – Not small variability in G can be result in considering two different values, upper value $G_{k,sup}$ and a lower value $G_{k,inf}$
- The prestressing (P) should be considered as a permanent action which created by controlled forces and/or controlled deformation to a structure.
- The design value $A_d$of accidental actions should be defined for each project.
- The variable actions shall be involved
- – Upper or lower value
- – Nominal value where statistical distribution is not known[28]
- Regarding characterization of ψ according to table A1.3 in EN0[28] is selected as frequent value, $\psi_1 Q_k$, used for verification of ULS including accidental actions.

Design situation	**Permanent actions**		**Leading accidental action**	**Accompanying variable actions**	
	Unfavorable	**Favorable**		**Main (if any)**	**Others**
Accidental	$G_{kj,sup}$	$G_{kj,inf}$	A_d	ψ_{11} or $\psi_{21} Q_{k1}$	$\psi_{2,i} Q_{k,i}$
"In the case of accidental design situations, the main variable action may be taken with its frequent value" Important cautious: by mentioning frequent value, selecting ψ_1 will be given as hint. For more information, readers can check out section 4 part 1.3 in [28]. Attached to EN0 [28], there is Norwegian National Annex. It is useful to check all variable that you choose.					

Table 6-1: Design values of actions for accidental actions

By considering Table 6-1 and Eq 6.2 it will be shortened into:

$$E_d = G_{kj,sup} + \psi_{11} Q_k \quad (6.3)$$

According to European code 1990 [28], ψ_1 will be found from following Table 6-2:

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category			
Category A: domestic, residential areas	0,7	0,5	0,3
Category B: office areas	0,7	0,5	0,3
Category C: congregation areas	0,7	0,7	0,6
Category D: shopping areas	0,7	0,7	0,6
Category E: storage areas	1,0	0,9	0,8
Category F: traffic area, vehicle weight≤30KN	0,7	0,7	0,6
Category G: traffic area, 30KN< vehicle weight≤160KN	0,7	0,5	0,6
Category H: roofs	0	0	0
Snow loads on buildings			
Finland, Iceland, Norway, Sweden	0,7	0,5	0,2
Reminder of CEN Member States, for sites located at altitude H >1000 m a.s.l	0,7	0,5	0,2
Reminder of CEN Member States, for sites located at altitude H≤1000 m a.s.l	0,5	0,2	0

Wind loads on buildings	0,6	0,2	0
Temperature (non-fire) in buildings	0,6	0,5	0
Note the ψ values may be set by the National annex.			

Table 6-2: Recommended values of ψ factors for buildings

According to EC1990 [28], where-ever it is required, it should be verified that limit states are not exceeded relevant design situation. As it was mentioned before, ultimate limit states shall be verified where-ever the following limits are relevant to your study: In EQU, STR, GEO, FAT limits.

When a limit state of static equilibrium of the structure EQU is related, the following criteria shall be verified:

$$E_{d,dst} \leq E_{d,stb} \quad (6.4)$$

Where $E_{d,dst}$ is the design value of the effect of destabilizing actions and $E_{d,stb}$ is the design value of the effect of stabilizing actions.

When a limit state of internal deformation or excessive deformation of a section, member or connection (STR and/or GEO) is related the following criteria shall be verified:

$E_d \leq R_d$

Where E_d is the design value of the effect actions like internal force, moment and R_d is the design value of the corresponding resistance.

V. Internal content of the structure meaning you need to have a good estimation of *amount* and *type* of combustible materials which is present in.

Note5: Effective on characteristics fuel load densities calculation. In this regard, design fuel load Eq 6.5 is provided by EC1991-1-2 [29].

$$q_{f,d} = q_{f,k} \,.\, m \,.\, \delta_{q1} \,.\, \delta_{q2} \,.\, \delta_n \quad (6.5)$$

While $q_{f,d}$ is the design value of fuel load, m is defined as combustible factor and for mainly cellulosic materials, the combustion factor may be assumed as $m = 0{,}8$.

δ_{q1} is a factor of fire activation risk due to the size of the compartment, δ_{q2} is a factor of fire activation risk due to the type of occupancy. Use Table 6-3 to find values for δ_{q1} and δ_{q2}.

Compartment floor area A_f (m^2)	**Fire Activation Factor δ_{q1} concerning compartment**	**Type of occupancy**	**Fire Activation Factor δ_{q2} concerning occupancy**
25	1,10	Art gallery, museum, swimming pool	0,78
250	1,50	offices, residence, hotel, paper industry	1,00
2500	1,90	manufactory for machinery & engines	1,22
5000	2,00	chemical laboratory,	1,44

		painting workshop	
10,000	2,13	manufactory of fireworks or paints	1,66

Table 6-3: Factors δ_{q1}, δ_{q2}

$\delta_n = \sum_{i=1}^{10} \delta_{ni}$ is a factor of the different active fire-fighting measures i (sprinkler, detection, automatic alarm transmission, firemen). Table 6-4 shows suggested values for $\delta_{n,i}$.

$\delta_{n,i}$ function of Activation of fire-fighting measures											
Automatic fire suppression				**Automatic fire detection**			**Manual fire suppression**				
Automatic Water Extinguishing System	independent Water Supplies			Automatic fire detection & Alarm		Automatic alarm transmission to fire brigade	Work fire brigade	Off-site fire brigade	Safe access routes	Fire fighting devices	Smoke exhaust system
	0	1	2	By heat	By smoke						
δ_{n1}	δ_{n2}			δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}
0.61	1	0.87	0.7	0.87	0.73	0.87	0.61 or 0.78		0.9 or 1 or 1.5	1.0 or 1.5	1.0 or 1.5

Table 6-4: Factors δ_{ni}

$q_{f,k}$ is the characteristic fire load density per unit floor area $\left({}^{MJ}/_{m^2}\right)$. In order to identify this parameter, there are two options that should be considered for further calculation:

- Considering specific studies and projects which had been performed already. This case happens when there are no relevant occupancies in the mentioned classification.

- Considering type of occupancies in the structure. This option is divided into two important elements namely fire loads from the occupancy in the building, given by the classification in regulations [29] and fire loads from the building itself (construction elements, linings and finishings) which are generally not included in the classification in regulation. In this situation, follow the following steps where-ever it is relevant.

For calculating characteristic fire load following Eq 6.6 is used:

$$Q_{fi,k} = \sum M_{k,i} \,.\, H_{ui} \cdot \psi_i = \sum Q_{fi,k,i} \qquad [MJ] \quad (6.6)$$

While $M_{k,i}$ is combustible material amount in Kg and it is calculable by defining permanent fuel load which are expected to exist during the structure life span. This information should be identified by stakeholders and variable fuel loads which are expected to vary during the structure life span and do not present in the structure more than 80% of the structure life span.

H_{ui} is net calorific value in ${}^{MJ}/_{kg}$. For determination of H_u values or gross heat of combustion refer to ISO 1716:2018 [56]. Eq 6.7 is usable to calculate net calorific:

$$H_u = H_{u0}\,(1 - 0.01)\mathrm{u} - 0{,}025u \qquad \left[{}^{MJ}/_{Kg}\right] \quad (6.7)$$

While u is moisture content and H_{u0} is the net calorific value of dry materials. In case you do not have moisture content of material (u) and/or H_{u0}, Table 6-5 depicts net calorific values of some solids/ gases/ liquids which had provided by EC1 [29] as the following:

Solids	
Wood	17,5
Other cellulosic materials • Clothes • Cork • Cotton • Paper, cardboard • Silk • Straw • Wool	20
Carbon • Anthracite • Charcoal • Coal	30
Chemicals	
Paraffin series • Methane • Ethane • Propane • Butane	50
Olefin series • Ethylene • Propylen • Butene	45
Aromatic series • Benzene • Toluene	40
Alcohols • Methanol • Ethanol • Ethyl alcohol	30
Fuels • Gasoline, petroleum • Diesel	45
Pure hydrocarbons plastics • Polyethylene • Polystyrene • Polypropylene	40
Other products	
ABS (plastic)	35
Polyester (plastic)	30
Polyisocyanerat and polyurethane (plastics)	25
Polyvinylchloride, PVC (plastic)	20
Leather	20

Table 6-5: Net calorific values H_u $\left({}^{MJ}/_{kg}\right)$ of combustible materials for calculation of fire loads

ψ_i is considered as an optional factor in assessing protected fire loads. If fire loads containments are designed to survive in exposure of fire, there is no need to take ψ_i into consideration. If fire loads are in non-combustible containments, although there is not special fire design considered fire loads remain intact in exposure of fire. In this situation two following conditions are possible:

- In case fire loads (meaning values inside the structure) are designed to tolerate exposing the fire, no need to consider this optional factor.
- In case fire loads have no specific fire design but still can survive in fire time, optional factor can consider as the following:
  - The largest fire load but at least 10% of the protected fire loads is associated with $\psi_i = 1,0$.
  - Some fuel loads are protected, some of them are unprotected but it is not large enough to add heat to have constant fire, then for those protected fuel loads $\psi_i = 0,0$.
  - Out of mentioned conditions, ψ_i needs to be assessed individually.

