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Scenario Based Risk Assessment; A Comparison of Swedish and Australian Pre-Accepted Fire Safety Codes for High-rise Buildings.

Emmanuel Carl Daniel Eriksson

WESTERN NORWAY UNIVERSITY OF APPLIED SCIENCES

Master Thesis in Fire Safety Engineering

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Høgskulen på Vestlandet

Scenario Based Risk Assessment; A Comparison of Swedish and Australian Pre-Accepted Fire Safety Codes for High-rise Buildings.

Master thesis in Fire Safety Engineering

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This thesis is a part of the master's program in Fire Safety engineering at Western Norway University of Applied Sciences. The author(s) is responsible for the methods used, the results that are presented, the conclusion and the assessments done in the thesis.

Abstract

This study evaluates the different fire safety level between the Swedish and Australian regulatory framework, with emphasis on prescripted solutions for high-rise office buildings. Two theoretical high-rise buildings have been designed in accordance with prescripted solutions, and evaluated with the use of scenarios based risk assessment. FDS and Pathfinder have been used to examine the fire safety levels within each high-rise, with life safety criteria objectives and tenable conditions used as acceptance criteria. The RSET vs. ASET method was used, and three fire and egress scenarios was designed to evaluate the performance of each high-rise. This study have indicated that the Australian building regulation have a higher level of safety incorporated within their minimum fire safety solutions, than the Swedish building regulation. The scenario based risk assessment conducted in this study, have also indicated that the Australian building regulation takes into account safer and more efficient egress, for larger numbers of occupants. The Australian building regulation also includes compulsory fire extinguishing systems and mandatory two independent evacuation routes from each floor level. The simulations have also presented a higher level of fire safety in the Australian high-rise building, in all simulated fire scenarios. It is therefore suggested that the three requirements, discussed in section 7.5 *Amendments to the Swedish building regulation*, are implemented into the Swedish building regulation:

1. Two independent evacuation routes connecting each floor requirement, for all buildings taller than of 25 m.
2. Smoke lobby or similar requirement enabling a holding area that will provide safe accommodation for a sufficient number of occupants, when congestion and delayed movement is expected into the staircase.
3. Sprinkler system as a suggested solution towards a compulsory requirement of a fire extinguishing system within all buildings taller than 25 m.

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Helsingborg, 31 May 2018

Emmanuel Eriksson

Summary

Sweden have always been more modest of constructing high-rise buildings, due to smaller population and larger land areas in comparison to other western countries. Upcoming urban plans are however showing a steady change towards higher and more complex constructions, as a response toward the growing population and economy in the major cities. Projects such as; Karla tower in Gothenburg, and Tellus tower in Stockholm reaching respective heights of 245 m and 237 m, are both pioneering projects in Swedish urban planning. This has led to several questions being raised in the Swedish fire safety community, about the adequacy of the current safety regulations for high-rise buildings.

The aim of this work is to investigate the level of fire safety for high-rise office buildings, incorporated within the current Swedish building legislation, and how it compares to a country with renowned experience within the field of high-rise building construction. The objective will further be to analyse and compare their differences, with the intent of suggesting possible additions to the Swedish building regulation towards high-rise buildings.

This study theoretically designed two high-rise buildings with 16 floors, in accordance and solely with prescripted solutions found in the Swedish and Australian building regulation. Each high-rise was then subjected to a deterministic scenario based risk assessment, with the use of CFD and egress simulator models named Pyrosim and Pathfinder. The objectives used to evaluate the fire safety levels within each high-rise, was in terms of life safety criteria, with tenable conditions used as acceptance criteria. The RSET vs. ASET method was used, and three fire and egress scenarios was designed to evaluate the performance of each high-rise.

By evaluating their performances in the risk assessment it could be observed that the Australian high-rise incorporated a high level of fire safety, than the Swedish high-rise. The Australian high-rise showed a more robust fire safety design, with longer time before untenable conditions (ASET) prevailed in all scenarios, in comparison to the Swedish high-rise. The egress simulations showed similar results, with two of three faster RSET values for the Australian high-rise. The Swedish high-rise achieved acceptable performance in two of three times, but did not meet the outlined objectives of the risk assessment.

The results from this study indicated that congestion caused by the Tr1 and Tr2 solutions was the main reason for deficiency in the Swedish design, when used for a larger number of occupants. The Australian smoke-lobby solution, showed in comparison to provide the Australian high-rise with both a faster evacuation component, and a holding area that could provide safe accommodation for a larger number of occupants. It was also observed during the design process of the theoretical high-rise buildings, that the Australian building regulation was more conservative, and required more robust safety solutions than the Swedish building regulation.

To summarise, this study have indicated that the Australian building regulation have a higher level of safety incorporated within their minimum fire safety solutions, than the Swedish building regulation. The scenario based risk assessment conducted in this study, have also indicated that the Australian building regulation takes into account safer and more efficient

egress, for larger numbers of occupants. The Australian building regulation also includes compulsory fire extinguishing systems and mandatory two independent evacuation routes from each floor level. The simulations have also presented a higher level of fire safety in the Australian high-rise building, in all simulated fire scenarios. It is therefore suggested that the three requirements, discussed in section 7.5 *Amendments to the Swedish building regulation*, are implemented into the Swedish building regulation:

1. Two independent evacuation routes connecting each floor requirement, for all buildings taller than of 25 m.
2. Smoke lobby or similar requirement enabling a holding area that will provide safe accommodation for a sufficient number of occupants, when congestion and delayed movement is expected into the staircase.
3. Sprinkler system as a suggested solution towards a compulsory requirement of a fire extinguishing system within all buildings taller than 25 m.

Sammendrag

Sverige har alltid vært mer beskjeden når det kommer til bygging av høyhus, pga. mindre befolkning og større arealer i forhold til andre vestlige land. Kommende byplaner viser imidlertid en jevn forandring mot høyere og mer komplekse konstruksjoner, som et svar mot den økende befolkningen og økonomien i de store byene. Prosjekter som; Karla tårnet i Göteborg og Tellus tårnet i Stockholm, som når respektive høyder på 245 m og 237 m, er begge banebrytende prosjekter i svensk byplanlegging. Dette har ført til at flere spørsmål har oppstått i det svenske brannsikkerhetssamfunnet, om tilstrekkelighet av dagens sikkerhetsforskrifter for høyhus.

Målet med denne oppgaven er å undersøke brannsikkerhetsnivået i den nåværende svenske bygg lovgivningen, mot høye kontorbygg, og hvordan det sammenlignes med et land med kjent erfaring innen høyhusbygging. Målet vil videre være å analysere og sammenligne forskjellene mellom disse to landene, med hensikt å vurdere mulige tillegg i den svenske byggeforskriften mot høyhus.

Denne oppgaven har utformet to teoretiske høyhus med 16 etasjer, i overensstemmelse og utelukkende med pre-aksepterte løsninger som finnes i de svenske og australske byggeforskriftene. Hvert høyhus ble deretter utsatt for en deterministisk scenariobasert risikovurdering, ved bruk av CFD- og evakueringssimulatormodellene Pyrosim og Pathfinder. Målene som ble brukt til å evaluere brannsikkerhetsnivåene i hvert høyhus, var i form av oppehåldsikkerhets-kriterier for personer, med holdbare forhold som brukes som akseptkriterier. RSET vs. ASET-metoden ble brukt, og tre brann- og utgangsscenarier ble utformet for å evaluere ytelsen til hver høyhus.

Ved å evaluere forholdene med risikovurderingen kunne det observeres at den australske høyden inneholdt et høyt brannsikkerhetsnivå enn det svenske høyhuset. Det australske høyhuset viste et mer robust brannsikkerhetsdesign, med lengre tid før forholdene ble uholdbare (ASET), i forhold til det svenske høyhuset. Evakueringssimuleringene viste lignende resultater, der to av tre simuleringene gav raskere evakuering (RSET) for det australske høyhuset. Det svenske høyhuset oppnådde akseptable resultater i to av tre av simuleringene, men oppfylte ikke målene for risikovurderingen.

Resultatene fra denne oppgaven indikerte at overbelastning forårsaket forstopping i Tr1- og Tr2-trapphusene. Dette var hovedårsaken til det svenske designet, da dette ble brukt til et større antall beboere. Den australske røyklobby-løsningen gav, i sammenligning en raskere evakueringskomponent og et oppholdsrom som kunne gi trygg innkvartering til et større antall beboere. Det ble også observert under designprosessen til de teoretiske høyhusene, at den australske byggeforskriften var mer konservativ og krevde mer robuste sikkerhetsløsninger enn den svenske byggeforskriften.

Oppsummere, har denne oppgaven indikert at den australske byggeforskriften har et høyere sikkerhetsnivå i deres pre-aksepterte løsninger enn den svenske byggeforskriften. Den scenariobaserte risikovurderingen som ble gjennomført i denne oppgaven har også vist at den australske byggeforskriften tar i betraktning sikrere og mer effektiv evakuering for større

antall beboere, obligatoriske brannslukkingssystemer og obligatoriske to uavhengige evakueringsveier fra hver etasje. Simuleringene har også vist et høyere nivå av brannsikkerhet i de australske høyhusene, for alle simulerte brannscenarier. Det foreslås derfor at følgende krav implementeres i den svenske byggeforskriften:

1. To uavhengige evakueringsveier som forbinder hver etasje, for alle bygninger med høyde over 25 m.
2. En røyklobby eller lignende krav som muliggjør et oppholdsområde som gir trygt opphold med tilstrekkelig kapasitet for alle beboere, når kø og forsinkelse forventes i trappehusene.
3. Sprinklersystem som en foreslått løsning mot et obligatorisk krav til brannslukkingssystem i alle bygninger med høyde over 25 m.

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1. Introduction

This chapter will present the background, aim, objective, limitation of this study.

1.1. Background

Sweden have always been more modest of constructing high-rise buildings, due to smaller population, and larger land areas in comparison to other western countries. Upcoming urban plans show however, a steady change towards higher and more complex constructions, as a response toward the growing population and economy in the major cities. Projects such as; Karla tower in Gothenburg, and Tellus tower in Stockholm reaching respective heights of 245 m and 237 m, are both pioneering projects in Swedish urban planning [1] [2]. The building and planning of higher buildings, has led to several questions being raised in the Swedish fire safety community, about the adequacy of the current safety regulations for high-rise buildings.

Building codes are a continuous product of years of accretion and evolution, created from the knowledge of previous constructions, past mistakes and great societal losses. It constitutes societies minimum demands, and clarifies the meaning of legislation for any construction. Every building must hence, follow the regulations to be deemed satisfactory for the societal norms, and constituted laws regarding public health, safety and general welfare. This also means that the minimum level of fire safety adapted into a building, may differ depending on different countries experience with the building type in question. [3]

To strengthen future high-rise building regulations, it becomes necessary to study the level of fire safety adapted for high-rise buildings in the Swedish building code, and how it differs compared to western countries with longer experience in high-rise building.

1.2. Aim and objective

The aim of this work is to investigate the level of fire safety for high-rise office buildings, incorporated within the current Swedish building legislation, and how it compares to a country with renowned experience within the field of high-rise building construction.

The objective of this report is to examine the strength and weaknesses of the Swedish and Australian building regulation with the use of scenario based risk assessment. The objective will further be to analyse and compare their differences, with the intent of suggesting possible additions to the Swedish building regulation towards high-rise buildings.

Specifically, this study will attempt to answer the following questions:

- Is the Swedish building code designed to ensure fire safety in new high-rise buildings in Sweden?
- How does the Swedish fire safety differ compared to a country with renowned experience with high-rise buildings, when evaluated in terms of risk perception?

1.3. Methods

This study shall design a high-rise office building for both Sweden and Australia, solely based on technical requirements and prescriptive solutions found in the associated building regulations. Each high-rise building will then undergo a full-scale scenario based risk analysis, with the purpose of disclosing their different fire safety performances. The performances shall in this study be based on the Required Safe Egress Time vs. Available Safe Egress Time (RSET vs. ASET) method. Hazards and other risk sources evaluated in the risk analysis as the ASET criteria, will be assessed using Fire Dynamic Simulator (FDS). Parallel and in conjunction with the FDS simulation, will the RSET criteria be assessed using the evacuation model Pathfinder.

Sources of risk translated into the FDS and egress simulations, will be based on fire scenario statistics, as well as design scenarios stated in international used guidelines.

The data gathered from the risk analysis will then form the basis for discussion and conclusions around the aims of this study, concluding with possible suggestions for changes to the Swedish building regulation.

1.4. Limitations

This report will mainly focus on the minimum fire safety level of building regulations in forms of stated technical requirements, as well as prescriptive solutions. This subsequently means that no regards are given to additional specific objectives (e.g. continuation of operation after fire), other than stated in the fire safety designs and risk analysis.

There are numerous fire scenario that could have been selected for this study, as part of the scenario based risk analysis. Three design fire scenarios from Boverkets general advice on analytical dimensioning for buildings fire protection (BBRAD), are used and presented in this report

In this work only office buildings have been investigated, and the results are therefore only applicable for this type of building use. Furthermore, zoned-evacuation is the only egress strategy that has been investigated in this study.

FDS is the only CFD tools that have been used to simulate and examine the fire, and smoke development in each design fire scenario. Pyrosim will be the modelling program used to construct each high-rise. Other CFD software's, as well as possible differences in simulated results are not considered in this study. Similarly is Pathfinder the only simulator used to evaluate the evacuation performance in this study.

This study is limited to the fire safety provisions found in the building regulations in Sweden and Australia. The Swedish versions used in this study is Boverket Building Regulations (BBR 25 - BFS 2011:6 with changes up to BFS 2017:5), and the building code of Australia ("BCA"), also referred to as *National Construction Code 2016 Volume One* (adopted by States and Territories on 1 May 2016).

2. Methodology

This report is divided in four parts: Theoretical study, building code study, model case study (risk analysis foundation), and analysis of the results. The report will end with a discussion and conclusion. Figure 1 illustrated the work process used in this study that will answer the aim and objective of the research. It should be mentioned that Building code- and Model case study is part of the same chapter.

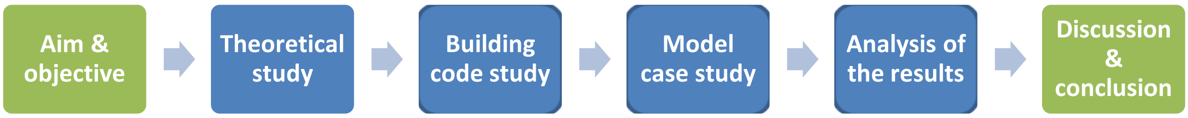


Figure 1- Flow chart illustrating the work process used in this study [Figure by Emmanuel Eriksson]

2.1. Theoretical study

This section provides the theoretical background on relevant topics used in this report. Initially, the definition of the term "high-rise" will be defined from an international point of view. The later parts consist of a literature study, on the origin of high-rise buildings, the building code of Sweden and Australia and risk perception and scenario based risk assessment. Databases, available libraries, existing regulations and literature were used to find the literature and resources used in this report.

2.2. Building code study

This section will examine the performance and prescriptive fire safety requirements found in Boverkets Building Regulation (BBR, version 25 (BFS 2011:6 up to BFS 2017:5), and the National Construction Code's Building Code of Australia Volume 1 (BCA 2016), with regard to high-rise office buildings. The aim of the building code study is to design two high-rise office buildings in accordance with the minimum fire safety provisions found in the respective countries building code.

2.3. Model case study

This section shall develop and establish the basis for the later scenario based risk analysis. The attention will be to establish objectives, acceptance criteria and to develop design scenarios that will measure the performance of each high-rise building. The fire and egress simulations shall be represented by design scenarios that will analyse the fire safety design, based on RSET vs ASET criteria.

The methodology followed in this section shall be the approach described in the BBRAD. The scenario based risk analysis will use design characteristics in the fire and egress simulations, based on specifications found in this guideline, but also from the International Fire Engineering Guideline (IFEG), and the handbooks provided from the Society of Fire Protection Engineers (SFPE).

2.4. Analysis of the results

This chapter will present the results derived from the scenario based risk analysis, and the fire and egress simulations. The aim of this chapter shall be to illustrate the differences in fire safety between the Swedish and Australian high-rise buildings, as well as relationship between the RSET and ASET criteria. The performance of each high-rise building, in terms of the risk analysis objectives, providing the basis for the later discussion and conclusion.

2.5. Discussion and conclusion

Performance results obtained from the risk analysis of the different fire and egress simulations are the basis for discussion and conclusion. It should be noted that the discussion and conclusion will attempt to answer to the aims and objectives presented in this study.

3. Theoretical study

This chapter will outline the theoretical background of the three main parts in this thesis: High- rise buildings (definition and purpose), Building code and Risk assessment. The objective of this chapter is to present how these parts relate in this study, and establish the base for subsequent chapters.

3.1. Definition of the term “high-rise building”

The term “high-rise building” do not have an internationally agreed definition. Depending on certain aspects such as: height of building, vehicle access for fire department intervention, as well as height limit for fire department equipment, definition changes accordingly to regulations in different countries. To facilitate a better understanding of the term “high-rise”, the aim of this section will be to present different western countries definition of the term (Australia, Britain, United States of America and Sweden).

The Australian definition of high-rise buildings is only related to building height. According to the BCA, buildings are considered to be high-rise, when the height of the building (measured from the floor above ground) is greater than 25 m [4]. Similarly in the USA, according to National Fire Protection Association (NFPA), high-rise buildings are defined as buildings higher than 75 feet or 23 m, measured from the lowest level of fire department vehicle access to the floor of highest occupiable story [5] [6]. USA do not have a common building code, the ones provided by NFPA are however widely used and acknowledged in several States.

The British building legislations do not have a definition for high-rise buildings. Interpretations of the “Approved Document B” which contains the legislating technical requirements, has special requirements for buildings that exceeds the height of 30 m above ground (25 m if the floor area is greater than 950 m^2). This will therefore be the assumed to be the British definition of high-rise buildings. [7]

The building code of Sweden (BBR) do not have a definition on the term high-rise. The performance based regulation is however divided as the floor count exceeds 16 floors. Here, interpretation shows that buildings that exceeds 16 floors must through analytical analysis verify that the performance based fire safety requirement are met. This eliminates the possibility to only use prescriptive solutions, otherwise sufficient to meet the performance requirements. The term high-rise building in accordance with Swedish regulations, will in this study be referred to buildings with 16 floors or more. [8]

3.2. Chicago: The urban development and invention of high-rise buildings

The purpose of the modern high-rise building has broadened since the hallmarked of its first appearance in Chicago, Illinois in 1885. The focus has more than ever been its charismatic attributes, and is even exploited for its abilities to reflect the city or countries economic status. A modern example is the world tallest building to this date, the Burj Khalifa tower in Dubai, which is the latest candidate in the contest to win the world tallest race, with a height of 830 m. [9] High-rise buildings have always represented a revolution in both architectural design, and vertical construction. The beauty and utility of the high-rise building represents the combination of genius of both the architectural and engineering fields, but the origin of the high-rise building was more an invention for the city of Chicago to break out of the traditional form, which limited the city expansion [10].

From the year of 1830 when Chicago was legally recognized as a town, until the years leading up to 1885, the modern industrial city had no means of horizontal transportation other than foot and horse, and no means of vertical travel other than climbing stairs. These limitations lasted until well into the nineteenth century, effectively preventing the city from expanding either horizontally or vertically, so that it could only grow interstitially into a compact mass [10].

Chicago experienced simultaneously, as other bigger cities in the U.S., an enormous influx of immigrant during this time, which led to an extraordinary increase of inhabitants. The rate of people entering USA was just over a million per year in the late 1870 to 1893, which increased to about 1.3 million per year in the following years. This resulted in increasingly stress to build the country in response to the extraordinary growth of new citizens. At the same time as the country experienced an unparalleled rate of economic growth. This growth of both economics and influx of people, laid the foundation for Chicago to invent and develop new technical inventions to meet the challenges of the urban site. The increase of population in Chicago, and inside the metropolitan area is presented in Table 1. It can be noticed from Table 1, that from the years of 1870 until 1930, the number of people living in Chicago increased with 500 000 each 10th year. [11] [10]

Table 1 - Population, area and density of Chicago 1830-1970 *[10]*

POPULATION, AREA AND DENSITY OF CHICAGO

YEAR	Population of City	Population of Metropolitan Area	Area of City Square Miles	Density per Square Mile
1830	Ca. 100	-	0.417	240
1840	4 470	-	10.186	439
1850	29 9636	-	9.311	3 218
1860	109 260	-	17.492	6 246
1870	298 977	-	35.152	8 505
1880	505 185	-	35.152	14 371
1890	1 099 850	-	178.052	6 177
1900	1 698 575	-	189 517	8 963
1910	2 185 283	2 805 869	190.204	11 489
1920	2 701 705	3 575 209	198.270	13 626
1930	3 376 438	4 733 777	207.204	15 862
1940	3 396 808	4 890 674	212.863	15 958
1950	3 620 962	5 586 096	212.863	17 011

1960	3 550 404	6 794 453	212.863	16 679
1970	3 366 951	6 892 509	227.251	14 816

The city outgrew the interstitially growth phase when a broad collection of fundamental inventions suddenly became available, to make possible the enormous expansion of the urban fabric in all direction. The technical developments that emerged during the decades around the mid-nineteenth century provided the city builders to break out of the traditional form. The most important of these in terms of this study were: 1) the internal iron frame for buildings, 2) fireproof construction, 3) power driven elevator, 4) hydraulic control, 5) sanitary systems and 6) the generation of electrical power. These interrelated techniques constitute the material basis of the new metropolitan life, and comprises the primary elements of high-rise construction, as well as urban technology. [10]

By 1890 all the mechanical and electrical inventions were available, with the profound consequence that the metropolis of Chicago now could spread out and evolve. Superseding the earlier city that had been shaped by the process of interstitial growth. Table 2, presents the net area of office space, in square feet added between 1872, one year after the great fire nearly destroyed the commercial area in Chicago, to the year 1911. It can be noticed that the net rate added, rapidly increases from the years of inventing the high-rise building (from 1885) [10].

Table 2- Office space constructed and net office space in Chicago 1872-1911 *[10]*.

OFFICE SPACE CONSTRUCTED IN THE CENTRAL BUSINESS DISTRICTS OF CHICAGO, 1872-1911

YEAR	Net area in square feet (area added less demolished space)	Continuing Total	YEAR	Net area in square feet (area added less demolished space)	Continuing Total
1872	322 007	322 007	**1892**	957 615	3 140 434
1873	-	-	**1893**	730 046	3 870 480
1874	-	-	**1894**	288 270	4 158 750
1875	49 550	371 557	**1895**	499 037	4 657 787
1876	-	-	**1896**	216 776	4 870 563
1877	-	-	**1897**	125 250	4 999 813
1878	-	-	**1898**	89 025	5 088 838
1879	-	-	**1899**	22 664	5 111 502
1880	-	-	**1900**	334 039	5 445 541
1881	-	-	**1901**	-	-
1882	88 430	459 987	**1902**	359 323	5 804 864
1883	-	-	**1903**	463 319	6 273 183
1884	92 266	552 253	**1904**	513 739	6 786 922
1885	319 560	871 813	**1905**	480 388	7 267 310
1886	418 480	1 290 293	**1906**	431 365	7 698 675
1887	17 953	1 308 246	**1907**	591 646	8 290 321
1888	303 703	1 611 949	**1908**	211 523	8 501 844
1889	45 901	1 657 850	**1909**	-	-
1890	335 046	1 992 896	**1910**	1 208 614	9 710 458
1891	189 923	2 182 819	**1911**	1 010 400	10 720 858

The high-rise building was the key invention made possible to meet the urban challenges of rapid increase of people, within the confined area of the city, in addition to the urban development and economic growth of the region. The relationship between Table 1 and 2 above, illustrates that the subsequent years after 1885 ushered Chicago into a time where both the central business district, and the municipal experienced a rapid growth.

Parallel but in conjunction, new possible risks were introduced, related to the increasing height of the high-rise buildings. New hazardous conditions that became clearer as the buildings became taller, was for instance the changed and sustained evacuation situation for both the building occupants and fire department. The increasing building height, also made it difficult for the fire department to extinguish the fire externally for the first time. Several other problems became relevant, such as: increasing the smoke stack effect potential, and importance of early interior fire attack on the upper floors, resulted in an increased "risk image" for fire scenarios in high-rise buildings. [12]

Fire have always been one of the main driving forces behind development of building regulation, and has almost exclusively been govern by gathered experiences from catastrophic fires. This is also true for the development of fire safety requirements for high-rise buildings, and is clearly exemplified from one of the earliest high-rise building fires "The triangle shirtwaist fire" in March 1911. This would later become known as the deadliest high-rise building fire in the U.S. for sixty years to come, and would initiate major fire- and building code improvements still in use in the U.S. today. Changes such as mandatory fire drills, periodic fire inspections, working fire hoses, sprinklers, exit signs and fire alarms, doors that swings in the direction of travel and staircase size restrictions, are some of the improvements that comes directly from the gathered experience from the Triangle fire. [13] [14]

This experience does not however seemed to have affected, nor contributed to any advances in the Swedish building regulations towards high-rise buildings. This exemplifies the level of impact previous catastrophic fires, great societal losses and experience constitutes on a legislative level. It is therefore of great concern to further evaluate the current level of safety incorporated in the Swedish building regulation towards high-rise configurations, and how it differs towards a country with renowned experience of high-rise structures.

Figure 2 - A picture of the Melbourne city sky-line, Australia [Photo by Emmanuel Eriksson]

3.3. Building code study

Building codes and regulations can be described as a set of rules that specifies the societal standards for buildings, as well as non-building structures. The main purpose of building regulations is to secure uniformity, and protect public health, safety and general welfare as they relate to construction and occupancy of the building. This means that all buildings must demonstrate their level of safety towards the building code, to be deemed as acceptable, and legally used. The use and development of building regulation have strongly been influenced by fire, and the threat it possesses towards urban life. [3]

It is important to understand that building codes are a product from many years of accretion and evolution. This means that the building code is a living document, under constant revision. The following chapters will focus on the Swedish and Australian building regulations, and the method adopted in each country to meet their current performance requirements as stated. [3]

3.3.1. Swedish building Regulation

From the transition period of 1994, when the practise turned from prescriptive to performance based regulations, several revisions have been conducted on the building regulation to its current state. The present version of the Swedish building code, BBR 25 (Boverkets Building Regulation), is based on, and contains regulations and general guidelines for the Planning and building act, PBL (2010:900), and Planning and building regulation, PBF (2011:338). [8] These are the laws that deals with, and regulate the fire safety protection for all constructions in Sweden. These are the core reference documents for the regulations, and advices published by Boverket. Besides drafting on the building code, Boverket also publishes reports that serves as guidelines to the BBR. [15]

An overview of the hierarchical structure of laws, regulations, guidelines in Sweden, and means of compliance, is illustrated in Figure 3.

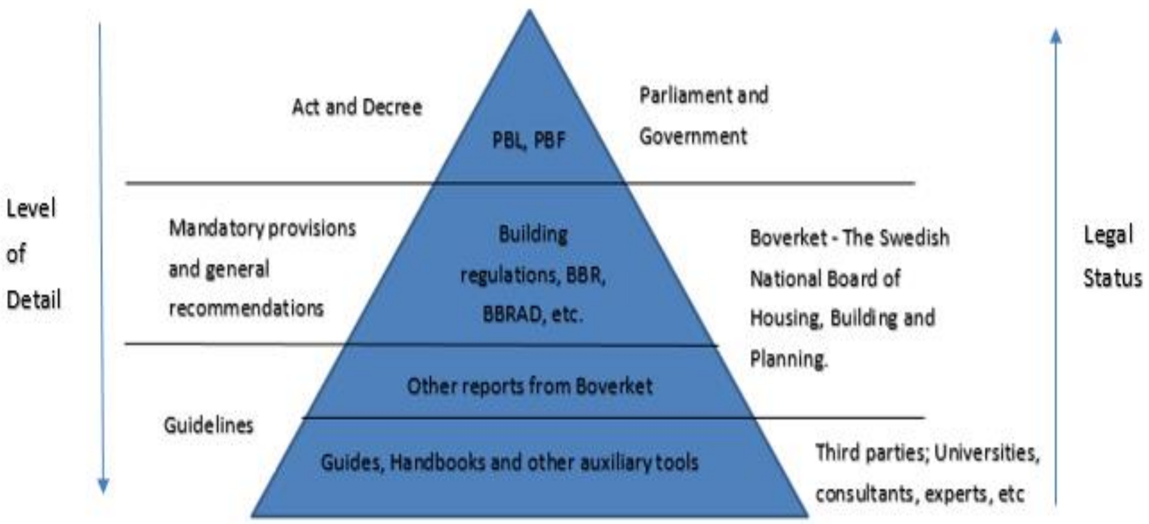


Figure 3 - Illustration of the Swedish building legislation system and means of compliance [Figure by Emmanuel Eriksson]

As illustrated in Figure 3, the PBL and PBF is administered by the Parliament and Government, and have the highest legal status with the respect of construction work. It is also important to notice the position of Boverket in this hierarchy, as the intermediary function between the legislation and the fire safety engineering practitioners.

From the PBL section 8 §4, all constructions must have sufficient technical properties with respect of fire safety, to be deemed acceptable in terms of the societal norms. [16] The PBF further describes the means to comply with the legislating demands in section 3 §8, and provides the following performance requirements:

1. *The load-bearing capabilities of the structure is likely to endure the event of fire, for a given period;*
2. *The development and spread of fire and smoke within the structure is limited;*
3. *Spread of fire to adjoining construction is limited;*
4. *People within limits of the structure can escape, or be rescued by other means in the event of a fire, and;*
5. *Consideration has been given to the safety of rescue personnel in the event of a fire*. [17]

These performance requirements are then adopted by Boverket, and translated in BBR as detailed descriptions referred to as prescripted solutions. These prescriptive solutions are not mandatory, but are generally accepted measures to comply with the performance requirements, often described as a guidance on how compliance can be achieved. [18]

Part 5 in the BBR contains all mandatory fire safety provisions from the PBL and PBF, as well as prescriptive solutions for all building structures, except for the load bearing capabilities required during a fire impact. The first performance requirement is provided in a separate document referred to as EKS, governing general advices and the application of European design standards (Eurocodes). The general objectives of section 5 in the BBR (translated to English), states the following functional goal [8] [18]:

> *Buildings must be designed with such fire protection to ensure that fire safety is satisfactory. The design of fire protection should be based on assumptions that fire may occur. The fire protection shall be designed with sufficient robustness, so that all or major parts of the protection are not fouled by individual events or stresses.* [8]

To comply with the functional requirements stated in the BBR, two general methods can be adopted. Either by conforming to the prescriptive solutions of the BBR, or by a performance based analysis that complies with the performance requirements stated in the BBR. These methods are often referred to as prescriptive and analytical design methods respectively. [8] [18]

Prescripted solution method

The prescripted solution method uses fire safety recommendations in chapter 5 of the BBR, to create a fire safe design for the building. These fire safety recommendations vary depending on two building specifics, namely the Occupancy classification and Building classification. Depending on the specifics of these classifications regarding the building in question, the prescriptive solutions varies, and different solutions might be adopted in the fire safety design. The Occupancy classification defines the extent to which people can be assumed knowledgeable about the building, its evacuation routes or procedures, and their abilities to evacuate on their own and if they are expected to be awake. There are 6 occupancy classification in the BBR, depending on the diversity of each variable, with the 6^{th} occupancy classification as the strictest. The Building classification mainly defines the buildings need for protection, and is based on assessment regarding the probability of fire development, potential consequences given the event of a fire and the geometric complexity of the building in question. There are four Building classifications ranging from Br0-Br3, with Br0 forming the strictest classification, defined in the code as; buildings with very high need for protection. The Br-classes are assigned to a building from BBR, depending on factors such as occupational class and height of the building. [8] [18]

It must be mentioned in correlation with this section, that the prescripted method can be used for all building except for buildings with Br0 classification, where performance based method is required. [8]

Analytical design method

The analytical design method is when a building is designed to meet the performance requirements of BBR, other than through complying with the prescriptive solutions. This method applies the concept of risk to determine compliance with the performance requirements. The verification of compliance with the functional requirements, is done by either qualitative or quantitative risk assessment or by the equivalent method (comparing to a reference building, constructed solely with prescriptive solutions). [19]

"Boverkets general advice on analytical dimensioning of buildings fire protection" (BBRAD 3, satisfying BFS 2013:12) is a document provided by Boverket, in order to provide guidance for performance based methods. This guidance document is structured into six sections, Table 3 provides a summary of each section in BBRAD. [19]

Table 3 - Outline of the sections and respective content provided in BBRAD 3 *[19]*

SECTION	TITLE	CONTENT
1.	Introduction	The scope and purpose of the document.
2.	The design process	This section describes the recommended design process. Included should be a description of the analysis method, acceptance criteria, identification of verification need, risk identification etc.
3.	Possibility of escaping in the event of fire	This section provides recommendations and parameters for analysing the means of escape, as well as fire modelling. Required fire scenarios, human behaviour, and egress and fire simulation input are among the topics discussed.
4.	Protection against fire and smoke spread within a building	The recommendations for assessment regarding fire and smoke spread within a building. This includes topics such as fire separations, ventilation systems and pressurization of spaces.
5.	Protection against fire spread between buildings.	Assessment regarding external fire spread between buildings, as well as parameters such as heat radiation, and acceptable limits of radiation is presented in this section.
6.	Documentation and control	The final section provides the recommendation regarding the documentation and level of verification needed for each project.

3.3.2. Australian building regulation

The national construction code (NCC) of Australia is a collection of performance based building codes, which contains and governs the technical requirements used to design and construct all buildings in Australia. The NCC comprises of the Building Code of Australia Volume One and Two, as well as the Plumbing Code of Australia (PCA) as Volume Three. The NCC is given legal effect by the representative legislation, depending on which state and territory it is being used in. Each state and territory in Australia consist of an act of parliament, and a subordinate legislation which empowers the regulation by prescribing, and "calling up" the NCC to fulfil any technical requirements that are required to be satisfied. As the Australian high-rise evaluated in this report is located in Melbourne, shall following part use the Victorian province to describe the legal hierarchy. [20] [21]

Figure 4 presents an overview of the legislative framework in the Victorian province in Australia, as well as the means of compliance and legal status of each part of the hierarchy. It can be noticed, that the building act used to govern building activities in the Victorian province is the Building Act of 1993, issued by the parliament is at the top of the hierarchy. Other provinces are govern by other acts and framework, the building codes provided by the NCC are however used in all Australia.

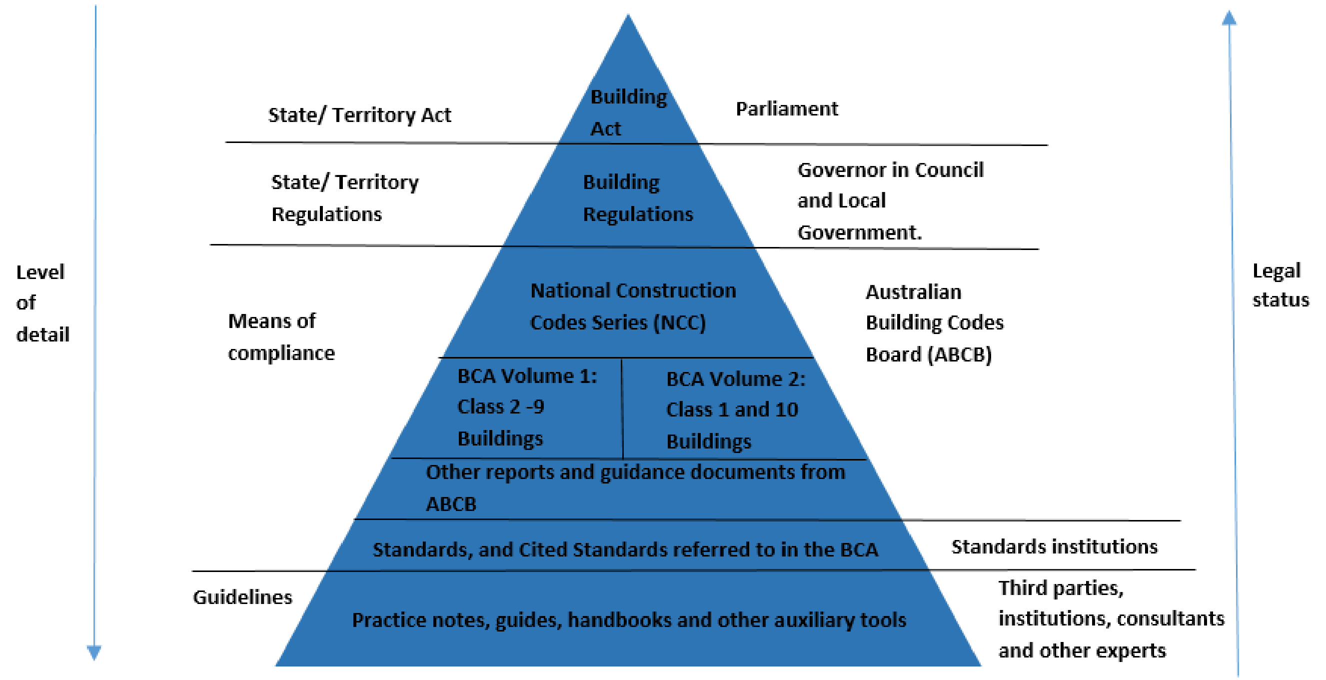


Figure 4 - Illustration of the Australian building legislation system and means of compliance [Figure by Emmanuel Eriksson]

Further down in the hierarchy is the "Building Regulations", which are derived from the Act, and contains amongst other things, the requirements relating to building permits, inspection, occupancy permits, etc. The regulations then "call up" the technical requirements of the BCA as a reference, which must be complied with. The regulation in effect in the Victorian region is the Building Regulations of 2006, which are enforced by the local government. [20] [21]

It can be noticed that the BCA and BBR are similarly at the same position in respective pyramid, as the intermediate function to meet compliance, between legislative framework and fire safety practitioners. They differ however strongly on content, as well as structure, and contains for example 30 directly fire safety related performance requirements, in comparison to the 5 presented in section 3.3.1. [4]

The provisions within the BCA can be divided into three level structure presented as following.

<u>Guidance levels:</u>

1) Objectives: The social objective that the building must achieve, and is used as an aid in interpreting the BCA.
2) Functional Statements: What the building must do to satisfy the social objective, and is used as an aid to interpretation of the BCA. [22]

<u>Compliance levels:</u>

3) Performance requirements: Outlines the levels of accomplishment different building must attain to be compliant with the building legislation system, and comprises the only NCC hierarchy levels that must be satisfied. [4]

Section C-E of the BCA contains all fire safety related provisions that all buildings must satisfy. Compliance of the performance requirement presented in these sections can be achieved through either using Performance solutions or Deemed-to-satisfy solutions ("DtS"), or a combination of both. DtS will further in this report be referred to as "Prescriptive solution" to be consistent with the Swedish respective version of the term. [22]

Prescriptive solution method

The BCA consist of prescriptive solutions which are provisions which are deemed to satisfy the performance requirements and make up the bulk of the NCC. The prescriptive solution method consists of a similar approach as the Swedish respective version, and uses parameters referred to as Building Class, and Building Type to implement various prescriptive provisions. The classification of a building or part of a building, ranges from 1 to 10, and is determined by the purpose for which it is designed, constructed or adapted to be used. This is used to bring clarity on to which extent the people can be assumed knowledgeable about the building, its evacuation routes and procedures, their abilities to evacuate on their own, and if they are expected to be awake. [4] [22]

The classification of building type describes the required fire-resisting construction required for the specific building. This factor is determined depending on the risk levels as indicated by the class of a building and the buildings height, as indicated by number of floors. In addition to factors, such as the maximum permissible size of fire compartment for the specific type of construction. The BCA prescribes three types of construction, ranging from Type A-C, with Type A construction as the most fire-resistant, Type C construction the least fire-resistant, and Type B ranging between. [22] If a building reaches four storeys or more, it is classified as a Type A building, which is half the storeys of a high-rise building.

Depending on what parameter that the specific building has been assigned, various fire safety provisions, and implementations are provided as prescriptive solutions. By following and implementing all prescriptive solution, the building follows the prescriptive solution method. [4]

Performance solution method

By meeting the performance requirements in the BCA through applying other solutions and designs then the prescriptive solutions, a process referred to as performance solution method is conducted. This method only complies with the BCA when the method can demonstrate satisfactory compliance according to one, or more of the assessment methods given in the building code. [22]

The acceptable methods presented in the BCA for assessing compliance with the performance requirements are following [22].