After defining all parameters for characteristic fire load density $Q_{f,k}$, by using Eq 6.8 fuel load density $q_{f,k}$ per unit area will be:

$$q_{f,k} = \frac{Q_{fi,k}}{A} \quad (6.8)$$

While A is floor area of the fire compartment or reference space, or inner surface area of the fire compartment.

In order to have fire load from the occupancies, Table 6-6 are suggested by EC1 [29]:

Occupancy	**Average**	**80% fractile**
Dwelling	780	948
Hospital (room)	230	280
Hotel (room)	310	377
Library	1500	1824
Office	420	511
Classroom of a school	285	347
Shopping centre	600	730
Theatre (cinema)	300	365
Transport (public space)	100	122
Note: Gumbel distribution is assumed for the 80 % fractile.		

Table 6-6: Fire load densities $q_{f,k}$ $\left[{}^{MJ}/_{m^2}\right]$ for different occupancies

For using Table 6-6 these conditions should be considered; first, the provided values in Table 6-6 are applicable when δ_{q2} is equal to $1,0$. Second, they are applicable when for ordinary compartments of occupancies. In case of special compartment which is not included in the above table try to use earlier equation for characteristic fire loads in Eq 6.5.

Finally, after considering fire load from occupancies it should be added to fire load from building.

Step2 – Identify most important objectives of your study, most relevant functional requirements and performance criteria. In the following the reason of importance and most relevant items in studies are explained.

I. Generally, in every single project there is an objective to achieve. In fire safety engineering based on performance checking of the structure, objectives are keeping safe people who are occupied and outside the structure and fire brigade, properties inside and outside the structure, current operations, heritage, environment. Most likely and important objective for most studies is life safety of people because people are most precise investment, and their lives are priceless. In this regard, you will take rest of objectives into account of your study in case first you have all required information related to surrounding environment of the place that fire happened, second fire happened in heritage area or place valued like a heritage, third you have all economic loss information (by considering losing reputation and operation interruption) in case fire occurrence.

II. The means to achieve identified fire safety objectives in previous sub clause are functional requirements [50]. They are necessary to be to link fire safety objectives to performance criteria [50]. FRs are defined in terms of two parameters namely compartmentation and stability of the structure. FRs related to compartmentation are supposed to prevent or limit the fire flame/smoke and/ or hot gases to enclosure and/ or to the outside of the built environment. These purposes are accessible when three critical items namely integrity(E), insulation(I) and, resistance or stability (R) are satisfied by load bearing elements (walls, floors) and non-load-bearing elements (partition walls, doors, windows). FRs related to stability and/ or integrity of the structure are supposed to prevent or limit the structural failure and maintain the integrity or limit the deformation. First purpose is achievable when structural elements specifically resistance or stability elements of columns, beams, frames and integrity element in floors and walls show sufficient structural fire performance. The Second one is considerable for load- bearing structural. For some FSOs and FRs example please check clause 5.2.1 in ISO 24679-1[6].

III. After deciding about FSOs and FRs, team need to decide about risk analysis approach. An idea behind risk analysis is to compare estimated results with acceptable risk in the field of study. Therefore, team by selecting their approach in risk assessment will be able to determine if acceptable criteria are exceeded or not by the end of study. In this regard, you can refer to comparison of NS 3901.E [57] and ISO 16732[45].

IV. Identifying performance criteria is an important part in fire safety because they will be scales to check if FSOs and FRs are satisfied or not. According to ISO 834-1 [58] some performance criteria are provided and They are still usable but to "have more realistic assessment PCs should not be expressed as fixed terms" [6]. In contrast with prescriptive criteria, the new version performance-based criteria should be stated as interaction between all considering effective elements which was defined in requirements. In this regard, in case of compartmentation functional requirement, fire safety analyst has to set values to limit and/ or prevent *first heat transfer* through load bearing and non-load bearing structural elements and *second thermal radiation* through these elements also. A performance criterion with abovementioned characteristics can be measured in terms of *heat flux* or *temperature of the unexposed side.* Moreover, fire safety analyst has to set values to limit and/ or prevent spreading hot fire gases through load and non-load bearing structural elements. A performance criterion with abovementioned characteristics can be measured in terms of *leakage rate*. In case of structural stability functional requirements, the fire safety analyst should set the limits concerning first *structural collapse of the structure or part of it* and second *deflection, elongation, contraction rate of deformation* of elements which may impose extra mechanical actions to the adjacent separating (load/ non-load bearing) elements and lead to cracks or opening in adjacent separating.

For load-bearing elements the criteria can be:

"a) the load-bearing capability for the entire duration of the fire or part of it.

b) the limit of the deflection/contraction/elongation with respect to the integrity of load-bearing separating elements.

c) the limit of structural damage (spalling, corrosion, charring, deformation) at which a structure can be repaired after fire.

For non-load-bearing separating elements the criteria can be:

a) the limit of the unexposed surface temperature.

b) the limit of the radiation level from the unexposed surface of the element.

c) the limit of cracks and boundary deformation in order to reduce leakage (e.g. flames and smoke) through the element.

For floors and load-bearing walls, both functions shall be satisfied." [6]

Step3 – In trial design plan fire protection strategies or set of design elements will be identified. To be acceptable for the rest of study, trial design should cover each performance criteria that fire safety analyst defined. It is suggested to consider the following options into your design elements:

I. Fire initiation and its development in enclosure which is effective on heat flux calculation
II. Spread of fire and/ or smoke through in compartment which is effective in leakage rate. By controlling and management of fire, you are able to control and manage the produced smoke which affect life safety objectives.
III. Fire detection and activation of suppression systems (including automatic or manual systems) which is effective in both reducing heat flux and leakage rate and afterwards, design fire step also.
IV. Human behavior and egression.
V. Passive fire protection which is effective on reducing leakage rate and totally structural stability.
VI. Fire brigade intervention if case study team found it relevant to their project. For example, grade and type of beam and/or columns or totally frame of the structure show if it is heated to a specific temperature and expose to pressurized water collapse process will speed up. Therefore, team need to propose a solution to improve the quality of structural elements to be able to stand toward different types of fire brigade's actions.

Step4 – Before moving forward, it seems necessary to mention again, the selection of fire risk assessment (Qualitative, deterministic, probabilistic) approach will be effective to the rest of study condition.

I. For identifying design scenario, it is important to mention that there are two subdivisions of that namely design fire scenarios (by considering fire behavior itself) and design behavioral scenarios (human behavioral reaction in both occupants and fire brigade) [8].

Note: In order to have fire scenario planning, a hazard identification play vital role. Historical fire incident data can be useful in similar built environment. There are different methods for Hazard Identification, but Fault Tree Analysis or Event tree analysis are the most approachable methods. In order to apply this method fire safety analyst or at least one person in the team needs to be familiar with most hazardous location in the structure and also hazardous action and reaction of people who are inside or participate in later stage.

Cont Step4 – To represent fire scenario the following options in the structure need to be considered, the nature of the facility and the sources of fire. By considering the important factors in *the facility* such as ventilation condition, ambient environmental condition, interactions between compartments, used material and dimensions in compartments, reliability of active and passive systems, all types of suppression systems, and by considering the important factors in the *source of fire* such as location of initial ignition, initial state of fire (e.g. flaming, smoldering) and combustion environment (the amount and distribution of available fuel in study environment), you are able to characterize fire scenarios.

Before starting design occupant behavioral scenarios and effective factors, it should be mentioned that if you had decided to have probabilistic fire risk assessment, you will need to identify likelihood and consequence of potential fire scenario and therefore, you will consider the occupant types and reaction which will affect the characterization of fire scenario. In this case most important items that you have to take into consideration are number of occupants, their distribution in the structure, familiarity of occupants with the structure, their dis/abilities to have safe exit, their physiological reaction to other fire effluent, their attributes, the provision of emergency- management strategies.

After all, you might face many different design fire scenarios. According to ISO 16733-1[54] there are three possible approaches to determine design fire scenarios including prescribed list of scenarios relevant to built environment which user need to get consultancy from regulatory document, qualitative or semi-quantitative systematic approach and comprehensive structurized quantitative technique like applying Event Tree Analysis which is required of likelihood and consequence information and knowledge and user can take advantages of ISO 16732-1 [45] Mentioned ISO is concerned about second approach.

II. When all these calculations were performed, you reach a stage that need to assess your suggested fire safety design met your defined fire safety objectives. Engineering methods are meant to help. They will help to check the accuracy and efficiency of the performance criteria. Some most useful and highlighted methods are:
    I. Fire Models: different type of models like algebraic calculation models or computer simulation software are used to predict the consequence of your suggested design fire scenario. These models are able to simulate different fire phenomena such as fire plumes, ceiling jet flows, smoke layers or fire and smoke spread in more generic level. Zone models or Computational Fluid Dynamics is one of those models which is most applicable model in different field. For more information, please check out ISO/ TS 13447[59].
    II. Evacuation Model: In terms of life safety of occupants and rescue team those models which simulate evacuation process seem applicable. Depending on

how to divide the built environment there are some models such as Coarse network model (divide according to nodes and arcs), Fine network model (divide according to the grids), Continuous model (divide as a continuum). For more information, please check out ISO 16738 [60].

III. Validation and Verification: It is necessary to validate the calculation method and models which is used to see if it is suitable for current study or not. For the following information you can use suggested standards; The process of validation and verification is described in ISO 16730-1[61], example of verification and validation of calculation models in fire zone model [62], example of verification and validation of calculation models in CFD models[63], example of verification and validation of calculation models in structural model[64], example of verification and validation of calculation models in egress model[65].

IV. Data from test methods and Surveys: This typical data is used in different type of engineering method as input data. It is necessary data from tests or experiments/ survey has the following conditions; first, they meet the requirements of that engineering method which they are going to use in and second, these data should meet specific reliability condition like measured by repeatability and reproducibility, also provide the accuracy requirement.

V. Analysis of results from reference fire scenario test: sometimes there is no available calculation method, or it is not credible for current study therefore it is possible to use the analysis of results from tests which have almost same characteristics even in another scale. In case this option is your interest please refer to ISO 23932-1 [8].

VI. Engineering Judgement: Sometimes there is neither valid calculation methods for current study nor reference scale tests. In this case, engineering judgement can be a scale about used data or distinguish if parts of fire safety design meet PCs.

In order to quantify design fire scenarios, design fire is glowed. Design fire can be described in terms of heat release rate, time-heat flux relationship or time-gas temperature relationship, yields of smoke and other fire effluents. Since, the most important parameter is heat release rate (both convective and radiative) therefore there are different approaches to determine a design fire curve namely using understanding of the product materials and geometry and chemistry and underlying combustion process, conducting heat release rate curve from individual components and finally assuming generalized HRR curve (e.g. t^2 curve). To construct a design fire curve please follow the following steps:

1. Try to extract related and effective information from design fire scenario like dimension of room, size of openings, etc.
2. Try to determine heat release rate by using data for special fuel package from experimental or using some mathematical calculation for fire growth.
3. Try to figure out when flashover will happen
4. Try to define maximum heat release rate by considering ventilation of the structure and configuration of fuel.
5. Try to find the duration of burning from the beginning till decay.
6. Try to find the decay duration

Step5 – released heat or produced smoke can directly (local action of fire to the element) or indirectly (heat transfer to the non-exposed zones) affect thermal behaviour of structural elements both load-bearing and non-load bearing. This heat release includes radiation, convection, conduction, and heat loss to adjacent elements. To calculate temperature profile of elements you might have different simplification as the following:

I. For materials with high thermal conductivity (such as steel or aluminium alloys), you can assume the uniform temperature through the cross-section.
II. For simple flat elements which heated on one side for example flat concrete slab or axisymmetric elements which fully heated (e.g. a circular concrete or concrete-filled column), you can assume one-dimensional heat transfer.
III. For obtaining the temperature field within a cross-section, you can assume two-dimensional (2D) heat transfer.
IV. For obtaining the temperature field within an element with non-uniform temperature distribution along its axis or over its surface, you can assume three-dimensional (3D) heat transfer analysis.

Step6 – In case of functional requirement, we mentioned that both load bearing and non-load bearing elements should satisfy stability of structure. The heating of elements can cause expansion contraction and totally losing mechanical properties like stiffness and strength. All these lead to deformation of elements. In this regard, fire safety analyst studies the mechanical response of the elements with these goals of determination of *the load bearing capacity of elements after exposing to the fire in specified time, the deformation of the structure or part of it.*

This study is approachable by the following analysis:

I. A global structural analysis: A specialist need to take account: all relevant failure mode of elements and connections, those properties of material which are temperature dependent, the effect of thermal contraction or expansion which can lead interaction between elements.
II. An analysis on part of the structure: A specialist need to take account: the amount of load at boundaries between the under-study elements and the rest of the structure. It is assumed to be time-independent during fire exposure.

Step7 – Now it is time to make an assessment against the fire safety objectives to check if all set performance criteria are met the result from analysis, test/ judgement. The level of structural design for fire safety is assessed by using related performance criteria to the chosen strategy. If performance criteria are met, team can go for finishing stage which is documentation part. If performance criteria are not met, literature suggest reconsidering appropriate steps, but the author suggest that team need to reconsider trial deign plan.

Step8 – Final stage is about documentation. All abovementioned steps in detail shall provide in documentation part. At the end of study, it is necessary to provide a conclusion from the project for interested or affected parties.

By proposing abovementioned procedure, a gap was found in risk analysis part in step2. By considering this study had been done at NTNU and by using of Norwegian Regulation in different sections, it was found useful to compare fire risk assessment methodology in ISO 16732-1[45] and NS 3901.E [57] to investigate what differences are between them.

6.2 Comparison study on ISO 16732-1 versus NS 3901.E

Performance based design approach provides an opportunity for construction industries to design the new building with the satisfied level of safety. These innovative designs may also impose lower fire protection costs. As it is mentioned before, based on the ISO 24679-1[6] first, Fire safety objectives and in following functional requirements should be specified. Then performance criteria are defined. This defined calculable proxy means that by meeting performance criteria, it is assumed functional requirements are satisfied. And when all functional requirements are satisfied, fire safety objectives are fulfilled. ISO 24679-1[6] framework requires designers to use risk analysis approach for defining performance criteria. In addition, ISO 24679-1[6] framework recommends starting risk analysis with concentrating on fire risks. Therefore, it seems a comprehensive fire risk assessment approach for construction is required.

In this part it is to dig deep into two applicable regulations for selecting an appropriate risk analysis approach for ISO 24679-1[6] framework, including NS 3901.E[57] "Requirements for risk assessment of fire in construction works" and ISO 16732-1 [45]"Fire safety engineering — Fire risk assessment".

Standard Norge has prepared a technical specification "prINSTA/TS 950[66] Fire Safety Engineering — Verification of fire safety design in buildings". This document provides a basis for analysing fire safety design deterministically, and by itself applies ISO 16732-1 [45] for fire risk assessment. The verification methods of this technical specification can be applied by practitioners to comply with the functional requirements and a guidance on performance criteria in a performance-based design approach. However, this project is to study the applicability of NS 3901.E[57] for fire risk assessment in constructions.