- *Evidence of suitability*
- *Verification methods*
- *Expert judgement*
- *Comparison with the prescriptive solutions*

Evidence of suitability is acquired by documenting that a material, construction or design meets the BCA requirements, and can be acquired by either an appropriate authority or a person certifying compliance with the BCA. Source of evidence from a “Registered testing authority” must show that the material or construction been subjected to standardised, and appropriate tests. Persons with certifying compliance with BCA refers to professional engineers, or persons with “appropriately” qualifications in the areas being tested. [22]

Verification methods refers to tests, inspections, calculations or other methods that determines whether a performance solution complies with the performance requirements. The NCC provides various approved verification methods, which could be used to satisfy the BCA requirements. In addition, verification methods provided by an appropriated authority be used to meet the performance requirements. [4] [22]

The use of expert judgement as an assessment method, means that the judgement of an expert who has documented qualifications, and experience to determine whether a performance- or prescripted solution complies with the performance requirements is used to document compliance. [22]

The last assessment method is through comparing and demonstrating that a designed solution provides as equivalent level of fire safety, as a prescriptive solution. By demonstrating that the same or better level of fire safety is achieved than the prescripted solution, it complies with the BCA. [4] [22]

The assessment method regarding evidence of suitability is the most interesting in consideration to this report, since it constitutes the use of fire safety engineering practitioners. In comparison to the Swedish performance solution guideline BBRAD, Australian Building Codes Board (ABCB) published the International Fire Engineering Guidelines [23] as a guideline for conducting a performance based solution. This guideline introduces the use of risk assessment, as a means of verifying the level of safety against the mandatory provisions of the building code. Compliance with the code can either be verified by qualitative or quantitative risk assessment, or by comparing the level of safety towards a reference building, solely constructed with prescriptive solutions, referred to as the equivalent method. Regardless on which method that is adopted, the overall aim is to use the study of risk, to measure the level of compliance towards mandatory provisions. Forming the minimum acceptable level of safety accepted by the society for all building, or non-building structures. [22]

Safety is often referred to as the complementary size of risk, in such that each one can be evaluated based on the other, for example; high risk equals low safety, and conversely. Since this study aims at disclosure the level of safety in high-rise buildings, it naturally requires the simultaneously study of risk associated with high-rise buildings. [24]

3.4. Risk assessment

Risk assessment have broad applicability in addressing safety issues, and is a tool that can be used to focus the attention on what is important towards fire safety. [25] It is important to clarify that a risk assessment is not a single procedure, but a continuous systematic process in which frequency and respective consequence, are identified towards human, material and environmental values, and evaluated acceptable or not. When evaluating the results and other findings from a risk assessment together with the outlined objectives, a concept defined in the literature as *risk informed decision making* is established. [25] A risk-based evaluation of different fire safety solutions, implemented within building regulations towards high-rise office buildings, could disclosure the quality difference between various buildings regulations and what level of safety the society deems as acceptable.

There are many ways and approaches to conduct fire risk assessments. To further clarify the use of risk assessment in this study, following sections will outline the concept of risk, and present the model that will be used to meet the respective aims and objective of this study.

3.4.1. Introduction of the term risk

In general, it can be said that risk can be defined as the probability or frequency of a specific event to occur, that either leads to an unwanted event or effect over a specific period. The two main components of risk are thus, probability or frequency, and respective consequence. Risk can subsequently be explained as, specific scenario(s) in the future that has a likelihood of occurring, with an associated negative effect. [26] When risk is used in technical and safety context, the two main components give risk a numerical value for its respective case e.g. probability of death in a fire per year. Equation (1) gives an example of the standard risk calculation, with C_i as consequence-, and p_i probability for scenario "i" to occur [24]:

$$Risk = \sum_{i=1}^{n} p_i \cdot C_i \qquad [1]$$

Where:

p_i	The numerical value for the probability or frequency for scenario i to occur.
C_i	The numerical value of consequence for scenario i.
n	The number of scenarios.

Risk can also be qualitatively assessed with the use of engineering assessment. The risk is then argued by the use of historical- or statistical data. Regardless of how risk is assessed, the objectives are to identify and assess potential risk factors is a system or operation. This systematic process of evaluating risk is referred to as a Risk assessment. When further including certain implementations, such as procedures or installations with the intent of reducing-, or control the level of risk, the process then becomes known as Risk management. Figure 5, illustrates the various steps in a three-part risk management process, namely A) risk analysis, B) risk evaluation, and C) risk reduction/control. [27]

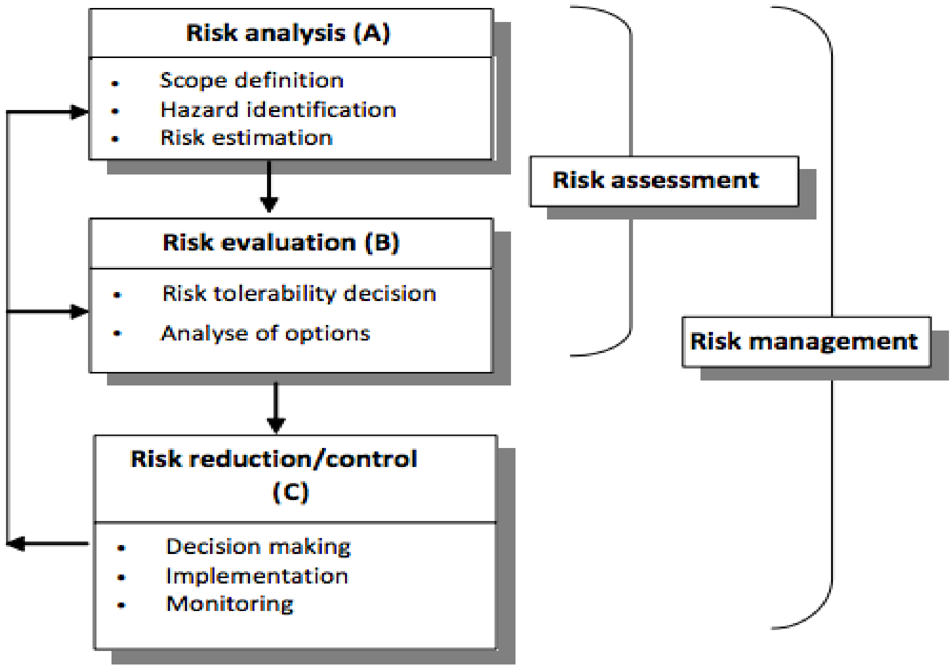


Figure 5 - Risk management model *[27]*

This report is placed within the risk evaluation part as the aim of this study is to assess the fire safety level incorporated within the respective building regulation, for high-rise office buildings. The aim of providing suggestions of possible improvements, could be argued as a form of risk reduction or control. Suggestions shall however be aimed towards a legislative level (BBR), and not the buildings subjected to the risk assessment. This report is therefore further defined as a risk assessment.

3.4.2. Scenario based risk assessment

To conduct a scenario based risk assessment of two high-rise office buildings, it first becomes important to facilitate understanding concerning the risk assessment approach. Following section will describe the scenario based risk assessment method used in this study.

The process of evaluating whether a building design meet the performance requirements, could be done through either quantitative or qualitative analyses. In qualitative analyses the suggested design solution is evaluated by comparing the performance of the design with prescriptive design solutions, using logical reasoning, statistics, experience or results from testing. Quantitative analyses are either deterministic or probabilistic, and differentiate from each other by the former having the probability for each design scenario described qualitatively, while the latter is described quantitatively. In both deterministic and probabilistic analysis, are the consequence derived from each scenario calculated, and presented quantitatively. [28]

Deterministic approach, or the process of performance based risk assessment with the use of scenario based analysis, is an internationally common practise for evaluating the fire safety design. This is especially exemplified in its appearance in both the Swedish and Australian building regulatory approach. The procedure is distinguished by using various fire scenarios to challenge the proposed fire safety design of the building, to evaluate if the proposed design delivers a sufficient level of safety. [19] [23]

Regardless on used method of analysis, the process of a risk assessment generally starts by defining the scope of the project, so that the fire engineer practitioner knows the boundaries of the design. The subsequent step is to identify the fire safety goals and objectives of the project, and describe them qualitatively. Goals are often divided into four fundamental categories: life safety, property protection, protection of continuity of operation and environmental protection. The objectives, are then translated by the fire engineering practitioner into quantifiable values, often referred to as design objectives. These design objectives are then converted into acceptance or performance criteria, which are engineering terms expressed in measurable values. These criteria might include, but not limit to, threshold values such as; tenability conditions, maximum temperature exposure, smoke and toxic concentrations or other measurable parameters. [28]

When acceptance criteria have been established, design alternatives must be developed and analysed, with intent of meeting these criteria. The first step in this process is referred to as hazard or risk identification, and is conducted by systematically review the fire-related hazards within the building, and their potential consequences. Possible fire scenarios that can occur are then derived, and chosen depending on the most relevant fire scenarios to analyse. These fire scenarios are often referred in the literature, as design fire scenarios. Potential designs solutions called trial designs are then developed based on the scope, goals and objectives, acceptance criteria, hazard identification and design fire scenarios. [28]

Since there is an infinite number of possible fire scenarios, the chosen design fire scenarios become representative fires, that is assumed to be credible, both in probability and consequence. Both Swedish and Australian have today nationally, as well as internationally accepted design procedures when choosing the representative design scenarios. One common practice, is the use of worst credible fire scenarios, in order to subject the building towards conservative and various strains. This practise also extends towards the next step, the selection of design fire for each fire scenario. These design fires are quantitative descriptions of assumed fire characteristics, often described in terms of heat release rate, fire load density, toxic species production rate et al. These are also values most commonly found in engineering guidelines such as BBRAD and IFEG, both containing approved variables for each fire characteristic. [28]

The process of evaluating the trial designs is what separates the analysis methods mentioned above. By conducting a scenario based risk assessment, the design fire scenarios are quantitatively evaluated based on physical, chemical and thermodynamic relationships, derived from theories and empirical relationships, against the acceptance criteria. One common practice of the deterministic approach is to evaluate the occupant safety, by evaluating the tenability conditions in a fire simulation, against an evacuation simulation. The deterministic analysis then becomes the evaluation of a set of circumstances against life safety criteria in the building, which will provide a single outcome; the design will either successfully provide a safe accommodation and evacuation in the event of fire, or it will not. [29]

This practice is referred to in the literature as Available Safe Egress Time vs. Required Safe Egress Time (ASET vs. RSET) method, and is conducted by estimating the time before untenable conditions arise, and evaluating it against the required evacuation time. To ensure that the level of occupant safety is satisfactory within a building, it becomes necessary to determine that occupants can reach a place of safety before untenable conditions occur. The aim of this method can therefore be described as; to ensure that all occupants can leave a threatened part of a building in reasonable safety, without assistance, and to ensure that the time available for escape is greater than the time required for escape (ASET > RSET). [28] [29]

In the context of performance-based design, the life safety criteria is the most interesting to consider for a high-rise office building. One factor is that office buildings generally have open concept floor plans, this reduces the possibility to contain the fire within the fire-compartment [30]. Another factor is the large number of occupants high-rise office buildings generally contains. The combination of these two factors can result in a large number of occupants that must reach an area of safety, before unacceptable conditions arise in the fire-compartment. To satisfy the life safety criteria in a high-rise office building, the environment inside a fire compartment during a fire scenario, as well as evacuation simulations is necessary to evaluate [31]. Simulating fire scenarios and human behaviour is essential to scenario based risk assessment, and to further clarify the use of risk assessment towards high-rise building safety, the following section will focus on the use of fire- and egress simulations in collaboration with the deterministic approach.

Figure 6 presents a schematic procedure of a deterministic life criteria approach, with the use of ASET vs. RSET method that will be used in this study.

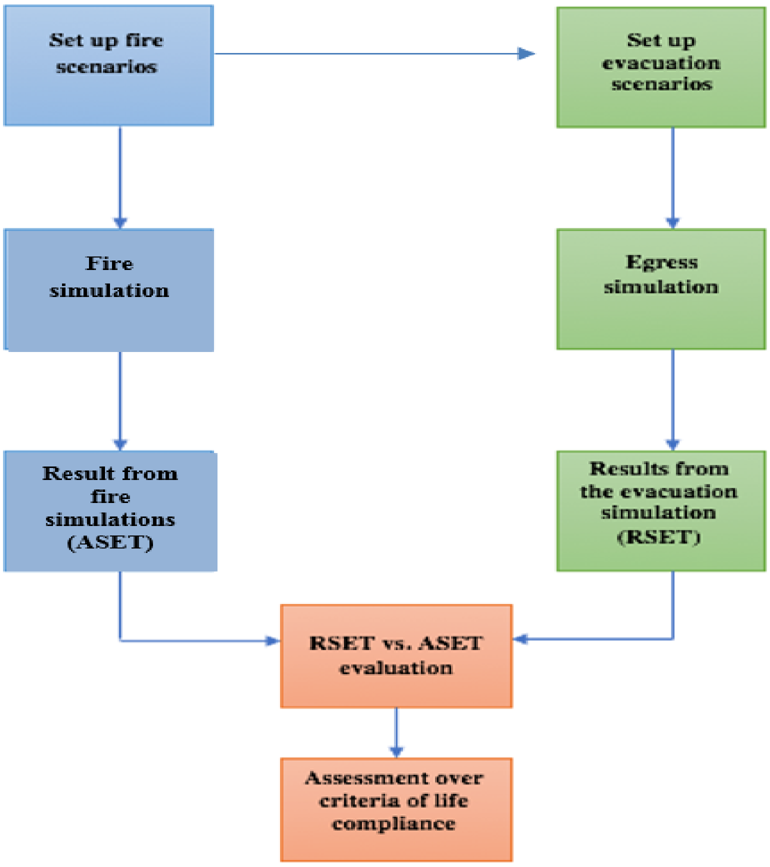


Figure 6 - Schematic procedure of a deterministic life safety approach, with the use of fire and egress simulations to evaluate ASET vs RSET [Figure by Emmanuel Eriksson]

3.4.3. Fire engineering models

Using fire engineering models to evaluate the strain from fire scenarios, are often used as basis for various building decision processes. [32] This requires the results to be of sufficiently high quality, so that correct decisions is taken on right premises. Nystedt [33] describes in a report financed by *National Fire Safety Group* (NBSG), that the way the analysis is presented and documented, will determine the quality and usefulness of the analysis. There are many factors that underlies the level of quality in a risk analysis report, with the use of fire engineering models, and some is summarised by Nystedt [33]:

- *Data used to quantify risks is often not entirely relevant to the specific situation investigated in the analysis.*
- *Risk analyses can be very resource- and time consuming, which may lead to a number of simplifications, and assumptions being made.*
- *Modelling can be too simplified compared with the complexity of the outside world (difficulty and simplifications in the modelling, limitations in calculation models, etc.)*
- *Simplifications and assumptions made to facilitate modelling and assessment of certain damage events, may be appropriated for a number of circumstances, but totally inappropriate for a specific situation to be investigated.*

It is important to acknowledge that all work in the earlier stages in the analysis effect all later activities. Meaning that small faults could subsequently lead to larger errors in the results. [34] The importance of a good defined objectives, scope and planned analysis process is also described by the Swedish sub-chapter of the Society of Fire Protection (BIV), which 2012 initiated a project to develop a Swedish best practise to ensure better use of Fire engineering models, with emphasis on CFD models for ASET analysis [32]. The process became in some extent inspired by the SFPE Engineering Guide to Performance-Based Fire Protection, and consists of a workflow in eight sequential steps, with a parallel process concerning quality assurance (presented in Figure 7). [32]

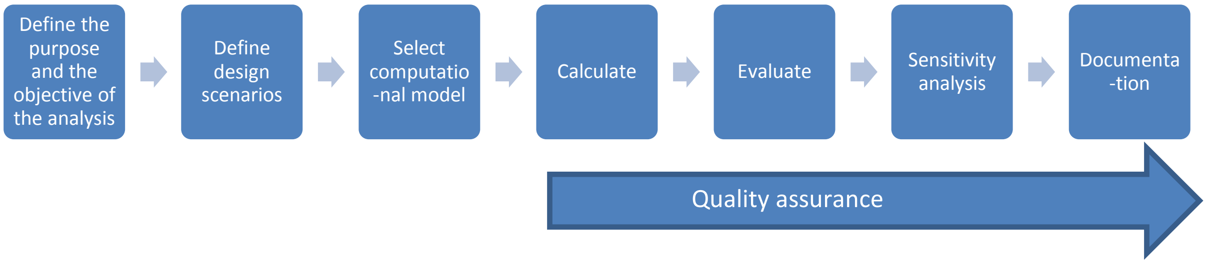


Figure 7 - This studies own representation of the flowchart for visualisation of the proposed working process from BIV *[32]* **[Figure by Emmanuel Eriksson]**

The selection of fire engineering models to analyse and calculate the outcome of a fire scenario in a building varies from simple hand calculation based on empirical correlation, to more advanced CFD models. The selection of model is based on the problem the risk analysis is facing, but also the building complexity. It must be mention in accordance, that models are all mathematical tools used to represent real situations, and that each models have limits associated with their use. It is therefore important that users knows the limitations of the model when taking into account the results, so that a degree of conservatism might be included to assess the accuracy of the model. [33] [34]

There are in broad terms three types of fire engineering models that can used in a deterministic fire risk assessment to evaluate the ASET criteria. A brief summary of the different models is presented below. It should be noted that there are different models within each respective model-field, and that the advancement and development within the field is fast [33] [34].

- **Hand calculation models:**
  - For empirical correlation for establishing flame height, temperature and height of smoke layer, et al.
  - Quick and based on experience.
  - Need to be taken into account large variance of uncertainty, and limited in area of use.
- **Zone-models:**
  - For simple geometries and uncomplicated problems.
  - Quick, many acceptable areas of use and possible to applicate on multiple rooms.

    - No local information and restrictions related to space and geometry.
- **Field/CFD models:**
    - Can be used for complicate geometries and problems.
    - Possible to evaluate local information in geometrically complicated areas with the lowest degree of empiricism.
    - Hard to learn and slow to conduct.

Taking into account the intended area of application for each model, and that high-rise buildings often comprises of complex and large constructions, it becomes clear that CFD models is the best suitable choice in this study. As the criteria of life safety threshold, ASET criteria, also comprises of the evaluation of local information, it limits its usage in ASET vs. RSET methods. The subsequent parts of this study shall therefor only focus on the use of CFD models, namely FDS for the use in scenario based risk assessment.

3.4.4. Computation Fluid Dynamic models

The use of CFD modelling software in deterministic risk assessment have broadened in the past decade, and field models such as FDS is today considered to provide the most complete approach to estimate- and conduct consequence analysis. The use of FDS when performing advanced ASET analysis is widely applied in Sweden, and has become one of the most common tools used by fire safety practitioners for design of buildings use. [32]

The CFD model FDS, solves numerically a form of the Navier-Stokes equations appropriate for heat conduction and low-speed fluid flow, with emphasis on heat transfer from fires and smoke with varied levels of complexity. The partial derivatives of the conservation equations of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid. [33] FDS considers in more detailed the most important fire mechanisms, which results in an immediate advantage and widens the applicability, compared to hand calculations and zone-models. Further clarified, divides FDS the room geometry in thousands of cells (control volumes or mesh cells), where temperature, and other variables are calculated for each cell. [35] [34]

This implies, that an increase in number of fundamental parameters is required, which results in further calibration and validation is needed when applied in risk assessment. In addition to more significant setup effort, as well as longer computational time to conduct, even on a modern desktop PC. With the rapid development of computer power, it is however expected that field modelling will become more available and less time-consuming to conduct, even when applied to larger developments. [35]

An advantage when using FDS to evaluate consequences of fire scenarios is that they provide a quantitative estimate, which is based on a rationalised method. It should however be added, that results that CFD models provides must be viewed as “reasonable estimates of physical conditions”, and not regarded as an expression of facts. [34]

3.4.5. Egress simulation for RSET analysis

There are many factors effecting the evacuation time from a building, such as; human and human perception of risk, building factors and fire related factors. Subsequently, these must therefore be taken into account when assessing the "Required safe egress time".

SFPEs *Handbook of Fire Protection Engineering*, describes various studies that undertakes the variant behaviour of humans in evacuation scenarios. Among these, such as studies conducted in a health centre, where the results indicated that the behaviour of the first occupants that could see the fire, had major effect of the outcome of the egress scenario. Further research on the subject of human perception of risk also indicated that the majority of occupants tend to behave in a way that they deemed "best for the society", for instance calling for help, and try to extinguish the fire, while "panic" is more infrequently in groups [34]. Social influence seems to delay responses until a clear sign of threat appears, and is explained in the literature as *normative social influence*, and is described as peoples fear to stand out or make a fool of oneself. People in groups tries instead to gain information about the situation by observing each other, the so called *informational social influence*. [27]

Research that is interesting to consider in the study of high-rise office buildings, is the study conducted by Horiuchi, Muraozaki and Hokugo on an eight story high office buildings. Their research showed that persons engaged in either trying to extinguish the fire, saving or alerting others where most likely the employees of the buildings, while visitors mainly focused on evacuating. Behaviour pattern of feeling responsible for evacuating in the event of fire was also reinforced by evacuation scenarios in public buildings, such as museums, where visitors neglect responsible behaviours when the fire alarm activates, but instead expects to be alerted when the situation is serious. [34]

Research on fire related factors from USA and England, concerning evacuation when subjected to smoke, shows that only some people turns around and starts evacuating when the visibility is greater than 10 m (3 % of 322 people and 6 % of 1316 people in the respective study of USA and England). It was not until the visibility was around 3 m that the majority (91 and 76.4%) of people began to turn around and evacuate. [34]

Human behaviour in an evacuation scenario can be simulated by egress simulator software, using algorithms that takes into account research reinforced behaviour patterns. [34] Pathfinder is an egress simulator that is used in many studies concerning high-rise and complex buildings, such as research conducted by *Haliti* [27] and *Dominguez* [36], and is widely applied in risk assessment works. The evaluation of the RSET criteria shall in this study further be based on egress simulations conducted in Pathfinder.

Pathfinder is an evacuation simulator which uses techniques of modern computing technology in order to simulate the movement of people, in contrast to flow – and cell based models. The program consists of three parts: a graphical user interface, a simulation model and a viewing model in 3D. Pathfinder provides to different modes that determined the algorithm of each individual, namely SFPE mode and Steering mode. [34]

SFPE mode is based on the principles described in SFPEs *Handbook of Fire Protection Engineering*, and is a stream-model where the walking speed is determined by the occupant density of the room, and flow speed through doors by the door width. The steering mode is based on inverse control behaviour, and opens up for more complex, and situation dependent behaviour. Further clarified, this means that unlike the SFPE model of linear escape route, people evacuating using the Steering model can choose different directions when disorder and congestion situation occurs in the simulation. This is more in line with actual escape behaviour in the event of an emergency, and therefore be further used when evaluating the RSET criteria value in Pathfinder. [34] [37]

4. Methods

This chapter presents the general assumptions made to establish the foundation for the subsequent high-rise building designs. Furthermore, detailed description of fire safety provisions found in the Swedish and Australian building code for high-rise buildings are also presented. At the end of this chapter the structure of the risk assessment, including the fire and egress modelling methods, are discussed.

Based on the theoretical study in chapter three, and the methodology presented in the previously chapter, the aim of this section is to further clarify the use of each method in this thesis. The emphasis in this section is to review each country building code, as well as to identify important sections containing either legislating, or prescriptive demands connected to the fire safety designs of high-rise buildings. The framework of the risk assessment, earlier mentioned in section *3.4. Risk assessment*, is also further clarified and presented with corresponding framework.

4.1. General assumptions

When designing two theoretical high-rise office buildings in accordance with prescripted solutions, some general assumptions must be made, to provide the framework for subsequent fire safety design. These general assumptions will provide a basis for interpreting building regulation requirements and prescriptive solutions into design solutions. Following assumptions are made for the high-rise buildings considered in this study:

1. The building is located within a metropolitan fire department jurisdiction, within 5 km driving distance of a fire station permanently manned by professional (i.e. not volunteer) fire fighters.
2. The building has 16 floors, with each floor having a slab to slab height of 3 m. Depending on the required slab thickness, the effective height of the building can be assumed to be around 50 m.
3. The building is assumed to only facilitate office occupation.
4. Every storey is assumed to be designed in the same way, various designed floor configuration is not included.
5. The building is considered to have a distance to nearest adjoining building, greater than 10 m.
6. None of the buildings considered in this study will have basement areas incorporated. Neither will this study include car parking levels to either high-rise design.

4.2. Model case study

This section provides information regarding the geometric configuration of each high-rise building, as well as the structural design used in this study to facilitate the office occupations.

There are many different load-bearing systems to consider when designing a high-rise building, depending on factors such as height, location and the design of the high-rise building. To provide a basis for converting prescriptive requirements into design specifics, the structural system of each high-rise considered in this study must be provided with an appropriated load bearing system. [38]

In this study shear walls in a core supported structural system will be used. This means that shear walls are surrounding elevators and stair shafts to create a central core of the building. This system alone can be used to create buildings up to 60 floors, and with possible additions such as *Outrigger structures* and *Belt walls* to reduce lateral displacements and rotation, buildings can reach up to 150 floors. [38] An illustration of a core- and outrigger system applied on a building is presented in Figure 8.

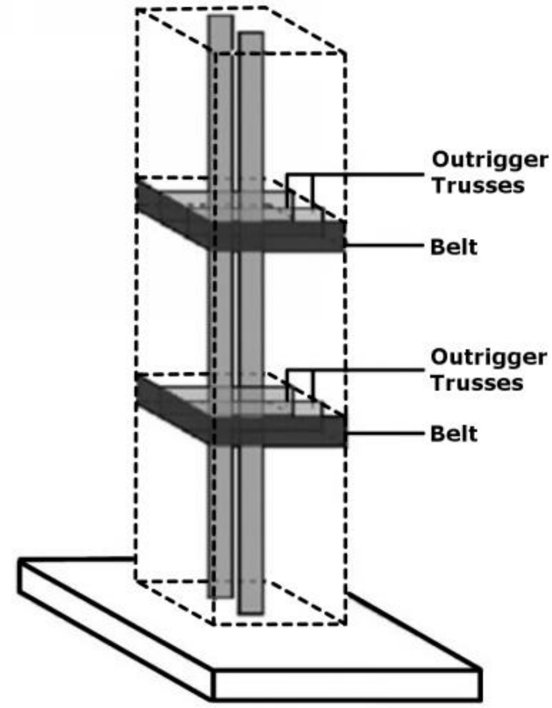


Figure 8 - Illustration of a core- and outrigger systems applied on a high-rise building *[38]*

This load bearing system is one of the most common approaches today when constructing high-rise buildings, due to its more possible application to enable higher constructions. It is therefore the load-bearing system that becomes to most interesting to consider, as *Shear walls* and *Rigid frames* load bearing systems both reaches their respective limits at 40 stories and 30 stories (for steel, for concrete around 20). Other load bearing systems such as *Braced frames* and *Shear trusses*, might also been used to investigate architectural strains, but due to their more complex nature, it becomes beyond the scope of this study. [38]

To provide a basis for converting prescriptive solutions into design configurations, this study will further only focus on the use of a rectangular shaped core structural load bearing system. Every floor plan will be represented by plate shapes, in accordance with prescriptive areal- or other design altering requirements, giving each high-rise different dimensions.

The core system in each high-rise building shall, as mentioned above, enclose the egress components of the building (stairs and elevators). Figure 9 presents the structural load bearing system, as well as the general assumptions of section *4.1. General assumptions*, constituting the framework of this study.

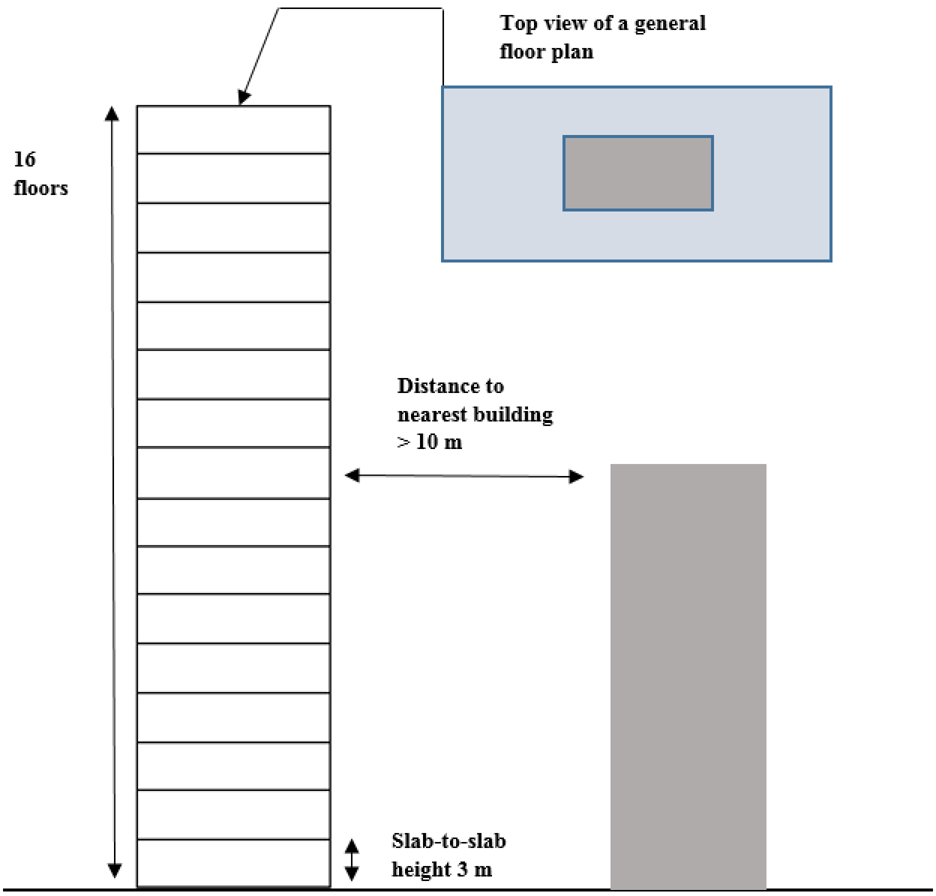


Figure 9 - Schematic representation of the basic high-rise office building for each configuration, in addition to general assumptions for this study [Figure by Emmanuel Eriksson]

4.3. Fire safety design

Following sections will present the method used to comply with the Swedish and Australian building regulations, as well as method to convert prescripted solutions into design features, used to design the subsequent high-rise buildings.

4.3.1. Sweden

The theoretical high-rise office building with 16 floors must be designed in accordance with the Swedish legislation, and meet mandatory and general requirement stated in BBR and EKS [8] [39].

To design a theoretical high-rise building in accordance to Swedish building regulation, prescripted building solutions that effects the design must be included. Following parts will only include important parameters in the BBR affecting the building design configuration. General assumption previously stated in section 4.1., is also taken into account. The design layout produced by the method presented in this study, and full fire safety concept is given in respective *Appendix A-B.*

From EKS [39], the structural stability required from a building in the event of fire is based on the level of risk of personnel injury, if a structural element of the building collapses during a fire. Depending on the level of risk, different building parts are given a corresponding fire safety class, see Table 4.

Table 4 - Fire safety class depending on the risk of personal injury due to structural collapse *[39]*

FIRE SAFETY CLASS	RISK OF PERSONAL INJURY FOLLOWING COLLAPSE OF STRUCTURAL ELEMENT
1.	Insignificant
2.	Slight
3.	Moderate
4.	Large
5.	Very large

To design the building in accordance to the classifications in Table 4, building components shall be constructed to ensure, that collapse does not occur during the period specified in Table 5. The specific fire load is referred and described in the European standard SS- EN 13501- 2. The first column ($f \leq 800$ MJ/m^2) can be applied without any special investigation for building uses, such as; residential and commercial properties, schools, hotels, and offices.

Table 5 - Fire safety class and correlated structural element requirement depending on assumed fire load *[39]*

FIRE SAFETY CLASS	FIRE RESISTANCE CLASS AT FIRE LOAD (MJ/m^2)		
	$f \leq 800$ MJ/m^2	$f \leq 1600$ MJ/m^2	$f > 1600$ MJ/m^2
1.	0	0	0
2.	R15	R15	R15
3.	R30 (R15*)	R30 (R15*)	R30 (R15*)
4.	R60	R120 (R90*)	R180 (R120*)
5.	R90 (R60*)	R180 (R120*)	R240 (R180*)

*Upon the installation of an automatic water sprinkler system in accordance to relevant section in the BBR [8]

The performance requirements 2-5 in *Building code study*, section 3.3.1, are fulfilled by complying with the general recommendations stated in section 5:2-5:7 in the BBR. These sections contain mandatory provisions in forms of methods and solutions (prescripted) depending on the occupational- and building class. Defining these classes are the initial step towards developing a fire safety design. Because the theoretical high-rise building in this study only contains office areas, the building will hence be placed as occupational class 1 according to BBR [8]:

> **5:211 Occupational class 1 – Industry, office, etc.**
> The occupational class includes spaces where people are expected to have good knowledge of their surroundings, who are able to make their way to safety, and are expected to be awake.
> ***General recommendation***
> Example of premises subjected to this regulation is industrial buildings, storages and offices. (Translated from Swedish to English)

The abilities described in 5:211 occupational class 1 are assumed applicable to all persons within this occupational class. The building class is determined by the subsequent section of the BBR [8]:

5:22 Building class
Buildings shall be divided in various building classes, Br, depending on the need for protection.

- *Buildings with a high level of protection needs, shall be designed in accordance to building class Br1.*

When assessing the need for protection, consideration shall be given to likelihood of fire, potential consequences of a fire and the complexity of the building.

General recommendation
Classification should consider factors related to evacuation and the consequence of the collapse of the building.
Buildings with three, or more levels [up to sixteen], should be designed in accordance to building class Br1. (Translated from Swedish to English)

The building class Br1 described in 5:22 Building class is applicable to the Swedish high-rise considered in this study. After the occupational- and buildings class been defined, the following chapters in BBR deals with material components, classes and building concepts. Depending on the specifics of the occupational- and building class, fire safety requirements varies. To incorporate these requirements into a theoretical high-rise office construction, the following systematically method of interpreting the prescripted requirements shall be used.

1. **Identification of requirement**: Identify prescriptive requirement, is the prescripted requirement aimed at the specific building considered in this study based on either the occupational class, building class, total height of the building, or a combination.
2. **Interpretation of requirement**: Identification of prescripted requirement. Identification of the minimum requirement proposed to be deemed acceptable by the regulation.
3. **Design altering application**: If the prescripted solution requires the design to be altered, this must be included in Building design layout in *Appendix A*, otherwise next step of this method.
4. **Application of requirement**: Application of prescripted solution in the respective fire safety concept in *Appendix B-C*.

In order to facilitate a better understanding of the method applied in this study, Figure 10 provides an example derived from section 5:56 *Protection from extensive fire spread* from BBR [8], with how the method shall be conducted described.

5:56 *Protection against extensive fire spread*

5:561 General 1)

Large buildings must be designed so that extensive spread of fire within buildings shall be limited.
(BFS 2011:26).

General advice.
2) To limit extensive spread of fire in large buildings these buildings should be designed with fire compartments, fire sections, fire technical installations or a combination of these. The assessment of the risk regarding extensive spread of fire should be taken into count be the specific fire load capacity of the building.
Example on a suitable design is by dividing the building in fire compartment in highest 1 250 m^2 or in fire sections in accordance with Table 5:561. If the fire load capacity is at highest 250 MJ/m^2 the space can be designed without any particular protection against extensive fire spread.

Table 5:561 Fire sectioning of large buildings

Protection system	**Maximum size (net area*) on fire section in regards of fire load capacity f (MJ/m^2)**	
	f ≤ 800	**f > 800**
No automatic fire alarm or automatic fire extinguishing system	2 500 m^2 2), 3), 4)	1 250 m^2
Automatic fire alarm	5 000 m^2	2 500 m^2
Automatic sprinkler system	Unlimited	Unlimited

* Net area is decided from all areas that is part of the fire compartmental or fire section boundaries. Horizontal sectioning boundaries can be performed as fire compartmental boundaries with corresponding level in accordance to 5:562 but without requirements regarding mechanical impact (M).
(MFS 2011:26)

Figure 10 - extract of a prescriptive solution from the BBR, translated into English. The numbers are related to the method presented in this section *[8]*

The first step 1) *Identification of requirement* disclosures the application of the requirement. As interpreted by the section *5:561 General*, the prescripted solution must be applied in all “large buildings” that falls within the size requirement.

Step 2) *Interpretation of requirement* indicates the *General advice* (prescripted solution). The intent behind the solution is described here, and a reference towards the Table below is presented where the prescripted values and minimum requirements is presented.

Interpreting the Table in step 3) *Design altering application*, the maximum size of a fire section is regulated depending on both fire load capacity, and the protection system. As the previous part of this section presented the value of fire load capacity of an office occupancy to 800 MJ/m^2, the minimum requirement is here that the maximum area of a fire section can reach up to 2 500 m^2. The maximum area of a fire section can only be 5 000 m^2 or unlimited, if another prescriptive solution requires the application of either an automatic fire alarm or automatic sprinkler system. This alters the design configuration of each floor level on the Swedish high-rise office building, by implementing an area limiting requirement.

Step 4) *Application of requirements*, indicates that this prescriptive requirement must be taken into account in the fire safety concept of the Swedish high-rise building.

This systematically review of the Swedish building regulation will result in the identification of all related fire safety features that must be complied with to meet the legislative requirements, and be deemed acceptable in terms of societal norms.

4.3.2. Australia

The building regulation in Australia is divided in sections, where each section of the BCA provides its own set of performance requirement, and prescriptive solutions. The performance requirements regulating the fire safety design, can be found in following sections in the BCA:

1. *Section C – Fire Resistance*
2. *Section D – Access and Egress*
3. *Section E – Services and Equipment*

The Australian high-rise building will meet the functional requirements from these section, by complying with the prescripted provisions described in the respective chapters. As identified in the theoretical study in section 3.3., the prescripted solutions from the BCA varies depending on building types and occupations, earlier in this report referred to as *Building Class*- and *Building Type*. Similarly as the Swedish high-rise, defining these are the initial step towards develop a fire safety design. As the theoretical high-rise building in this study only contains office occupations, the building will hence be placed in occupational class 5 as described in BCA:

> **Class 5**
>
> Class 5 buildings include: professional chambers or suites, lawyers offices, government offices, advertising agencies and accountants offices. [22]

From the BCA volume 1, following descriptions is given for a Class 5 occupancy; *an office building used for professional or commercial purposes, excluding buildings of Class 6 (Shops), 7 (carpark or storage), 8 (laboratory or building with handicraft or process for production) , or 9 (building of a public nature such as assembly and health-care building).* [4] Since the building solely will be used for office occupancy, the building is considered as a sole occupancy class 5 building.

The following step is to define the building type parameter based on the building use and rise in storeys. For the specifics of the building considered in this study, the building is classified in accordance to the BCA as a Type A construction, by following Table 6:

Table 6 - Type of construction required *[4]*

Rise in storeys	Class of building 2, 3, 9	5, 6, 7, 8
4 or more	Type A	Type A
3	Type A	Type B
2	Type B	Type C
1	Type C	Type C

(Adapted from the BCA)

Based on these defining parameters, and the respective height of the building, prescriptive measurements found in the BCA will serve to comply and satisfy the performance requirements.

It must also be mentioned that Australian regulation use a different material description format, then the European code incorporated within the Swedish regulation. Fire-resistance level (FRL), is only used in prescriptive measurements in the BCA for building elements, and is determined by conducting Standard tests on material prototypes in accordance to AS 1530.4. For further clarification might the BCA require an element to have an FRL of 120/ 60/ 30, this corresponds into that the element must maintain, when tested in accordance with AS 1530.4 [22]:

- *A structural adequacy for a period of 120 minutes;*
- *Integrity for a period of 60 minutes; and*
- *Insulation for a period of 30 minutes.*

After the occupational- and buildings type been defined, the subsequent chapters in BCA deals with material components, classes and building concepts. Building elements are given fire classes in order to easily read which properties the building elements have in the event of fire.

Depending on the specifics of the occupational- and building type, fire safety requirements varies. To incorporate these requirements and design a theoretical high-rise building in accordance to Australian building regulation, prescriptive solutions shaping the building must be identified and applied on the construction. The same method of identifying design configuring requirements, which was described in previous chapters for the Swedish regulation, will be used in this section. General assumption previously stated in section 4.1. *General assumptions* and 4.2. *Model case study*, will be taken into account. The design layout and fire safety concept is given in respective *Appendix A*, *Appendix C.*

In order to facilitate a better understanding of the method applied in this study, Figure 11 provides an example derived from section C2.2 *General floor area and volume limitations* from BCA volume 1, with how the method shall be conducted described.