ISO 16732-1 [45] presents a conceptual fundamental for interpreting and quantifying the fire-related risks. Moreover, ISO 16732-1 [45]can be applied to five typical fire safety objectives same as typical FSOs which is considered in ISO 24679-1[6]:

- Safety of life
- Conservation of property
- Safety of operations
- Preservation of the environment
- Preservation of heritage

It is also mentioned that ISO 16732-1[45] should be a framework for the future similar standard with specified application (Figure 6.1). On the other side, NS 3901.E [57] is provided for assessing the risk of entire life cycle of construction works. Figure 6.2 flow chart indeed presents the NS 3901.E[57] framework for fire risk assessment of construction works.

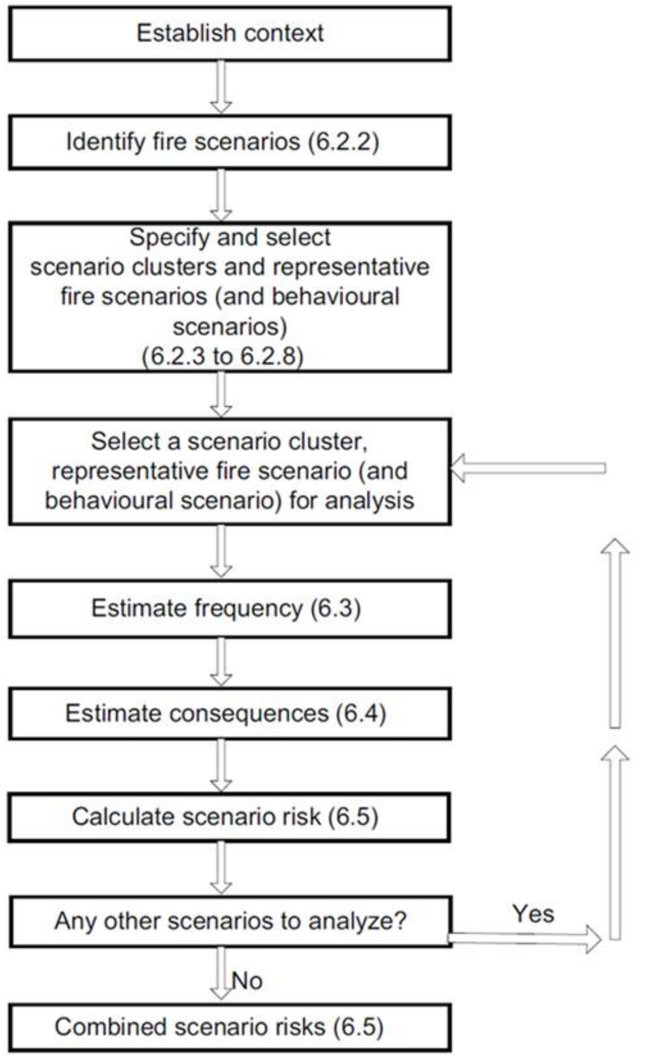


Figure 6.1: Flow chart for fire risk estimation ISO 16732-1[40]

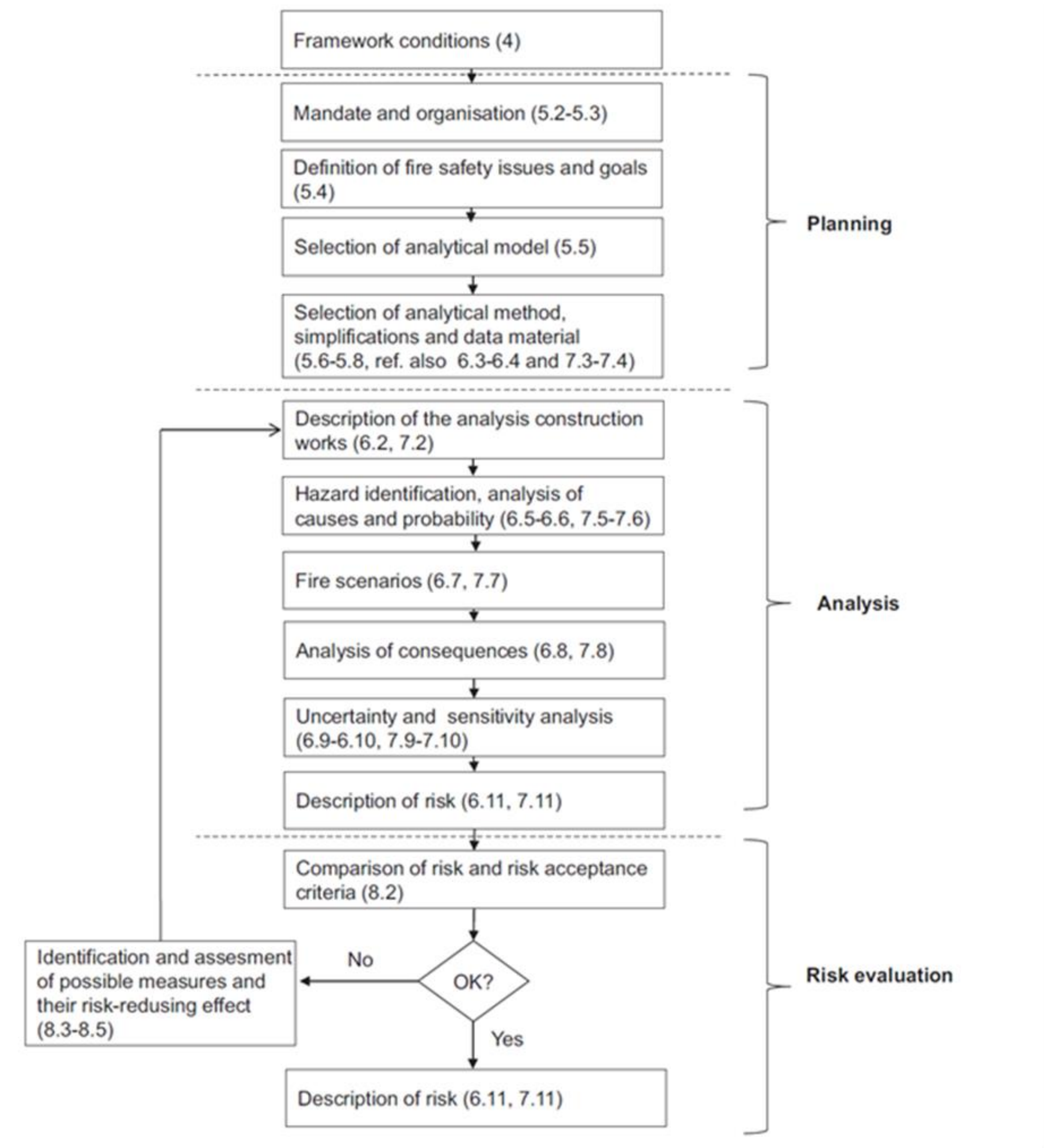


Figure 6.2: Flow chart for fire risk assessment in construction work NS 3901.E[59]

Two analytical method is described in NS 3901.E[57] for risk assessment, risk analysis and comparative analysis.

prINSTA/TS 950[66] presents a general iterative procedure at section 4 for verifying the fire safety of a building:

- Fire safety objective: Identification of deviation and fire safety objective
- Verification methods: Verification of fire safety objective
- Performance criteria:
- Managing the uncertainties
- Documentation

ISO16732-1[45] also stated that the proposed design specification and objectives are two prerequisites for beginning fire risk assessment. It means the fire risk assessment should be at the second step of general procedure of prINSTA/TS 950[66].

At subsection 4.3 verification methods, prINSTA/TS 950 [66] divides the risk assessment into two groups, namely qualitative risk identification and quantitative risk assessment. In other word, qualitative risk identification is applied to describe the applicability of the possible scenarios and by means of quantitative assessment it would be possible to verify the fire safety objectives. The authors of prINSTA/TS 950[66] believe that deterministic of probabilistic analysis can be performed in the case of quantitative assessment based on the designer’s conservatism.