1) **C2.2 General floor area and volume limitations**

(a) The size of any *fire compartment* or *atrium* in a Class 5, 6, 7, 8, or 9 building must not exceed the relevant maximum *floor area* nor the relevant maximum volume set out in Table **C2.2** and **C2.5** except as permitted in **C2.3**. 2)

(b) A part of a building which contains only heating, ventilating, or lift equipment, water tanks, or similar service units is not counted in the *floor area* or volume of a *fire compartment* or *atrium* if it is situated at the top of the building.

(c) In a building containing an *atrium*, the part of the *atrium well* bounded by the perimeter of the openings in the floors and extending from the level of the first floor above the *atrium* floor to the roof covering is not counted in the volume of the *atrium* for the purposes of this clause.

Table C2.2 MAXIMUM SIZE OF FIRE COMPARTMENTS OR ATRIA

	Classification		**Type of construction of building**			
			Type A		**Type B**	**Type C**
2)	5, 9b or 9c *aged care building*	Max floor area- Max volume	8 000 m^2 48 000 m^3	3), 4)	5 500 m^2 33 000 m^3	3 000 m^2 18 000 m^3
	6, 7, 8, or 9a (except for patient care areas)	Max floor area- Max volume	5 000 m^2 30 000 m^3		3 500 m^2 21 000 m^3	2 000 m^2 12 000 m^3
	Note: See **C2.5** for maximum size compartments in *patient care areas* in Class 9a *health care buildings*					

Figure 11 - Extract of a prescriptive solution from the BCA. The numbers are related to the method presented in this section *[4]*

From the primary step 1) *Identification of requirement*, it can be noticed that this section is required to be satisfied by buildings with Class 5 occupancy. Step 2) indicates the *General advice* (prescripted solution), here the intent is described with a reference towards the prescriptive solution in Table C2.2.

Step 3) *Design altering application*, by interpreting the Table the maximum area and volume of a fire compartment is regulated depending on the building type and building class. The minimum requirement is here that the maximum area of a fire section can reach up to 8 000 m^2 or 48 000 m^3. This alters the design configuration of each floor level on the Australian high-rise office building, by implementing an area limiting requirement.

Step 4) *Application of requirements*, indicated only that this prescriptive requirement must be taken into account in the fire safety concept of the Australian high-rise building.

Similarly, this systematically review of the Australian building regulation will result in the identification of all related fire safety features that must be complied with, to meet the legislative requirements, and be deemed acceptable in terms of societal norms.

The theoretical high-rise buildings made in accordance with the design configuring requirements in the BBR and BCA, presented in *Appendix A*, shall further in this study represent its respective countries required level of fire safety in the subsequent risk assessment. Compliance with the performance requirement through prescriptive solutions is presented in corresponding fire safety concept in *Appendix B-C*.

4.4. Risk assessment

The study concerning the inherent fire safety in legislating requirements for high-rise buildings, will be analysed with the use of scenario based risk assessment. The risk assessment process earlier mentioned in chapter 3.4. *Risk assessment*, will be further outlined in this section. A summary of the process is demonstrated in Figure 12, where the various elements that will be utilised are presented. These elements will be described in more detail in sub-sections below, and including how they are being implemented in the study of fire safety in high-rise buildings.

The risk analysis conducted is presented in *Appendix D*, with corresponding assessment part presented in section 5. *Results* in this report.

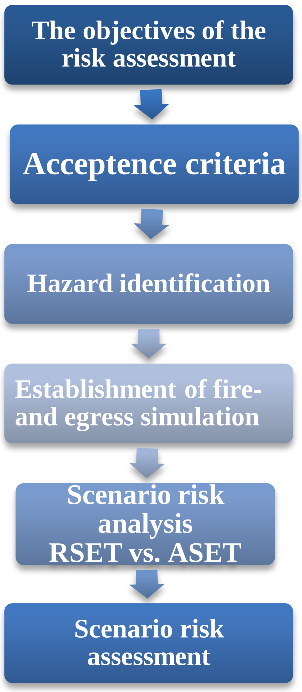


Figure 12 - Schematic process of the risk assessment used in this study [Figure by Emmanuel Eriksson]

The basis of the risk assessment, will foremost be the various dissimilarities in building design configuration, between the Swedish and Australian building regulations. Secondly the design configurations, embodied in a hypothetical design in accordance to respective countries prescriptive requirements. This shall enable the use of CFD and egress simulations to test the various design configurations towards their level of fire safety. The performance of the two theoretically designed high-rise buildings in each CFD and egress simulation, towards the risk criteria, will form the ground for further assessment in this study.

4.4.1. Risk assessment objectives

When conducting a risk assessment, it is important that the project planner establishes goals in forms of objectives, for which the analysis is to be carried out. In the fields of fire safety engineering, the objectives are normally to evaluate if the fire safety design satisfies the legislating requirements. As this study aims at disclosing the level of safety incorporated within building regulatory provisions, towards high-rise buildings, following objectives will be used in the risk analysis:

1. To evaluate which building regulation provides the highest level of safety for occupants, from injury due to fire.
2. Evaluate the Criteria of Life Safety provisions in each high-rise office building

These objectives are broadly in line with the objective set out in this study, in additions to some BCA objectives found in the guide to volume 1. The assessment of which building regulation that meets the objectives best, shall be based on the performance of each high-rise towards the risk criteria.

4.4.2. Risk criteria

The design objectives of the risk assessment presented above must be converted into accept criteria, which in engineering terms are expressed in measurable values. The use of CFD and egress simulation requires proper metrics, which can document the results in a way that facilitates, and guide decision making regarding the satisfactory of the objectives. Since the assessment will be based on the simulated performance of the high-rise designs, the risk analysis requires criteria that is possible to evaluate in the CFD/simulator tools used in this study. Since the objectives are specifications regarding the health of building occupants during the event of fire, the risk criteria must be defined as such, that each simulation provides results of the environment, and its "expected" effect towards occupants.

The acceptance criteria used in this study will therefore use *Tenability conditions*, as specified in Table 7, to estimate the performance of each high-rise building. By estimating the time where a scenario reaches one of these tenability conditions, the robustness of each fire safety design can be evaluated.

Table 7 - Acceptance criteria for the current study *[19]*

Acceptance criteria	
Tenability conditions	
Criteria	**Objective**
1. Smoke level above floor	Lowest position 1.6 m + (room height (m) x 0.1).
2. Visibility 2 m above floor	10 m in areas > 100 m^2, or; 5 m in areas ≤ 100 m^2.
3. Heat radiation	Max 2.5 kW/m^2, or short heat radiation of max 10 kW/m^2.
4. Temperature	Max 80°C
5. Toxicity 2 m above floor	Carbon monoxide concentration (CO) < 2000 ppm. Carbon dioxide concentration (CO_2) < 5%. Oxygen concentration (O_2) > 15%.

The acceptance criteria used in this study, is based on the Swedish guidelines on analytical design of fire protection of buildings (BBRAD). Measuring the tenability conditions will give an estimate of how long the design configuration is able to provide safe accommodation for its occupants. This provides a time-frame for how long occupants will have to evacuate, before risk of fatality becomes extreme. This is referred to in the literature as the *Available Safe Egress Time* (ASET).

By employing the ASET factor in an egress simulation, and measuring the time for all occupants to evacuate *Required Safe Egress Time* (RSET), the simulation might provide one of two results.

1. Occupants are provided with means in the building design to safely evacuate the premises before it reaches any of the tenability conditions endangering them, and the building design is deemed as acceptable (RSET < ASET) or;
2. The required time for occupants to evacuate the premises, exceeds time until tenability conditions is considered dangerous, and the building design configuration is considered failing to provide safe accommodation for its occupants (RSET ≥ ASET).

Figure 13 illustrates the basic concept of ASET vs RSET, used in this study to assess if the prescriptive means can provide egress before hazardous conditions sets in. Important egress simulation parameters can also be noted, these are further discussed in subsequent section.

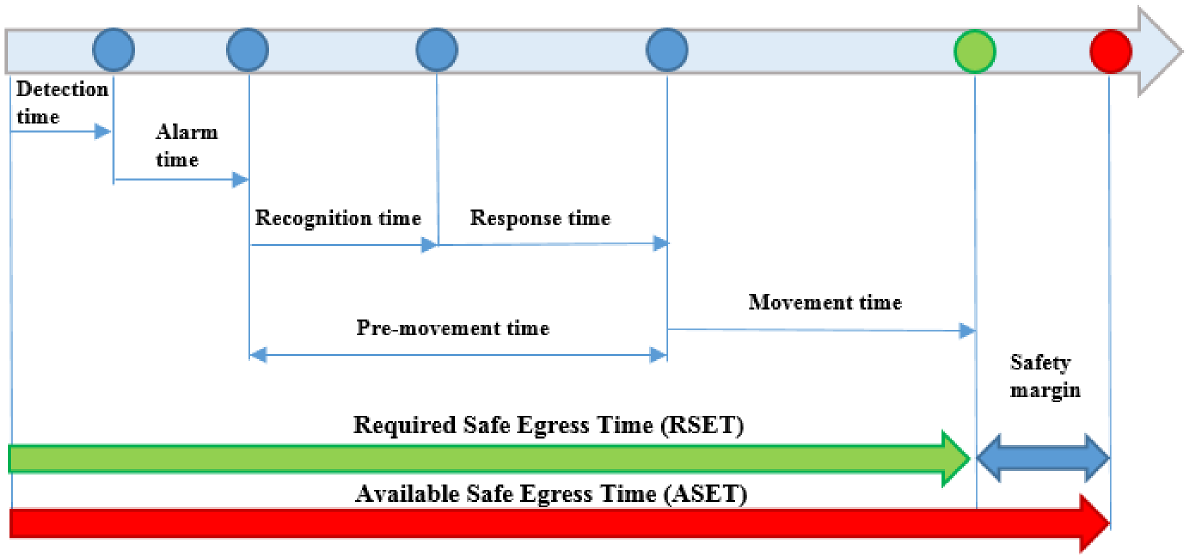


Figure 13 - Visualisation of the ASET vs. RSET method [Figure by Emmanuel Eriksson based on *[40]*]

Observed from Figure 13, the available evacuation time must be longer than the required evacuation time in all scenarios. The "Safety margin" in Figure 13, is a factor of safety between the RSET and ASET value, and must be taken into account when evaluating the robustness of the results. By taking the RSET and ASET factors into account, an egress simulation is able to provide insight if the fire safety design meets the outlined objectives.

4.4.3. Hazard identification

The hazard identification will provide the base for establishing the later fire and egress scenarios. It will require a systematically review of the fire-related hazards within the building, and their potential consequences. This will be done through extensive review of each fire safety concept given in *Appendix B-C*, as well as statistical research on the area of high-rise building fires. Possible fire scenarios that may occur must be derived, and chosen depending on the most relevant fire scenarios to analyse. The hazard identification process must provide and support the development of fire scenarios with important design characteristics in a way that provides the basis for defining worst credible scenarios.

By using worst credible scenarios as a means of subjecting a higher strain on a building, it enables the analysis to evaluate the robustness of the structure. This could eventually illustrate possible weaknesses and strengths from each building regulation, incorporated within each prescriptive solution.

4.4.4. Establishment of fire and egress scenarios

To evaluate the level of fire safety incorporated within the two reference buildings, each building must be assessed by determining the expected performance of its implemented sub-systems, and building configuration in the event of fire. The performance is linked to the safety the building provides its occupants.

For every building, it exists an infinite number of possible fire scenarios. Based on risk identification, the fire safety engineering process must find a correct number of scenarios constituting likely worst credible scenarios. Verification with scenario analysis should include a sensitivity analysis to identify variables that greatly affect the security level, including the egress simulation. Such variables should be treated conservatively. Examples of variables that can be included in the sensitivity analysis are fire effect, flame temperature, walking speed of escaping persons and the distribution of persons between different evacuation routes.

The selection of fire scenarios must be based on research regarding high-rise building fires, as well as the required fire scenarios specified in the Swedish guidelines on analytical design of fire protection of buildings (BBRAD). Foremost, gathering of statistical data will play an important part of establishing credible fire scenarios that shall measure the fire safety design of each high-rise. Statistics regarding high-rise building fires features, origin and cause will help creating the most credible scenarios, by implementing realistically worst-case characteristics. This will mitigate the risk of not predicting features such as; the most credible, and unfavourable location of the fire. Secondly, the adoption of the required fire scenarios specified in the BBRAD, shall be taken into account in this study. These scenarios are designed to examine and implement stress on the building, by applying a variation of worst-credible conditions that will subject the building to a likely worst strain. The following scenarios specified below, are based on the required scenarios detailed in the BBRAD [19]:

Scenario 1

Fire scenario 1 is characterised by a serious fire sequence, with fast development and high heat release rate, a likely worst-case scenario. Implemented technical protection systems may be assumed to function as intended, with the effect of these credited in the scenario.

Scenario 2

Fire scenario 2 is characterized by a fire in a space where there are usually no persons staying, but adjacent to a space that has many persons. Technical protection systems can be assumed to function as intended and the effect of these can be credited.

Scenario 3

Fire scenario 3 is characterized by a fire process that can be seen as a minor strain on the building's fire protection, but which develops while individual protection systems do not work as intended. The technical systems each separately should be made unavailable in the required fire scenario 3 are as follows:

i. *Automatic fire and evacuation alarm.*
ii. *Automatic extinguishing system.*
iii. *Automatic flue gas ventilation or other system for limiting fire and flue gas dispersion.*
iv. *Lifts used for evacuation.*

Consequential faults should be considered if the error means that multiple systems can be knocked out of an event, for example, if power supply falls or if control signals fail.

Each high-rise building considered in this study will be subjected to the fire scenarios specified above. These scenario descriptions will provide the frame, and in accordance with the risk identification and statistical gathering, create a more tailored scenarios risk analysis. In this sense, each scenario mentioned, constitute a framework for statistical gathering of fire scenario characteristics to influence, and create as mentioned earlier; the most credible worst-case scenarios.

The design fire scenarios will be based on the statistical gathering, on the subject of high-rise building fires and input from the building layout (see *Appendix A*). The design fire characteristics for each fire scenario, follows the Swedish guidelines on analytical design of fire protection of buildings (BBRAD), including parameters found in the literature review. Parameters given in Table 8 have been selected based on which presented the most conservative values, as part of the sensitivity analysis. The risk analysis process is presented in *Appendix D*. Table 8 presents the design fire characteristics used in each fire scenario above.

Table 8 - Design fire characteristics and values for each scenario *[19] [41]*

Parameter	Value	Description
Fire type	Flaming fire	This was chosen since smouldering fire most likely would have limited impact on other occupants in other floor levels.
Fuel load	800 MJ/m^2	Value based on the occupancy value used in the fire safety concept for each building examined in this study.
Fire growth	T-squared	A medium t-squared was recommended for the type of occupancy used in this study.
Fire growth rate	0.012 kW/s^2	Value recommended in the Swedish guidelines.
HRR control	Max 5 MW	See section about the effect of sprinkler systems below the Table. The HRR for scenario 3 is prescribed as max 2 MW in the guidelines.
Radiative fraction	0.3	Used value from the literature review.
Soot yield	0.1 g/g	For scenario 1 and 2, soot yield for scenario 3 is 0.06 g/g. Values recommended in the guidelines.
CO production	0.1 g/g	For scenario 1 and 2, CO production for scenario 3 is 0.06 g/g. Values recommended in the guidelines.
CO_2 production	2.5 g/g	For scenario 1-3, values recommended in the guidelines.
Heat of combustion	16 MJ/kg	Value recommended in the guidelines. Heat of combustion for scenario 3 is specified as 20 MJ/kg in the guidelines.

Values in Table 8 for soot yield, and CO/CO_2 for fire scenario 3 shall be used for scenario 1-2 if the presence of an automatic sprinkler system is within the enclosure. If the expected HRR control during a discharge of a sprinkler system is max 5 MW, the HRR value shall be max 5 MW for 1 minute after discharge, thereafter within 1 minute be reduced to 1/3 of the MW effect for the remainder of the simulation.

Establishment of egress simulation

The verification of the egress possibilities during fire will be examined by egress simulations, and will foremost be based on the maximum numbers of persons expected within the premises, as well as occupant characteristics. These values are both derived from the fire safety concept, for each high-rise building, presented in *Appendix B-C*. The assessment of egress safety during the event of fire, will be based on time between evacuation, and time until critical tenable condition arise (RSET vs ASET). The performance of the egress simulations will determine the level of safety incorporated within each high-rise building configuration.

When selecting the conditions for the simulation, the behaviour patterns, occupancy characteristics for the activity and the scenarios of the risk identification shall be included. The egress simulation must also be done in correlation with the fire scenarios presented earlier. This due to the impact the fire scenarios will have on the evacuation process. This is especially important where the evacuation process is affected by missing technology systems required (fire scenario 3), and where the location of the fire may block the primary evacuation route.

The occupancy description given in each regulation for office building occupants was presented in previous section of this chapter (see sections 4.3.1. and 4.3.2.). A more detailed explanation must however be presented to further conduct the egress simulations. These occupancy characteristics, included further assumptions regarding their behaviour state during fire, is given in Table 9.

Table 9 - Occupant characteristics used to establish evacuation behaviour for each high-rise building

Subject	Characteristics
State	The building occupants are assumed to be awake, as well as fully conscious.
Level of assistance required	Most occupants are assumed to be capable of self-evacuation from the building using the stairs. Where occupants with disability is taken into account, the building design configuration, as well as needed evacuation time shall be further assessed.
Familiarity	The building is expected to be the workplace for the occupants, and will therefore be assumed that the occupants knows the building well, and understand alarms and evacuation notes, as well as be able to locate the exit routes.
Emergency training	Occupants are assumed to have basic emergency training, and be able to locate the exits. Training regarding hand-held emergency equipment are not taking into account.

The RSET vs ASET method used in this study shall implement parameters given in the Swedish guidelines on analytical design of fire protection of buildings (BBRAD), in addition to parameters found in the literature study. The Required Safe Egress Time will in this study consist of following occupant movement parameters:

RSET = Cue period (P_c) + Response period (P_r) + Delay period (P_d) + Movement period (P_m)

The cue period (P_c) is explained as the time from ignition to a detection system detect the fire and alarms the occupants. This parameter is determined by the smoke alarm detection time and shall be obtained by the fire scenario simulations. The pre-movement time consists of the Response and Delay period, and is described as the time for occupants to perceive the conception of danger within the building, and determine to evacuate. These values differ depending on if occupants can see the fire or not, and are given in the BBRAD (see Table 10).

Table 10 - Establishment of occupant pre-movement parameter *[19]*

Parameter	Can the occupant see the fire	Pre-movement time (P_r+ P_d)
Office occupant	Yes	30 s
	No	1 minute

The pre-movement time for occupants observing the fire is considered reasonable, as the occupants will be familiar with the egress routes and can see the smoke. The open floor layout (see *Appendix A* for floor layout design for each high-rise building) will enable most of the floor occupants to see the smoke, triggering a faster decision-making process to evacuate. The movement period will be determined through egress simulations, using the egress simulator *Pathfinder* computer model, with movement parameters from BBRAD.

To iterate the use of the egress software, Pathfinder provides tools to build a 3D model of the building to be analysed. The exit system to be evaluated, and occupants are then added inside the modelled building. Evacuation is the simulated, with features that considers every person to act as an individual person, leading to that each simulated occupant follows a unique process of egress. [41]

The movement of each agent can be simulated in the model using two methods, either 1) the SFPE mode, and 2) Steering mode. SFPE mode uses the assumptions and calculations presented in the SFPE handbook of Fire Protection Engineering. Steering mode is based on Reynolds steering model, and is more dependent on collision avoidance and occupant interaction. [42] As mentioned earlier in section 3.4.5., this study will use the steering based model to simulate the occupant evacuation.

To be consistent with the guidance provided in the BBRAD, unimpeded walking speeds of the office occupants are implemented into the egress simulation, in accordance with the values provided (see Table 11).

Table 11 - Unimpeded walking speeds for Standard- and office occupants with disability *[19]*

Standard office occupants			**Occupant with disabilities**		
Mean (m/s)	Standard deviation (m/s)	Range (m/s)	Mean (m/s)	Standard deviation (m/s)	Range (m/s)
1.05	0.45	0.6-1.5	0.7	0.3	0.4-1.0

Both Swedish and Australian regulation has legislating requirements for emergency and firefighting lifts. Pathfinder support lifts operation in egress mode operations, and is based on guidelines in *Using Elevators in Fires*. As both building considered in this study has emergency elevators included in their fire safety concept, and the Swedish guidelines for analytical dimensions prescribes the use of emergency elevators in egress simulation, this feature will be further implemented in all egress simulations.

4.4.5. Risk analysis

The output from the respective fire and egress simulation will be used in conjunction with each other, for the subsequent assessment of the fire safety level in the building. This will be done by first combining the result from respective simulation. The following results from the fire scenarios, will give an estimated time until untenable conditions arise. This time interval will serve as the ASET criteria, later used in correlation with egress simulation results, serving as the RSET criteria. Figure 6 earlier presented in section 3.4. *Risk assessment,* illustrates the scenario based risk analysis procedure to this point in the risk assessment process.

The correlation of the results from respective simulation, must be illustrated in a way, which can be used to reach an assessment whether the objectives has been met, or not. This will be done by illustrating each simulation result within the same time interval graph. This will present a clear overview of both the required and available safe escape time for each respective scenario cluster. But most importantly, a clear presentation whether untenable condition will arrive before occupants can be assured safe egress.

4.4.6. Risk assessment

The assessment of the scenario based risk analysis results will be carried out on qualitatively approach, and be undertaken by discussion only. This is argued from that the complex quantitative approach of scenario based risk analysis, will emphasise results that will need no further clarification.

5. Computer simulation

This chapter will describe the different parts of the risk analysis conducted in this study, and serves as an intermediate chapter between the following risk analysis results, and previous method. This chapter goes foremost through the implementation of the Swedish high-rise building design into the simulation softwares, before the establishment of fire and egress simulations is presented.

Simplifications of the high-rise building design have been avoided as far as possible, to ensure consistence with the fire safety concepts and the prescriptive provisions. The geometry and simplifications regarding adapting the design, with the control volumes (mesh) of each program, is a necessity in order to implement the constructions into the scenario based analysis, and is further discussed in the following sections.

It must be mentioned in accordance with this section, that the same process described below for scenario 1 has been used for all other scenarios, but with various design alterations, such as placement of fire source, Heat release rate value, et.al. See *Appendix D – Risk analysis* for the full risk analysis process.

5.1. Pyrosim model solution

The Swedish high-rise office building comprises of 16 floors, and in accordance with the Swedish fire safety concepts, the floor area of each floor level have a dimensions of 62.5 m x 40 m x 3.17 m (length x width x height). To be consistent with modern office solutions, the minimum ceiling height is taken into account as the lower side of a suspended ceiling solution (2.5 m). The remaining height, in order to satisfy the slab to slab specification of 3 m, is assumed to be used for ventilation, water and electrical installations specified in the fire safety concepts.

To simplify and customise the design for the fire simulation software, as mentioned earlier, only one floor level is constructed in Pyrosim, with following dimensions of 62 m x 40 m x 3.17 m. The design is also simplified within the model, and shafts, staircases, elevators et.al, comprises only of open spaces not included in the simulations. All measurements on rooms, walls and such are made accordingly to the Swedish fire safety concept and building design, as specified in *Appendix A-B*, with wall and floor thickness to comply with the regulations. To facilitate better understanding of the simulations, the floor layout is divided into two sections (A and B), see Figure 14.

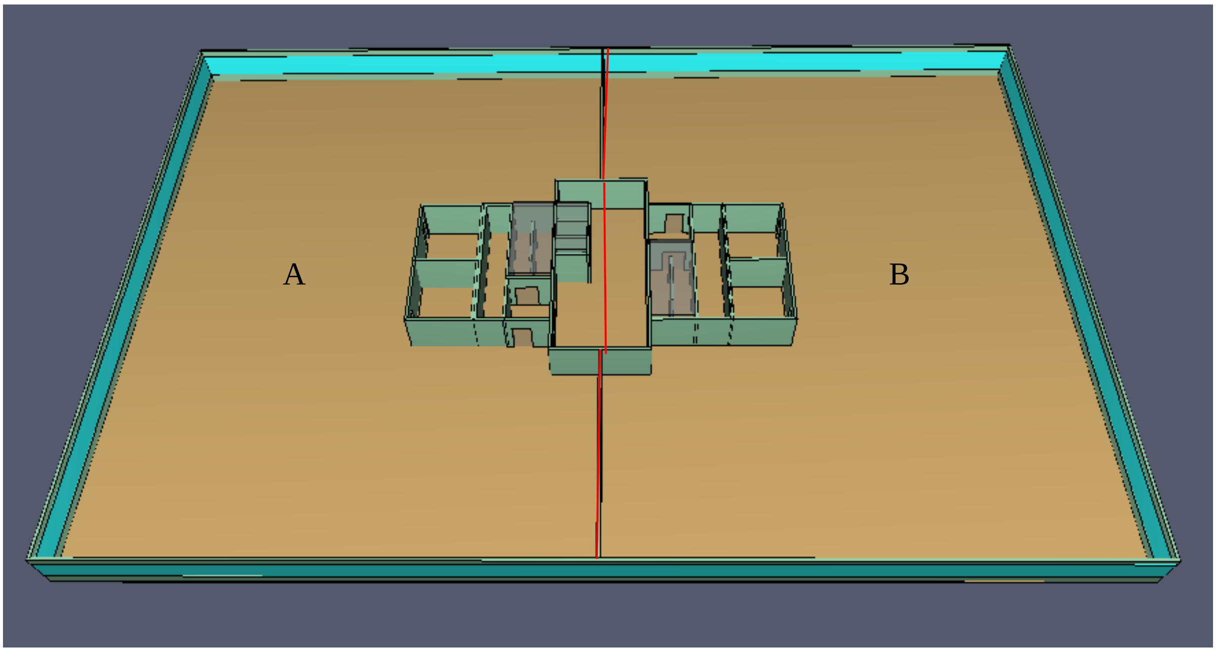


Figure 14- Swedish high-rise floor layout customised in Pyrosim

As Figure 14 shows, the suspended ceiling have not been taken into count in the fire simulation. A suspended ceiling can be modelled but have not been revised due to lack of time. This is a simplification of the design and is a source of error.

Section A is used to simulate the fire scenario, while section B is beyond fire compartmental boundaries and not included from the fire simulation (the red lines in Figure 14 indicated the border between section A and B). It is therefore further assumed, that the smoke will not venture from section A to B. This is due to both time and computer capacity saving reasons. Section A have a dimension of approximately 1 250 m^2 in the Swedish model.

From the *Hazard identification* in section 5, *Appendix D - Risk analysis*, it was concluded that the worst credible location for a fire to develop within the Swedish and Australian high-rise office buildings, was beyond the reach for fire department intervention (7^{th} floor or higher), inside the confined office areas (section A). The statistics were low regarding fire development in means of egresses in high-rise office buildings (4 %), compared other areas such as kitchens or cooking areas 31 %, but was taken into count to represent a worst case scenario. The leading cause of a fire inside high-rise office buildings, taking the specifics of each building into count, is due to faulty electrical components.

Considering these statistical characteristics from previous high-rise office fires, the design of scenario 1 in BBRAD was in accordance to the specifics of the Swedish high-rise. The performance of the Swedish high-rise was evaluated on its performance from following fire scenario design presented, derived from section 10.1 in the risk analysis (*Appendix D*):

"*In this scenario [scenario 1] the fire has started on the 8th floor, located in the left-wing office area, adjacent to the egress route into the fire safe passage, part of the Tr1 staircase configuration [see Figure 15]. The fire blocks the egress path into the Tr1 staircase for nearby occupants. The fire scenario is assumed to originate from a faulty electrical component on an office desk. The fire is assumed to spread along the office desk surface, with dimension 2 m x 2 m. The faulty electrical component is assumed to ignite wood materials (red oak $CH_{1.7}O_{0.72}N$). The scenario is described as a serious fire sequence, with fast development and high heat release rate.* "

Figure 15 shows a cut-out from the Pyrosim model of scenario 1. As illustrated in the cut-out the fire surface have been placed at a distance that is meant to simulate the blockage of the entrance to the Tr1 staircase and communication area. The occupants must therefore either venture over the fire compartmental boundaries (illustrated as red dotted lines), or into the upper entrance of the communication area, the green marks illustrates the various means of egress. The distance to the nearest smoke detector is conservatively placed as far as possible from the fire origin (10 m).

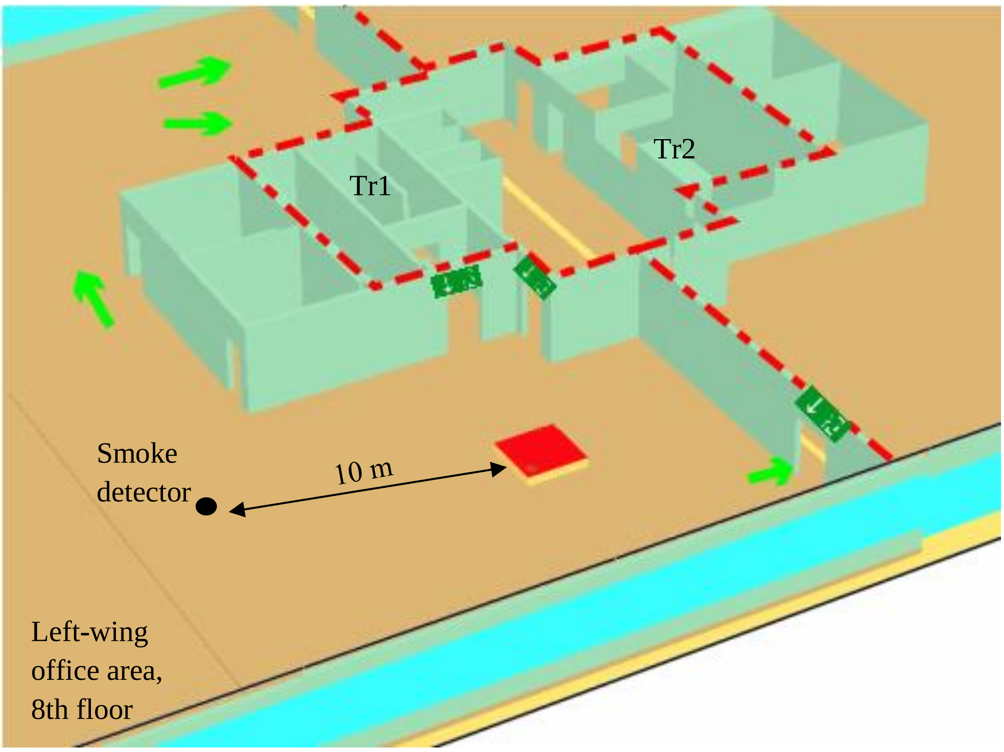


Figure 15 - Cut-out of scenario 1 from the Swedish high-rise building, modelled in Pyrosim

Data derived from BBRAD is selected and used as input for the office desk fire, used to simulate scenario 1, and is presented in Table 8 in chapter 4 in this report. The burner used to simulate the fire has the dimension 2 m x 2 m and is located on a surface 0.5 m above the floor. A real office fire scenario would include the fire spread and pyrolysis of a number of materials, not solely the cellulose material of "Red Oak". Pyrosim is however limited to only one reaction, and is a simplification of the fire scenario design, taking into consideration as an error source.

Mesh sizes is one of the most important parameters to consider when conducting a fire simulation in FDS/Pyrosim, and adapting the cells to fit the model can be problematic. It can therefore be necessary to use coarser or finer meshes (larger or smaller cell dimensions) in determined regions inside the model, in order to ensure the quality of the simulation results. When fluid transfers from a finer to coarser mesh size some of the information regarding the fluid property (example temperature, velocity, et.al.) is lost.

Due to capacity and time reducing reasons, it becomes desirable to choose as course as possible mesh resolution. At the same time it is desirable to obtain as realistic and accurate results as possible. A fine mesh resolution is therefore used in the fire area, as well as adjoining areas, with coarser mesh resolution further away from the fire area.

The mesh resolution chosen for scenario 1 in the Swedish high-rise building is presented in Figure 16. Figure 16 illustrates a horizontal view of the mesh resolution in the Pyrosim model. Mesh 1, 2 and 3 represent areas with different mesh resolution, ranging from 1 being the finest and 3 the courses size. Table 12 present the cell sizes used in each mesh category from Figure 16. The validation and quality assessment regarding the used cell size for each scenario is presented in *Appendix D – Risk assessment.*

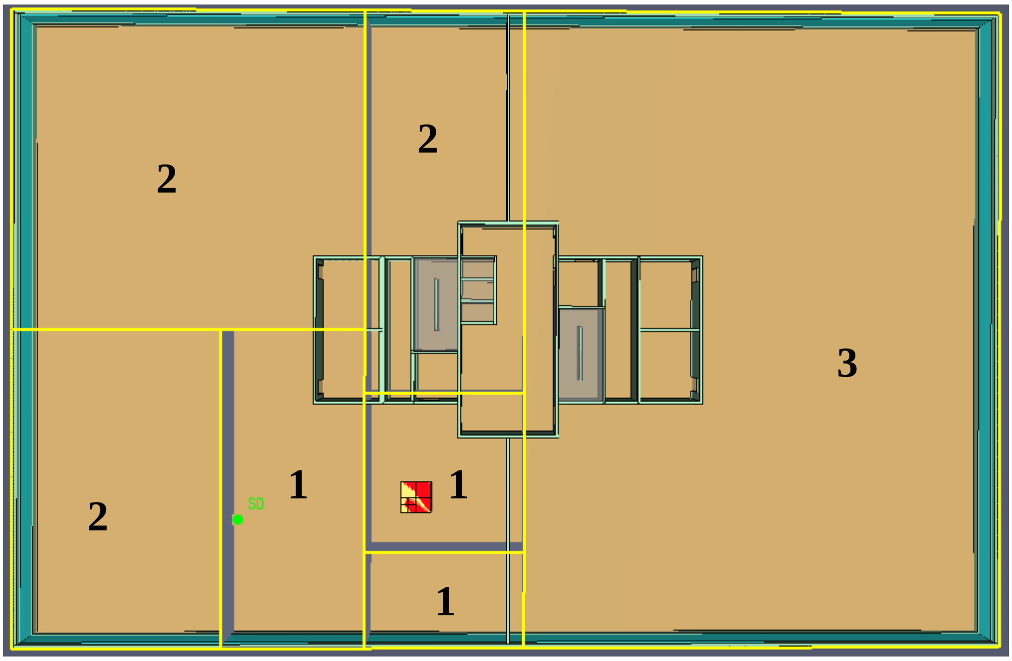


Figure 16 - Horizontal cut-out from the Pyrosim model of scenario 1 for the Swedish high-rise, illustrating the various meshes used as well as category of resolution (1-3) in accordance to Table 12.

Table 12 - Mesh resolution of scenario 1 for the Swedish high-rise

Simulation ID	**Cell size (m)**			**Description of cell resolution**		
	Cat. 1	Cat. 2	Cat. 3	Cat.1	Cat. 2	Cat. 3
Scenario 1 - SWEDEN	0.1	0.2	1.0	Fine	Medium	Coarse

As the risk criteria used in this study is defined in terms of tenability criteria (see Table 7 in section 4.4. in this report) the measurements used in Pyrosim must be able to measure and present data on each criteria. Following instruments available in Pyrosim have been used to estimate the various tenability criteria used to determine the ASET value.

- Thermocouples to measure temperature
- Layer zoning device to measure the height up to the smoke layer
- Animated Isosurface on areas where visibility is reduced to 10 m
- Animated Isosurface on areas where temperature have reached 80 °C
- Smoke detector to measure the detection time for evacuation simulations

In addition to these instruments have the model included the use of different “slice-files” (SLCF) to measure and visualize both the fluid pattern and distribution on following risk criteria:

- CO (Volume fraction)
- CO_2 (Volume fraction)
- Temperature
- Visibility
- SOOT (Visibility and Mass fraction)
- O_2 (Volume fraction)

The exact location on each measurement device and instrument used for all fire simulation is presented their respective FDS-code scripts in *Appendix F*.

The results derived from the fire simulation for scenario 1 is presented with the remainder of the fire and egress scenarios, in the following chapter 6. *Results*.

5.2. Pathfinder model solution

The geometry of the Swedish high-rise in Pathfinder, is similar to the model in Pyrosim, simplified to 62 m x 40 m. The model in Pathfinder includes however, in comparison to the Pyrosim model, all floors (16 floors). The total high-rise is also modelled with maximum number of occupants in accordance with specifications in the Swedish fire safety concept. The typical floor layout of the Swedish high-rise building, as modelled in Pathfinder is presented in Figure 17, with the full vertical model of the high-rise in following Figure 18.

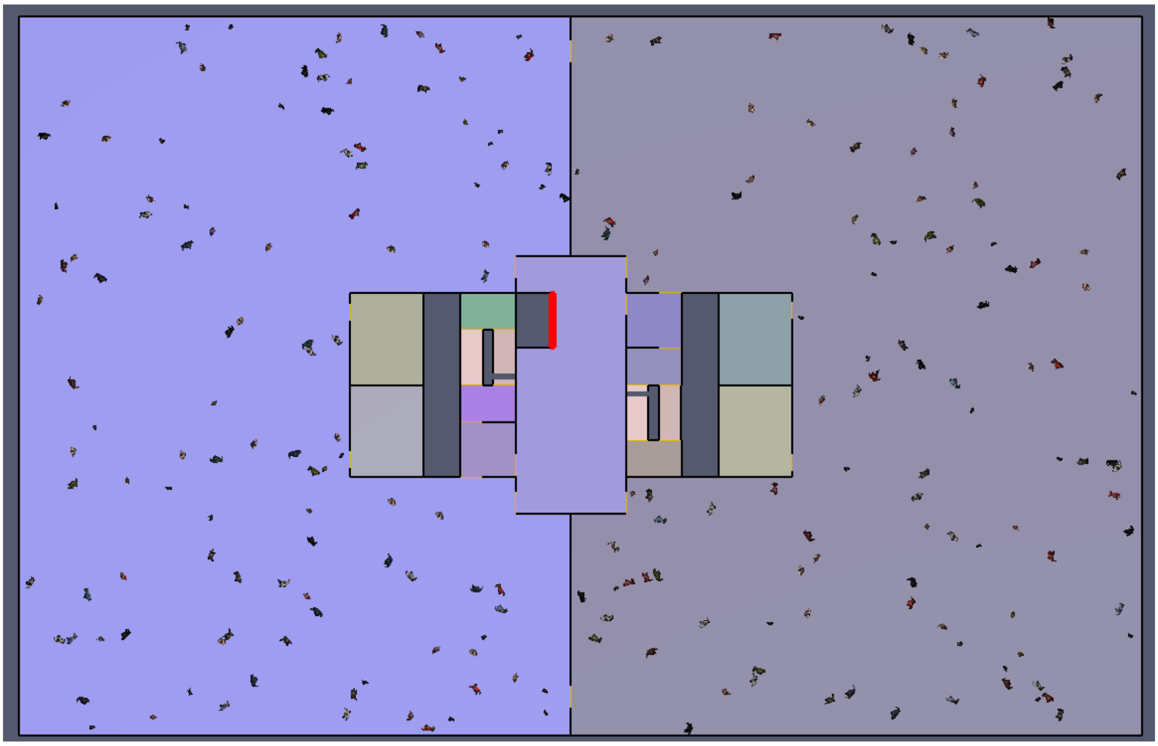


Figure 17 - Horizontal view of a typical floor layout design of the Swedish high-rise building, modelled in Pathfinder. The dots is modelled occupants

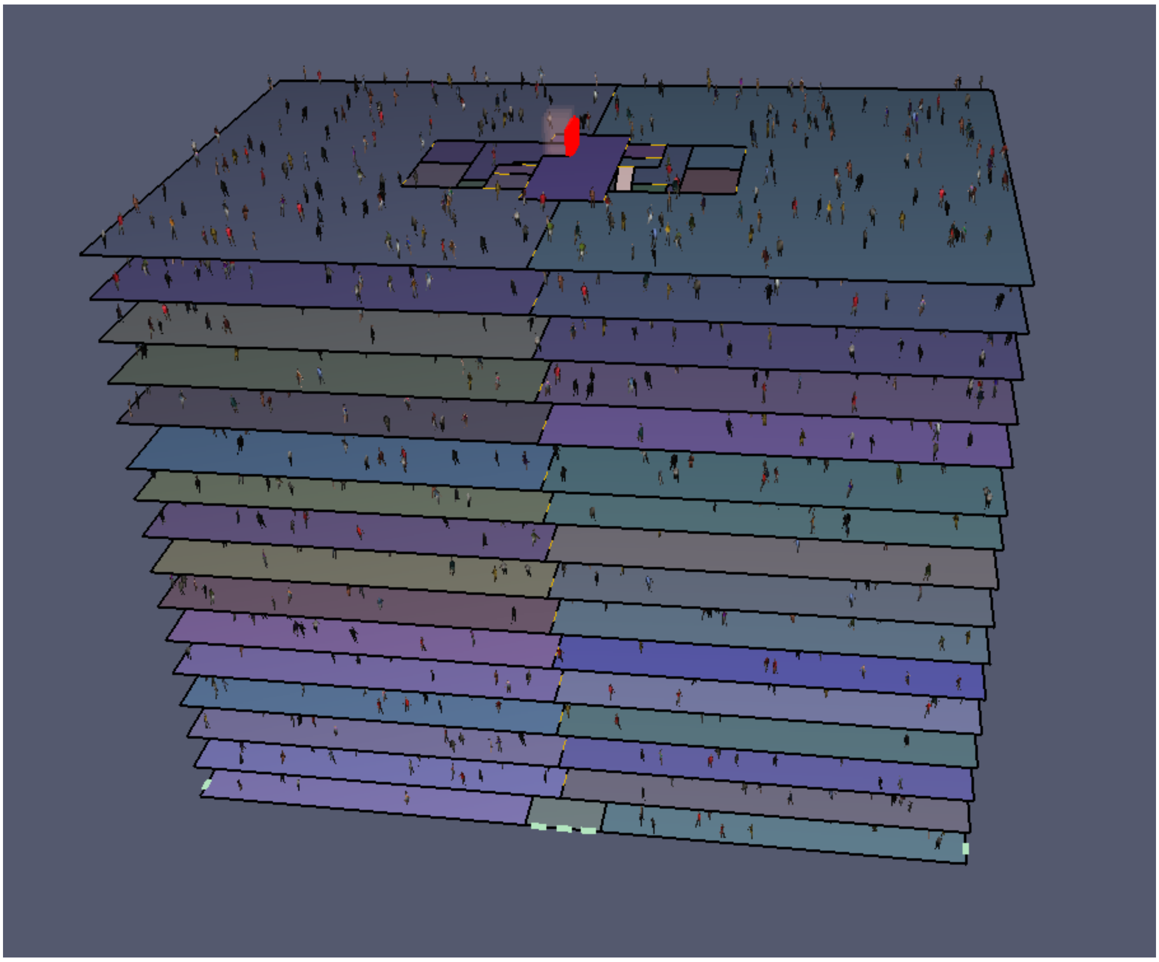


Figure 18 - Model of the Swedish high-rise building in Pathfinder

The Swedish high-rise can in accordance with the fire safety concept accommodate a total of 3561 occupants, with each floor containing 223 people. The ground floor can only accommodate 216 occupants, due to less office space available. The Pathfinder model of the Swedish building however, contains 3576 occupants. With each floor accommodating 224 people, except the ground floor, to evenly distribute the numbers of occupants on each office area (fire compartment). This will be the most conservatory value to be used in each simulation, and give more robust values of RSET results.