ISO16732-1[45] does not address definition fire safety objectives and analytical models explicitly. In fact, in chapter 5. Overview of fire risk management, ISO16732-1 [45]presents a general flow chart for fire risk management and regarding fire safety objectives and analytical models refers to the ISO 23932[8] subsection 11.2. However, NS 3901.E[57] tries to cover fire safety objective and analytical models extendedly. Indeed, in section 5. Planning, NS 3901.E[57] is describing how to plan a fire risk assessment for construction works life cycle. In this way first, the general features of a risk assessment plan are depicted. Then, the mandates, responsibilities, commitments, and organizations are clarified. In following, subsection 5.4 defines fire safety issues and goals, subsection 5.5 elect an analytical model between risk analysis and comparative analysis, and subsection 5.6 discusses decision-making criteria. Before going to describe these three steps, it is worth saying that this difference between NS 3901.E[57] and ISO 16732-1 [45] is due to generality of ISO 16732-1[45].

NS 3901.E[57] 5.4

Definition of fire safety issues and goals first, requires the users to describe the necessity of performing risk assessments. Then by analysing the construction activities and fire-related consequences, the target parties should be specified. Therefore, the fire risk assessment would be more precise, and the goal of risk assessment can be specified more systematic. However, the heart of this part is to link the determined goals and issues to the main fire safety strategy. When the goals are put into a strategy, automatically, the goals would be prioritized

NS 3901.E[57] 5.5

Selection of analytical models remind the users to select an appropriate analytical model. Indeed, prioritized goal of fire risk assessment alongside the performed analysis on construction analysis enable practitioners to select an analytical model, including risk analysis or comparative. On the opposite side, technical specification prINSTA/TS 950[66] which is based on the ISO16732-1 makes decision about analytical model by considering the applicable scenarios. prINSTA/TS 950 [66] recommends performing a qualitative risk assessment to identify the applicable scenarios and then talks about the a comprehensive quantitative risk assessment.

NS 3901.E[57] 5.6

Selection of analytical method and decision-making criteria part of standard mainly focuses on verification requirements within the planning and access to data. In this step for example, the users can make decision about availability of pre-accepted solution for a comparative analysis, or required simulation and analysis in the case of deviation from the pre-accepted solution

A considerable similarity is that prINSTA/TS 950[66] nominates quantitative risk assessment as a verifying tool for safety objective, and NS 3901.E[57] requires establishing acceptance criteria before starting a quantitative risk assessment. In other word, ISO16732-1 [45]compares the alternative design based on comparing the estimated risk for the design and acceptance criteria.

Apart from what have mentioned, NS 3901.E[57] accounts for three more steps which cannot be found in prINSTA/TS 950[66] and ISO16732-1[45], namely simplification, data material, and initiation of analysis. It seems, NS 3901.E[57] have tried to encompass more aspects.

Always NS 3901.E[57] emphasize the proportionate and commensurate risk assessment methodology rather than imposing unnecessarily extra expenditure, for example:

- "In instances where the fire safety issues are sufficiently comprehensible and manageable, and the literature available provides generally accepted answers to the questions posed, it is not necessary to supplement the qualitative analysis with calculations".
- "In comparative analyses (see clause 7), analysis of presuppositions assumed to be identical in the analysis construction works and the reference construction works may be omitted. For example, potential fire hazards, causes and associated probabilities will tend to be the same".
- "If the fire safety issues are such that risk assessment may be performed without addressing certain elements in the standard, reasons shall be given. A clear statement shall be made as to which parts of the standard have not been followed".

In data material part NS 3901.E[57] requires users to document the uncertainty of the data and specify the source of the data traceably. Most importantly, NS 3901.E[57] considers it necessary to familiarize the participants with the goal of risk assessment and the framework for the analysis.

It seems, it is important for NS 3901.E[57] to establish a easy and affordable fire risk assessment process. Then by adding an extra part, namely planning, in comparison to ISO16732-1, NS 3901.E[65] is trying to identify the scope and the goals of fire risk assessment more accurately. So that, probably construction-related fire risk assessment based on NS 3901.E[57] would cheaper and more user friendly than ISO16732-1[45].

Risk analysis

In subsection 6.2 Description of the analysis construction works, NS 3901.E[57] initiates the risk analysis process by describing the analysis construction works with respect to organizational limitations, functional limitations, and physical limitations. In addition, NS 3901.E[57] recommends classifying the construction works based on the hazard and fire classes. However, ISO 16732-1 [45] in subsection 6.1 Overview of fire risk estimation, begins fire risk estimation by establishing a context. Context means a set of relevant quantitative assumption to the design specifications and the objectives. Then, hazard identification is emphasized as the next step for clustering the fire scenarios.

For the next step, NS 3901.E[57] introduces five factors for selecting an appropriate analytical method (subsection 6.3 selection of analytical method). Afterwards, it is suggested (6.4 Determination of risk acceptance criteria) defining the risk acceptance criteria and matching them to the goals, frameworks, and methods. It is mentioned that although the acceptance criteria may be in different forms, including words, numerical values, expected values, distribution, zones, and loss of safety functions, the consistency of them should be determined. NS 3901.E:2012 also requires a hazard identification (6.5 Hazard Identification) and a detailed causal analysis (6.6 Analysis of causes and probability) as the other basis for choosing a relevant fire scenario. Hazard identification process should classify the fire hazard according to their applicability in different fire scenarios. Moreover, Analysis of causes and probability clarifies potential causes and probability of occurring fire based on technical factors, and human and organizational factors. NS 3901.E[57]

By considering the first six-steps of clause 6 of NS 3901.E[57] in a holistically, it seems NS 3901.E[57] goes into the details step by step, and at the end of each step the degree of freedom for making decision is clarifies. For instance, it is recommended in subsection 6.6 Analysis of causes and probability, performing an initially qualitative risk analysis to find the most important risk factors and map risk area. Then a semi-quantitative risk analysis for scaling the probabilities, and finally determining the probabilities in a quantitative risk analysis and based on available data. Even if this gradually improvement in risk analysis prolonged the risk assessment process, the designer would be led to revise the goals and know the limitations and strengths.

On the opposite side, ISO16732-1 initiates fire risk assessment by concentrating on overviewing of fire scenarios. In this regard, ISO16732-1 clusters the fire scenarios according to the hazard identification and then excludes the fire scenarios with negligible risk. The systematic framework of ISO/TS 16733:2006 is recommended for this purpose. The advantage of this approach is that any fire scenario is developed based on a specified fire risk assessment. Therefore, characterization and in the following clustering the significant fire scenarios can be feasible. While it seems, NS 3901.E[57] does not have ability enough to deal with identifying the proportionate fire scenarios. Three minimums are proposed by NS 3901.E[57] to identify the relevant fire scenarios:

- Fire location
- Fire type
- Operational conditions

Briefly, subsection 6.2 Use of scenarios in fire risk assessment of ISO16732-1 by applying the systematic framework of ISO/TS 16733:2006 within 8 steps has provided an accurate manner for distinguishing, characterizing, clustering, and prioritizing the relevant fire scenarios. Also, identifying the consistent fire scenarios is a considerable weakness of NS 3901.E[57].

After identifying the commensurate scenarios ISO16732-1 goes to 6.3 Estimation of frequency and probability then 6.4 Estimation of consequence, and NS 3901.E:2012 talks about 6.8 Analysis of consequences. ISO16732-1 firstly talks about estimating the frequency using diverse general methods, including estimation directly from data, estimation using models, and estimation using engineering judgement. Then, for specific state, estimation of frequency of ignition and system status probabilities are discussed.

NS 3901.E[57] believe firstly the consequence analysis of picked fire scenarios should be performed, and according to sufficient provided details from the subsections 6.4, 6.5, and 6.6, the probability can be established. Two important points are mentioned in this part, firstly prioritizing the effective factors on developing the fire, and secondly, picturing the ensuing events from the fire by an event tree analysis. Preparing these two points alongside the goals of fire risk assessment can clarify the proportionate extent level of fire risk analysis. In this regard, each branch of event tree represents a fire scenario. Apart from event tree, fault tree analysis is also emphasized by ISO16732-1, and for supplementary descriptions, ISO/TS 16733:2006, Fire safety engineering — Selection of design fire scenarios and design fires, is referred.