People with reduced mobility has been takin into count and represents 6 % of the people on each floor (total 224 people with reduced mobility in the building). The BBRAD specifies that at least 1% of the total number of occupants must be modelled with reduced mobility in public places, but do not provide any guideline for office use. The selection of 6 % is assumed conservative, and taken into count to obtain more robust results from the egress simulations. These are modelled with reduced physical properties in correlation with the standard office occupant modelled in this study (see Table 13).

Every person simulated within Pathfinder have a behaviour profile with evacuating factors such as walking speed, acceleration, size and delay. Values used in this study have been consistent with the values specified in the BBRAD, both for the standard- and physical reduced occupants. Table 13 is extracted from *Appendix D – Risk analysis*, and presents the occupant characteristics, evacuation mode and simulation mode used in the scenario 1 simulation.

Table 13 - Pathfinder egress simulation input parameters extracted from the risk analysis

DESIGN EGRESS SCENARIO PARAMS

	Parameter	Value	Comment
OCCUPANT CHARACTERISTICS	Cue period (P_c).	30 s	For agent located at a position at viewing distance to the fire.
	Cue period (P_c).	Depending on smoke detector activation time.	Agents not seeing the fire, value obtained by the FDS simulation.
	Pre-movement time (Response period (P_r) + Delay period (P_d)).	30 s	For agents near and at a viewing distance of the fire. 60 s for agents not seeing the fire.
	Walking speed on horizontal surfaces.	Min: 0.6m/s Max: 1.5m/s	Values for a standard agent as specified in the guidelines.
	Walking speed along sloping planes.	Min: 0.5m/s Max: 0.75m/s	Values for a standard agent as specified in the guidelines.
	Walking speed on horizontal surfaces.	Min: 0.4m/s Max: 1m/s	Values for agents with reduced mobility as specified in the guidelines. [19]
	Walking speed along sloping planes.	Min: 0.33m/s Max: 0.5m/s	Values for agents with reduced mobility as specified in the guidelines. [19]
	Shoulder width.	0.4558m	Standard value used in the software. [42]
EVACUATION MODE	Zoned evacuation.	2 floors at a time.	After pre-movement time: - The occupants at the 8th- 9th floor begin evacuate the building. - 1 level above and 1 level below at every 4 minutes interval.
	Occupant load.	Refers to Table 2 in the risk analysis.	
SIMULATION MODE	This study will use the steering based model to simulate the occupant evacuation.		

As discussed in the previous section, is the design fire for scenario 1 meant to simulate a blockage of the primary evacuation route for occupants on the 8th floor. This must be taken into count in the evacuation simulation in order to obtain as realistic results as possible.

The egress strategy for the Swedish high-rise in scenario 1, extracted from the risk analysis in *Appendix D – Risk analysis*, is presented in Table 14.

Table 14 - Egress scenario description for the egress simulation of scenario 1 of the Swedish high-rise

Building design	People using the stair configurations [%]	People using the emergency elevators [%]	Floor level subjected to the scenario. [Floor/16]
Swedish	94	6	8/16

In this scenario (scenario 1, see Figure 19), the fire is placed in order to block the egress path for the left-wing office occupants into the Tr1 staircase (red “X” in Figure 19). With the primary evacuation route blocked by the fire, the left-wing office occupants must either evacuate through the fire compartmental boundaries (1), and into the communication area to reach the Tr1 or Tr2 configurations. Alternatively evacuate a longer distance around the central core of the building into the communication area (2), prior to evacuating through either the Tr1 or Tr2 staircase, to ground level.

In this scenario it is assumed that 94 % of each floor consists of occupants with standard agent physic, and evacuate through either of the Tr1 or Tr2 configuration, until they reach the ground floor and evacuate the building. However, 6 % of the population of each floor is counted as people with reduced mobility, and modelled with reduced horizontal speed. These occupants shall be simulated with egress path leading to the emergency elevator to safely evacuate the building.

The egress modelling parameters for this scenario are presented in Table 13, earlier in this section.

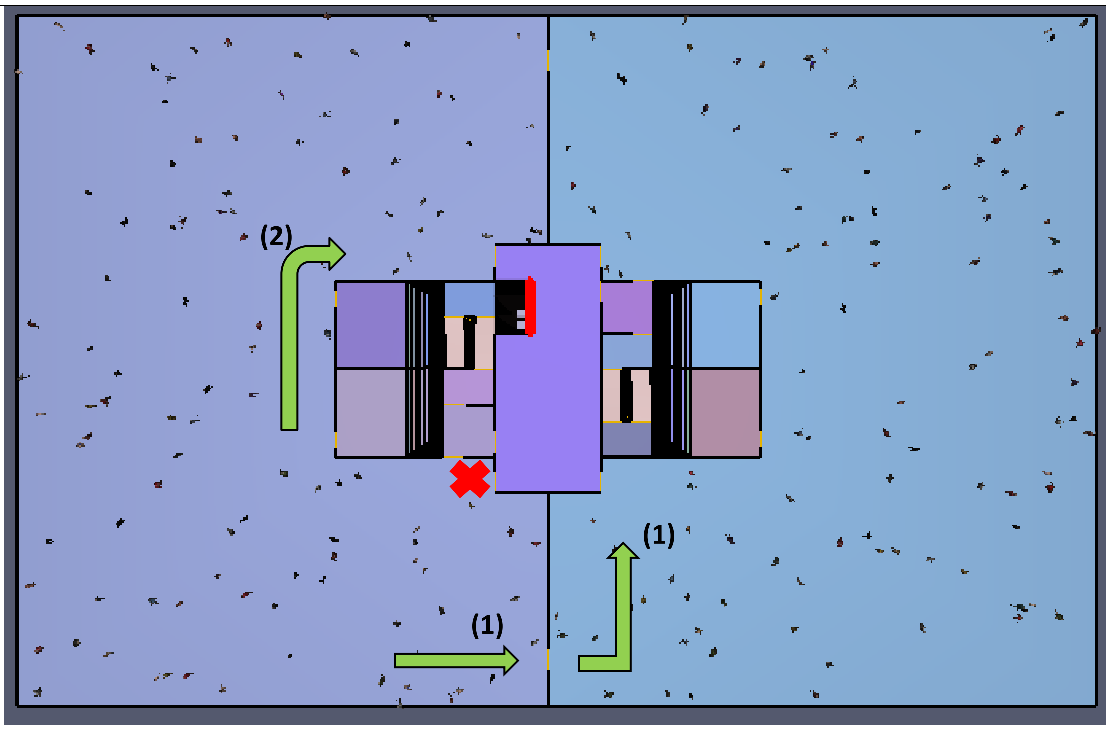


Figure 19 - Egress strategy interpretation SS1

The RSET result from the egress simulations, as mentioned earlier in this report, is measured in terms of; time for all occupants in scenario 1 to reach a location of safety. Areas considered as positions of safety for the Swedish high-rise building is the fire safe passages, each staircase configuration (Tr1 and Tr2), through the fire compartmental boundaries and the outside area.

The results derived from the egress simulation for scenario 1 is presented with the remainder of the fire and egress scenarios, in subsequent chapter of this report.

6. Results

This chapter presents the results from the fire and egress simulations conducted on the Swedish and Australian high-rise buildings. The results are presented under subheadings in order to facilitate understanding. The chapter will primarily present the results from the fire scenarios, in accordance with cut-outs from respective simulation. Thereafter, the results derived from the egress simulations are presented.

6.1. Simulation results from Pyrosim

This section present the simulation results from the fire scenarios evaluated in Pyrosim for the Swedish and Australian high-rise buildings. A summary of the key characteristics of each scenario, and simulation parameter is given in Table 15. It should be noted that only the relevant simulation results are presented. Other results not affecting the RSET vs ASET method is not taken into count in this chapter. All results presented in this section are derived from *Appendix D – Risk analysis*.

Table 15 - Summary of fire scenario characteristics and parameters

Scenario Nr.	Design fire description	Fire source description	HRR	Blocking of egress
1.	Serious fire sequence and possible worst-case.	Office desk of wood, dimension 4 m^2	5 MW	Yes.
2.	Fire developing adjacent to a space that has many persons.	Sanitary compartment wood-bench, 4 m^2	5 MW	No.
3.	Minor strain fire sequence but developing while individual protection systems do not work.	Wooden office bench, dimension 1.6 m^2	2 MW	Yes.
Total area of the fire compartment available for the fire and spread of smoke, is approximately 1250 m^2 and 3 000 m^2 for respective Swedish and Australian high-rise.				

6.1.1. Design scenario 1 – Worst case

The results from the first fire scenarios, showed that the visibility level was the first tenability criteria that was met for both the Swedish and Australian high-rise building. Figure 20 and 21 present cut-outs from the first fire scenario for the Swedish and Australian high-rise building respectively. Figure 20 illustrates the smoke development after 260 s and Figure 21 after 360 s. The first cut-out (for both Figures) shows an overview of the smoke development inside the fire compartment, when the ASET criteria in the buildings was reached (see *Appendix D – Risk analysis*). The second cut-out (for both Figures) is a slice-file that illustrates the visibility level in the smoke layer during the same time. The blue area illustrates areas where the visibility level has become less than 10 m.

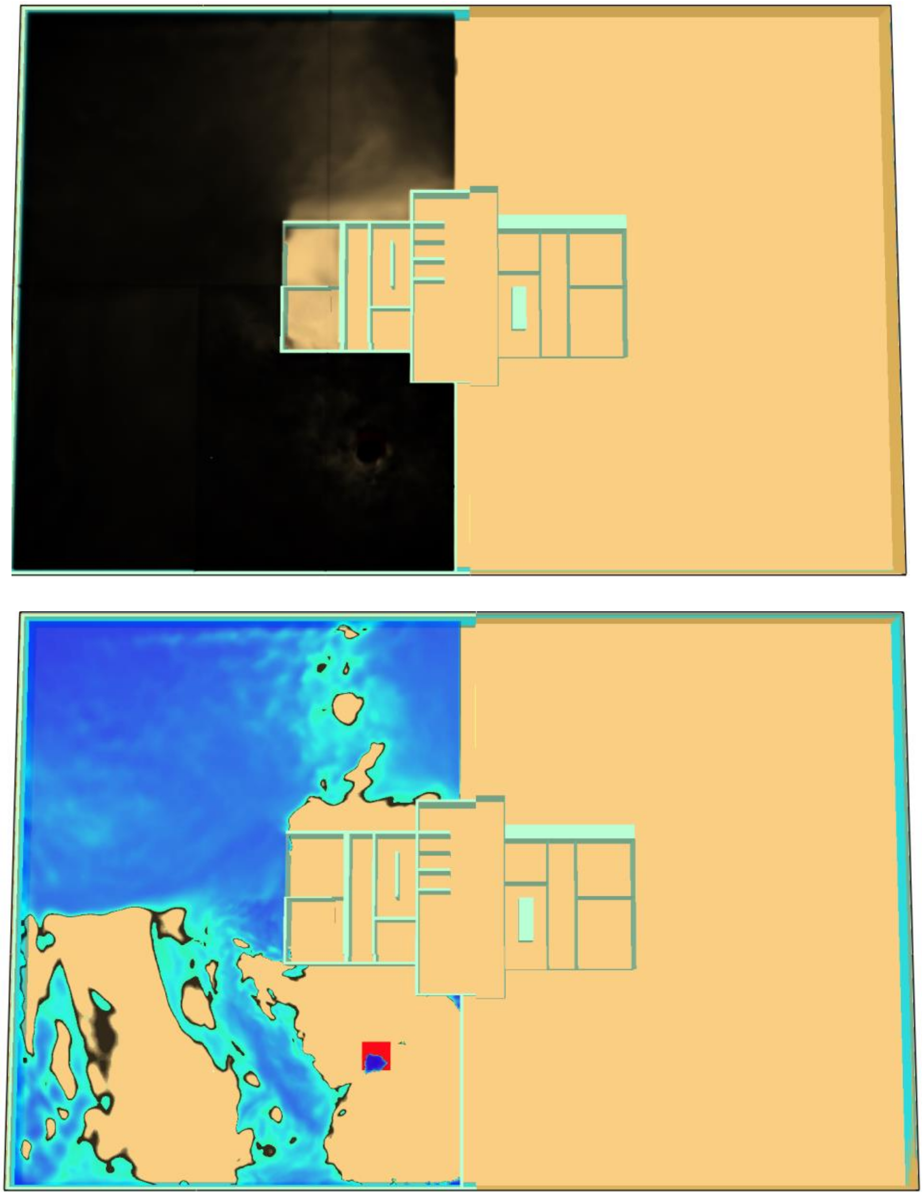


Figure 20 - Smoke development and visibility level at 260 s in design fire 1 simulation of the Swedish high-rise

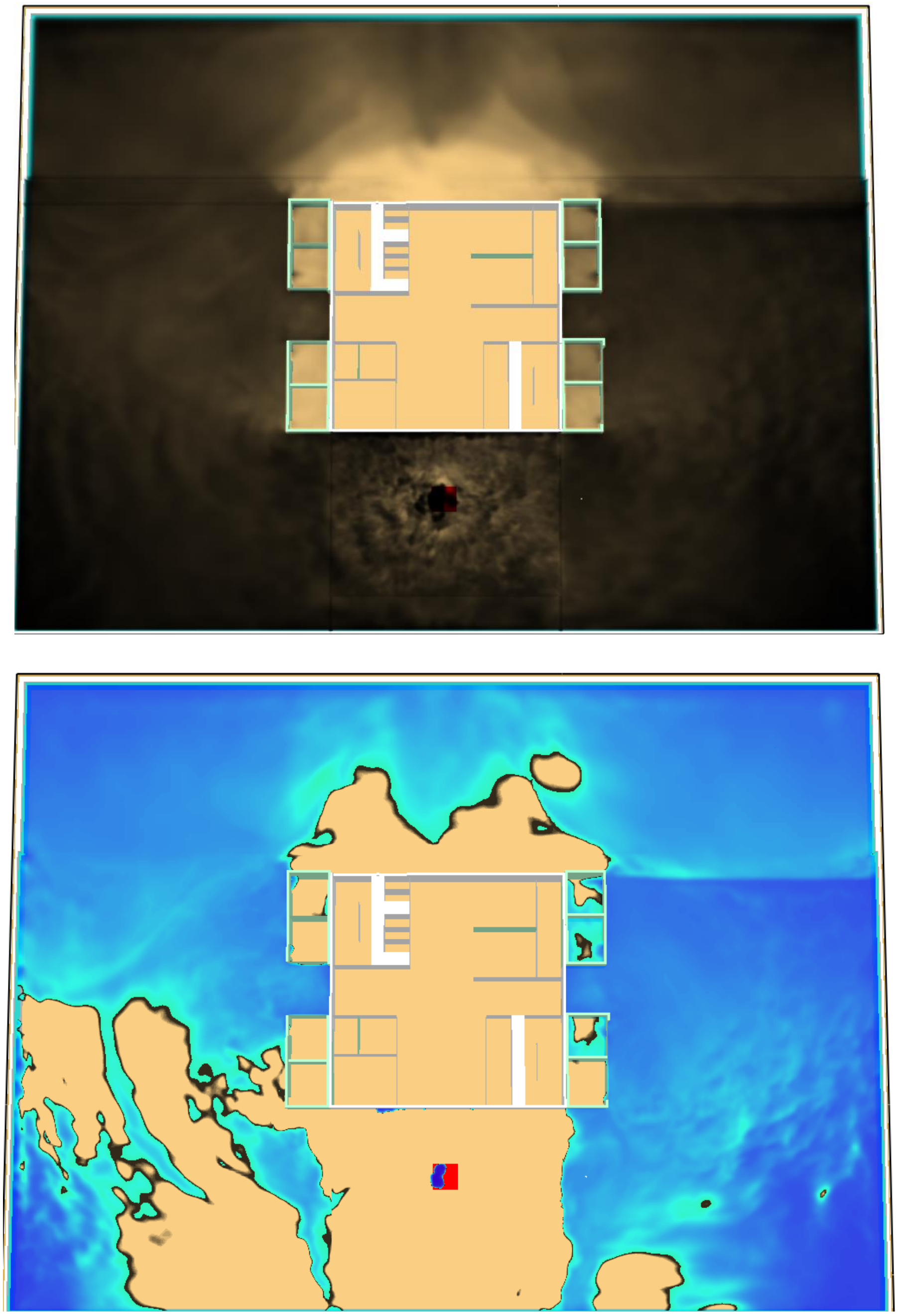


Figure 21 - Smoke development and visibility level at 360 s in design fire 1 simulation in the Australian high-rise

In both Figures (20 and 21), the smoke has spread beyond the point of origin and to the furthest point in the fire compartment. The visibility level is observed to be higher near the fire source than areas further way. The Australian high-rise managed to sustain acceptable level of 100 s more than the Swedish high-rise, and is arguably due to larger rooms and less obstructions such as walls.

Noticeable from the slice-file in Figure 21, is that the smoke jet forms a straight horizontal line (upper right corner). This is explained from the change in mesh-cell resolution from a volume of finer to coarser cell sizes. When information, calculated within a finer grid-cell is transported to a coarser cell size, information is lost in the process. This can affect the calculated information (in this case smoke spread) both ways, so that it movements becomes less accurate and more simplified. This could also be observed in other simulations.

The results derived from the Pyrosim simulation also showed that the other tenability criteria, such as CO, CO_2 and temperature had much lower values during the time that the ASET value was reached (see Table 16), and is therefore not further assessed in design scenario 1.

Table 16 - Time until tenable conditions arise in the Australian and Swedish high-rise during scenario 1

Design Scenario 1

Nationality	**Time until tenability criteria was reached (s)**				
	Visibility	**Temperature**	**CO**	**CO_2**	**O_2**
Sweden	260	NRDS*	NRDS*	NRDS*	NRDS*
Australia	360	NRDS*	NRDS*	NRDS*	NRDS*
*NRDS: Not Reached During Simulation					

6.1.2. Design scenario 2 – Hidden fire

The results from the s fire scenarios, also show that the visibility level was the first tenability criteria that was met for both the Swedish and Australian high-rise building.

Figure 22 and 23 present cut-outs from the second fire scenario for the Swedish and Australian high-rise building respectively. Figure 22 illustrates the smoke development after 267 s and Figure 23 after 467 s. The first cut-out (for both Figures) shows an overview of the smoke development inside the fire compartment, when the ASET criteria in the buildings was reached (see *Appendix D – Risk analysis*). The second cut-out (for both Figures) is a slice-file that illustrates the visibility level in the smoke layer during the same time. The blue area illustrates areas where the visibility level has become less than 10 m.

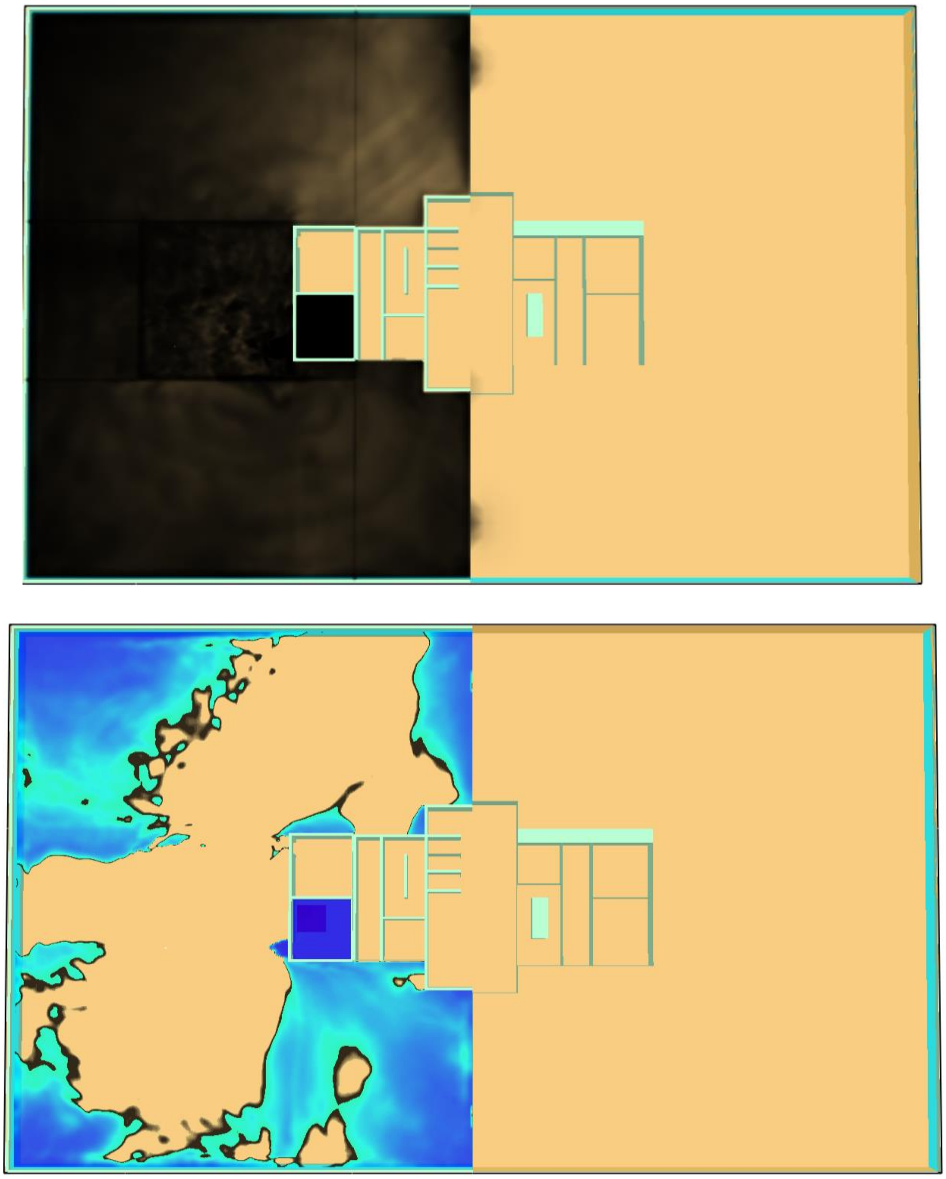


Figure 22 - Smoke development and visibility level at 267 s in design fire 2 simulation in the Swedish high-rise

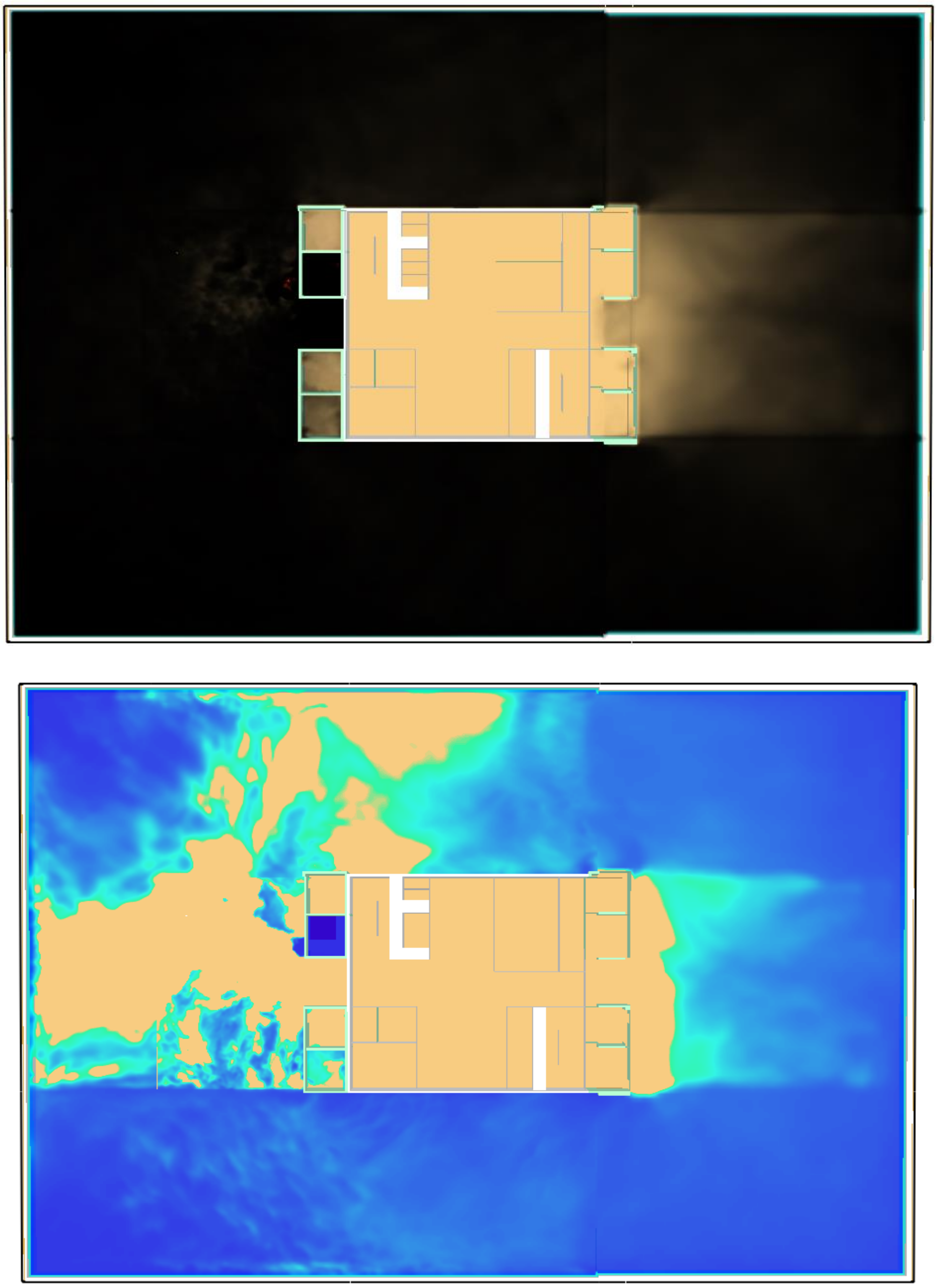


Figure 23 - Smoke development and visibility level at 467 s in design fire 2 simulation in the Australian high-rise

Figure 22 and 23 both illustrates that the smoke layer has started to accumulate as a more dens layer near evacuation routes, leading to reduced visibility level below the accept criteria. The visibility level around the entrance area to the sanitary compartment, where the fire is placed, is much higher than adjoining areas. The Australian high-rise managed to sustain acceptable level at 200 s more than the Swedish high-rise, due to larger rooms and less obstructions such as walls.

The results derived from the Pyrosim simulation also showed that the other tenability criteria, such as CO, CO_2 and temperature had much lower values during the time that the ASET value was reached (see Table 17), and is therefore not further assessed in design scenario 2.

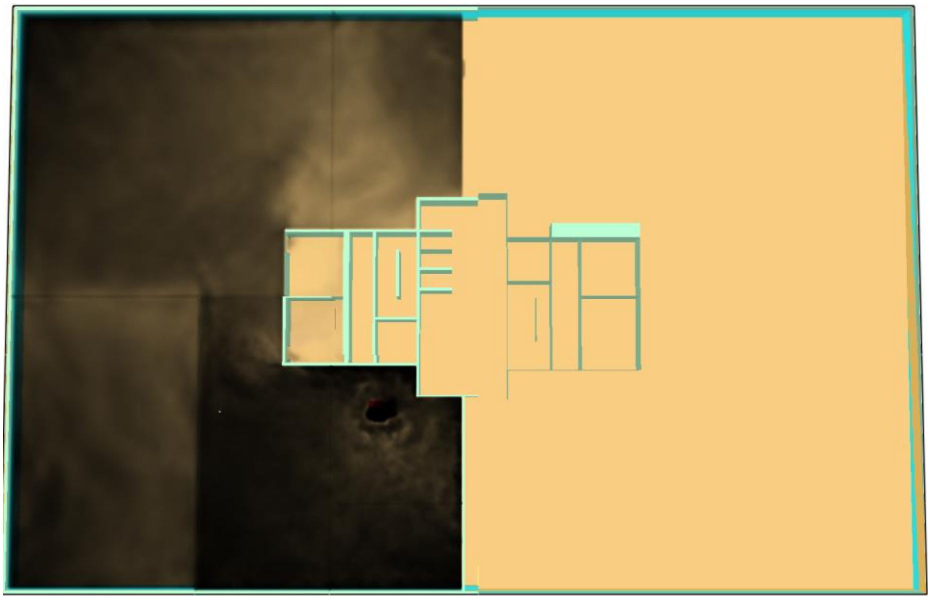
Table 17 - Time until tenable conditions arise in the Australian and Swedish high-rise during scenario 2

Design Scenario 2					
Nationality	**Time until tenability criteria was reached (s)**				
	Visibility	**Temperature**	**CO**	**CO_2**	**O_2**
Sweden	267	850	NRDS*	NRDS*	NRDS*
Australia	467	NRDS*	NRDS*	NRDS*	NRDS*
*NRDS: Not reached During Simulation					

6.1.3. Design scenario 3 – Technical error fire

The results from the third fire scenarios, shows that the visibility level was the first tenability criteria that was met for both the Swedish and Australian high-rise building.

Figure 24 and 25 present cut-outs from the second fire scenario for the Swedish and Australian high-rise building respectively. Figure 24 illustrates the smoke development after 272 s and Figure 25 after 375 s. The first cut-out (for both Figures) shows an overview of the smoke development inside the fire compartment, when the ASET criteria in the buildings was reached (see *Appendix D – Risk analysis*). The second cut-out (for both Figures) is a slice-file that illustrates the visibility level in the smoke layer during the same time. The blue area illustrates areas where the visibility level has become less than 10 m.



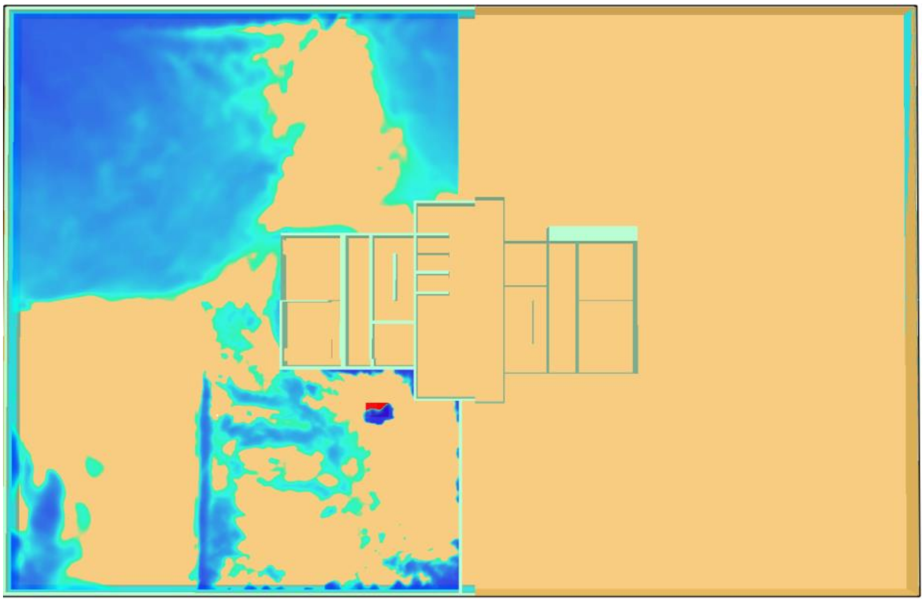
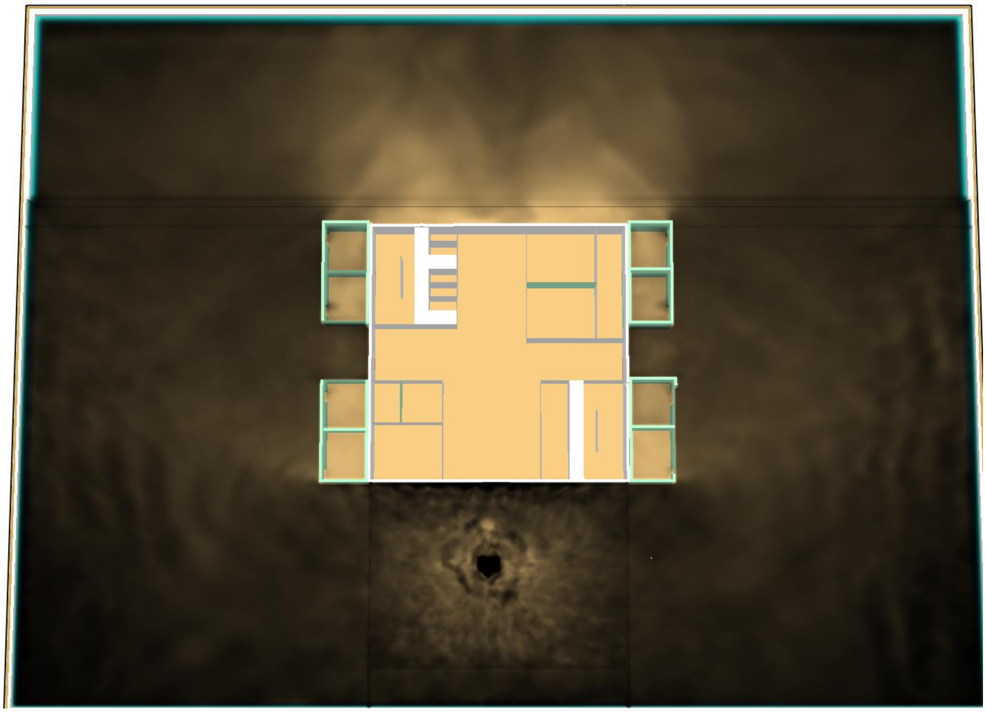


Figure 24 - Smoke development and visibility level at 272 s in design fire 3 simulation in the Swedish high-rise



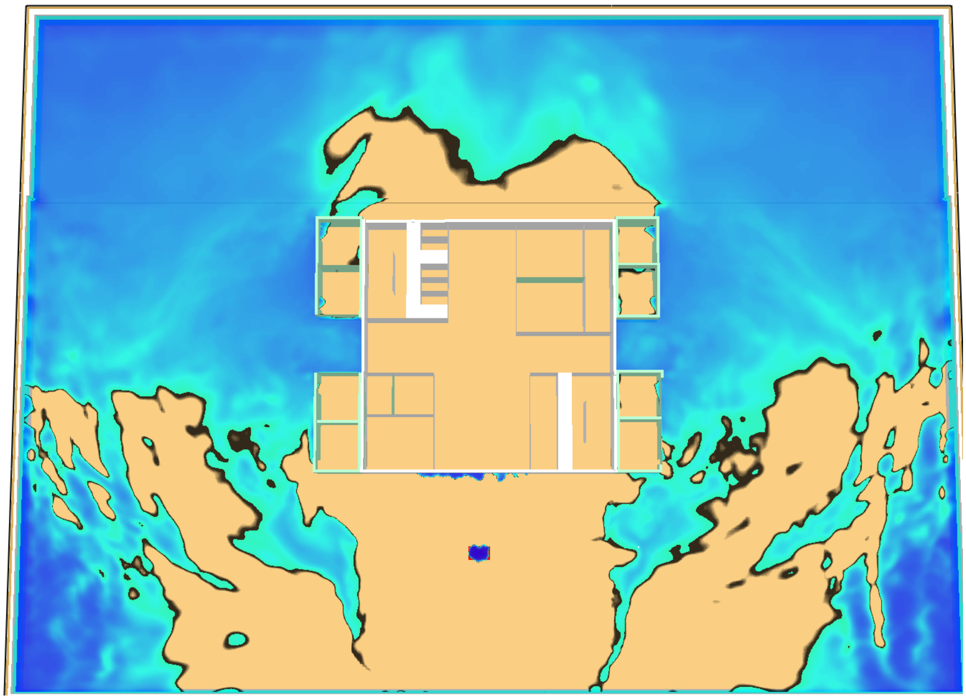


Figure 25 - Smoke development and visibility level at 375 s in design fire 3 simulation in the Australian high-rise

As Figure 24 and 25 shows, the fire is located close to the same place in both design scenario 1 and 3. The fire-load is, however smaller in design scenario 3, and modelled to have a lower HRR and surface area than design scenario 1 (see Table 15). Scenario 3 also includes technical errors within the design scenario. Similar results regarding smoke spread and approximate time until the tenability criteria was reached, where therefore expected prior to the simulation.

In both Figure 24 and 25, the smoke has spread beyond the point of origin and to the furthest point in the fire compartment. The visibility level are higher near the fire source than areas further way. The Australian high-rise managed to sustain acceptable level of 103 s more than the Swedish high-rise, and is arguably due to larger rooms and less obstructions such as walls.

The results derived from the Pyrosim simulation also showed that the other tenability criteria, such as CO, CO_2 and temperature where sustained at much lower value during the time that the ASET value was reached (see Table 18), and is therefore not further assessed in design scenario 3.

Table 18 - Time until tenable conditions arise in the Australian and Swedish high-rise during scenario 3

Design Scenario 3					
Nationality	**Time until tenability criteria was reached (s)**				
	Visibility	**Temperature**	**CO**	**CO_2**	**O_2**
Sweden	260	NRDS*	NRDS*	NRDS*	NRDS*
Australia	375	NRDS*	NRDS*	NRDS*	NRDS*
*NRDS: Not Reached During Simulation					

6.2. Summary of fire simulations

Observations from the fire simulation in the Swedish and Australian high-rise show that the smoke, due to buoyancy, rises and spreads quickly underneath the ceiling. Since both high-rises consists of an open design layout with no interior walls, etc., the smoke spread is only stopped by the exterior walls, fire compartmental boundaries and sanitary compartment walls. The distribution pattern of the spread of smoke, could in each simulation be observed to behave as described in the literature [34], and therefore further regarded as accurate.

As the smoke is spreading underneath the ceiling, it also mixes with the surrounding colder air. Resulting in the lowering of both its temperature and buoyancy driven height. The smoke also declines and lose temperature when the ceiling jet hits the walls surrounding the office compartment. When the smoke reaches areas further away, it also drops and cools more rapidly, as a result of the temperature being colder further away from the fire source. As the spread of smoke eventually starts to reverse from the exterior wall (located furthest away from the fire source), the smoke layer consisted of a more dense and cold layer. This behaviour was the same in each simulation, and coincided with the phase when the ASET criteria for Visibility occurred. This is showed in the cut-outs from various time sequences, from each fire simulation presented in *Appendix D – Risk analysis*.

The position of the fire source had some, but not much effect on the analysis. As scenario 2 consisted of a hidden fire development inside a sanitary compartment, the spread of smoke became enabled by vent flow from the door connecting the two areas (office area and the sanitary compartment). This phenomenon had different effect on the ASET time for the Australian and Swedish high-rise, with 107 s and 7 s increased available time for the respective buildings, when comparing with design scenario 1. The spread of smoke was observed to spread along the walls in these simulations, something that explains the difference in increased ASET time between the Australian and Swedish high-rise, as all evacuation routes where much closer to the vent flow in the Swedish case.

The maximum heat release rate (HRR), had little effect on the ASET time. As the visibility criteria was reached much earlier than all simulated fires reached maximum HRR value, the intensity of the fire was generally measured around or below 1 MW in all simulations (except the second Australian scenario which was around 2.5 MW). This is clearly illustrated with the little time difference between scenario 1 and 3 for both buildings (maximum 5- and 2 MW), where the ASET time only increased by 12- and 15 s for respective Swedish and Australian high-rise.

As the ASET criteria occurred before any simulated fire reached a maximum value of HRR, very low values of CO- and CO_2 concentrations, as well as temperature could be observed in each simulation. The oxygen level was also high when the ASET criteria was reached in all simulation, something that argues for relative low personal risk.

The spread of smoke represents an imminent risk in the entire fire compartment, while the temperature and radiant heat from the fire constitutes a more local hazard. As the spread of fire and HRR value is relatively low in the time the ASET, the observation of relatively low temperature around the evacuation routes are reasonable. The temperature around the fire source is high. It is however assumed that people will move away from any imposing heat source.

The tenability condition visibility is in itself not a deadly factor, but could lead to prevented or delayed evacuation, something that enables other tenability criteria's to have larger effects, such as; radiation and high temperature exposure and toxicity concentrations. Studies shows that reduced visibility level is often the tenability criteria that is reached first, this is also reinforced in this study where all fire simulation experienced reduced visibility, prior to any other tenability criteria [29] [34]. Toxicity- and temperature levels where observed below acceptable conditions when the visibility criteria reached untenable levels.

It must also be mentioned that this study assumes that the smoke detectors and door-closing installations works as intended in all simulations.

6.3. Simulation results from Pathfinder

This section will present the results from the evacuation simulations done in Pathfinder for the Swedish and Australian high-rise building. Table 19 summaries the key characteristics used in each egress simulation, as well as number of occupants and available evacuation routes. Three values are of interests from each simulation, namely; RSET value, time until floor levels above the floor of fire origin have evacuated past the floor, and time until the total building has been evacuated. All results presented in this section are described in more details in *Appendix D – Risk analysis*.

Table 19 - Summary of evacuation scenario characteristics and parameters

	Number of occupants (p)		Scenario Nr.	Blocking of egress	% Nr. physical impaired occupants	Nr. of evacuation routes available	ASET (s)
Sweden	Ground	216	1.	Yes	6 %	3 of 5	260
	2-16	224	2.	No	6 %	All	267
	Total	3561	3.	Yes	6 %	3 of 5	272
Australia	Ground	266	1.	Yes	6 %	3 of 4	360
	2-16	306	2.	No	6 %	All	467
	Total	4857	3.	Yes	6 %	3 of 4	375

It must be mentioned prior to the results being presented, that the evacuation strategies varies depending on the related fire scenario. Factors such as possible direction of egress due to blocking of fire, and changing of pre-movement factors due to time before smoke alarm activation changes the output of the evacuation simulation, and must be taken into account from the risk analysis presented in *Appendix D – Risk analysis*.

Table 20 presents the RSET and evacuation time for the various design scenarios considered in this study. The RSET was determined as the time for all occupants on the floor to reach an area, referred to as a position of safety (see *Appendix D – Risk analysis)*. Position of safety for the Swedish high-rise was behind fire compartmental boundaries from the fire, the communication area, both Tr1 and Tr2 staircases and outside. Position of safety for the Australian was inside the smoke lobby, behind fire compartmental boundaries, both fire safe staircases and outside.

Table 20 - RSET and other evacuation times for the various design scenarios

	Scenario Nr.	RSET (s)	Time until floor 8-16 is evacuated (s)	Total evacuation time (s)
Sweden	1.	226	2119	2284
	2.	280	2135	2308
	3.	210	2160	2363
Australia	1.	208	2106	2325
	2.	201	2116	2334
	3.	225	2118	2324

All egress simulation have used the steering mode programmed into Pathfinder. As mentioned in the literature study, steering mode is considered to simulate more realistic egress patterns, and was therefore chosen for all simulations. All results and cut-outs illustrating the various steps of each evacuation simulation conducted in Pathfinder, is found in *Appendix D*.

Not unexpected, the Australian high-rise building, with fewer rooms before entering the staircase, was the building that presented the fastest evacuation times. Passageways and congestion was the two factors preventing the Swedish high-rise from having a smooth and fast evacuation. This is illustrated in the RSET results for scenario 2 of the Swedish high-rise, where the primary evacuation route to the Tr1 staircase was available for occupants in the left office. The large number of occupants evacuating through the passageway in the Swedish high-rise, resulted in congestion, which also resulted in a longer evacuation time. In contrast, the wider stair recommendations of the Australian high-rise, as well as four entries into the smoke lobby, enabled each floor level to efficiently evacuate its occupants. The evacuation simulations also showed that the smoke lobby solution provided a safe holding area for the occupants to wait out the congestion. It must also be taken into account, that the Australian building consisted of 82 occupants more per floor, and not starting the evacuation simulation with half of the occupant load in a position of safety (beyond fire compartmental boundary).

Figure 26 presents three cut-outs from the second evacuation simulation on the Swedish and Australian high-rise model. As shown in the two first cut-outs in Figure 26, the smaller areas in the Tr1 and Tr2 solutions results in increased time for occupants to enter the staircases, due to congestion in the doorways and passageways. The third cut-out illustrates the smoke-lobby solution in the Australian regulation, successfully providing a holding area for a larger number of occupants, safely behind fire compartment boundaries.

(a) Swedish high-rise, evacuation simulation 2, after ca. 145 s.

(b) Swedish high-rise, evacuation simulation 2, after ca. 210 s.

(c) Australian high-rise, evacuation simulation 2, after ca 176 s.

Figure 26 - Cut-outs from the second evacuation simulation for the Swedish and Australian high-rise. (a) and (b) shows the Swedish occupants in two time sequences during the evacuation. (c) shows the Australian occupants in a time sequence during the evacuation, and is meant to illustrate the holding area function of the smoke lobby. [Figure by Emmanuel Eriksson]

The total evacuation time proved however the Swedish-high-rise building to be the fastest. The Australian building generally simulated faster values of both RSET and time until floor 8-16 was evacuated past the floor of fire origin, but since the Australian building contains 1 296 occupants more, it is was not unexpected.

Scenario 3 of the Swedish high-rise was the only simulation provided with fastest evacuation time, in comparison to the Australian high-rise building. The time difference between these simulations is only 15 s, and shows that horizontal evacuation is as efficient to reduce the RSET time, as the smoke lobby requirement.

Table 21 presents the difference between the Swedish and Australian high-rise building, when comparing their performance in the three simulated design scenarios.

Table 21 - Evacuation time difference in the various design scenarios between the Swedish and Australian high-rise buildings

Comparison of the various design scenarios simulation times (s)		Design scenario 1 - Worst case, blocking of egress route	Design scenario 2 - Hidden fire, all egress routes available	Design scenario 3 - Small strain fire, blocking of egress route	Average evacuation time (rounded up or down)
	Sweden	226	280	210	240
	Australia	208	201	225	210
Time difference (s)		18	79	15	30

As can be noticed from Table 21, the evacuation time difference between design scenario 1 and 3 is not great (18- and 15 s), while design scenario 2 presented the longest RSET value difference (79 s). This illustrates again, that horizontal evacuation is much more efficient to reduce the RSET value then directly evacuating into the Tr1/Tr2 configurations, when larger numbers of occupants and congestion is expected.

Available egress routes have effect on the evacuation time, something that the difference of RSET time illustrates in the Australian building, where design scenario 2 simulated the fastest evacuation time. This shows that the smoke lobby incorporated within the Australian high-rise provides all floor occupants with a fast and flexible means of egress, even in larger numbers. This is however not shown in the Swedish Tr1 and Tr2 solution, where the passageways between the office area and staircase, only led to increased evacuation time due to congestion.

As presented in Table 21, the Australian building provides the best RSET value in two of three scenarios. The average evacuation time shows the expected performance between the Swedish and Australian building (240 s and 210 s), and gives good estimations of expected evacuation times, for both high-rise buildings.

6.4. RSET vs. ASET

The required- and available safe egress time where in this study defined as respective time for all occupants to reach an area of safety, and time until the untenable conditions occurs around the evacuation routes. The correlation between these time criteria’s have been discussed in earlier chapters in this study.

This study will use the relationship and difference between these time criteria, to express the occupants- and life safety criteria of each high-rise building, by presenting results that illustrates if the available safe egress time is longer than the required safe egress time. The results derived from the fire and egress simulation and their correlation (RSET vs ASET), derived from the risk analysis in *Appendix D – Risk analysis*, is presented in Table 22.

Table 22 - presentation of the ASET vs RSET results for each design scenario, for each high-rise building

	Sweden			***Australia***		
Design scenario	1	2	3	1	2	3
ASET (s)	260	267	272	360	467	375
RSET (s)	226	280	210	208	201	225
ASET/ RSET	1.1	0.9	1.3	1.7	2.32	1.6
Safety factor (s)	34	-13	62	152	266	150

As Table 22 illustrates, the Australian building have maintained a satisfactory level of occupant safety, and acceptable performance in all design scenarios. The Swedish high-rise building maintained a satisfactory level of occupant safety in two of three cases, with relative small safety factor value in comparison to the Australian high-rise.

The Swedish high-rise maintained the required occupancy safety level in scenario 1 and 3, with small time margins for the office workers to reach a position of safety before untenable conditions prevail. 34 s could be argued to present insufficient safety margins for human and unfortunate circumstances, while the safety margins of 62 s is a more robust time value. Nevertheless the satisfactory performance in two of three scenarios is not sufficient to be deemed acceptable in terms of the objectives in the risk analysis. This situation in a fire safety analysis, would require revised analysis of the fire safety solution within the building. As the Swedish building however is acceptable in terms of the prescripted solution, the design solution is therefore not required to be revised, but is not considered to be sufficient towards the objectives of the risk analysis.

The Australian high-rise maintains the requirements and presents longer tolerance limits for the tenability conditions, with 1.7, 2.3 and 1.6 times longer ASET value than required for all occupants to reach a position of safety. This illustrates a more robust design that could take into account unfortunate circumstances, which otherwise would risk the occupancy safety level. This is considered to be sufficient towards the objectives stated in the risk analysis.

6.5. Sources of error

The quality of the results presented in this study is greatly affected by all simplifications, assumptions and conditions used in the risk analysis, and shall be further described in this section.

Plotted and input data used in the simulation tools could be mistyped. This applies to both FDS and Pathfinder, but especially FDS as it requires more numbers of input in comparison to Pathfinder, in addition is errors in the FDS code sheet hard to detect. Error sources linked to the selected input data used to represent the simulated problem are also a possibility. This is especially directed towards the reaction used in Pyrosim, which only consisted of the reaction of “Red Oak” wood, and not a number of reactions, but also where input data was selected from referenced sources and not specified in the guideline BBRAD.

The fire was simulated on a pre-determined surface. This is a source of error as a real office fire would result in the fire propagating on- and to objects within the compartment. The choice of higher HRR values, in relationship with the low time until the tenability conditions occurred, is assumed to however minimise this affecting the results.

The selected mesh cell size is also a factor that could impact the quality of the results. The cell sized used in the various simulations have ranged from 10 cm, 20 cm, 40 cm and 1 m, depending on the distance of the mesh from the fire source, as well as if the mesh is involved in the simulation or not. This can give wrong estimates of the tenability conditions, and the spread of smoke pattern measured in the simulations. The ideal mesh solution would be to have the same cell size everywhere, but as each high-rise consists of large volumes with many measurements, the computer power needed would vastly exceed what would be possible for the used computer. It should be mentioned in correlation to this source of error that the mesh size used in each simulation, is the “finest” mesh cell possible for the used computer, and is in accordance with specifications from the literature.

The time limit for this study could also have an effect of the quality of the results. The simulations and research have been conducted with a deadline in mind, which has prevented re-runs of simulations, or a mesh sensitivity analysis, other than evaluation of the dimensionless numbers and specifications in the literature. The results derived from Pyrosim and Pathfinder includes the use of distribution and/or probabilistic variables to simulate the complex behaviours of both fire and human scenarios. This means that the models and scenarios may produce different results for the same model, which would require multiple runs on each simulation to give as qualitative and representative results as possible.

FDS required the out-data to be specified prior to the simulations, and opens up for errors in accordance to the selection of these out-data. It is also not possible to place measurement devices and evaluate every square meter of the high-rises, something that could lead to some values not discovered. The use of slice-files has therefore been used to visualize the flor pattern and save planar slices of data. The use of slice-files allow recording of various gas phase quantities at more than a single point, and have been used to monitor and evaluate some of the conditions (Fraction Effective Dose, FED) in the simulation domains. It must however be mentioned, in accordance with this, that FDS requires much input to be specified, and there is some chance that any requirements in the FDS user guide might have been wrongly interpreted. [43]

Many simplifications of the fire simulations have been made to enable the simulations of the design scenarios. These simplifications limits the results to only be applicable on the case and limitations, specified in this study. It is therefore a possibility that these results do not encompass, or can be used in any other relationships, than specified in this study. This is however not explicitly granted, but the results must be viewed in correlations with the limitations and assumptions made in this study.

Assumptions and necessary limitations has been made over the course of this study to enable this study. These are sources of errors as they do not encompass the same premises as reality, and must be taken into account.

According to the literature is uncertainty in the area of 20 % linked to the results when the HRR is known [34]. The exact HRR was not known but was values from sources used by fire engineering practitioners and guidelines provided by the government, and used to simulate a harder strain of fire to test the buildings safety level, the same percentage of uncertainty is taken into account in the results. Uncertainty of the results and from the simulations have not been considered in the evaluation of the results derived from the risk analysis.

There are some possibilities that the interpretation of the prescriptive requirements, and implementation of requirement used in both high-rises could been done by wrongly interpreting the building regulation of Sweden and Australia. Both fire safety concepts conducted in this study, have been quality assured by professional fire engineering practitioners, but there is still some chance that any requirements might have been mistakenly interpreted.

As mentioned in the risk analysis, is the number of possible fire scenarios endlessly. The use of risk perception is also strongly influenced by the people and knowledge by the author, the design fire scenarios used to evaluate the fire safety performance of each high-rise, is therefore strongly influenced by the knowledge and thoughts of the author of this study.

The time for the fire simulations, scenario 1 and scenario 3 for the Swedish high-rise, and scenario 1 and 2 for the Australian high-rise ended around 500 s. This was 500 s shorter than remaining fire simulations. This means that other possible results, regarding time before untenable conditions occur, was not evaluated in these simulations. As the value of interest was the ASET criteria for each simulation, this shorter time had no effect on the results because the criteria was reached before 500 s. It is therefore not fully regarded as a source of error.

The visibility level, in all fire simulations (except Australian scenario 3), was measured at 1.9 m instead of 2 m above the floor, as specified in the guidelines. This is a source of error as the time sequence for the smoke layer to descend 10 cm and reduce the visibility level, is taken into account in the results. This means that the ASET criteria would have occurred earlier than presented for the respective simulations. It is however assumed, that this would have negligible effect on the outcome of the risk assessment, as the performance of the Swedish high-rise still would fail to meet the outlined objectives of the risk analysis, in comparison to the Australian high-rise. The safety margin would be smaller in the Australian scenarios 1 and 2, but the robust results is however assumed to have no effect on the outcome of the risk assessment.

The wrong measurement device was used in in fire simulation 1 for both high-rise buildings. This means that the concentrations of CO, CO_2 and O_2 was not measured correctly in these simulations. By evaluating and comparing the results from the fire simulations that used the correct measurement device, it was observed that neither of the toxicity concentrations was close to effecting the tenability condition around the time where the visibility condition reached unacceptable values (between the time interval of 250 s to 450 s). This source of error would therefore not have any effect on the results from the risk analysis, since the ASET criteria *Visibility* occurred prior to the time where the toxicity concentration would reach unacceptable levels.

There are some possibilities of sources of errors made in this study without the knowledge of the author. This is for instance error sources such as; typing error or mistyped input of data into this report, calculation errors or rounding of values not correct. Assumptions and conditions made in this study, could also been made without sufficient level of knowledge within the respective subject. This source of error could also have effected other areas in this report such as interpreting the results. This is however regarded as a general uncertainty which is present in any study made, regardless of size.

7. Discussion

In this chapter, results from the risk analysis will be discussed together with other findings. The first section (7.1), discusses the regulatory differences between the Swedish BBR and Australian BCA for high-rise office buildings, with emphasis on prescriptive requirements. Subsequent sections discusses the results derived from the scenario based risk analysis, as well as the fire and egress simulations. At the end of this chapter, possible fire safety recommendation will be proposed to the Swedish building regulation, based on the risk analysis results.

7.1. Discussion of the simulation results

The results from the risk analysis indicates that congestion into the Tr1 and Tr2 staircase configuration was the main cause of deficiency in the Swedish evacuation design. The high density of occupants on each floor level, in combination with the passageways prior to the staircase entrances, resulted in a bottleneck effect. This effectively increased the RSET value, as people could not continue forward, and as a result required longer time to evacuate the premises. This was observed in varying degree in all evacuation simulation on the Swedish high-rise. The RSET result from design scenario 2 exemplified this, with 54 s longer required time to evacuate than the *worst credible* scenario 1. The underlying reason for the increased RSET value in scenario 2 is clearly connected to the Tr1 and Tr2 configurations, and their capacity to provide fast but safe passage through the passageway into the staircase.

In comparison to the Swedish solution, two of three egress simulations (see Table 22) indicates that the prescripted Australian solution of a *Smoke lobby* configuration was much more efficient for a larger number of occupants. The smoke lobby intentionally provided sufficient holding area for more occupants to wait-out the congestion into the staircase configuration, in contrast to the Tr1 and Tr2 solutions. This counteracted the congestion into the staircase configuration to effect the RSET, but instead provided safe accommodation behind compartmental boundaries for the occupants.

As the Australian building, in two of three simulations, managed to obtain better RSET value than the Swedish high-rise (with a larger number of occupants and floor area), it can be argued that the prescripted solution of a smoke lobby is more suited for buildings with a larger number of occupants. Furthermore, results from this study indicates that the function of a holding area for occupants waiting to enter the staircase, enhances the safety during evacuation from a high-rise building. This requirement is therefore seen as a solution to increase the safety within tall buildings, where a larger number of occupants is expected. Based on this result, it is proposed that a similar prescripted requirement as the smoke lobby, or allowing the combining of the fire safe passageways to enclose more occupants, are adopted within the Swedish building regulation.

7.2. The detail level of performance-based requirements

The differences between the Australian and Swedish building regulation where first observed in the number of performance requirements. As the prescriptive fire safety requirements in Sweden aims to satisfy only five performance requirements, the Australian building regulation provides over 30 fire related performance requirements [4]. As mentioned earlier in this report (see section 3.3.1.), the performance requirements in Sweden are very general, while the Australian are more detailed. The Swedish performance requirements are broad, and addresses the specific functional components of the building structure, for instance the structural stability in the event of fire. These performance requirements do not however, provide any measures to quantify compliance against. The absence of specificity is not necessarily negative, it may contribute to increasing the creativity in the finishing solutions. This does however mean that sufficient guidance is needed somewhere else in the regulatory system, in order to provide sufficient level of context to interpreting these general statements towards the fire safety design [44]. It is often here that the prescripted solution comes in as one measuring tool for compliance.

The intention of the performance-based regulation is to focus on the intended functions and performance to be achieved. This can result in flexibility in design and innovation in material. At the same time, performance-based regulation have challenges with respect to defining performance measures to facilitate, and ease a better understanding regarding regulatory compliance, as well as allowing qualified professionals to make appropriate decisions [44].

In a report by Professor Brian Meacham, with the topic; *Observations on the Situation with Performance-Based Building Regulation and Fire Safety Engineering Design in Sweden and the Potential for Incorporation of More Risk-Based Concepts*, the balance between fewer and broader or several detailed regulations was recognised [44]. The report provided observations, discussions and opinions expressed by Boverket and experienced fire safety engineering practitioners. Suggestions where brought up based on feedback on potential "Boverket Work Items" regarding fire provisions. Amongst the various suggestions was a request amongst the participants for further clarification of the intent of various fire safety requirements. It was also brought up a suggestion to provide, to the extent practicable, the basis for the criteria that resides in the prescriptive requirements of the general recommendations (e.g., the basis of performance). It was also highlighted in an interview with one of the fire safety engineering practitioner, that it had for a long time been observed a lack of national consistency of safety being practised across the country. [44]

To further clarify the difference between the Swedish and Australian legislative framework, the same performance requirement on the topic "spread of smoke and fire" is presented.

From the Plan- and Building regulation (PBF, Sweden) [17]:

2. The development and spread of fire and smoke within the structure is limited.

As noticeable from the Swedish performance requirement, a variety of interpretation can be made to find a fire safety solution.

From the Building Code of Australia (Volume 1, Australia) [8]:

CP2:

a) *A building must have elements which will, to the degree necessary, avoid the spread of fire-*

$i.To\ exits;$
$\vdots$
$iv.In\ a\ building.$

b) *Avoidance of the spread of fire referred to in (a) must be appropriate to-*
$i.The\ function\ or\ use\ of\ the\ building;$
$\vdots$
$xi.The\ evacuation\ time.$

CP3: A building must be protected from the spread of fire and smoke to allow sufficient time for the orderly evacuation of the building in an emergency

CP4: To maintain tenable conditions during occupant evacuation, a material and an assembly must, to the degree necessary, resist the spread of fire and limit the generation of smoke and heat, and any toxic gases likely to be produced, appropriate to-

$a)\ The\ evacuation\ time;$
$\vdots$
$d)\ Any\ active\ fire\ safety\ systems\ installed\ in\ the\ building.$

CP6: A building must have elements, which will, to the degree necessary, avoid the spread of fire from service equipment having-

$a)\ A\ high\ fire\ hazard; and$
$b)\ A\ potential\ explosion\ resulting\ from\ a\ high\ fire\ hazard$

CP7: A building must have elements, which will, to the degree necessary, avoid the spread of fire so that emergency equipment provided in a building will continue to operate for a given period of time necessary to ensure that the intended function of the equipment is maintained during a fire

CP8: Any building element provided to resist the spread of fire must be protected, to the degree necessary, so that an adequate level of performance is maintained-

$a)\ Where\ openings, construction\ joints\ and\ the\ like\ occur;\ and$
$b)\ Where\ penetration\ occur\ for\ building\ services.$

With the explicit desire from the fire safety practitioners, and more complex projects initiating in Sweden today, it could be argued that a more thorough and quantitative building regulation is needed, to minimise uneven level of fire safety distributed within Sweden. The Australian building regulation is in comparison to the Swedish much more detailed, and provides quantitative measures to both the performance and prescriptive solutions. The results derived from this study also indicates that the Australian high-rise incorporated a higher level of fire safety than the Swedish building. Nevertheless, this is a scenario based risk assessment evaluation study, and it need to be validated by both experimental- and interview-studies to confirm if a wider applicable performance regulation can increase the effectiveness of fire safety within high-rise buildings.

7.3. Reflection on the Tr1 staircase configuration

The prescriptive provisions within the Swedish building regulation, recommends that fire safe stairs with passageways (Tr1 and Tr2 solutions), should be used to evacuate high-rise buildings. These stair configurations do provide a minimised risk of smoke or fire spreading inside the staircase, and weaken the construction of the building, as well as the safety of the occupants. The risk analysis carried out in this study, do however point out a weakness in these configurations when used for a greater number of people. The simulations illustrated that the fire safe passageways into the staircase caused congestion, due to the number of occupants. As a result this provided little level of safety for the office occupants. It must also be mentioned, that the Swedish building regulation allows for only one Tr1 staircase in a 16 storey office building. This is a prescripted solution that is prohibited by the Australian regulation. This solution was not incorporated within the Swedish high-rise building design in this report for two reasons. Foremost, it was desirable for the two buildings to imitate each other as far as applicable, to provide the same conditions for the occupants in both buildings. Secondly, using only one staircase configuration inside the Swedish building, would lead to difficulties in the risk analysis, in terms of providing safe egress for the occupants.

With these factors in mind, and the growing trend of high-rise buildings as a response to a growing population, it can be argued that the Tr1 solution do not encompass the ability to provide safety in terms egress for a greater number of occupants. The evacuation simulation conducted as part of the risk analysis, indicates that further evaluation on the adequacy in terms of egress from the Tr1 solution must be validated further by experimental studies.

7.4. Reflection on the Swedish requirements for high-rise office buildings

There is a greater risk associated with fire development in a high-rise building than for low- and mid-rise buildings. This is especially exemplified in building regulations where, as a response to higher numbers of floors, technical installations and other requirements, are implemented to reduce the hazard [45]. These implementations within the prescriptive solutions, are often associated with helping both fire- and emergency personal, during the event of fire. There is an apparent difference between the Australian and Swedish building regulation, regarding what is necessary in terms of active and passive fire protection, after the number of floors exceeds the reach of the fire department (ca. 25 m). Prescripted solutions for a high-rise office building with 16 floors in Sweden, do not see the need for further safety features to be incorporated than; pressurized water pipes, emergency elevator and smoke ventilation inside the single Tr1 staircase configuration [8]. It is noticeable that emphasis on these requirements, is clearly to make the evacuation more effective for occupants on higher floor levels. It must however, also be mentioned that neither of these requirements seems to ensure or fulfil the underlying performance requirement, earlier presented in section 3.3.1. in this report:

> *2. The development and spread of fire and smoke within the structure is limited*

In accordance with Boverket, this performance requirement is clarified in BBR section 5:5, and motivated by following; *to limit the spread of a fire within a building, fire protection both within and between fire compartments is required. In order to achieve compliance with this section, regulations regarding fire compartments et.al, are primarily required*. [46]. Prescripted solution regarding fire compartmental boundaries, provides no restrictions to separate an open space until 1 250 m^2 is reached. This solution is used in the Swedish high-rise evaluated in this study. In accordance with the prescripted solution in BBR, it could be argued that neither technical nor structural requirements are presented, to limit either the development or spread of fire and smoke within the high-rise considered in this study.

In an article from Swedish Television (SVT), the deputy director of the Swedish Civil Contingencies Agency (MSB) Jan Wisén, and duty officer on Stockholm fire department Göran Svensson, was interviewed about the Grenfell Tower Accident in London. Concern regarding the newly adopted trend of high-rise buildings was expressed, and the problem with fire propagating beyond the reach of the fire brigade, was highlighted [47]. The risk- and vulnerability analysis (ROS) for the Swedish municipals, Stockholm and Malmö, also highlights the risk of fire developing in a Swedish high-rise. The analysis for Malmö, presented little- or none handling-capability of both the fire- and emergency-department in the event of fire. The weaknesses identified in the management capacities, where reported as either “Clear problems” or “Uncertain”, when handling fire scenarios in city areas [48]. The Stockholm municipal could not present any information regarding the handling-capability of their management or performance in the event of fire in their analysis [49]. This increases the uncertainty regarding the overall level of fire safety in high-rise office buildings, and the Swedish fire- and emergency department resources available to handle fire scenarios.

For the equivalent building, designed in accordance to the Australian prescripted solutions, an automatic sprinkler system, a minimum of two independent evacuation routes from each floor, and a fire-control centre are required in addition to the Swedish requirements. Similar prescriptive solutions are also used in other western countries with renowned experience of high-rise buildings, like the USA and UK [6] [12].

Automatic sprinkler system is today a standard solution to mitigate the level of risk associated with a fire scenario. The implementation of sprinkler and the associated effect, have been documented for decades, and have today a documented efficiency ranging from 70 % to 95 % [29]. Based on the results from this study, it is therefore suggested that sprinkler system, as a mitigating requirement, is implemented in all buildings with an effective height beyond the capacity of the fire department. Installation of a sprinkler system in these buildings would address, and satisfy the performance requirement stated earlier in this section, since results shows that the “development of fire and smoke within the structure” is not limited. The handling capability of the fire department, is also a factor that needs to be taken into account, since analysis shows that their performances is inadequate.

Results presented in Table 17 (see section 6.1.1.), shows that the temperature within the smoke layer have reached untenable condition (80 ℃) furthest away from the fire, ca. 14 minutes after ignition. This temperature will only increase until the fire is suppressed. The spread of fire and smoke within the fire compartment, may reach a critical level prior to the fire department reaches the endangered floor level, as no active system is required to control the fire development. It is therefore suggested that Sweden follows the example of western more experienced countries building requirements, and incorporate sprinkler system for high-rise buildings exceeding the reach of the fire department vehicle.

7.5. Amendments to the Swedish building regulation

From this report, three main weaknesses have been identified in the prescripted solutions within the Swedish building regulation for high-rise office buildings, compared to the Australian prescripted solution. As this study aims at disclosing the level of safety within the Swedish building regulation, and provide improvements in forms of suggested requirements, a summary of the discussed improvements is presented:

1. Two independent evacuation routes connecting each floor requirement, for all buildings taller than 25 m.
2. Smoke lobby or similar requirement enabling a holding area that will provide safe accommodation for a sufficient number of occupants, when congestion and delayed movement is expected into the staircase.
3. Sprinkler system as a suggested solution towards a compulsory requirement of a fire extinguishing system within all buildings taller than 25 m.

The first two "improvements" listed above, aims towards occupant safety during the event of fire. The third aims more towards structural fire safety, as well as mitigating the risk of fire and smoke spread within the building.

By evaluating the performance of the Swedish high-rise, it can be argued that these three suggested requirements would provide the means for the building to meet the outlined objectives, and provide safe accommodation for the building occupants. The first requirement would ensure minimum two egress components in all high-rise buildings. As high-rise buildings generally accommodates a higher number of occupants, two independent evacuation routes would provide a robust means for occupants to safely evacuate in the event of fire. The second suggested requirement would provide a safe holding area for the occupants, to safely wait out expected congestion to enter the staircases. The third suggested requirement would not only extend the time available for the occupants to evacuate, but also provide a more robust structural safety level. As current regulation do not require any technical solution to prevent the spread of fire and smoke within the building, and the fire compartment can reach an area of 1 250 m^2, a sprinkler system could help control the fire. The effect of the sprinkler system would also assist the fire department, by providing more time to extinguishing the fire, as well as the building would sustain its structural ability much longer.

8. Conclusion

A scenario-based risk assessment has been conducted to evaluate the Swedish and Australian building regulations, with emphasis on high-rise office buildings. The evaluation, regarded the different level of fire safety provided from prescriptive solutions between Sweden, and a country with renowned experience with high-rise buildings. Following chapter points out the conclusion made from this study, by answering the two questions stated in section 1.2. *Aim and objective*.

The first question is regarding the modification of the Swedish building regulation for high-rise office buildings, compared to the Australian building regulation. It was observed during the identification of prescripted solutions and design process of the theoretical high-rise buildings, that the Australian building regulation was more conservative than the Swedish building regulation. The Australian building regulation also required more safety solutions for lower and less complex constructions. Already after 25 m, prescripted solutions such as: sprinkler system, minimum two independent fire-safe evacuation routes connecting each floor level, a fire control centre, pressurized smoke system, emergency elevator, pressurized fire hydrants and hose reels et.al, where required in order to satisfy the minimum fire safety level. For the same building in Sweden, the prescripted solution requires minimum one fire-safe evacuation route, smoke ventilation in stair configuration and pressurized fire hydrant in buildings with a height of 25 m vertically. The fire safety level within the Swedish building regulation do not seem to require much fire protective measures for office building until after 16 floors, when the building becomes Br0 classified and the use of risk assessment becomes mandatory to satisfy the performance requirements. With this said, it must be mention that both countries seems to deviate on what is necessary, in terms of fire safety requirements, after the effective height of a building exceeds the reach of the fire department (around 25 m). This is greatly reflected in the results from the scenario based risk assessment made in this study, where the Australian high-rise illustrated better performance and satisfied the risk analysis objectives.

The second question is regarding the fire safety difference between Sweden and Australia, when evaluated based on risk perception. Comparing the performance of each high-rise building towards the criteria of life safety objective, showed that the Swedish high-rise did not provide sufficient level of safety for the occupants to satisfy the objectives. The reason for this was the Tr1 and Tr2 configurations, which could not provide the same safe accommodation function in comparison to the Australian smoke lobby configuration. This led to congestion to enter the staircases, which increased the evacuation time and RSET value. The results indicates that the smoke lobby requirement provides a more robust safe egress for larger number of occupants, and when congestion can be expected.

To summarise the conclusions above, this study have indicated that the Australian building regulation have a higher level of safety incorporated within their minimum fire safety solutions, than the Swedish building regulation. The scenario based risk assessment conducted in this study, have also indicated that the Australian building regulation takes into account safer and more efficient egress, for larger numbers of occupants. The Australian building regulation also includes compulsory fire extinguishing systems and mandatory two independent evacuation routes from each floor level. The simulations have also presented a higher level of fire safety in the Australian high-rise building, in all simulated fire scenarios. It is therefore suggested that the three requirements, discussed in section 7.5 *Amendments to the Swedish building regulation*, are implemented into the Swedish building regulation:

4. Two independent evacuation routes connecting each floor requirement, for all buildings taller than of 25 m.
5. Smoke lobby or similar requirement enabling a holding area that will provide safe accommodation for a sufficient number of occupants, when congestion and delayed movement is expected into the staircase.
6. Sprinkler system as a suggested solution towards a compulsory requirement of a fire extinguishing system within all buildings taller than 25 m.

9. Further work

This study have been motivated by proactively work towards regulation change, prior to and instead of changes motivated by catastrophic and great societal fires incidents. Since this study have indicated a difference in the level of fire safety, within prescripted solution towards high-rise office buildings, between two countries like Sweden and Australia, further research around this topic might be of great concern for future regulatory change. Some suggestions on future research are described.

- **Conduct similar studies but for other aspects of fire safety**

  The objectives used as a metric to measure the level of safety within each high-rise have been in terms of occupant safety, a suggestion would be to instead evaluate the level of safety between Australian and Swedish building regulation in terms of material requirement. For instance, is there any difference in the level of safety in a high-rise building when evaluated on required material basis?

- **Conduct similar studies but with other building use**

  This study have only been conducted on buildings having a sole-occupancy of office use, it would therefore be of interest to evaluate the fire safety level in prescripted solutions for other building uses as well.

- **Conduct experimental studies on Tr1 vs Smoke lobby requirement**

  It was observed in this study that the holding ability of the smoke lobby did not get as affected by congestion into the staircase configuration as the Swedish Tr1 and Tr2 solutions. Experimental studies on the effectiveness of the Tr-solutions when used for a larger number of people, must therefore be conducted in order to examined and evaluate possible design changes when used in high-rise buildings.

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11. Appendix A – Building design layout

11.1. Swedish building layout

Following Table A1 enlists important building design configuring requirements, which influenced the final building design layout for the Swedish high-rise building evaluated in this study.

For a building with occupational class 1 and building class Br1, following list of material requirements is stated in the Swedish building regulations (see Table A1).

Table A1 - Material and building element requirements for a Br1 office occupational construction *[8] [39]*

MATERIAL AND BUILDING ELEMENT REQUIREMENTS GIVEN IN THE BBR

General requirements for separating structures				
Building class: Br1			Building element: EI 60	
Requirements for load-bearing structures				
Building class: Br1, > 3 floors			Grid system: R90	
Surface coat and covering in escape routes				
Building class: Br1	**WALLS:** B-S1,D0	**FLOORS:** C_{FL}-S1	**ROOF:** B-S1,D0	**Fire protective covering of combustible Walls:** $K_2$10/ B-S1,D0
Surface coat and covering in NON-escape routes				
Building class: Br1	**WALLS:** C-S2,D0		**ROOF:** B-S1,D0	**Fire protective covering of combustible Roof & Walls:** $K_2$10/ B-S1,D0

As can be noticed from Table A1, the European standard code for material classification have fully been adopted into the Swedish regulations. Following step after required material properties been evaluated, protection against fire spread within the building frame is addressed. This includes fire compartments, section and wall characterisations, as well as selecting required staircase. Table A2, summarise the general recommendations given in the BBR, as well as specific recommendations for the Swedish high-rise considered in this study.

Table A2 - Prescriptive requirements for a Br1 office occupational building given in the BBR *[8]*

PROTECTION AGAINST FIRE SPREAD

FIRE COMPARTMENTATION		
General recommendations: A general requirement for dividing building areas into fire compartments: Areas in different occupational classes must be divided by fire compartmentation. In addition, all evacuation routes must be composed as a fire compartment. Elevators is recommended to be constructed as a fire compartment. But as a means for compliance, it can also be a part of a staircase configuration, see staircase section.	**Br1 class recommendations:** Fire safety classification for fire compartments, need to be designed to meet EI60 requirements.	**Occupational class 1 recommendations:** Office apartments need to be designed as individual fire compartments.

FIRE SECTION		
General recommendations: To mitigate the spread of fire, BBR limits the maximum area of each floor depending on expected fire load, and which protection systems incorporated in the design. Maximum area of any floor with fire load less or like 800 MJ/m^2: - 2500 m^2 without protection measurements - 5000 m^2 with automatic fire detection system - Unlimited with sprinkler system	**Br1 class recommendations:** -	**Occupational class 1 recommendations:** -
STAIRCASE		
General recommendations: In buildings with > 8 floors but maximum 16 floors, areas must have at least access to one Tr2 classified staircase. In buildings with more than 16 floors, areas must have access to at least one Tr1 classified staircase, additional staircases must at least fulfil Tr2 classification. Tr1 shall be constructed with separating structures to mitigate fire and hot gas spread to staircase. It must have a fire safe passage built as a fire compartment between staircase and adjoining areas. Cannot have a connection to areas such as basements, garages, storage rooms, or similar. Tr2 Shall be constructed with separating structures to mitigate fire and hot gas spread to staircase. Adjoining area must be constructed as a fire compartment, but do not need an additional fire safe passage. Elevator shaft can be constructed in the same fire compartment. Cannot have a connection with basements if it represents the only escape route.	**Staircase Tr1 recommendations:** Following material/element recommendations: - Inner walls according to EI60 - Door to staircase E30-S_mC - Elevator door with EI60-C - Door to passage with EI60-S_mC, or EI30-S_mC if adjoining area is constructed as a fire compartment. - Must have a door in ground floor for fire department intervention	**Staircase Tr2 recommendations:** Following material/element recommendations: - Inner walls according to EI60 - Door to staircase EI60-S_mC - Door out from adjoining area with EI30-S_a - Elevator door with EI60-C - Must have a door in ground floor for fire department intervention

After requirements concerned with mitigating and containing the spread of fire and smoke within the building have been evaluated, following part focuses on means of egress in the event of fire. Here BBR emphasises on the specifics regarding evacuation routes, walking distance, various ways of evacuating the building as well as rescue personal intervention. Table A3, presents a summarisation of the requirements for the Swedish high-rise.