It seems, in the case of consequence analysis, NS 3901.E:2012 has tried to provide a comprehensive description rather than discussing special conditions.

Regarding the risk calculation ISO16732-1 has provided a stronger and more structured procedure, in return, NS 3901.E:2012 describes the risk based on the causal and consequence analysis. Although NS 3901.E:2012 mentions also calculating risk for a individual fire scenario and combined fire scenarios, these is not any specified manner for distinguishing differences. However, by enlisting ISO/TR 13387 "Fire safety engineering", ISO16732-1 presents general definition of fire risk. ISO16732-1 states that decency of the definition is dependent on acceptance criteria and objectives.

Indeed, for scenario fire risk in the case of expected risk values, following description is suggested by ISO16732-1, and sum of the scenario fire risk estimates the combined fire risk:

$Risk = \sum (Frequency \times Consequence)$ For all scenarios

But, when the consequence of a fire scenario is unacceptable the following description is applied

$Risk = \sum(Combined\ frequency)$ For all scenarios

In this case for acceptable consequences, frequency should be multiplied by 0, and for unacceptable multiplies by 1.

Apart from defining risk with a logic and temporal sequencing on event tree and fault tree ("6.5.2 Event trees, fault trees, and alternative definitions of fire risk"), sufficiently large mechanical load ("6.5.3 Risk defined by the design load or limit state"), ISO16732-1 tries to characterize consequence and frequency of risk calculation at subsection "6.5.3 Other aspects of risk calculation". In this part, it is tried to characterize shortly the most commonly used approach for estimating, measuring, and presenting the risks.

Therefore, it seems, regarding the risk calculation ISO16732-1[45] is more comprehensive, explicit, and organized.

An important superiority of NS 3901 [57], is describing comparative analysis. NS 3901.E:2012 defines comparative analysis as:

"Comparing fire safety in the analysis construction works and in a corresponding reference construction works constructed in accordance with one set of pre-accepted solutions. Unlike in a risk analysis, fire safety is not expressed as a fixed risk metric or evaluated against risk acceptance criteria. Instead, risk in the analysis construction works is compared with the risk in the reference construction works for a limited number of fire scenarios".

Although most steps of comparative analytical method are in accordance with 6. Risk analysis clause, specific adjustments are required. The importance of this approach is to show the under-study conditions is at least with the same level of the reference (for more information NS 3901.E[57], 7).

Risk evaluation is the last step by two standards. Standards both define risk evaluation as comparing identified or estimated risk with predetermined acceptance criteria. It is important to be sure that there is not any interpretation, assessment, and bias on the criteria.

7 Conclusion

Performance-based design is defined as an engineering approach in fire protection design based on three important parts including first fire safety objectives, functional requirements, performance criteria and second, qualitative/deterministic/probabilistic analysis of fire scenarios and third, quantitative assessment of fire safety objectives using engineering method [7]. Since, everything in this methodology is based on defining performance criteria, it is known as performance-based design. This project was about investigation of performance of structure using ISO 24679-1 [6] which includes eight main steps. In this regard, two types of literature review on performance of structure in fire using ISO 24679-1[6] was performed. In first type, those studies which assess applicability of mentioned ISO investigated and advantages and disadvantages were extracted. In second type, some published technical reports as evidence of implementation ISO 24679-1 in different cases were taken into account. In this part, those studies which took a part of this methodology, or some ideas of related technical reports were also investigated.

Afterwards, the project was offered to implement ISO 24679-1 on a case study. This case study was a multi-functional spectrum which visit of the place revealed that it is arena with 5 different halls with different capacity while a glass facade hallway connected all halls in one corridor. In some sections (halls) second floor was built to use as offices for personnel. Totally, four first steps in ISO 24679-1 were performed. Appropriate formula for calculation of fuel load density and mechanical actions were extracted from related Eurocodes. Then, Fuel loads and combination of actions were calculated according to assumed amounts of combustible materials inside and live/dead loads respectively. Fire safety objectives, functional requirements and performance criteria were set. For identifying performance criteria, a semi quantitative risk analysis approach had been selected. A qualitative ETA was performed to clarify probable fire scenarios. In trial design, identified primary beam and column were suggested to encased by concrete. Finally, the power law design was used to have estimation on heat release rate. By using estimated data, a fire curve was sketched.

In next step, by using literature review and case study that had been performed, a procedure for implementation of ISO 24679-1[6] was proposed. During this procedure it was tried to give specific hints on application of mentioned ISO where-ever the author found there is lack of information. The procedure was provided by considering accidental condition (fire, explosion, seismic, etc.) which is exposed to the structure. The proposed procedure is a meant to help fire safety team to apply ISO 24679-1 into their project therefore, they might need to modify some parts to be more applicable. A gap in fire risk assessment in technical reports was found. It was suggested to have a comparison on two different framework of risk assessment. In this regard, an investigation on main parts was performed to provide some options for readers to select one framework to do fire risk analysis.

At the end, it can be recommended to whom would find this methodology applicable to their study to have this knowledge or these specialists in their team; structural engineer or architects or who has deep understanding of structural diagram and has knowledge in map reading, construction elements, linings and finishings, possible improvement in the structure and etc. Risk analyst who has deep knowledge in risk phenomena, fire hazard identification, different risk methods and finding most applicable method. Fire safety engineer who has knowledge in fire phenomena, thermal and mechanical actions in different kind of structural elements and last but not least, someone who has knowledge in simulation using engineering tools like CFD to be able to use this information which fire safety engineer will give her/him at final stage to simulate and analyze thermal or mechanical responses on specified structural elements. It is necessary to mention this kind of study is a group work rather than individual study, since team members need to share ideas, scenarios, and possibilities.