Table A3 - Continuation of prescriptive requirements given for a Br1 office occupational class building from BBR *[8]*

Possibility of evacuation in case of fire

<table>
<tr><th>Subject</th><th>Requirement</th></tr>
<tr><td>General/Access to evacuation route
Buildings should be designed to allow for adequate evacuation in the event of fire. Satisfactory evacuation means that persons who, with sufficient safety, are not exposed to falling building components, high temperature, high heat radiation, toxic gases or poor visibility that prevent evacuation to a safe place.</td><td>Unless otherwise stated, buildings shall be designed with access to at least two independent escape routes
Evacuation routes should be placed with distance of at least 5 m, to enable safe evacuation in the event of fire blocking one route. One evacuation route could be through an adjoining fire compartment, if the route is accessible without use of keys or other tools.
In building with 8 < floors ≤ 16, one staircase must be in accordance to Tr2 demands.
In building with 16 > floors, one staircase must be in accordance to Tr1 demands, other staircases should be at least in accordance to Tr2 demands.</td></tr>
<tr><td>Walking distance
Walking distance should be measured from the most unfavourable position. The road should be measured by assuming that the directional changes during the movement are right-angled. If the pathway to two independent escape routes partially coincides or may coincide, the common part is counted 1.5 times the actual length, to the nearest staircase or escape route.</td><td>Building class Br1, and Occupational class 1 requirements:
- Maximum distance to an escape route not to exceed 45 m
- Maximum distance within an escape route not to exceed 30 m</td></tr>
<tr><td>Dimensioning number of people
The evacuation route and road to the evacuation route(s) must be based on the maximum amount of people who can be expected to be inside the premises.</td><td>Offices in Occupational class 1: The personal density could be expected to be 1 person/m^2 net area</td></tr>
<tr><td colspan="2">Design of the escape route
• Escape routes serving less than 150 people should at least have a free width of 0.9 m, handrails and the like may interfere with no more than 0.10 m per side of the escape route, and doors must have at least a free width of 0.8 m.
• Escape routes serving more than 150 people should at least have a free width of 1.2 m, handrails and the like may interfere with no more than 0.05 m on the escape route. The total free width of the escape route must at least be 1 m per 150 persons, if one path is blocked the other should at least have a width corresponding to 1 m per 300 persons.
• No obstacle can be placed in the escape route
• Stairs cannot be designed closer than 0.8 m to a door.
• Free width of any stair should not exceed
• Passages forming its own fire compartment, must be should be separated every 60 m and designed in accordance to E15 and doors in E15-C.</td></tr>
</table>

Following part of BBR addresses recommendations for spread of fire between neighbouring buildings. Exterior requirements changes depending on the shape, height and classification of the building, as well as distances to neighbouring buildings. Table A4 presents the recommendations given in BBR.

Table A4 - Continuation of prescriptive requirements given for a Br1 office occupational class building from BBR *[8]*

PROTECTION AGAINST FIRE SPREAD

SUBJECT	**REQUIREMENT**
GENERALL	Requirements regarding spread of fire between neighbouring buildings are assumed satisfactory when the distance between the buildings exceed 8 m.
EXTERIOR WALL	Exterior walls in Br1 buildings must: - Separation function must be maintained between fire cells - Fire in the wall to be limited by combustible insulation is interrupted by a fire safely - The risk of the spread of fire along the facade surface should be limited - Risk of falling parts they panel, glass and plaster from the wall should be limited since it can damage the evacuation or emergency services
EXTERIOR WALL MATERIALS	Materials on the exterior walls for Br1 buildings must be in accordance to A2-s1,d0 classification, or D-s2,d2 classification if limited only to the bottom floor.
WINDOWS	Windows vertically separated with distance < 1.2 m must satisfy window classification E30 or both E15.
ROOF	Roof covering must be in accordance to A2-s1,d0 classification, or in accordance to B_{ROOF}(t2) on ulterior A2-s1,d0 classified materials.

Subsequent chapters in BBR presents requirements for passive and active fire safety installations, as well as requirements regarding fire department and rescue personal intervention. These requirements will not be addressed here, but rather be included in the more detailed fire safety concept, presented in *Appendix B.*

Taking into account following design configuring requirements, a building design for the Swedish high-rise building was constructed. The building design was influenced and constructed solely in accordance with requirements specified in the BBR. Figures A1-A2, illustrates the final design layout for the Swedish high-rise building evaluated in this study.

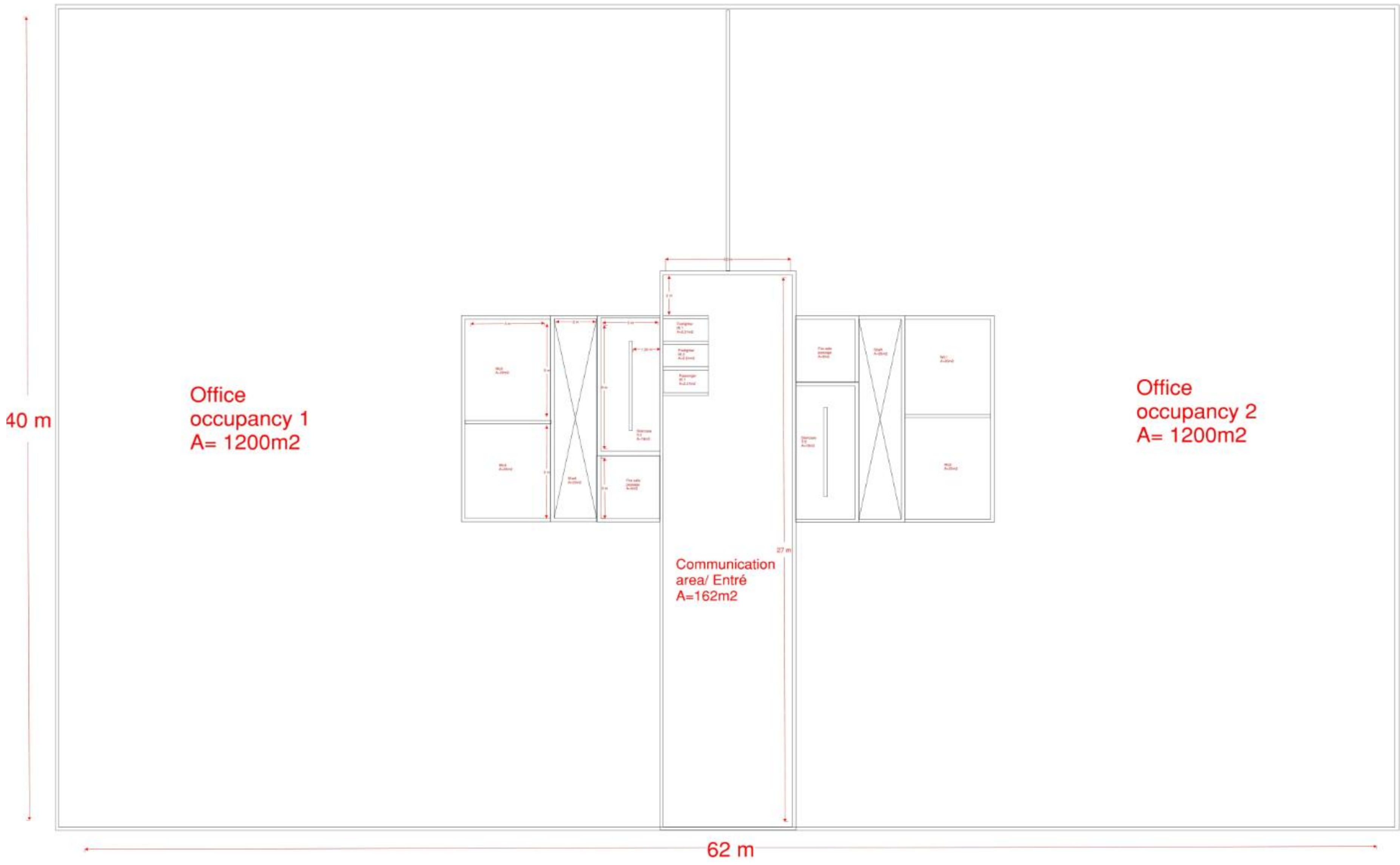


Figure A1 - Schematic representation of the ground floor in the Swedish high-rise building

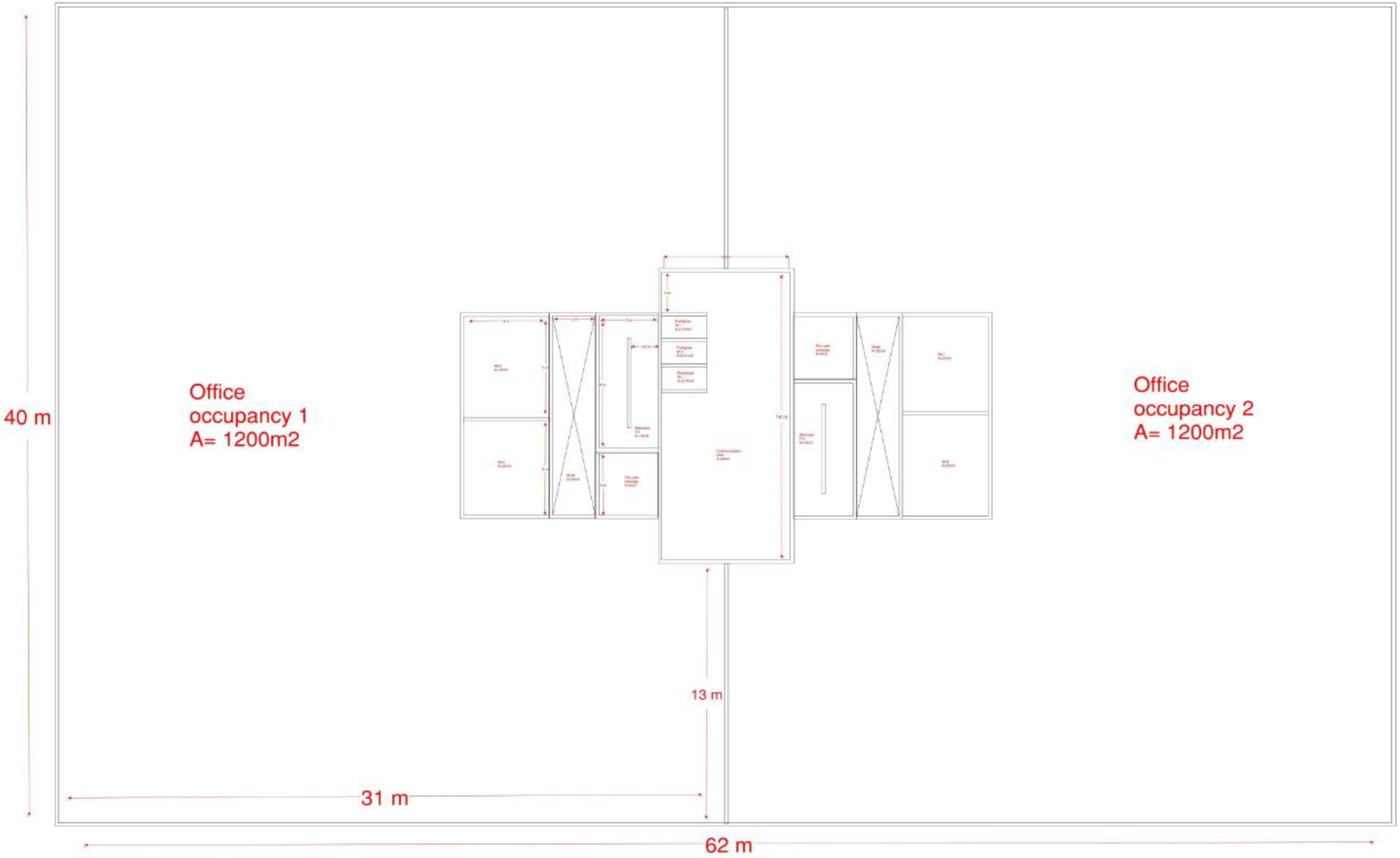


Figure A2 - Schematic representation of floor 2-16 in the Swedish high-rise building

11.2. Australian building layout

Following Tables (A5-A7) presents important design configuring requirements, which influenced the final building design layout results for the Australian high-rise building evaluated in this study.

Table A5 - Prescriptive solutions for a Type A Occupational class 5 high-rise building from section C in the BCA volume 1

SECTION C – FIRE RESISTANCE			
CLAUSE	**Subject**	**Requirement**	**Comment**
C1.1	Type of construction required.	With rise in storey > 4 storeys and Occupational class 5: - Type A construction.	The minimum type of fire-resisting construction of a building must be specified in accordance to C1.1. Type A construction is the most fire-resistant type of construction.
C2.2	General Floor area and volume limitations.	Class 5/ Type A: - Max floor area: 8000m^2 - Max volume 48000m^3	The size of a fire compartment in a building may exceed the specified requirements, if; - Sprinkler system installed - Perimeter vehicular access provided.
C2.6	Vertical separation of openings in external walls.	Type A: Any window/opening above another window/opening must be separated with non- combustible or fire-resistant materials.	This requirement does not apply if the building in question have a sprinkler system installed, and if the vertical distance exceeds 0.45 m.
C2.10	Separation of lifts shaft.	Type A: The walls enclosing the shafts must have relevant FRL by specification C1.1.	Any lift connecting more than 2 storeys (3 with sprinkler) must be separated from the remainder of the building by enclosure in a shaft.
C2.11	Staircases and lifts in one shaft.	A staircase and lift does not have to be in the same shaft if either is required to be in a fire-resisting shaft.	
C3.2	Protection of openings in external walls	If adjacent buildings are closer than 6 m, openings in the external walls must have a Fire-resistant level (FRL) in accordance to C3.4.	Distance to adjacent buildings are assumed to exceed 6 m.
C3.8	Openings in fire-isolated exits	Doorways that opens to fire-isolated staircases, passageways or ramps, and not leading to a road or open space must be protected by FRL -/60/30 and be either self-closing or automatic-closing.	The automatic closing must be initiated by either a smoke, or other type of detector. Including the activation of sprinkler system discharge.
C3.10	Openings in fire-isolated lift shafts	Doorways leading in to fire-isolated lift shafts must be protected by doors satisfying FRL level -/60/-	Must comply with standards and set to remain closed except when discharging or receiving

			passengers.
C3.12	Openings in floors and ceilings for services	Type A: Services passing through floors and ceilings required to have either an FRL or resistance towards spread of fire, must be constructed as a shaft complying with specification C1.1	
Spec. C1.1	Fire resisting construction	Element — FRL (minutes) External wall: - Loadbearing — 120/ 60/ 30 - Non-loadbearing — -/ -/ - Internal walls: Fire-resisting lifts and stair shafts. - Loadbearing — 120/ 120/ 120 - Non- loadbearing — -/ 120/ 120 Internal walls: Bounding public corridors, lobbies and like. - Loadbearing — 120/ -/ - - Non-loadbearing — -/ -/ - Internal walls: Between or bounding sole-occupancy units - Loadbearing — 120/ -/ - - Non-loadbearing — -/ -/ - Other loadbearing elements — 120/ -/ - Floors — 120/ 120/ 120 Roofs — 120/ 60/ 30	Specification C1.1 sets out the required FRLs of building elements in a type A construction For the specifics of the building considered in this study, building elements required to be non-combustible is given in the guide to volume 1: - External wall - Common wall - Floor and floor framing of lift pit - Non-loadbearing walls required to be fire-resisting - all loadbearing internal walls (including those of shafts) The roof and its primary structure can remain unrated in accordance to prescriptive measurements if the building is fitted with a sprinkler system.
Spec. C1.10	Fire Hazard Properties	Class 5: Floor linings and floor coverings must not be of materials with less critical radiant flux than: - 2.2 kw/m^2 or; - 1.2 kw/m^2 if sprinkler systems are installed in building. - Fire- isolated exits and control room requires 2.2 kw/m^2. Class 5, walls and ceiling linings must comply with respective group number: Fire- isolated exits and fire control rooms — Un-sprinkled 1; Sprinkled 1	A materials critical radiant flux is determined by testing the material in accordance with AS ISO 9239.1. This test is the floor radiant panel test. The higher a material's critical radiant flux is, the better the material performs. A material's group number is determined by testing the material in accordance with AS 5637.1. For the BCA, a Group 1 material

	Public corridors	Un-sprinkled Sprinkled	1,2 1-3	indicates the best performing material and a Group 4 material is the worst performing material.
	Specific areas	Un-sprinkled	1,2	
	Other areas	Un-sprinkled Sprinkled	1-3 1-3	Specific areas: Open plan offices with minimum floor dimension/ Floor to ceiling height > 5.

Table A6 - Prescriptive solutions for a Type A Occupational class 5 high-rise building from section D in the BCA volume 1

SECTION D – ACCESS AND EGRESS

CLAUSE	Subject	Requirement	Comment
D1.2	Numbers of exits required	Class 5: In addition to any horizontal exit, each storey must have no less than 2 exits from each storey.	This applies if the effective height of the building is more than 25 m.
D1.3	When fire-isolated staircases or ramps are required	Class 5: Every staircase or ramp serving as a required exit must be fire- isolated.	
D1.4	Exit travel distance	Class 5: With 2 required exits, no point on a floor must be more than 40 m from an exit.	
D1.5	Distance between alternative exits	Exits that are required as alternative means of egress must be: - Not less than 9 m apart, and; - In Class 5: not more than 60 m apart, and; - Located so that alternative paths of travel become less than 6 m apart.	If alternative paths of travel converge too closely, both paths can be blocked by the same fire. The minimum distance between the paths of travel aims to negate this.
D1.6	Dimensions of exits and paths of travel to exits	In a required exit or path of travel to an exit: - Unobstructed height throughout must not be less than 2 m - Unobstructed width except for doorways no less than 1 m. If storey accommodates more than 100 persons but less than 200, or if storey accommodates more than 200 persons, the unobstructed width of exit and path of travel to exit must increase (see comment).	101- 200 persons: 1 m in width plus 0.25 m for each 25 persons in excess of 100. From 201 persons and further, if egress involves change in floor level greater than 1:12: 2 m plus 0.5 m for each 60 persons in excess of 200, or; 2 m plus 0.75 m for each 75 persons in excess of 200 in all other cases.
D1.7	Travel via fire-isolated exits	Only following rooms can open directly into a fire-isolated staircase, passageway or ramp: - A public corridor, lobby or like - A sole-occupancy unit occupying all or a storey - A sanitary compartment, airlock or	Any room besides given in the requirement must not open directly into a fire-isolated staircase, passageway or ramp. Each fire-isolated

		like If more than 2 access doorways, not from a sanitary compartment or the like, open to a required fire-isolated exit in the same storey, a smoke lobby in accordance to D2.6 must be provided.	staircase must provide independent egress from each storey served and discharge directly, or by way of its fire-isolated passageway to an open space or to a storey only used fir pedestrian movement.
D1.13	Number of persons accommodated	The number of persons accommodated in a storey or room must be determined with consideration to the purpose for which it is used and the layout of the floor area. Excluding areas such as staircases, escalators, corridors and like. Office accommodation: 10 m^2/ person	
D2.2	Fire-isolated staircases and ramps	A staircase or ramp that is required to be within a fire-resisting shaft must be constructed: - Of non-combustible materials, and; - So that is there is local failure it will not cause structural damage to, or impair the fire-resistance of the shaft	
D2.6	Smoke lobbies	A smoke lobby required by D1.7 must: Have a floor area not less than 6 m^2, and be separated from occupied areas in the storey by walls impervious to smoke with FRL of no less than 60/60/-, and either extend from slab to slab, or to the underside of a ceiling. All openings from occupied areas must have smoke doors complying with Clause 3 of Specification C3.4	
D2.9	Width of required staircases and ramps	A required staircase or ramp that exceeds 2 m in width is counted as having a width of only 2 m.	
D2.11	Fire-isolated passageways	The enclosing construction of a fire-isolated passageway must: Have an FRL as fire-isolated staircase which passageway discharges from, or FRL not less than 60/60/60.	If FRL level not met, then the top of passageway need not to have an FRL, if the walls of the passageway extend to the underside of a non-combustible roof ceiling or a ceiling having resistance towards spread of fire of not less than 60 minutes.
D2.13	Goings and risers	A staircase must: - Have maximum 18 and minimum 2 risers in each flight. - Max 0.19 m and min 0.115 m in	

		rise (R) - Max 0.355 m and min 0.25 m in going (G) - Quantity (2R+G) of max 0.7 and min 0.55.

Table A7 - Prescriptive solutions for a Type A Occupational class 5 high-rise building from section E in the BCA volume 1

SECTION E – SERVICES AND EQUIPMENT

CLAUSE	Subject	Requirement	Comment
E1.3	Fire hydrants	A fire hydrant system must be provided to serve a building having a total floor area greater than 500 m^2, and fire department are available to attend a building fire.	Must be installed in accordance to AS 2419.1. Where internal fire hydrants are provided, they must serve only the storey on which they are located.
E1.4	Fire hose reels	A fire hose reel system must be provided to serve the whole building where one or more internal fire hydrants are installed. Fire hose reels must be located internally, externally or in combination to achieve sufficient coverage specified in the standard. Alternative prescriptive solution: Fire hose reels must be located within 4 m of an exit, and must be located so that any point on the floor is within 40 m of a fire hose reel nozzle end when laid to avoid obstructions.	The fire hose reel system must be installed in accordance to AS 2441, and only serve the storey at which they are located.
E1.5	Sprinkler	A sprinkler system must be installed in throughout the whole building if any part of the building has an effective height of more than 25 m.	The building has an effective height > 25 m, the building is hence forced to install a sprinkler system in accordance to specification E1.5
E1.8	Fire control centres	A fire control centre facility in accordance with specification E1.8 must be provided for buildings with an effective height of more than 25 m.	
E2.3	Provision for special hazards	Buildings more than 25 m in effective height and Class 5: Building must be provided with a zone smoke control system in accordance with AS/NZS 1668.1	
E3.2	Stretcher facility in lifts	A stretcher facility must be provided in at least one emergency lift required by E3.4. A stretcher facility must accommodate a raised stretcher with a patient lying in it horizontally, with dimension no less than 0.6 m wide x 2 m long x 1.4 m high above the floor level.	
E3.4	Emergency lifts	At least one emergency lift must be installed in a building with effective height of more than	

		25 m, and serve all available stories for occupants. Emergency lifts must be contained within a fire- resisting shaft in accordance to C2.10.
E3.7	Fire service controls	Lifts serving any storey above an effective height om 12 m must be provided with: - A fire service control switch complying with E3.9 - A lift car fire service drive control switch complying with E3.10 for every lift

Taking into account following design configuring requirements, a design for the Australian high-rise was constructed. The building design was influenced and constructed solely in accordance with requirements specified in the BCA volume 1/guide to BCA. Figures A3-A4, illustrates the final design layout for the Australian high-rise building evaluated in this study. The following building design have a dimension of 51m x 68m (height x length).

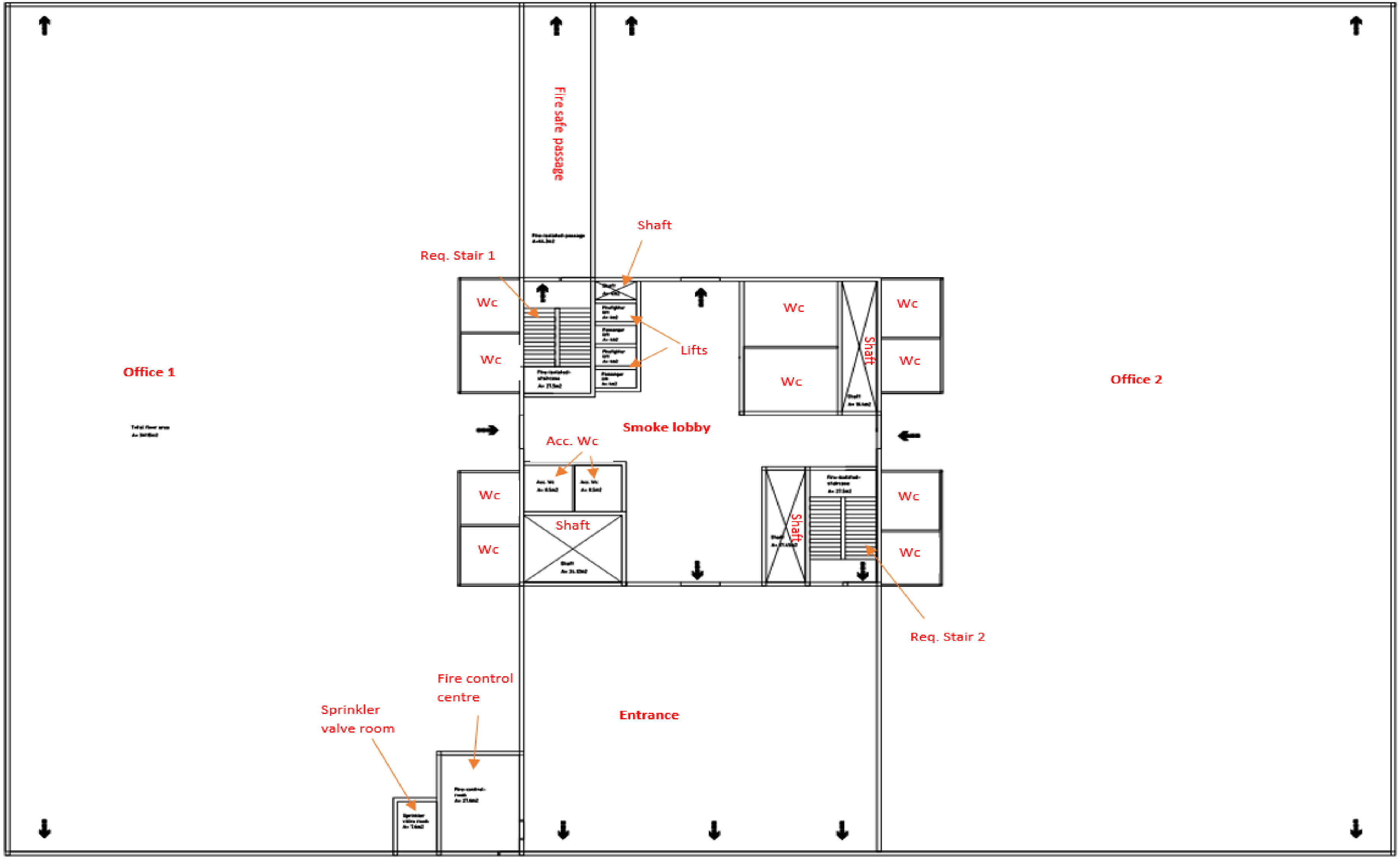


Figure A3- Schematic representation of the ground floor in the Australian high-rise building

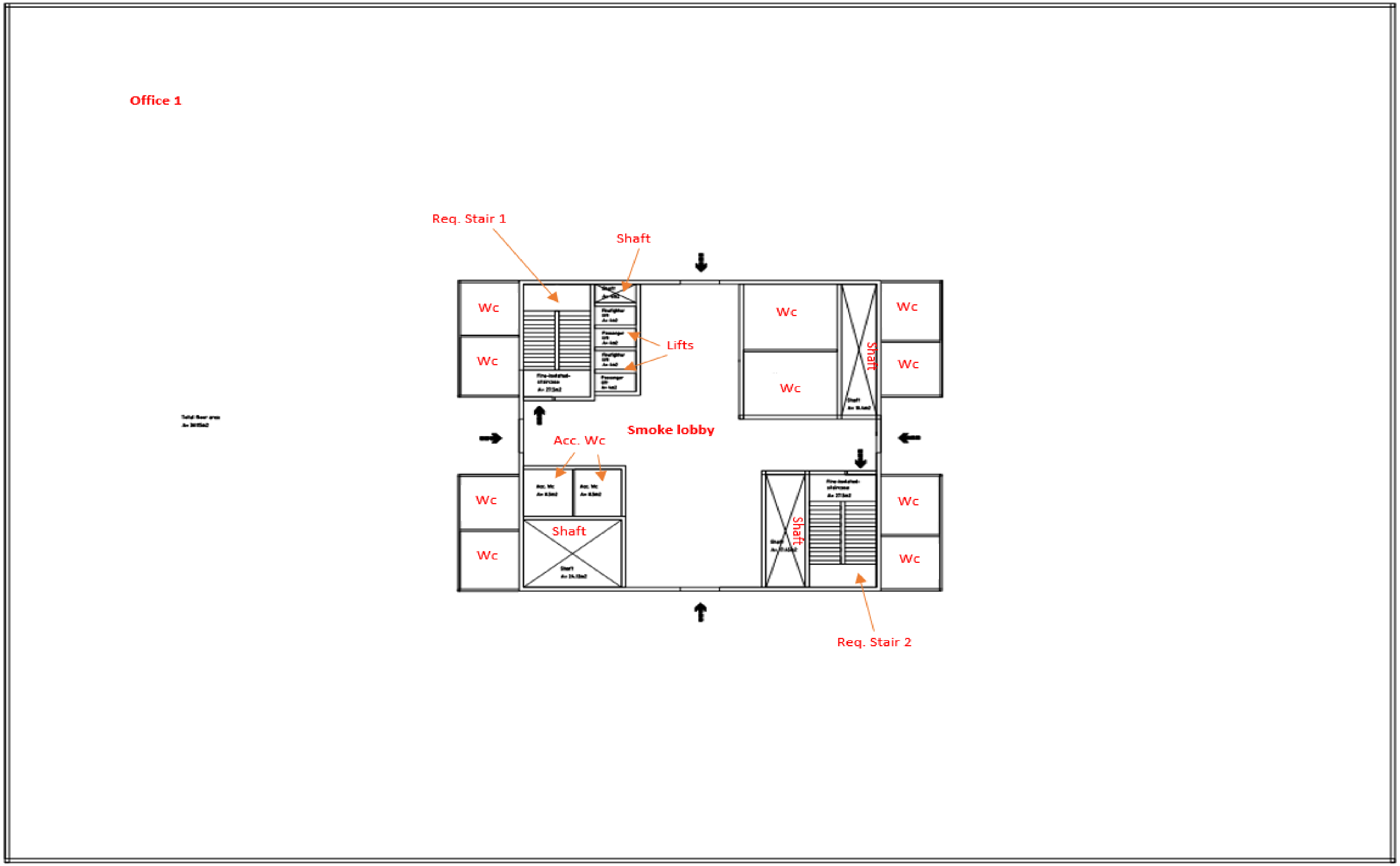


Figure A4 - Schematic representation of floor 2-16 in the Australian high-rise building

12. Appendix B – Fire safety concept, Sweden

FIRE SAFETY CONCEPT - SWEDEN

THIS DOCUMENT IS PREPARED FOR A THEORETICAL HIGH-RISE BUILDING STUDY

This fire safety concept is prepared and completed as a part of a masters study conducted on the area of high-rise buildings.

Fire and Risk Engineering

Emmanuel Eriksson, Fire engineer

1 Introduction

This fire safety concept specifies the solution that meet the functional requirements in chapter 5 in the BFS (2011:6 with changes up to BFS 2017:5), for the high-rise building considered in this study [8].

The fire safety concept has been based on the data reported in the following Table A1.

Table A1 - Basis for project.

Report name	Date	Status	Executed by
General floor layout design – Sweden	26/10 – 17	Complete	Emmanuel Eriksson
General section design – Sweden	26/10 – 17	Complete	Emmanuel Eriksson
Main thesis document	1/6 – 18	Complete	Emmanuel Eriksson

1.1 Scope and limitations

The fire safety concept discussed herein is only applicable to the theoretical high-rise building considered in this study. The fire safety concept, is therefore only to be consider in connection with the theoretical- case study, as well as high-rise presented in this master thesis.

Since the building considered in this fire safety concept is theoretical, no regards will be given to fire protection demands for organizational- and construction periods, otherwise stated in the fire safety concept. Inspection plans forming a part of a fire safety document is not considered either.

The consideration of factors such as; asset protection, continuity of use of the facility after a fire and other emergency incidents or extreme forms of scenarios is outside the scope of this fire safety concept, and has therefore not been addressed in this report.

Further limitations listed in the main document for this thesis are additional adopted in this fire safety concept. This subsequently means that this document need to be viewed in correspondence with the main thesis document.

2 Departure from current building rules – BBR

The high-rise construction considered in this report, will not make any departure from the functional requirements of BBR chapter 5, nor make any minor deviation of the kind referred to in section 1:21 of the BBR.

2 Design method

The fire protection design of the building has solely been designed by prescripted solution specified in chapter 5 of the BBR.

3 Design conditions

The fire protection design of the building has solely been designed by prescripted solution specified in chapter 5 of the BBR.

4 Design conditions

The high-rise building considered in this study is a sixteen (16) storey building, with a sole-occupancy consistent of office occupation. The building is rectangular-shaped of dimension 40m x 62,5m with a total area of 2500m^2 on each floor.

With the ground floor as an exception, each floor comprises of the same design, with two open areas forming the office accommodation spaces. The core centre of the building is primary as a communication space between each occupancy, as well as each floor level.

The building comprises two staircase configurations serving each floor, with discharge into the building entrance at ground floor.

4.1 Building classification

From the specified floor rise of 16 stories, the building is to be constructed in accordance to building classification Br 1.

4.2 Activity, occupational class and number of persons

Table A2 - Activity, occupational class and number of persons.

Activity	**Floor**	**Occupational class**	**Nr. Of people**
Office occupation	1	Occupational class 1	216 people/floor
Office occupation	2-16	Occupational class 1	223 people/floor

The number of occupants presented in Table A2 is based on the total office area available on each floor level. The total number of occupants that is to be expected within the building configuration is 3561 people.

4.3 Fire load

The dimensioning fire load (f) of the building has been determined in accordance to BFS to ≤ 800 MJ/m^2 floor area. [50]

4.4 Flammable products

The fire safety design assumes that no handling of flammable products will occur in the high-rise building considered in this study.

5 Construction engineering

5.1 Building description

Table A3 - Building description.

Location of building	Detached building with distance to adjoining building > 10 m
Number of floors	16 stories without either basement or loft construction.
Frame	Reinforced concrete structure on a concrete slab
Exterior walls	Reinforced concrete with a glazed external layer, complying with relevant requirements.
Roof	Insulated steel with sheet sealing layer
Inner walls	Lightweight wall constructions consistent of concrete
Air handling installations	Sufficient type of system for current legislating requirements for the building described in this document.
Heating system	Sufficient type of heating system for current legislating requirements for the building described in this document.

5.2 Requirements relating to materials, coating and clothing

The materials, coatings and clothing of the building configuration shall be in accordance to following Table.

Table A4 - Requirements for surface layers in Br1 buildings. *[8]*

Surface	**Surface layer classification**
Roofs in escape routes	To be design in accordance with B-s1,d0 classification, attached on materials with A2-s1,d0, or $K_2$10/B-s1,d0 classification.
Walls in escape routes	To be design in accordance with B-s1,d0 classification, attached on materials with A2-s1,d0, or $K_2$10/B-s1,d0 classification.
Floors in escape routes	To be design in accordance with at least C_{fl}-s1 classification.
Roofs in other areas	To be design in accordance with B-s1,d0 classification, attached on materials with A2-s1,d0, or $K_2$10/B-s1,d0 classification..
Walls in other areas	To be design in accordance with at least C-s2,d0 classification.
Elevator configuration placed in own shaft, satisfying fire compartment requirements	Roof and walls assemblies shall be designed in accordance with at least D-s2,d0 classification.
Pipe insulation for pipe installations whose total exposed enclosure area covers a smaller part of the adjacent wall or ceiling surface (≤ 20%)	To be design in accordance with at least BL-s1, d0 with surrounding surfaces in accordance with the B-s1, d0 requirement.
Pipe insulation for pipe installations whose total exposed	The insulation must comply with class A2-s1, d0 or surface layer requirement for adjoining surfaces.

enclosure area covers a larger part of the adjacent wall or ceiling surface (> 20%)	
Signal cables for telecommunications- and data traffic and power cables	Cables shall be carried out to meet the material class D_{ca}-s2,d2. Alternatively, may cables be in accordance with fire protection requirements given in SS 4364000. [51] Cable ducts and cable ladders can be designed according to SS-EN 61537. [52] Cable rails can be designed according to SS-EN 61534. [53] Suspension devices in escape routes shall be carried out in Class A2-s1, d0.

5.3 Fire compartments

5.3.1 Fire class

Fire compartmental components must at least satisfy fire safety classification EI 60, unless otherwise specified in subsequent chapter dealing with relevant building element in detail. All existing penetrations in fire separation building elements shall be constructed with at least the same fire resistance class as the interrupted part of the building.

5.3.2 Fire compartment separation

The following parts of the building shall be designed as individual fire compartments in accordance with EI 60 classification. Other required fire safety classifications are indicated in parentheses.

- Each staircase (Tr1 and Tr2), including their respective fire safe passageways
- The fire safe passage linking staircase and elevators with adjoining areas
- Each installation shafts
- Communication space between each staircase configuration
- Office occupational areas
- Firefighting elevator shafts
- Passenger elevator shafts

5.3.3 Elevator shaft

Lift shafts shall be designed to protect against fire- and combustion gas spread between fire compartments is maintained. The following options apply.

- The elevator shaft is designed as its own fire cell, where the fire resistance of the elevator doors is verified according to SS-EN 81-58 [54]. The elevator shaft should then be designed with a flue gas ventilation (mechanical fan or smoke trap).

Special consideration needs to be taken into account for the elevators serving as firefighting elevator during the event of a fire. Each firefighting elevator needs to meet the design, and configuration requirements of standard SS-EN 81-72 [55]. These requirements are specified in section 10.4 in this fire safety document.

5.3.4 Fire section

No floor area exceeds the area of 1 250 m^2, fire section requirements are therefore not taken into consideration in this fire safety document.

Table A5 - Maximum size of fire department. *[50]*

Protection design	Maximum size (net area[1]) of floor area with fire load f (MJ/m^2)	
	$f \leq 800$	$f > 800$
No automatic fire alarm- or automatic fire extinguishing system	2 500 m^2	1 250 m^2

As mentioned above, are these requirements not relevant due to that none of the fire compartments size exceeds 1 250 m^2.

5.3.5 Doors in fire compartment elements

Doors, shutters and gates between fire compartments must be designed in accordance to following Table.

Table A6 - Functional requirements for doors, shutters and gates in fire compartment construction – Br1 construction. *[8]*

Doors (applies to shutters and gates as well)	Fire safety classification
Doors between fire compartments, general.	EI 60
Doors between fire compartments that are expected to be open.	EI 60-C
Door to staircase configuration	EI 30-S_mC
Door to evacuation route	EI 30-S_aC
Door to Tr2 stair configuration in a building with more than 8 floors	EI 60-S_mC
Door between offices in Occupational class 1 and comparable spaces where persons stay more than temporary and space in their own fire cells which connect to Tr2 staircases	EI 30-S_a
Door between other spaces office in Occupational class 1 and comparable spaces where people stay more than temporary, and fire safe passage to Tr2 staircases	EI 60-S_mC
Elevator door between elevator shaft and fire compartment, or area forming a fire compartment	EI 60-C (verified in accordance to

[1] Net area is determined based on all plans included in the fire cell or fire department. Horizontal sectional boundaries may be performed as a fire cell limit with the corresponding requirements of section 5.3 but without the requirement of protection against mechanical impact (M).

which connects to Tr2 staircase configuration	SS-EN 81-58 [54])
Door between fire safe passage and Tr1 staircase configuration	E 30-S_mC
Door between premises and fire safe passage to Tr1 staircase configuration	EI 60-S_mC
Door between connection, corridor or similar spaces in own fire compartments, and fire safe passage to Tr1 staircase configuration	EI 30-S_mC
Elevator door between elevator shaft forming a fire compartment and fire safe passage connecting to a Tr1 staircase configuration	EI 60-C (verified in accordance to SS-EN 81-58 [54])

The doors marked with "-C" in the Table A6 should be provided with a door closer. Door closer shall at least satisfy fire class C1.

In cases where fire compartment doors need to be kept in the installed position, they shall be carried out with a door closer as well as a mounting device that closes the door on smoke detector signals located on both sides of the fire compartment boundary.

5.3.6 Windows in fire compartment constructions

Windows and glass constructions in fire compartment elements shall be designed with fire classes specified in accordance to Table A7.

When measuring distances according to Table A7, heat radiation is assumed to be perpendicular and oblique from the window at a 135 ° angle from the window surface. Generally, fire-rated windows may only be openable with tools, keys or similar.

Table A7 Fire class functional requirements for windows/glass constructions between fire compartments - Br1 construction. *[8]*

Windows/glass construction	**Distance (m) between windows**	**Fire class**
Glass construction between fire compartment, general	---	EI 60
Windows placed above each other in vertical direction	≥ 1,2	No required fire class

The vertical distance between windows placed in the exterior exceeds distances specified in Table A7, no fire class requirements other than for the exterior wall needs to be taken into account.

5.3.7 Exterior wall protection against fire spread

Exterior walls shall be designed to prevent vertical fire spread between fire compartments via exterior wall assemblies. Functional fire safety class for windows and other glass constructions in the exterior wall is stated in section 5.3.6.

Table A8 Functional requirements for protection against fire spread via exterior wall assembly – Br1 construction. *[8]*

Functional requirements	Exterior wall design
1. Separating function between fire compartment	Exterior wall constructions should be designed to maintain the separation function between fire compartments.
2. Limitation of fire spread within the wall	Exterior wall should consist of materials satisfying the grade A2-s1, d0 or separated so that a fire inside the wall is prevented from spreading past the separation structure for 60 minutes.
3. Limitation of risk of fire spread along the facade surface	Exterior wall should consist of materials satisfying the grade A2-s1, d0
4. Limitation of risk of personal injury due to falling parts of the exterior wall	Exterior walls should be designed to minimise the risk of falling building components, such as glass slabs, small slabs and the like.

Exterior wall constructions, in accordance with SS-EN 13501-2 [56], with fire performance according to the standard fire curve, fulfil the functional requirements for fire compartmental separation, meet functional requirement 1 according to Table A8.

Approved exterior wall constructions tested according to SP FIRE 105 edition 5 [57], with conditions specified below, fulfils functional requirements 2-4 from Table A8.

- No large parts of the façade must fall off, e.g. large pieces of exterior slabs, plates or glass slabs, which can cause danger to unsuspecting people or rescue personnel, and;
- The spread of fire in the surface layer and inside the wall is limited to the bottom of the window, two floors above the fire compartment, and;
- No external flames appear that can ignite the roof feet located above the window two floors above the fire compartment. As an equivalent criterion, the gas temperature just below the ceiling foot does not exceed 500 ° C for a continuous period longer than 2 minutes or 450 ° C for longer than 10 minutes.

5.4 Structural ability in case of fire

In subsequent part, functional requirements for the building is specified in accordance to EKS, concerning the structural stability requirements for building elements during fire. Dimensioning of the required fire performance has been carried out according to the fire dimensioning process described in SS-EN 1990 section 5.1.4. [58].

Any design part that is in danger of raising the integrity of a fire compartment shall retain the capacity of the same class as the applicable fire compartment.

5.4.1 Requirements

Requirements other than those for maintaining the fire compartment limits are presented in the following Table.

Table A9 - Functional requirements for load bearing capacity during fire – Br1 building *[8] [39]*

Safety class	Building element	Fire class	Comment
5	Main structural system	R 90	Primary-bearing columns, beams, slabs and panels
	Stabilizing system		System for e.g. wind load, staircase configuration and elevator shaft.
	Other structural elements that might result in the collapse of a floor area > 150 m2		-
	Floor beams and floor tiles		-
4	Roof constructions except light surface constructions[2] (50 kg/m^2)	R 60	Ability to descend into a lower fire class may be available for roof construction, on fire compartmental-separating floor joints, if it can be shown that a collapse of the outer roof structure does not lead to falling buildings parts
	Attachment of heavy exterior finishes (50 kg/m^2) located 3.5 m above ground.		Exterior construction not included in the main load system
3	Eaves	R 30	Valid when the eaves come out more than 0.5 m
2	-	-	-
1	Light exterior construction[3] (50 kg/m^2) Included in the roof construction	R 0	Requirements for attachment, as for roof construction
	Eaves		Valid when the eaves come out not more than 0.5 m
	Carrying system for elevator in shaft		Which are not part of the main structural system

[2] With light surface construction, it is referred to elements such as; free bearing roofing panel, reinforced sheets, metallic plates, etc.
[3] With light surface construction, it is referred to elements such as; free bearing roofing panel, reinforced sheets, metallic plates, etc.

Safety class	Building element	Fire class	Comment
	Other structures that do not belong to the safety class 2-5		-

5.4.2 Compliance of requirements

To satisfy the requirements presented in Table A9, following element assemblies will be used to meet following Fire class [59]:

- R 90: 170 mm thick reinforced concrete wall/ slab/ floors with 25 mm cover to reinforcing
- R 60: 140 mm thick reinforced concrete wall/ slab/ floors with 10 mm cover to reinforcing
- R 30: 120 mm thick reinforced concrete wall/ slab/ floors with 10 mm cover to reinforcing

5.5 Protection against fire development

The building is assumed to have a sufficient type of heating system, complying with current legislating requirements for the building described in this document. The system is assumed to have sufficient preventative measures for the possibility of developing, and spreading of fire to adjoining parts of the building.

5.6 Protection against fire spread to adjoining buildings

5.6.1 Distance between adjoining building

Functional requirements for protection against fire spread to another building are met since the horizontal distance to such building is at least 8 m.

6 Ventilation fire protection

The specified solution to satisfy the safety requirements of fire- and hot gas spread between adjoining fire compartment is detailed in this chapter. The building is assumed to have a type of ventilation system, complying with current legislating requirements for the building described in this document.

The air handling systems in the building shall be designed to be switched off, when detecting smoke and hot gases within the vent channel premises. In addition, fire dampers must be fitted in each section where vent channels penetrate fire compartmental elements, and designed to be closed when detecting the presents of smoke.

Table A10 presents a summary of the buildings air treatment installations.

Table A10 - Summary of the buildings air treatment system.

Location of the ventilation unit		
The main ventilation unit is located on top of the building and is assumed to supply all floor levels, and comply with current regulation.		
		System 1
Served fire compartments		All fire compartments in all respective floors of the building.
Requirement level	Protection against fire spread between fire compartments	EI 60
Protection method	Protection against fire spread between fire compartments	Fire dampers in each fire compartment with material requirements in accordance with respective fire compartment.
	Protection against smoke spread between fire compartments	Fire dampers in each fire compartment with material requirements in accordance with respective fire compartment.

6.1 Protection against fire spread within the fire compartment

The ventilation system with respective channels, isolation and units shall be constructed and consist of non-combustible materials. Lower fire class is acceptable only for system parts presented in following Table.

Table A11 - Requirements for surface layers, materials and exterior clothing for ventilation systems. *[8]*

Unit in ventilation system	Requirements
Smaller details such as filter material, seals, fan units and electrical installations.	Class F material
Ventilation channels, except kitchen channels.	Corresponding surface layer requirements as connecting wall or ceiling surfaces. The exception applies for both the inside and outside of the channel.
Channels in the shaft and system room, if designed so that fire cannot be spread to, or from the shaft or system room for the time corresponding to the fire resistance of the fire compartmental boundaries in the current building.	Class E material
Air terminals	Class E material

6.2 Protection against fire/smoke spread between fire compartments

The ventilation system shall be design fire dampers placed between all fire compartmental boundaries. The ventilation system will be fitted with smoke detectors within the channel system. Detection will lead to shutdown of the ventilation system, and closing of fire dampers between building elements, to mitigate the spread of fire to adjoining fire compartments.

6.3 Control, detection and power supply

Damper that will mechanically change position in case of fire shall be tested and checked in accordance with the manufacturer's instructions, however, with an interval of no more than 6 months, see SS-EN 15650 [60]. This is the minimum requirement of BBR.

Detection of hot gases will be through channel positioned smoke detectors. A smoke detector shall be placed in the air inlet duct, directly after the ventilation system for the detection of hot gases coming outside or in the ventilation system.

The fire dampers must in the event of power failure be switched to closed position.

7 Possibility of evacuation in case of fire

7.1 Access to escape route

The building must be designed so that safe evacuation is provided in the event of fire. Escape must be provided from every space where people are permanently, or more than sporadically staying, by at least two independent escape routes in the building considered in this report.

An escape route can be one of the following:

- Discharge directly out into the free.
- Fire-safe constructed space in the building that leads from an area to an exit, example: Staircase configuration.

The escape routes in the building consists of the following:

- Two staircase configurations (One Tr1 and Tr2) located at the core centre of the building. Both staircase configurations connect with each building floor, and discharges at ground floor level.
- Evacuation doors in office accommodation areas only for offices at the ground floor
- The entrance door for the building, forming the exit discharge out into the free for floor level 1-16

7.1.1 Evacuation strategy

Each floor consists of the same floor layout, with two identical but inverted open office spaces, enclosing a building core, see the layout in *Appendix A*. This means that the evacuation strategy given for one floor, subsequently applies for every floor except ground floor.

Table A12 - Evacuation strategy for the building.

Area	Escape route 1	Escape route 2
Ground floor (left & right wing)	Office occupants will discharge directly out into the free, by evacuation doors installed for evacuating purposes off office occupants on the ground floor.	Office occupants will venture into the communication space, which discharges directly out into the free
Left wing office space. (floor 2-16)	Office occupants will venture into the fire safe passage, discharging directly into the Tr1 configured staircase. The staircase will then lead to ground level where exits will discharge directly out into the free.	Depending on the shortest travel distance; Office occupants will either horizontally travel through the fire compartmental boundaries to the right-wing office space, then subsequently move into the Tr2 staircase configuration.
Right wing office space (floor 2-16)	Depending on the shortest Office occupants will venture into the fire safe passage, discharging directly into the Tr2 configured staircase. The staircase will then lead to ground level where exits will discharge directly out into the free.	Depending on the shortest travel distance; Office occupants will either horizontally travel through the fire compartmental boundaries to the left-wing office space, then subsequently move into the Tr1 staircase configuration.
Alternative route (Offices floor 2-16)	Office occupants will venture into the communication space in the centre of the building core, forming a fire compartment. Here will they venture into the fire safe passage, and subsequently the Tr1 or Tr2 staircase configuration. The staircase will then lead occupants to ground level, where discharge will be provided out into the free.	

7.1.2 Evacuation for people with reduced mobility

Special installations for people with disabilities are not taken into account in this fire safety concept. According to current building legislation, there is no requirement for the building to be equipped with special facilities to enable persons with disabilities to put themselves in safety in the event of fire (example evacuation or evacuation hoist).

According to the Work Environment Authority (AFS 2009: 2), it is the responsibility of each employer to ensure that workplaces are accessible to people with disabilities and that evacuation from these premises is possible [61].

7.2 Walking distance

7.2.1 To escape route

The maximum walking distance to the nearest evacuation route in the building, which cannot be exceeded is given in Table A13.

Table A13 - Maximum allowed walking distance to nearest escape route. *[8]*

Activity/area	Walking distance to nearest escape route	Factor for calculating walking distances
Office accommodation area	45 m	1,5
Communication area on ground floor	< 45 m	1.5

7.3 Doors and walkways in and to escape routes

7.3.1 Door-discharge direction

The discharge direction for doors leading to, and placed in evacuation routes shall be outward in the evacuation direction.

7.3.2 Door fittings and re-entering

Doors leading to and placed in evacuation routes shall generally be easily openable without a key or other tool.

Doors too any staircase configuration or fire-safe passage shall be designed so that people can re-enter the premise. This will be done by allowing handlebars on the other side to open the door without lock interference.

Each office accommodation area on respective side of the core centre, accommodates 125 people respectively. For requirements on each door see the following Table:

Table A14 - Door fittings. *[8]*

Door/ area	Fittings
Door between office area and the fire safe passage connected to staircase configuration	Door fittings with conveniently handle, in accordance to SS-EN 179 [62]
Door between the communication space and the fire safe passage	
Door between office areas and communication space	
Door between the fire safe passage and staircase configuration	
Door from office areas at ground floor out into the free	
Door in the fire compartmental boundary between office occupancies.	

7.3.3 Evacuation passage dimension

The following Table A15 presents requirements for the dimensions of the evacuation passage for each door/ passage.

Table A15 - Passage dimension. *[8]*

Door/ passage	**Free width**	**Free Height.**
Door between office area and the fire safe passage connected to staircase configuration	1.2m	2m
Door between the communication space and the fire safe passage		
Door between office areas and communication space		
Door between the fire safe passage and staircase configuration		
Door from office areas at ground floor out into the free		
Door between office occupancies in fire compartmental boundaries		
Door between sanitary compartments and office areas	0,9m	2m
Distance between door and staircase should at least be 0.8 m		

7.4 Elevator

7.4.1 Lifts for passenger transport in normal operation

Elevators for passenger transport shall be carried out with so-called fire function which means that the elevator goes to the nearest stop plane and opens the doors in case of power failure.

7.4.2 Firefighting elevator

The building has a respective floor count that exceeds 10 floors, and a floor area over 900 m^2. This requires the building to have two firefighting elevators connected with each floor.

Firefighting lifts shall be carried out in accordance with SS 81-72 "Safety rules for the construction and installation of lifts - Special applications for persons and passenger lifts - Part 72: Fire-fighting lifts" [55]. This is further specified in subsequent chapter 10.4 in this report.

7.5 Emergency service involvement in evacuation

The buildings fire safety design is based on that emergency personal service will not contribute to assist evacuation.

8 Fire technical installations

8.1 Guiding marks

Escape routes shall be provided with luminescent guiding marks and guidance marking in accordance with AFS 2008: 13th luminescent markings should be carried out and placed in accordance with the general guidelines to BBR 5: 341 and AFS 2009: 02 [61] [63].

The guiding marks should at least be 0.1 m high.

The principle of organising luminescent guidance markings, including guidance marks, shall be as follows: wherever in the building (except for toilets and for the sake of evacuation of similar spaces) you must see at least one indicative mark or reference indicative marking.

Each firefighting lift must be provided with a pictogram identifying which elevator which can be used during the event of a fire.

8.2 Lighting

8.2.1 Emergency lighting

Luminescent guiding marks must be supplied with emergency lighting. In addition, the staircase configuration in the building must be supplied with emergency lighting. Emergency lighting in guiding marks and in staircase configurations must be designed to maintain its function for at least 60 minutes during power failure.

The illumination intensity must be at least 5 lux in the walkway.

Emergency lighting should be designed with either local or centrally located battery. In the case of centrally located batteries, power cables for emergency lighting must be placed separately in fire class EI 30 or have equivalent fire resistance. Emergency lighting should not be extinguished in other parts of the building than the fire compartment in which the fire is located. Guidance markings shall be performed and placed in accordance with the general advice for BBR 5: 341, AFS 2009: 02 and SS-EN 1838 [61] [64].

8.2.2 General lighting

General lighting should be provided in all escape routes. The illumination intensity should not be less than 100 lux in the escape route.

The general lighting should be on during the normal operation of the building, and be switched on automatic when occupants enters the premises. Lights supplied in either staircase (Tr1 and Tr2) and walkways must come from two various group fuses, so that they do not go out due to the same failure. Electricity supply cables for general lighting shall be separated in the fire class EI 30, or have equivalent fire resistance, in those parts of the building served by the staircase. The general lighting is to be carried out in accordance with AFS 2009: 02 §§ 10-15 [61].

8.3 Alarm

Smoke and fire detection will only be fitted in each staircase configuration, as well as in the ventilation channels. Not relevant for other areas of the building considered in this report.

There are no requirements for fire detection alarm in the BBR for any of the building specifics. Smoke/ fire detection and alarm is therefore not included in the fire safety design of the building, for any other areas than the staircase, and vent channel configuration.

8.4 Signage

8.4.1 Evacuation plans

Not relevant for the building considered in this report.

Evacuation plans are a separate product to the fire safety concept, and there are no requirements evacuation plans in the BBR for any of the building specifics. Evacuation plans is therefore not included in the fire safety design of the building. For clarifying purposes of the evacuation strategy, see *Appendix A – Buildings design layout* in correlation to the evacuation strategy in section 7.1.1.

8.5 Fire extinguishing equipment

8.5.1 Water risers

Each staircase configuration must have a pressurised pipeline for discharge of extinguishing water installed.

There must be withdrawals from floor level three, and thereafter in at least every subsequent floor level. The working pressure at the outlet from the riser shall be between 0.8 MPa and 1.2 MPa. Staircase configurations should be designed to connect at least two steel pipelines, with each pipeline serving a flow of 300 l/min.

The distance shall not exceed 50 m between a riser and the most distant part of the space to be serviced.

Staircases should be designed according to SS 3112 [65]. If gaps to the outlets should be locked, they should be openable with fire protection key designed according to SS 3654 [66].

The withdrawal must be marked with signs designed according to AFS 2008: 13 [63].

9 Smoke and heat ventilation

9.1 Staircase configuration

Staircase configurations Tr1 and Tr2 in the building shall be designed with smoke and heat ventilation.

The method that will be used in to satisfy the requirements given in the BBR is the following:

- Access fuel fans dimensioned to exhaust fire gases with an average temperature of 300 ° C (max. 350 ° C) for 30 minutes and the capacity to convert the full staircase volume 20 times/h.

Fire extinguisher fan must be operated electrically from the entrance level of the staircase configuration, with the control device marked with a clear sign made in accordance with AFS 2008: 13 [63]. The control device is advantageously placed behind the locked door made with lock that can be opened with so-called fire locker key.

The fan power supply and control device must be protected against direct fire impact for at least 30 minutes.

10 Possibility of rescue operations

10.1 Accessibility

The fire- and emergency service shall have access to the building for fire-fighting, and evacuation operation via the public road network, and through internal real estate roads. The distance between the location and nearest point of attack shall not must not exceed 50 m.

The road for fire and emergency rescue personal is assumed satisfactory to the requirement stated earlier. The fire and rescue services access routes for internal operations are the escape routes reported in section 7.1.

10.2 Rescue service deployment time

As mentioned in section 4.1. *General assumptions* in the main document, is it assumed that the building considered in this fire safety document, is located within a 5km driving distance to a metropolitan fire station. Deployment time for emergency rescue personal can therefore be assumed to be ≤ 10 minutes.

10.3 Fire hydrant

Supply of fire water is met by the following option:

- A municipal fire post network (performed according to VAV P76 / P83 [67] [68])

The adjoining area for the building considered in this report is assumed to be able to supply with several municipal fire hydrants within a satisfying distance.

10.4 Firefighters lifts

Two firefighting lifts are included in the fire safety design of the building, located within the communication space. These are designed to meet the functional requirements set out in standard SS-EN 81-72, and comply with both design configuration, as well as operational demands listed in the standard [55].

Both firefighting lifts are located within the same fire compartmental shaft, divided from the adjoining passenger lift by elements in accordance to fire compartmental requirements. Each landing entrance forming the communication space prior to the office areas, are required to be a smoke and fire protected lobby (fire compartment). This requirement is met by the structural design requirement, laid out in previous chapters.

The primary and secondary electrical power supply cables shall be fire protected and separated from each other and other power supplies. Electrical equipment within the lift shaft and on the elevator car, must be protected from dripping and splashing of water. Suitable means shall be provided to ensure water is mitigated to enter the firefighter lift.

13. Appendix C – Fire safety concept, Australia

FIRE SAFETY CONCEPT - AUSTRALIA

THIS DOCUMENT IS PREPARED FOR A THEORETICAL HIGH-RISE BUILDING STUDY

This fire safety concept is prepared and completed as a part of a masters study conducted on the area of high-rise buildings.

Fire and Risk Engineering

Emmanuel Eriksson, Fire engineer

1 Executive summery

This fire safety concept documents a review of a theoretical high-rise building against prescripted requirements of the Building Code of Australia (BCA).

Documentation used in collaboration to assess requirements include:

- Architectural drawings for the office occupancy used building (see *Appendix A*).
- Main thesis chapters.

The classification for the theoretical high-rise pursuant to the BCA is a class 5 office.

The building structure is to be designed to resist loads and load combination as described in the relevant standards, specified in the BCA.

The building has a total rise in storeys of sixteen (16), and is therefore required to meet the minimum construction requirements of Type A. The fire-resistant construction requirements for Type A includes walls, roofs, floors, columns and beams, and are specified in the subsequent chapters of this document.

The building is required to provide access and egress for all people, such that people with disability can access all areas of the building. Two independent exits are required to serve each floor to meet the minimum fire life safety provisions. Number of exits is based on the specifics of the building considered in this study, and exit travel distance, distance between exits and estimated number of occupants. Each staircase configuration, serving as a required exit, must be fire-isolated and discharge through safe passage directly to the street or open space.

The requirements for fire services, and smoke hazard management for the building considered in this study include following:

1. The installation of an automatic sprinkler system,
2. Two fire isolated exits and passageways,
3. A zone smoke control system,
4. An automatic air pressurisation system,
5. Smoke detection and alarm system,
6. A fire control centre within the building enclosure,
7. Fire hydrants and hose reels coverage throughout the building,
8. Emergency Warning and Intercommunication System (EWIS) throughout the building.

2 Introduction

This fire safety concept specifies the solution that meet the functional requirements of the Building Code of Australia, for the high-rise building considered in this study.

The fire safety concept has been based on the data reported in Table C1

Table C1 - Basis for project.

Report name	Date	Status	Executed by
General floor layout design – Australia	26/10 – 17	Complete	Emmanuel Eriksson
General section design – Australia	26/10 – 17	Complete	Emmanuel Eriksson
Main thesis document	1/6 - 18	Complete	Emmanuel Eriksson

2.1 Scope and limitations

This report identifies compliance requirements from the BCA, based on design drawings for a theoretical high-rise containing a sole-occupancy office use.

The fire safety concept discussed herein is only applicable to the theoretical high-rise building considered in this study. The fire safety concept, is therefore only to be consider in correlation with the theoretical- case study, as well as high-rise presented in this master thesis.

Since the building considered in this fire safety concept is theoretical, no regards will be given for organizational- and construction period fire protection demands, otherwise stated in the fire safety concept. Inspection plans also forming a part of a fire safety document is also not considered.

The consideration of factors such as; asset protection, continuity of use of the facility after a fire and other emergency incidents or extreme forms of scenarios is outside the scope of this fire safety concept, and has therefore not been addressed in this report.

This fire safety concept will not include sections F to J of the BCA. This is argued from that only the fire safety requirements of the BCA are of subject to this thesis, and to include these sections would be outside the scope importance, and time given.

Further limitations listed in the main document for this thesis are additional adopted in this fire safety concept. This subsequently means that this document need to be viewed in correspondence with the main thesis document.

All requirements, including clause recommendations and solutions discussed in this body of work is referenced to the Building code: Building Code of Australia (BCA), Volume 1 Class 2-9 Buildings. [4]

2.2 General assumptions

General assumptions made to provide the common ground for translating building regulation requirements are listed below. These assumptions provide important building characteristics, and location features that needs to be considered in correlation with this fire safety concept.

1. Assumed that this building is located within metropolitan fire department jurisdiction, within 5 km driving distance of a fire station permanently manned by professional (i.e. not volunteer) fire fighters.
2. The building has a floor rise of 16, with each floor having a slab to slab height of 3 m. Depending on the required slab thickness, the effective height of the building can be assumed to be around 50 m.
3. The building is assumed to only facilitate office occupation.
4. Every storey is assumed to be designed in the same way, various designed floor configuration is hence neglected.

5. The building is considered to have a distance to nearest adjoining building, greater than 10 m.
6. The buildings considered in this study will not have basement areas, nor car parking levels incorporated into its design.

3 Departure from current building requirement – BCA

The high-rise construction considered in this report, will not make any departure from the functional requirements of BCA, nor make any minor deviation of the prescripted solutions stated in corresponding section of the regulation.

4 Design method

This fire safety concept documents compliance, and has solely been designed against the BCA "Deemed-to-satisfy" (DtS) provisions, also mentioned in this report as prescriptive solutions.

5 Building compliance assessment

5.1 Design conditions

The development site for the building considered in this report is located in Melbourne, Australia. The considered development includes the construction of a sixteen (16) storey building, incorporating a primary use of office occupancy. The effective height of the building is 51.52 m.

The building is a rectangle shaped with a central core, containing services, plant rooms, stairs and lifts. Each floor level is a separated fire compartment with floor area of 51m x 68m (3468m^2).

The external façade is glazed, with the wall system behind covered to assume a single façade arrangement.

6 BCA Part A – General provisions

This part of the BCA prescribes the building classification, and is based on the proposed occupancy and functional uses that is to be expected within the building. Following occupancy classification, in accordance with Clause A3.2 of the BCA, for the building considered in this report is presented in Table C2.

Table C2 - Occupancy classification of the building

Floor level	Use	BCA classification
1 – 16	Office	5.

The definition of the occupancy class is following:

- Class 5: An office building used for professional or commercial purposes, excluding buildings of Class 6, 7, 8 or 9.

The system, materials, construction and use of the building must comply, as outlined in Specification A1.3, with prescribed Australian Standards. Where this is not possible, the use must be verified through validated test methods, calculation methods or research sources acceptable to the Relevant Building Surveyor, [4]and in accordance with Part A of the building code.

Where a prescriptive provision requires a building element to have a FRL, the procedures for determining the FRL of the building element must be done in conjunction with specification A2.3, and Table C1 of the BCA. If the FRL of the building element is not listed in Table C1 of this section, or

[4] The Relevant Building Surveyor is an authority appointed pursuant to the building Act 1993.

verified in accordance with the specific standard referred to in this section, the FRL must be determined by either calculation as specified in this clause of the BCA, or subjected to a standard fire test.

7 BCA Part B – Structural provisions

7.1 Resistance and magnitude of actions

Part B prescribes the structural requirements for the building. The building structure must be designed to resist loads, as well as combinations of loads as prescribed in relevant Australian Standards, including other relevant standards outlined in the BCA. Loads and parameters that need to be taken into account includes:

- Importance levels of buildings and structures
- Design events for safety
- Dead and live load combinations
- Wind loads
- Snow loads
- Earthquake loads
- Etc. (see clause B1.2 of the BCA for further actions).

The construction materials and forms, must as mentioned above comply with the relevant Australian Standards. This includes consideration of design for fire limit state, serviceability and durability outlined in the BCA.

As the building considered in this study only exists theoretically, the resistance of individual actions described in part B1.1-3, B1.5-6 and specification B1.2 of the BCA is assumed to be met.

7.2 B1.4 Structural resistance and forms of construction

The structural resistance of materials and forms of construction requirements of B1.4 must be taken into account as materials and construction listed in the clause are used. The structural performance of the building is thus, further assumed to be sufficiently applicable to actions such as specified in this clause, and the resistance of those actions.

8 BCA Part C – Fire resisting construction and compartmentation

8.1 C1.1 Type of construction

This part of the BCA prescribes the required fire- resistance, compartmentation and separation parameters for all buildings. The type of construction required to meet the minimum level of fire resistance is determined by Table C1.1 of the BCA, and regulates the level of fire resistance of the building based on both the rise in stories, and building classification.

The building considered in this study has a total number of 16 storeys, with a sole-occupancy in class 5. The prescripted building classification by the BCA is therefore Type A.

The building structure will be constructed of fire resistance rated reinforced concrete walls, floors, columns and beams and/or other equivalent construction materials that satisfies the required minimum fire-resistant levels (FRL) outlined further down in this document. All load-bearing construction needs also to be non-combustible as per BCA definition.

8.2 C1.8 Lightweight construction

Lightweight construction must comply with specification C1.8 if it is used in a wall system either required to have an FRL, or in a lift, stair or service shaft, including external walls and public corridors. All lightweight construction must also be non-combustible.

The building does not use any lightweight construction, in any wall construction incorporated within the building required to have a fire resistance level. Wall systems incorporating any shaft, corridor or like will meet the requirements specified in further down in this document.

8.3 C1.10 Fire hazard properties

To mitigate to spread of fire and development, linings, materials and assemblies used in the building considered in this report, must comply with specification C1.10. This includes following:

- Floor linings and floor coverings.
- Wall linings and ceiling linings
- Air-handling ductwork.

This exclude materials, or assembly of materials listed in clause C1.10(c). These materials are deemed to comply with the requirements, and does not need to further proof of compliance.

8.4 General floor area and volume limitation

This section also specifies the floor area and volume limitations for the building, as well as any fire compartments within the building frame. These limitations are outlined in Table C3.

Table C3 - Floor area and volume limitation

Classification		**Type A**
5.	Area	8 000 m^2
	Volume	48 000 m^3

The building considered in this report does not have a fire compartment larger than 8 000 m^2 or 48 000 m^3, thus complies with the area and volume limitations.

8.5 C2.6 Vertical separation of openings in external walls

As the building in question is protected with an automatic sprinkler system, passive vertical separation is not required. The building is therefore in compliance with the clause.

8.6 C2.7 Separation by fire wall

The building considered in this study is located with sufficient distance to adjoining properties, openings and such that could expose the building to any heat sources. The external wall is therefore not required to satisfy the FRL level of a fire wall specified in clause C2.7 and specification C1.1 of the BCA.

8.7 C2.10 Separation by lift shafts

All lift shafts within the building must be separated from the remainder of the building by a shaft configuration satisfying the requirements of a Type A construction, with FRL in accordance to specification C1.1.

All emergency lifts must be enclosed within a fire-resisting shaft having an FRL of not less than 120/120/120.

Openings for lift landing doors and services must be protected in accordance with prescripted solutions, specified in part C3.

8.8 C2.12-13 Separation of equipment and electrical supply system

Special equipment and systems that need to continue operating during an emergency, or with high potential for explosion as well as fire, requires to be separated from the remainder of the building to comply with the prescriptive requirements.

Following equipment listed below, needs to be separated within an enclosure with FRL of not less than 120/120/120, and have any doorway protected with self-closing fire door having an FRL of not less than -/120/30. The assembly of construction used to meet the requirements specified in this clause is further specified in section 8.16.

- Lift motors and lift control panels, and;
- Emergency generators used to sustain emergency equipment operating in the emergency mode, and;
- The central smoke control plant, and;
- The main switchboard sustaining emergency equipment operating, and;
- Electrical conductors supplying any substation within the building which supplies a main switchboard, or switchboard as explained above, within the building, and;
- Pumps for the automatic sprinkler system, and;
- Air handling systems, and;
- Emergency lifts, and;
- Control and indicating equipment, and;
- Sound systems and intercom systems for emergency purposes.

It must be mentioned in correlation with this section, that where emergency equipment is required in a building, all switchboards in the electrical installation, sustaining the electrical supply to the emergency equipment. Must be constructed so that emergency equipment switchgears are separated from the non-emergency equipment switchgear by a metal partition designed to minimise the spread of a fault.

Equipment specified in clause C2.12 (b) used within the building considered in this study that do not need to be separated in accordance to specifications above, comprises of:

- The stair pressurising equipment installed in compliance to the relevant standards, specified in the BCA.
- Equipment otherwise adequately separated from the remainder of the building.

8.9 C3.2 Protection of openings in external walls

The distance to nearest adjoining building is assumed to be at a sufficient distant not requiring the openings to have an FRL, this and corresponding clauses is therefore assumed to be met.

8.10 C3.8 Openings in fire isolated exits

All doorways leading to either a fire-isolated staircase, passageway or ramp, and are not doorways opening to a road or open space, must be constructed to satisfy a FRL of -/60/30 fire doors. Each door must also be design to either be self, or automatically closed during the activation of a smoke, fire or alarm system fitted within the building.

8.11 C3.9 Service penetrations in fire isolated exits

To maintain the integrity of each fire-isolated exit, no exit must be penetrated my any service other than following:

- Electrical wiring to lighting, detection, or pressurisation system serving the exit, and;
- Electrical wiring serving a security, surveillance or management system, and;
- Electrical wiring serving an intercommunication system, an audible or visual alarm system in accordance with clause D2.22 of the BCA, and;
- Electrical wiring of the monitors of hydrants and sprinkler isolating valves, and;
- Water supply pipes for fire services, and;
- Ducting associated with pressurisation systems in accordance with C3.9 (b).

The location of any service penetration, in any fire-isolated exit permitted by clause C3.9 of the BCA, must not reduce the exit width required by clause D1.6.

8.12 C3.10 Openings in fire isolated lift shafts

Doorways leading into a lift shaft that is required to be fire-isolated, requires to be constructed so satisfy FRL -/60/- requirement, and be designed to remain closed except when discharging, or receiving passengers, goods or vehicles. The entrance door to into fire-isolated lift shafts must comply with the relevant standards specified in the BCA.

Lift indicator panels exceeding 35 000 m^2 in area must be backed by construction satisfying an FRL of not less than -/60/60.

8.13 C3.12 Openings in floors and ceilings for service

To limit the spread of fire through service openings, floors that is required to have an FRL with respect to integrity and insulation, must be protected either a shaft complying with specification C1.1 or satisfy clause C3.15 of the BCA

8.14 C3.13 Openings in shafts

Openings in a wall providing access to a ventilating, pipe or other service shafts specified in clause C3.13, must be protected as follows:

- If the openings are located within a sanitary compartment, a door or panel together with its frame must consist of non-combustible materials or satisfy an FRL of not less than -/30/30, or;

- Door or hopper design to be self-closing with an FRL of -/60/30, or
- Access panel having an FRL of not less than -/60/30.

The building considered in this study is assumed not to have a garbage shaft incorporated within the building.

8.15 C3.15 Openings for service installations

Where service installations such as electrical, electronic, plumbing, mechanical ventilation, air-conditioning or other penetrates a building element required to have an FRL, with respect of either integrity, insulation or have a resistance to the incipient spread of fire. That service installation must comply with one of the provisions set out in clause C3.15 (a), (b) or with specification C3.15.

The building considered in this study is assumed to have all service installation openings incorporated within the building, complying with the specifications of clause C3.15, and specification C3.15.

8.16 Specification C1.1 Fire resisting construction

The building considered in this study is assumed to be located with a distance to nearest adjoining building, to exceed any requirements taking into account fire source features from other buildings. The building is not subjected to any external heat sources or features.

Fire protection for a support of another part

Building elements with FRL requirements, depending on the lateral support of another building element to maintain its FRL, the supporting part subjected to a heat source must have an FRL as required by specification C1.1 and be of non-combustible material.

Structures on roofs

A non-combustible structure situated on a roof need not comply with the other provisions of specification C1.1 if it only contains lift motor equipment, water tanks, ventilating ductwork and respective configuration, air-conditioning chiller, window cleaning equipment or other non-combustible units.

Enclosure of shafts

Shafts required to have an FRL must be enclosed at the top and bottom by construction having an FRL not less than required for the walls of a non-loadbearing shaft in the same building. The bottom of the shaft must not comply with this requirement if it is constructed with non-combustible materials, or laid directly on the ground.

The minimum FRL specified in Part C of the BCA, for an office building with Type A construction requirements, are presented in Table C4. As mentioned in previous clauses, the distance to nearest adjoining building is assumed to be more than 3 m.

Table C4 - Fire FRL requirements per element

Element	Loadbearing	Class 5 requirements – FRL (in minutes): Structural adequacy/ Integrity/ Insulation
External wall (including any column and other building element incorporated therein)	Yes.	120/ 60/ 30
	No.	-/ -/ -
External column (not incorporated in an external wall)	-	120/ -/ -
Common walls and fire walls	-	120/ 120/ 120
Internal walls: Fire-resisting lifts and stair shafts	Yes	120/ 120/ 120
	No	-/ 120/ 120
Internal walls: Bounding public corridors, lobbies and like	Yes	120/ -/ -
	No	-/ -/ -
Internal walls: Between or bounding sole- occupancy units	Yes	120/ -/ -
	No	-/ -/ -
Ventilating, pipe, garbage, and like shafts not used for discharge of hot products	Yes	120/ 90/ 90
	No	-/ 90/ 90
All other loadbearing elements	-	120/ -/ -
Floors	-	120/ 120/ 120
Roofs	-	120/ 60/ 30

To comply with the prescriptive requirements of the BCA presented in Table C4, the structure will consist of following [59]:

- Loadbearing elements requiring 120min structural adequacy will consist of 220mm thick reinforced concrete with minimum 35mm cover to critical reinforcing.
- Non-loadbearing elements requiring 120min structural adequacy, integrity or insulation will consist of 220mm thick reinforced concrete with minimum 35mm cover to critical reinforcing.
- Non-loadbearing elements not requiring 90min integrity or insulation will consist of 170mm thick reinforced concrete with minimum 25mm cover to critical reinforcing.
- Prescriptive provisions permit the roof configuration to remain unrated as the building is fitted with a sprinkler system, and roof covering being non-combustible.
- Fire separations shall be provided between each level in the building with requirement shown as per Table C4, as well as to separate lifts, stairs, services risers and other special equipment shown below. The two fire service lifts shall be incorporated within separate shafts.

All materials and assembly of materials used to satisfy any FRL requirements specified in Table C4 shall be non-combustible

8.17 Specification C1.10 Fire hazard properties

Material used as a finish or lining must satisfy prescripted Fire Hazard Indices in accordance with specification C1.10. Floor linings and floor coverings must not be of materials with less critical radiant flux than 1.2 kw/m^2, and 2.2 kw/m^2 in fire- isolated exits and control room. Walls and ceiling linings must comply with respective group number:

- Fire- isolated exits and fire control rooms requires materials with group number 1.
- All other areas require materials with group number of either 1, 2 or 3.

The group number must be determined in accordance to relevant standard specified in the BCA. Building components or assemblies required to have a fire hazard property, must comply with specification A2.4, clause 4(b) of not or specification C1.10 of the BCA to meet the prescriptive requirements. The group number of a material and its respective critical heat flux value must comply with relevant standards specified in clause C1.10 of the BCA.

Special regard need to be taken for the materials in the air-handling ductwork, and must comply with the relevant materials specified in the BCA.

8.18 Specification C3.4 Fire and smoke doors

Fire resistant doors fitted within the building needs to comply with the relevant standards specified in this clause. Glazed parts must not fail by radiation during the period specified for the integrity part of the required FRL.

Smoke doors must be constructed so that smoke will not pass from one side of the doorway to the other. Following smoke doors needs to satisfy the requirements by following:

- The leaves must swing in the direction of egress, and;
- Resist smoke at 200℃ for 30min and have solid leaves at least 35mm thick, and;
- Each door leave must be fitted with smoke seals, and;
- Be normally in closed position or be fitted with automatically closing devices initiating by smoke, fire or like detectors in accordance with relevant standards specified in the BCA, and;
- Smoke detectors must be located on each side of the doorway not more than 1.5 m in horizontal distance from the doorway, and;
- If fitted with an automatic closing device, have fail-safe operations closing the door in the event of power failure, and;
- The leaves must return to closed position after each manual opening sequence, and;
- Any glazing part must be in accordance with relevant standards as specified in the BCA.

9 BCA Part D – Access and egress

9.1 D1.2 Number of exits required

Part D of the BCA prescribes the minimum requirements for access and egress to a building. The required number of exits required for the specifics of the buildings, from each floor is not less than 2 from each floor, in addition to any horizontal exits. The building considered in this study, have two fire isolated staircase configurations, serving each floor providing every occupant of a story with two independent exits.

9.2 D1.3 Required fire isolated staircases and ramps

Each fire isolated staircase serving as a required exit must be fire-isolated. Both staircase configurations within the building, must be designed to satisfy the fire-isolated requirements.

9.3 D1.4 Exit travel distance

For the specifics of the building considered in this study, no point on a floor level must be located more than 20 m from an exit, or a point from which travel in different directions to 2 exits are available, in which the travel distance to one of these exits must not exceed 40 m.

The building considered in this study has two alternative exits serving each floor with not more than 40 m, from any point of the floor exceeding the distance specified in this clause. In addition, the travel distance to a point of choice where access to alternative exits is below 20 m.

9.4 D1.5 Distance between alternative exits

Each exit must be distributed as uniformly as practicable within the building enclosure, with an access to at least 2 available exits from all points of the floor. The distance between each exit must not be less than 9 m apart, or exceed a maximum of 60 m.

The building considered in this study has two alternative exits serving each floor, located at 9 m apart, horizontally.

9.5 D1.6 Dimensions of exits and path of travel

Each required exit, or path or travel to a required exit must have an unobstructed height throughout not less than 2 m, with the unobstructed height of any doorway reduced to not less than 1.98 m.

If egress requires vertical movement, the unobstructed width in each required exit, or path of travel to each exit, must not for any story accommodating more than 200 people, be no less than 2 m plus 0.5 m for every 60 persons (or part) in excess of 200. In other cases, the unobstructed width in each required exit, or path of travel to each exit, must not for any story accommodating more than 200 people, be no less than 2 m plus 0.5 m for every 75 persons (or part) in excess of 200. The unobstructed width of a doorway must be no less than the unobstructed width requirements, minus 0.25 m.

Based on the exit travel distance, distance between exits and the estimated population, the building considered in this study requires two exits from each floor level. Table C5, outlines the estimated population per floor with corresponding requirement for exit width, based on the population/ area ratio from clause D1.13 of the BCA.

Table C5 - Required exit width per floor and exit, based on expected occupant load.

Levels	Space	Total floor area (m^2)	Floor area (m^2)	Area per person (m^{-2})	Occupant load per level	Required exit width (m)	Unobstructed width per exit (m)
Ground	Offices Entrance	3468	Office occupancy: - 2660 Other (staircase, shafts, etc.) - 472 Entrance - 300	10	266 occupants	2.5	1.5
2- 16	Offices	3468	Office occupancy: - 3060 Other (staircase, shafts, etc.) - 408	10	306 occupants	3	1.5
Total Nr. occupants					4856 occupants		

The required unobstructed exit width from each floor level, and fire isolated staircase configurations is 3 m. Each required exit route, serving each floor will have an aggregated exit width of 1.5 m, included each of the fire isolated staircase configuration. The floor to ceiling height in the office areas will be 2.4m, with 2.1m inside smoke-lobby and sanitary compartmental enclosures.

9.6 D1.7 Travel via fire isolated exits

Doorways must not open directly into a fire-isolated staircase- or passage way configuration unless it is from of following:

- A public corridor, public lobby or like, or;
- A sole-occupancy unit occupying all of a story, or;
- A sanitary compartment, airlock or like.

If more than 2 access doorways, not from a sanitary compartment or the like, open to a required fire isolated exit in the same storey, a smoke lobby in accordance with clause D2.6 of the BCA must be provided. In addition, must each fire-isolated staircase provide independent egress from each storey served, and be designed to discharge directly, or by a fire-isolated passageway to a road or open space.