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Appendices

Appendix 1: NOVA information

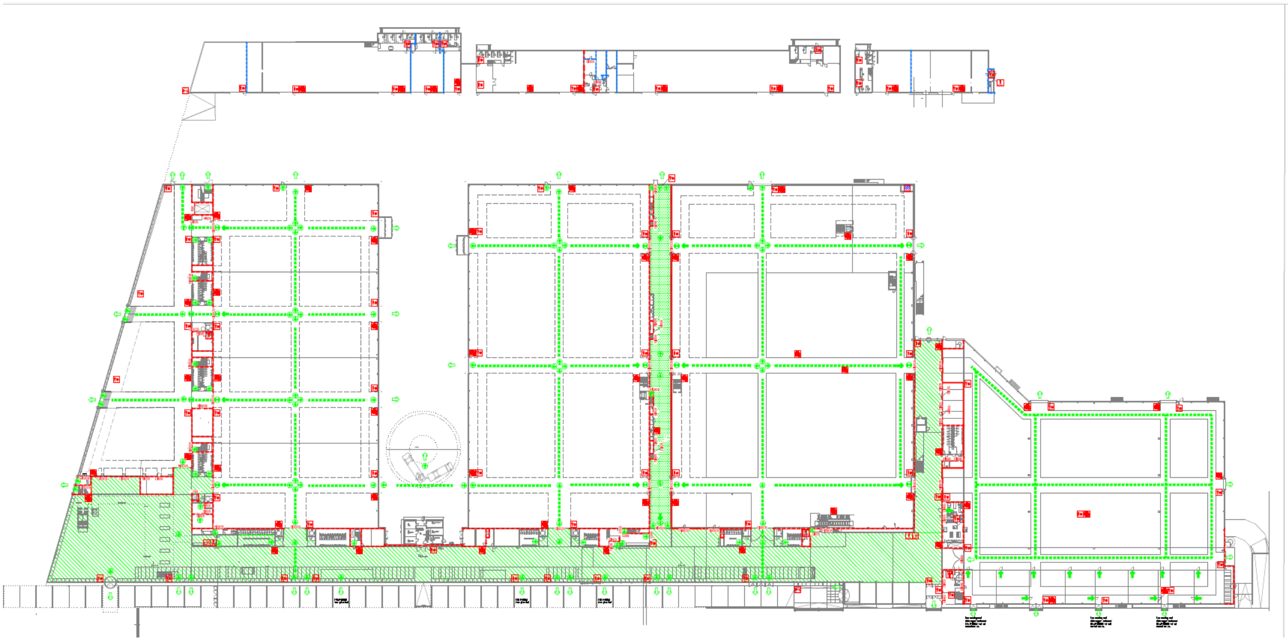

Figure A.1: Fire plan in first floor

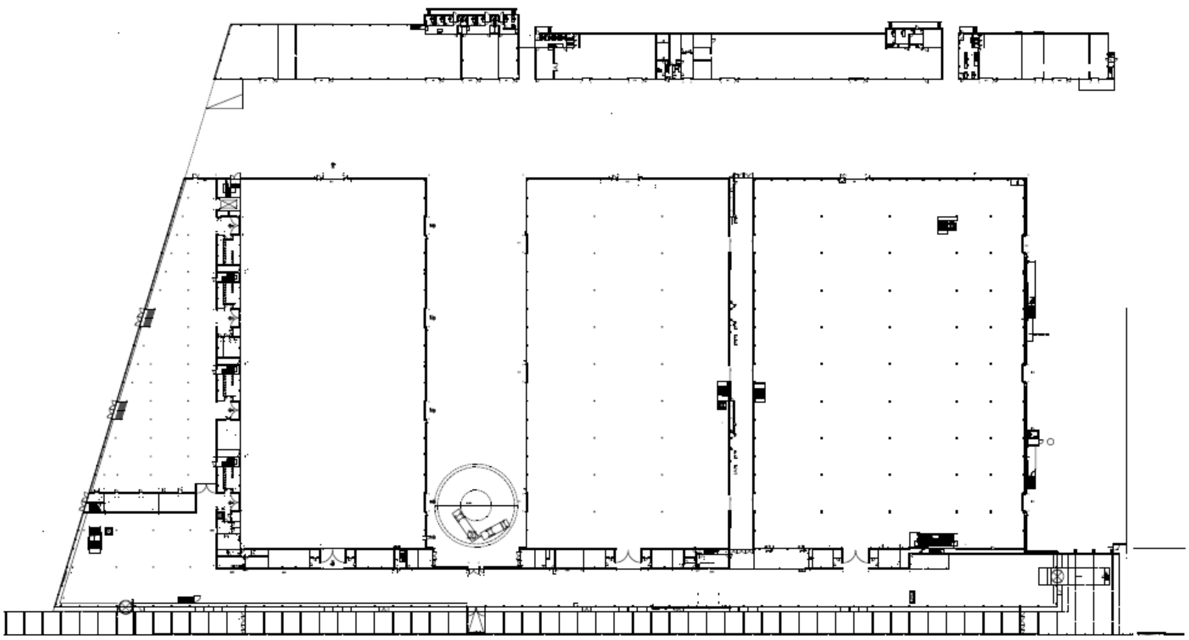

Figure A.2: First floor drawing

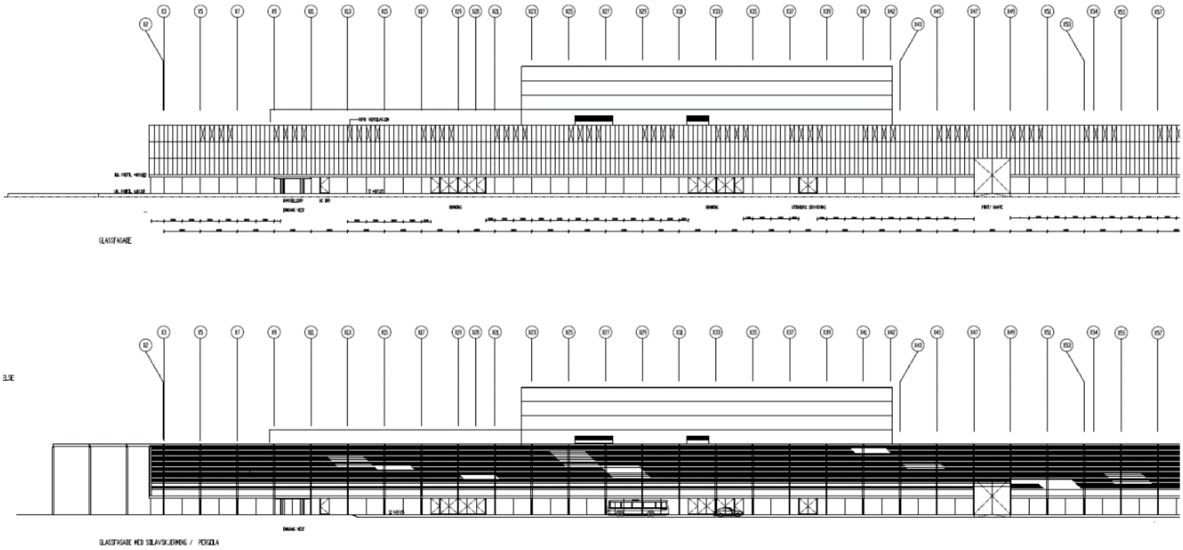

Figure A.3: Façade drawing

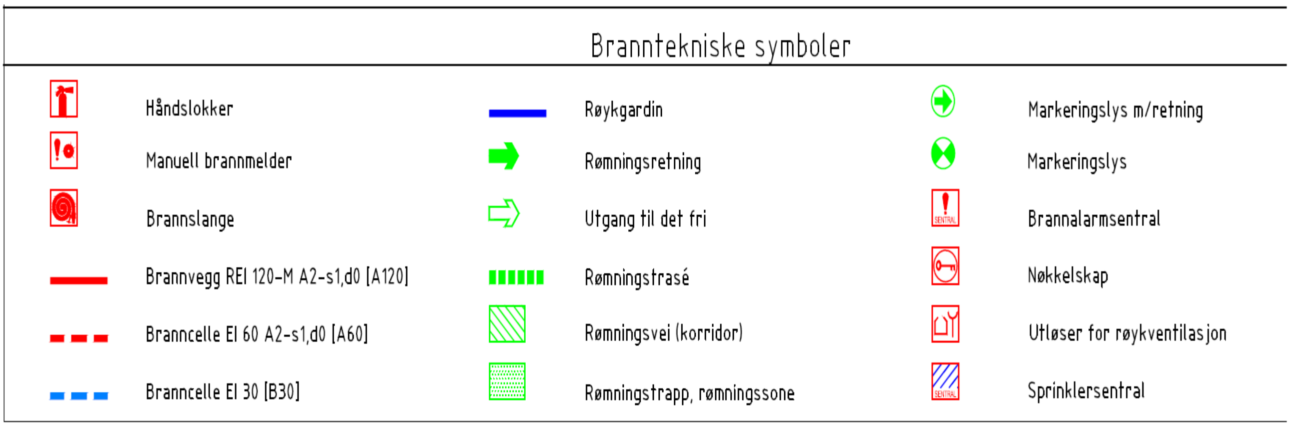

Figure A.4: List of active & passive system in first floor

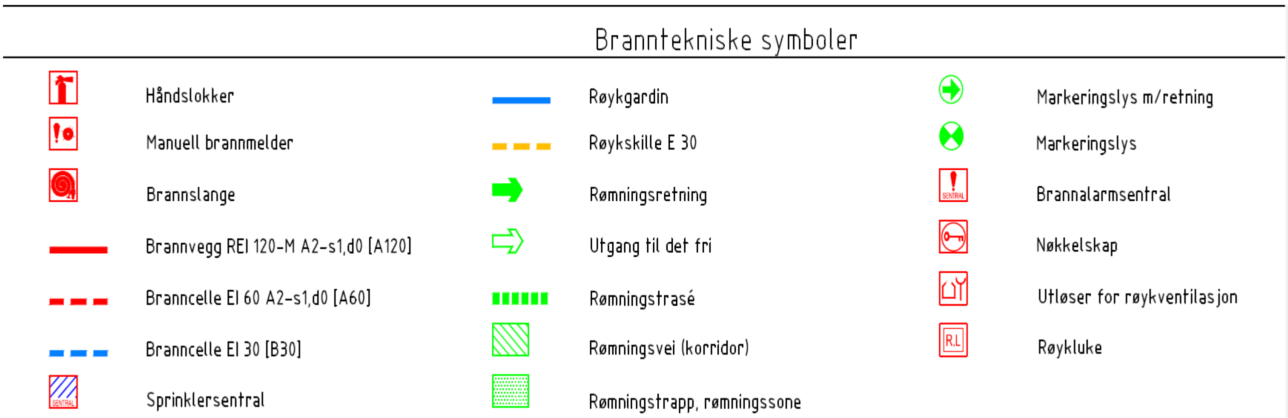

Figure A.5: List of active & passive in second floor

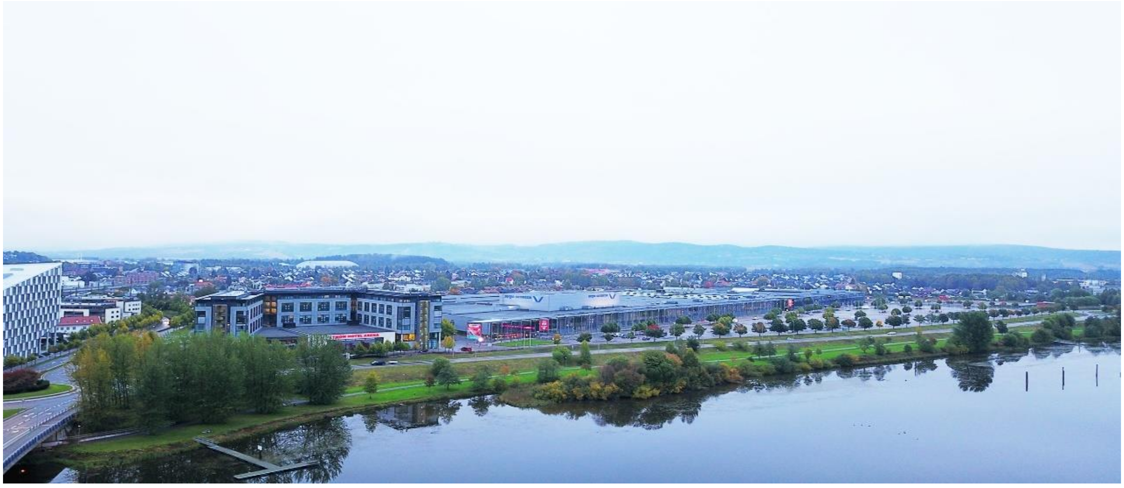

Figure A.6: Nova spectrum

Figure A.7: inside view of Hall C. oldest hall

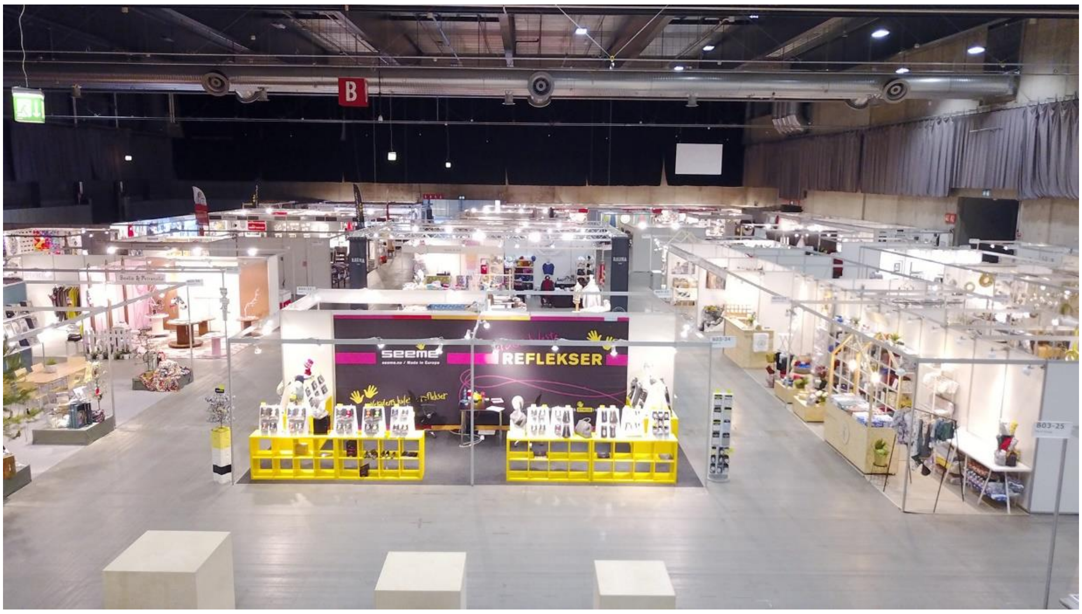

Figure A.8: Inside view of Hall B

Appendix 2: Accepted Abstract in Conference NFSD

Construction performance in case of fire

Analysis of possibilities using ISO 24679-1

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Introduction

Demonstrating the adequacy of fire safety measures in the built environment requires assessment a variety of elements, concerning the level of uncertainties in the designing stage. The recently published standard *ISO 24679-1:2019 Fire safety engineering — Performance of structures in fire — Part 1: General* [6]is focusing on the performance of built structure in occurrence of a *real fire*.

There is a low likelihood that a building will face a serious fire, but if it happens, the outcome can be a disaster [48].The process of changes in fire safety in buildings started from plain prescriptive codes developing into rational engineering based on performance goals[67]. In the past, fire resistance in buildings was achieved by designing the building for performing in ambient temperature and in the next step add extra elements like insulation into individual part of structure to enhance the safety of building[48]. These extra elements were defined according to regulations and standards like the Eurocodes. Nowadays, fire safety may be assessed by using engineering approaches, based on the consequences on life and health, property, continuity of operations, the environment, and cultural heritage. Fire safety engineering (FSE) is applied to support performance-based strategies highlighting fire safety objectives, functional requirement sand performance criteria [7]

As it was mentioned earlier, the standard ISO 24679-1 provides a methodology for assessing the performance of structure in the built environment which is developed in compliance with *ISO 23932-1 Fire safety engineering — General principles — Part 1: General* [8]. This abstract presents the outline of a Master's degree project that is performed during the spring 2022.

Objectives

The aim of the project is to describe some steps of the process when applying ISO 24679-1 to a case object. Advantages and weaknesses by using this method compared to traditional methods shall be described, including what kind of obstacles engineers may face during the process, and the efforts required to implement the standard. Which information that is required shall be defined in a sensible and understandable way and finally recommendations that will make it easier for fire safety engineers to apply this standard in their work shall be given.

Methods

A two-storey steel structure called *Nova spectrum* [68]is considered as the case study. In this regard, a review of related published technical reports will be performed:

- ISO 24679-2: Example of an airport terminal [34]
- ISO 24679-3: Example of an open car park [26]

- ISO 24679-4: Example of a fifteen-storey steel-framed office building [69]
- ISO 24679-6 Example of an eight-storey office concrete building [43]

NOVA Spektrum is an arena for trade fairs, exhibitions, congresses, conferences, banquets, concerts and events and conducts business in connection with this. It was established in 1920 with area of over 46000 square metres. This arena includes 9 different halls which it was suggested to consider just one hall with area 7274 square meters called hall B. This hall hosts 6000 people in trade fair event with different stands or 12000 people in concerts without stands and chairs. So, it will be occupied by quite a lot of people. On the other hand, by considering a fire consequence which endanger life, society, environment a construction can be categorized into 4 fire classes [70]. Due the high capacity of this place, the impact of occurring fire can be defined very serious. Therefore, this building is classified into fire class 4. According to "(Byggteknisk forskrift - TEK17)" when a building is considered as fire class 4 it means main load bearing systems in the structure shall be designed to bear completely the load bearing capacity and stability during the event of fire [70]. More detailed information will be provided in the final study.

Figure A.9: A landscape picture of case study in this project, NOVA Spectrum

Results

A comprehensive study of the related published technical reports is done so far. In these technical reports, results from analyses of a 2-storey airport terminal, an open car park, a fifteen-storey steel- framework office and an eight-storey office concrete building are presented. Two more technical reports are under development but not published yet. The information from the technical reports will be applied in the analysis of the case study. Final results of the case study and conclusions will be presented in the conference.

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