A smoke lobby encloses each fire-isolated staircase at the core centre of each floor level. Each fire-isolated staircase configuration, including each smoke lobby is fitted with an air pressurisation system. Each fire-isolated staircase configuration discharges at ground floor, with a pedestrian distance of 16 m to a road. One staircase serving as a required exit discharges through a fire-isolated passage, the other through the entrance area (see ground floor layout in *Appendix A – Building design layout*).

9.7 D1.10 Discharge from exits

Each path to, within and point of discharge from an exit must not be blocked, or at point prevent access to it. The unobstructed width of discharge from a required exit to an open space must be as the minimum width of the required exit, and in accordance with clause D1.13 of the BCA. The unobstructed width of each exit must not be less than 1.5m.

9.8 D1.13 Number of persons accommodated

To meet the prescriptive provisions of part D of the BCA, the number of occupants accommodating each floor, must be established in accordance with clause D1.13, with consideration to the purpose and floor layout.

In accordance with Table D1.13 of the BCA, office accommodation prescribes 10 m^2 per person. See section 8.5 earlier for the calculated number of occupants expected per each floor.

9.9 D2.2 Fire isolated staircases

Each fire-isolated staircase configuration forming a required exit meets the requirements of clause D2.2. Each staircase configuration is located within a fire-resisting shaft, constructed with non-combustible materials as specified in section 7 of this report. Each staircase configuration shall be constructed in a manner that local failure will not cause structural damage to, or impair with the fire resistance of the shaft.

9.10 D2.6 smoke lobbies

The smoke lobby located at the centre of each floor level must meet the requirements of the BCA. The smoke lobby must be separated from the occupied areas in the storey by walls which are impervious to smoke, and meet the FRL requirements of no less than 60/60/-. In addition, must the walls extend from slab to slab, and at any opening from occupied areas have smoke doors complying with specification C3.4 of the BCA.

The building considered in this study has four doors opening into the smoke lobby from each floor. Each door shall be designed to meet the smoke door requirements from specification C3.4 of the BCA. The wall enclosing the smoke lobby consists of fire-isolated staircases and shafts, with FRL exceeding the smoke lobby wall requirements.

The smoke lobby must be fitted with an air pressurisation system in accordance with relevant standards specified in the BCA.

9.11 D2.11 Fire isolated passageways

The enclosing construction of a fire-isolated passageway must have an FRL when tested for a fire outside the passageway in another part of the building not less than that required for the staircase configuration, see specification of the required FRL in section C.

9.12 D2.13-14 Staircase configuration: going, risers and landings

Each staircase configuration within the building perimeter must comply with following provision:

- Have maximum 18 and minimum 2 risers in each flight.
- Max 0.19 m and min 0.115 m in rise (R)
- Max 0.355 m and min 0.25 m in going (G)

The quantity (2R+G) of max 0.7 m and min 0.55 m. Each staircase located within the building is assumed to meet the requirements of clause D2.13 of the BCA. Each staircase will also have landings incorporated within its configuration, in accordance with the specifications of clause D2.14 of the BCA.

9.13 D2.15-16 Thresholds and barriers to prevent falls

The threshold of a doorway must not incorporate a step or ramp at any point closer to the doorway than the width of the door leaf, unless the doorway opens to a road or open space, and is provided with a threshold ramp in accordance with relevant standard specified in the BCA.

Barriers to prevent falls must be provided along the side of each staircase configuration, in addition to floor, corridor, hallway or the like, in accordance with specifications in Table D2.16a of the BCA.

9.14 D2.17 handrails

Handrails fitted within the building considered in this study, must be located along the side of the ramp and flight of each stair, in addition to each side of the staircase configurations. The height of the handrails must not be positioned less than 0.865 m measured above the nosing of stair treads, the floor surface or the ramp, landing or the like. The hand-hold of each handrail must be continuous between stair flight landings, and shall not have any form of obstruction on or above that will break the hand hold of the handrail.

The handrails of the building considered in this study is assumed to meet the requirements in clause D2.17 and be in accordance with requirements provided in D3.3 of the BCA.

9.15 D2.19 Doorways and doors

In addition to previous requirements for doorways specified in sections earlier, a doorway serving as a required exit or forming a part of a required exit, must:

- Not be fitted with a revolving door, and;
- Not be fitted with a roller shutter or tilt-up door, and;
- Not be fitted with sliding door, unless it leads directly to a road or open space and the door is able to be opened manually under a force not exceeding 110 N, and;

If fitted with a door which is power-operated, the door must be able to be opened manually under a force of not more than 110 N if failure of the power source would occur. If located at a position which directly leads to a road or open space, in must open automatically during activation of any alarm, and power failure.

9.16 D2.21-22 Operations of latch and re-entry from fire isolated exits

Each door in a required exit, or forming a part of a required exit or path of travel to a required exit, must be readily openable without a key in accordance to the provisions of clause D2.21 of the BCA.

All doors within the building enclosure must by be designed to meet the accessible requirements of part D3 of the BCA.

Every 4th floor is required to be open, and re-entry provisions must be available from fire isolated staircase configurations, back into the occupied floor level. For the specifics of the building considered in this study, no door leading directly in to a fire-isolated exit must be locked from the inside, or alternatively be designed with a fail-safe device that automatically unlocks the door upon the activation of a fire alarm. Signage on the door must be provided to satisfy the clause.

9.17 D2.23 Sign on doors

Signage is required to all fire- and smoke doors forming or serving an exit. In addition, must the building throughout be supplied with sufficient braille and tactile signage, hearing augmentation and tactile indicators, in accordance to relevant standards specified in the BCA.

9.18 D3.1 General building access requirements

The required access for people with disabilities is required to be sufficient throughout the building is specified in Table D3.2 of the BCA. For the specifics of the building considered in this study, people with disability must have access to, and within all areas normally used by occupants.

9.19 D3.2 Access to buildings

The building is required to provide an access-way from the main point of the pedestrian entry. Where the pedestrian entrance required to be accessible has multiple doorways, and the pedestrian entrance consist of not more than 3 doorways, not less than 1 of those doorways must be accessible. If the entrance consists of more than 3 doorways, not less than 50 % of those doorways must be accessible.

The building entrance is assumed to meet the building requirements for accessible entrances to the building, and shall have 50 % of its pedestrian entrances made accessible to people with disabilities.

9.20 D3.6-8 Signage, hearing augmentation and tactile indicators

The building is required to provide signage in accordance with relevant standards and specification D3.6 of the BCA, identify each sanitary compartment, space with hearing augmentation system and each door required to be provided with an exit sign.

Conference, meeting rooms, reception areas and such, are required to be provided with hearing augmentation systems to aid people with hearing disability, in accordance with clause D3.7 of the BCA.

Tactile indicators must be sufficiently provided throughout the building for people with vision disability.

9.21 Specification D3.6 Braille and tactile signs

The building is required to design and install braille and tactile signage as required by D3.6 and specification D3.6. The location and design must comply with specifications set out in this clause

The building considered in this report shall meet the requirements of D3.6 and specification D3.6, and have all braille and tactile signs comply with the required provisions, to aid all people with disabilities occupying the building premises.

10 BCA Part E – Fire services and equipment

This part prescribes the requirements for the fire services and equipment, necessary in a building to provide the fire service/ department with sufficient means to conduct search, rescue and fire operations.

10.1 E1.3 Fire hydrants

The building considered in this study has a floor area exceeding $500m^2$, fire hydrants must then in accordance with relevant standard specified in the BCA, be provided throughout the facility. Internal-and external hydrants must in correlation with the chief officer, be located at a satisfactory location and provide necessary floor area coverage.

The fire hydrants are assumed to be connected to a town's main supply and be able to provide water for the time required. Hydrants coverage is achieved through the positioning of hydrants in each fire isolated staircase configuration.

10.2 E1.4 Fire hose reels

Fire hose reels must be located within 4 m of an exit, and must be located so that any point on the floor is within 40 m of a fire hose reel nozzle end when laid to avoid obstructions. The design, installation and water supply of the fire hose reel system shall be done in accordance with relevant standards specified in the BCA.

10.3 E1.5 Sprinklers

The effective height of the building exceeds 25 m, the building must hence be sprinkler protected throughout in accordance to relevant standards specified in clause Specification E1.5 of the BCA.

In accordance with specification E1.5 of the BCA, shall the sprinkler alarm valves be located in a secure room with direct egress to a road or open space, and secured with a system to the satisfactory to the chief officer. The water supply must also be secured by a secondary water supply storage, with the capacity of at least 25,000 l located at the topmost storey of the building.

The sprinkler system must be linked with the smoke hazard management system installed, and during discharge activate the smoke management system. The sprinkler alarm valve serving the building is located at ground floor level, with a door opening towards the road.

10.4 E1.8 Fire control centres

The building considered in this study has an effective height exceeding 25 m. The building must hence, in accordance with specification E1.8 be provided with a fire control centre/room, located to the satisfactory of the chief officer. To meet the requirements for a fire control centre, it must in accordance with specification E1.8 be located at ground floor, and enclose neither of following equipment:

- Internal combustion engine.
- Pump valve.
- Sprinkler control valve.
- Pipe and pipe fittings.

The ambient sound level within the fire control centre, when all fire safety equipment is operating, in the way it operates during an emergency, must not exceed 65 db. The sound level must be tested in accordance with test and procedures specified in the BCA.

The control centre will be located at ground floor of the building, separated from adjoining office occupational areas. The enclosing construction will consist of materials specified in section 7 of this report, and meet an FRL of not less than 120/120/120. Materials used as a finish, surface, linings or the like must comply with the requirements of specification C1.10 of the BCA.

Services such as pipes, ducts and the like which are not required for the proper functioning of the fire control room, must not pass through it. Openings on the fire control room enclosure must only be confined to openings such as; doorways, ventilation and other services necessary for the proper functioning of the facility.

Openings in the floor, ceiling and internal walls enclosing the fire control room must, except for doorways, be protected in accordance with section 7 in this fire safety document. Door openings in the internal walls enclosing the fire control room, must meet an FRL requirement of at least -/120/30 smoke door, and be designed to self-close.

The building considered in this study will have two openings into the fire control room. One opening towards the road in front of the building, and the other from inside the entrance area at ground floor. These locations are assumed not to be obstructed or hindered by occupants using the escape routes. Size and contents of the fire control room are in accordance with specification E1.8, and assumed to have all equipment listed in clause 9 of the corresponding specification. The fire control room meets the ventilation requirements through natural ventilation from the doorway, fitted in the external wall of the building, leading directly to the fire control room.

10.5 E2.2 General requirements for smoke hazard management

Each fire isolated exit within the building considered in this study must be provided with an automatic air pressurisation system in accordance with relevant standards specified in the BCA. In addition, each part of the building must be provided with a zone smoke control system in accordance with the standard referred to in clause E2.3 of the BCA.

10.6 Specification E2.2a Smoke detection and alarm systems

For the specifics of this building, a smoke detection system must be installed in accordance with specifications in clause 4 of this specification. The smoke detection system must comply with relevant standards specified in the BCA, and during operation, activate a building occupant warning system in accordance with requirements specified below.

Smoke detectors required to activate either the air pressurisation system, for each fire-isolated exit within the building, or the zone smoke control system must be installed in accordance with relevant standards specified in the BCA, and have additional smoke detectors installed adjacent, not more than 3 m horizontally from any lift landing door.

The building occupant warning system must comply with the relevant standards specified in the BCA, and sound through all occupied areas of the building. The building considered in this study shall be supplied with a smoke hazard management system comprising of following:

- An automatic air pressurization system, and;
- An automatic detection and alarm system complying with specification E2.2, and relevant standard specified in the BCA, and;
- A zone smoke control system, and;
- An automatic sprinkler system.

The automatic detection system must in addition to internal system, also be connected to a fire alarm monitoring system connected to a fire station, and meet the requirements of the relevant standard specified in specification E2.2a of the BCA.

10.7 E3.2 Stretcher facilities

A stretcher facility must be provided in at least one emergency lift required by E3.4 of the BCA. A stretcher facility must accommodate a raised stretcher with a patient lying in it horizontally, with dimension no less than 0.6 m wide x 2 m long x 1.4 m high above the floor level.

10.8 E3.4 Emergency lifts

For the specifics of this building, at least two of the passenger lifts serving each floor must be constructed as emergency lifts. Each emergency lift shall be combined as passenger lifts, and contained in a fire resisting shaft in accordance with section 7.7 of this report.

Each lift in the building considered in this study, must be made accessible to all occupants, and provide access and egress to, and from all lift-well landings complying with provisions of part D of the BCA. Each lift must meet the requirements for the application of features specified in Table E3.6b of the BCA.

10.9 E3.7 Fire service controls

Each lift incorporated within the building enclosure must be provided with a fire service recall control switch, and a lift car fire service drive control switch complying with clause E3.9 and E3.10 of the BCA respectively.

10.10 E3.9 Fire service recall control switch

Each passenger lift must be designed and provided with on fire service control switch in accordance with specifications in clause E3.9 of the BCA.

10.11 E3.10 Lift car fire service drive control switch

Each passenger lift must be designed and provided with a lift car service drive control switch in accordance with specifications in clause E3.10 of the BCA.

10.12 E4 Visibility in an emergency, exit signs and warning systems

The building must be provided with emergency lighting and exit signage throughout the construction in accordance to relevant standards specified in the BCA. In addition, the building is required to have an emergency warning or intercommunication system (EWIS) in accordance to relevant standard.

It must be mention in correlation to part E of the fire safety concept, that locations, provisions of facilities and/or any variation to prescribed fire department equipment, may be subjected to a report and consent of the chief officer.

14. Appendix D – Risk analysis

RISK ANALYSIS REPORT

THIS DOCUMENT IS PREPARED FOR A MASTER THESIS CONCERNING THE LEVEL OF SAFETY, INCORPORATED WITHIN BUILDING REGULATIONS, TOWARDS HIGH-RISE BUILDINGS IN SWEDEN AND AUSTRALIA.

This risk analysis is prepared and completed as a part of a masters study conducted on the area of high-rise buildings.

Fire and Risk engineering

Emmanuel Eriksson, Fire engineer

1 Scope of this report

This fire risk analysis is conducted as an associated part of a master study, concerning fire safety levels in prescriptive requirements for high-rise office buildings.

This analysis documents a review of two theoretically designed high-rise buildings, designed in accordance with prescriptive building code provisions stated in the *Building code of Australia* (BCA Volume 1), and *Boverkets Building Regulations* (BBR 25). The review is later compared to fire safety objectives, with the use of scenario based risk analysis criteria set in this report.

This report is based on information that has been processed in the main part of this thesis, as well as relevant documents presented as appendices, and must be viewed in correlation with this report.

The aim of this report is to evaluate the level of safety incorporated within two theoretically constructed high-rise buildings, with the use of scenario based risk analysis. The risk analysis shall be both quantitative, qualitative and deterministic, and use Computational Fluid Dynamic (CFD) and Egress Simulations to identify the level of safety, towards human life criteria. The simulator softwares used in this report is Fire dynamic Simulation (FDS) and Pathfinder.

The methodology adopted in this fire risk analysis is presented in section 4. *Methods* in the main part of this thesis.

Each high-rise building presented in this report has documented compliance, based on its proposed design, against the prescriptive provisions from its respective building code, presented in *Appendix B-C*.

The framework and method of approach of this risk analysis, is partially influenced by the International Fire Engineering Guidelines [23] and the SFPE: Guide to Application of Risk Analysis in Fire Protection Design [69].

A sensitivity analysis was conducted on this risk analysis, prior to any simulation was initiated, as a means to quality assure the robustness of the results. The sensitivity analysis was executed by adjusting values, as well as selecting design scenarios to implement as much strain as possible. Where adjustments have been made to evaluate the robustness of each high-rise, is mentioned throughout this report.

2 Building characteristics

The building characteristics for each high-rise building are presented in *Appendix A* and respective building fire safety concept, in *Appendix B-C*.

As an important part of this thesis, each high-rise building has been designed in accordance with prescriptive building code provisions. The building characteristics are therefore not selected by relevant stakeholders in a project brief, but important design configuration requirements stated in respective building code.

The characteristics for each high-rise building is summarized and presented in Table D1.

Table D1 - Building characteristics for the Swedish and Australian High-rise building. Prescriptive demands in accordance with respective building code *[8] [4]*.

Characteristics	Sweden	Australia	Comment
Occupancy	Office occupancy	Office occupancy	-
- **Regulation classification**	Occupational classification 1. Building classification Br1.	Class 5 occupancy Type A construction requirement.	Classifications in accordance with respective building code.
Location - **Proximity to other buildings**	Nearest adjoining building > 10m.	Nearest adjoining building > 10m.	Assumed parameter. See main thesis document
- **Proximity to fire station(s).**	The building is located within a 5 km driving distance.	The building is located within a 5 km driving distance.	Assumed parameter. See main thesis document.
- **Fire service access.**	The building has a satisfactory fire service access.	The building has a satisfactory fire service access.	Assumed parameter. See main thesis document.
- **Proximity to hazards.**	Not located near any prominent external hazards.	Not located near any prominent external hazards.	External hazards are beyond the scope of this report.
Size and Shape.	16 floor levels.	16 floor levels.	-
- **Nr. of floors.** - **Area of each floor.**	2500 m^2 Rectangular shaped with dimension 40 m x 62.5 m.	3468 m^2 Rectangular shaped with dimension 51 m x 68 m.	See respective fire safety concept.
Structure - **Construction material.**	The building frame and loadbearing structure consists of reinforced concrete walls/slabs/ columns with 170 mm thickness, with 25 mm to critical reinforcing. The external walls are glazed with an additional layer of glass.	The building frame and loadbearing structure consists of reinforced concrete walls/slabs/ columns with 220 mm thickness, with 35 mm to critical reinforcing. The external walls are glazed with an additional layer of glass.	See the respective fire safety concept for further details. *Appendix B-C.*
- **Openings, shafts and ducts**	Following configurations are constructed as separated shafts: The Tr1 and Tr2 staircase. Each firefighting elevator. The passenger lifts, and service shafts.	Following configurations are constructed as separated shafts: Each fire-isolated staircase. Each emergency elevator, and passenger lift. Each service shafts.	See the respective fire safety concepts, including the design layouts in *Appendix A* for further illustration.
- **Ventilation and air movement.**	Openings in service shafts are reserved for water risers in each fire	Openings are reserved for fire hydrants within each staircase, as well as	Openings are required in both regulations to

	safe passage.	the sprinkler and heat and smoke detection system.	acquire the same fire-resistant classification as the building element it passes through.
	Both staircase configurations shall be fitted with a smoke and heat ventilation system. Ventilation system is required throughout the building, and are separated with fire dampers between fire compartment elements.	Both staircase configurations, including the smoke lobby, shall be fitted with an automatic air pressurisation system. Ventilation system is required throughout the building, and are separated with fire dampers between fire compartment elements.	
Hazards	See section 5 in this report.		
Fire preventative and protective measures	See section 6 in this report.		
Management and use	The building is assumed to have regular inspections of preventative and protection systems. The building occupants are assumed to have a satisfying level of training.	The building is assumed to have regular inspections of preventative and protection systems. The building occupants are assumed to have a satisfying level of training.	
Environmental conditions	The building is assumed to provide a satisfying level of environmental condition in accordance to the regulations.	The building is assumed to provide a satisfying level of environmental condition in accordance to the regulations.	

3 Occupant characteristics

The occupant characteristics have been identified and presented in section 4.4.4 *Establishment of fire and egress scenarios* of the main document.

The occupant characteristics are influenced by the description of the occupational class, given in each respective building code for office occupants. The number of occupants are assumed to be within the building perimeter, is the maximum number of occupants the building can facilitate, based on the building design.

The occupant characteristics used in this risk analysis, is summarized and presented in Table D2.

Table D2 - Building occupant characteristics and number. *[19] [23]*

Subject	Characteristics			
Number of occupants	**Sweden**		**Australia**	
	Location (floor)	Number (ppl.)	Location (floor)	Number (ppl.)
	Ground floor 2-16 Total	216 223 3561	Ground floor 2-16 Total	266 306 4856
State	The building occupants are assumed to be awake, as well as fully conscious.			
Level of assistance required	Most occupants are assumed to be capable of self-evacuation from the building using the stairs. Where occupants with disability is taken into account, the building design configuration, as well as needed evacuation time shall be further assessed.			
Familiarity	The building is expected to be the workplace for the occupants, and will therefore be assumed that the occupants knows the building well, and understand alarms and evacuation notes, as well as be able to locate the exit routes.			
Emergency training	Occupants are assumed to have basic emergency training, and be able to locate the exits. Training regarding hand-held emergency equipment are not taking into account.			

4 General objective

The fire safety objectives for this risk analysis, shall be with respect of building regulatory objectives, with the building occupants used as metrics.

As this study aims at disclosing the level of safety incorporated within building regulatory provisions, towards high-rise buildings, following objectives will be used in the risk analysis:

- To evaluate which building regulation provides the highest level of safety for occupants, from injury due to fire.
- Evaluate the Criteria of Life Safety provisions in each high-rise office building

The assessment of which building regulation that meets the objectives best, shall be based on the performance of each high-rise towards the acceptance criteria, presented in section 9 of this report.

5 Hazard identification

The hazard identification will provide the base for establishing the later fire and egress scenarios. In accordance with the sensitivity analysis, the hazard identification process must provide and support the development of fire scenarios with important design characteristics in a way that provides the basis for defining worst credible scenarios.

It must be mentioned in this hazard identification process that gathering of historical data and statistics, do not encompass all possible hazards. Known company procedures is also an important part in the process of reviewing possible hazards [69]. As the high-rise buildings considered in this analysis only exists theoretically, company procedures becomes hard to predict and analyse. The use of historical data considering office, and high-rise fires is therefore argued as a satisfactory means to conduct the hazard identification process.

For emergency personal, events involving a high-rise building can be regarded as more hazardous than low-, and mid-rise buildings. This is especially observed in building regulations where, as a response, requirements for i.e. additional technical installations are implemented to aid the emergency personal. According to a report published by BIV (Association of Fire Engineer's Science) and SFPE, on the matter of intervention supporting measurements for high buildings, associated conditions was described as impossible for an efficient and safe operation to be ensured. [45]

The hazardous picture for emergency service personal that is described in contrast to fire scenarios in other building types are i.e.; the difficulty of creating an overview of the course of events, time and resource utilization in vertical movement upwards and access to the higher parts of the facade and the roof. As the key feature of a high-rise building is related to its height above ground, it also leads to reduced ability for the fire department to externally extinguish the fire. [45]

According to NFPA research on high-rise fires during 2009-2013, a statistical representative of 35 % of all fires in office accommodations, originated on the 7th or higher floor level. Followed by fire originated between the second to sixth floor, and ground floor by respective 31 % and 25 % of all fires. [70] This means that more than 1/3 of all fires in high-rise buildings, develops beyond the reach of fire department vehicles to combat.

Derived from this it can be argued that the worst credible location for a fire scenario is on the 7th or higher floor level for the high-rise buildings considered in this study.

Research regarding leading areas where fire originated from in high-rise building fires from NFPA research shows, that kitchen or cooking areas are the leading areas where fire originates from, regardless of occupancy class. [70] Figure D1, shows a graphical presentation over the top five areas of fire origin in all office buildings during 2009-2013.

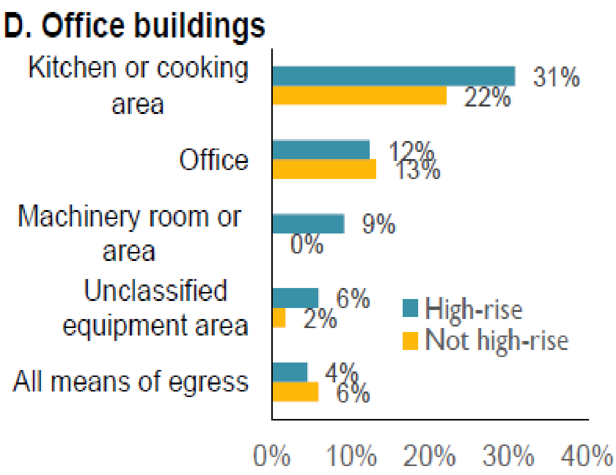


Figure D1 - Top fire areas of fire origin in high-rise fires, and their share in shorter building fires 2009-2013 *[70]*

Figure D1, illustrates clearly that the most credible area for a fire to originate from, is from the kitchen or cooking area. It also shows that building height makes little difference in causes that have a strong human component, such as cooking. Office and machinery room areas also represent credible locations, both containing objects that emits sufficient heat to ignite combustibles, and where candidate heat sources might be extracted for subsequent fire scenarios.

Fire originating in means of egress areas are low in the statistics brought from the NFPA research. Fire blocking an egress passage would however represent a clear worst-case scenario in comparison to the other evaluated areas, as it effects the egress possibilities for the occupants. [70]

As the high-rise buildings only consist of a conceptual design layout, with no location of possible heating or cooking areas, the specific locations for each fire scenario must be in accordance with the other credible areas. Both high-rise buildings evaluated in this report, consist of an open-floor office area enclosing a core centre, in which all means of egress and shaft areas are located. Taking the statistics above into account, is it arguably the combination of office/egress path area that will provide the best location for a worst credible fire scenario.

As possible areas for the subsequent fire scenarios been presented, the initiating hazard and lead cause must be determined. Figure D2, presents NFPA research regarding the lead causes of office fires in high-rise buildings, as well as shorter buildings during the period 2009-2013.

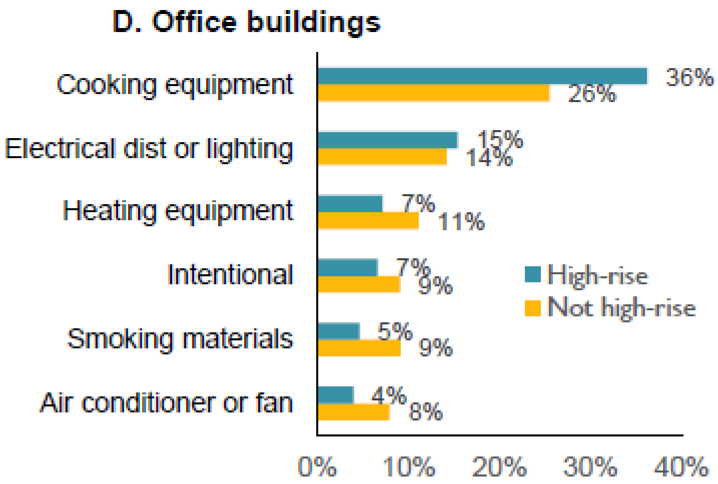


Figure D2 - Leading causes of high-rise fires and their share in shorter building fires 2009-2013 *[70]*

Statistics regarding leading cause of fire presented in Figure D2, reinforces the previous observation regarding the minimal difference in building height, in causes that have a strong human component, such as cooking, smoking and intentional [70].

Taking the design layout for each high-rise, and the proposed location areas for fire scenarios discussed above. It can be argued that the most probable initiating hazard for the buildings considered in this analysis, is from electrical components in the office/egress area.

An intentional fire could be counted as the worst initiating hazard, with liquid fuel (i.e. petrol) used as an accelerator for the ignition of a fire [71]. An intentionally liquid fuel fire scenario would however, be beyond the capability of what minimum level fire safety provision could ensure for its occupants. As this study aims at disclosing the level of safety provided by minimum provisions, including arson as an initiating event, would not provide any valuable result regarding the intentional safety provided by the regulations. Arson will therefore not be further included as a potential initiating hazard.

6 Preventative/protective measures available

Each high-rise considered in this analysis, has solely been designed with preventative and protective measures in accordance with prescriptive provisions, stated in their respective building code.

The preventative/ protective measures available in each high-rise building is presented in Table D3.

Table D3 - Preventative/protective measures incorporated within each high-rise building.

SUB-SYSTEM		SWEDEN	AUSTRALIA
A: FIRE INITIATION AND DEVELOPMENT CONTROL	Limitation of ignition sources Limitation of nature and quantity of fuel Arrangement and configuration of fuel Electrical safety Housekeeping and regular plant maintenance	The building contains a fuel load as specified in the BBRBE 800 MJ/m^2. [50] The office areas are assumed to be arranged as open office landscapes. No storage of flammable liquids or solids are taken into account. The building is assumed to have satisfactory maintenance, and housekeeping as organizational procedures, to maintain electrical and house standards at a normal level of risk.	The building contains a fuel load as specified in the IFEG 800 MJ/m^2. [23] The office areas are assumed to be arranged as open office landscapes. No storage of flammable liquids or solids are taken into account. The building is assumed to have satisfactory maintenance, and housekeeping as organizational procedures, to maintain electrical and house standards at a normal level of risk.
B: SMOKE DEVELOPMENT, SPREAD AND CONTROL	Smoke barriers Mechanical smoke management	Each doorway leading into egress paths are fitted with smoke seals, including to the communication area at the core of each floor. Both the Tr1 and Tr2 staircase configuration are fitted with a mechanical smoke system. Every vent channel penetrating a fire compartmental element is fitted with smoke dampers that will close when fire or smoke is detected.	Egress paths, such as doors leading into the smoke lobby, as well as to any staircase configuration are fitted with smoke seals. Both the smoke lobby, and every staircase configuration are fitted with an air pressurizing system. Every vent channel penetrating a fire compartmental element is fitted with smoke dampers that will close when fire or smoke is detected.
C: FIRE SPREAD AND IMPACT AND CONTROL	Separation of buildings Fire resistive barriers Fire resistive structural elements Fire resistive dampers Exposure protection	Openings in the exterior is vertically separated by 1.4 m. In addition to the externally glazed façade. Building elements and fire compartments enclosing the communication space, staircases and service shafts, fire resistive passageways and firefighting elevator shafts, is constructed to satisfy Eurocode EI60 requirements.	Openings in the exterior is vertically separated by 1.4 m. In addition to the externally glazed façade. Walls enclosing the smoke lobby must have an FRL of no less than 60/60/-. Building elements enclosing staircase configuration, shafts, fire-isolated passageways, firefighting elevator and passenger lifts must meet the FRL requirements of 120/120/120.

		The building frame structure, including the floor/ceiling satisfies R90 requirements. Dampers are fitted between all fire compartmental element penetrations.	Floors and roofs must have a FRL of 120/120/120 and 120/60/30 respectively. The external building frame structure satisfies FRL 120/60/30. Dampers are fitted between all fire compartmental element penetrations.
D: FIRE DETECTION, WARNING AND SUPPRESSION	Automatic and manual detection equipment Automatic and manual warning equipment Automatic suppression equipment Manual suppression equipment	Automatic detection is only fitted inside the vents and staircase configurations. The building is fitted with pressurized water risers in each staircase configuration.	Automatic and manual smoke and fire detection equipment fitted throughout the building. The building is fitted with an emergency warning or intercommunication system (EWIS). The building is fitted with a sprinkler system throughout the building. The building is fitted with fire hose reels and pressurized water risers in every floor. The building is provided with a fire control centre.
E: OCCUPANT EVACUATION AND CONTROL	Evacuation plans Occupant training Emergency communication Egress signage Egress routes	The primary evacuation procedure is by venturing into the fire safe passage to the nearest staircase configuration, or by horizontally evacuate through the emergency door, then evacuate through the staircase configuration into the entrance area and subsequently out into the open. Occupants are assumed to be familiar with the premises, in an awake state and able to locate the nearest exit. Occupant are assumed to have basic emergency training. Satisfactory egress signage is provided throughout the building. The Tr1/Tr2 staircase	The evacuation plan is to venture through the smoke lobby, into any staircase configuration, leading either into the entrance area, or into a fire-isolated passage, both leading into the open. Offices on ground floor have emergency doors fitted into the exterior wall, a can evacuate directly into the open. Occupants are assumed to be familiar with the premises, in an awake state and able to locate the nearest exit. Occupant are assumed to have basic emergency training. Manual suppression equipment is provided but not assumed to be used. Satisfactory egress signage

		configurations are the primary egress route. Secondary egress components are the entrance configuration, and the emergency doors fitted in the exterior walls on ground floor.	is provided throughout the building. The smoke lobby and staircase configurations, with adjoining fire safe passage and entrance are the primary egress routes. Secondary egress routes are the entrance configuration, and the emergency doors fitted in the exterior walls on ground floor.
F: FIRE SERVICE INTERVENTION	Type and characteristics of fire services available	The building is located within metropolitan fire department jurisdiction, within 5 km driving distance of a fire station permanently manned by professional (i.e. not volunteer) fire fighters.	The building is located within metropolitan fire department jurisdiction, within 5 km driving distance of a fire station permanently manned by professional (i.e. not volunteer) fire fighters.
	Fire service access to the site and building	The building has a satisfactory fire service access.	The building has a satisfactory fire service access.
	Water supplies and infrastructure	Pressurized water risers located in each staircase, on each floor.	Pressurized water risers located in each staircase, on each floor. The building has a Fire Control Centre.

7 High-rise design for evaluation

The chosen design configuration, with respective floor layouts for each high-rise are presented in *Appendix A – Building design layout*.

8 Approaches and method of analysis

To formulate a fire engineering solution, the approach can be:

- Comparative or absolute
- Qualitative or quantitative
- Deterministic or probabilistic

The methods and used approach are discussed in the subsequent sections of this report. A combination of qualitative, quantitative and deterministic approaches shall be used in this risk analysis. [23]

Qualitative and quantitative

Qualitative approach is characterized as analyses undertaken by discussion only. This approach is often used for minor non-compliances, including in more complex solution when combined with quantitative assessment.

A quantitative approach where the analysis involves calculation, full scale test, computer simulations or like. [23]

Deterministic

Deterministic methods are based on physical relationships derived from scientific theories and empirical results, and often involves a timeline of events where outcomes are compared. [23]

9 Acceptance criteria

The design objectives of the risk assessment presented earlier must be converted into accept criteria, which in engineering terms are expressed in measurable values. The use of CFD and egress simulation requires proper metrics, which can document the results in a way that facilitates, and guide decision making regarding the satisfactory of the objectives. Since the assessment will be based on the simulated performance of the high-rise designs, the risk analysis requires criteria that is possible to evaluate in the CFD/simulator tools used in this study. Since the objectives are specifications regarding the health of building occupants during the event of fire, the risk criteria must be defined as such, that each simulation provides results of the environment, and its "expected" effect towards occupants.

The acceptance criteria used in this study will therefore use *Tenability conditions*, as specified in Table D4, to estimate the performance of each high-rise building. By estimating the time where a scenario reaches one of these tenability conditions, the robustness of each fire safety design can be evaluated.

Table D4 – Acceptance criteria for the risk analysis. *[19]*

Acceptance criteria

Tenability conditions	
Criteria	**Level**
1. Smoke level above floor	Lowest position 1.6 m + (room height (m) x 0.1).
2. Visibility 2 m above floor	10 m in areas > 100 m^2, or; 5 m in areas ≤ 100 m^2.
3. Heat radiation	Max 2.5 kW/m^2, or short heat radiation of max 10 kW/m^2.
4. Temperature	Max 80℃
5. Toxicity 2 m above floor	Carbon monoxide concentration (CO) < 2000 ppm. Carbon dioxide concentration (CO_2) < 5%. Oxygen concentration (O_2) > 15%.

The acceptance criteria used in this study is based on the Swedish guidelines on analytical design of fire protection of buildings (BBRAD). Measuring the tenability conditions will give an estimate of how long the design configuration is able to provide safe accommodation for its occupants. This provides a time-frame for how long occupants will have to evacuate, before risk of fatality becomes extreme. This is referred to in the literature as the *Available Safe Egress Time* (ASET). [23] [19]

By employing the ASET factor in an egress simulation, and measuring the time for all occupants to evacuate *Required Safe Egress Time* (RSET), the simulation might provide one of two results. [23]

1. Occupants are provided with means in the building design to safely evacuate the premises before it reaches any of the tenability conditions endangering them, and the building design is deemed as acceptable (RSET < ASET) or;
2. The required time for occupants to evacuate the premises, exceeds time until tenability conditions is considered dangerous, and the building design configuration is considered failing to provide safe accommodation for its occupants (RSET ≥ ASET).

Figure D3 illustrates the basic concept of ASET vs RSET, used in this study to assess if the prescriptive means can provide egress before hazardous conditions sets in. Important egress simulation parameters can also be noted, these are further discussed in subsequent section.

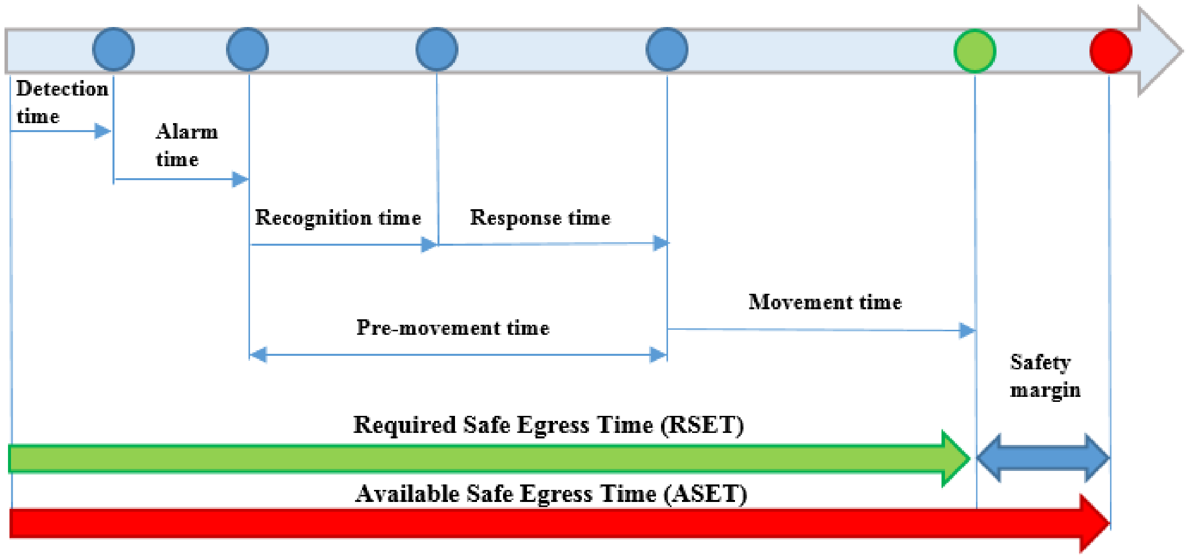


Figure D3 - Visualisation of the ASET vs. RSET method [Figure by Emmanuel Eriksson based on *[40]*]

Observed from Figure D3, the available evacuation time must be longer than the required evacuation time in all scenarios. The “Safety margin” in Figure D3, is a factor of safety between the RSET and ASET value, and must be taken into account when evaluating the robustness of the results. By taking the RSET and ASET factors into account, an egress simulation is able to provide insight if the fire safety design meets the outlined objectives. [40]

10 CFD simulation

To determine the Available Safe Egress Time (ASET), the use of computational fluid dynamic (CFD) software FDS, shall be used to carry out the simulations. This section presents the framework used to conduct the fire simulations, and later the subsequent results, extracted from the simulations.

The software Pyrosim is used in this section to construct the models. As mentioned in the main part of this thesis, is Pyrosim a graphical interface that allows each building considered to be constructed in a 3D graphical setting. While the program interacts, and creates input files that are imported into FDS [72].

Each high-rise building will be evaluated based on their performance against selected fire scenarios, with design characteristics from the hazard identification process. The following scenarios are based on the required scenarios detailed in the BBRAD [19]:

Scenario 1

The first scenario is characterized by a serious fire sequence, with fast development and high heat release rate, a likely worst-case scenario. Implemented technical protection systems may be assumed to function as intended, with the effect of these credited in the scenario.

Scenario 2

Fire scenario 2 is characterized by a fire in a space where there are usually no persons staying, but adjacent to a space that has many persons. Technical protection systems can be assumed to function as intended and the effect of these can be credited.

Scenario 3

Fire scenario 3 is characterized by a fire process that can be seen as a minor strain on the building's fire protection, but which develops while individual protection systems do not work as intended. The technical systems each separately should be made unavailable in the required fire scenario 3 are as follows:

i. *Automatic fire and evacuation alarm.*
ii. *Automatic extinguishing system.*
iii. *Automatic flue gas ventilation or other system for limiting fire and flue gas dispersion.*
iv. *Lifts used for evacuation.*

Consequential faults should be considered if the error means that multiple systems can be knocked out of an event, for example, if power supply falls or if control signals fail.

Each fire scenario is designed to implement stress on the construction in various ways. By including the worst credible hazards, presented in chapter 5 in this report, each scenario becomes more tailored for the specifics of the building. Table D5-D10, presents the different fire scenarios evaluated in this study, in accordance with important design characteristics.

10.1 Fire scenario descriptions

10.1.1 Fire scenario 1

Table D5 - Description of fire scenario 1 for the Swedish high-rise building.

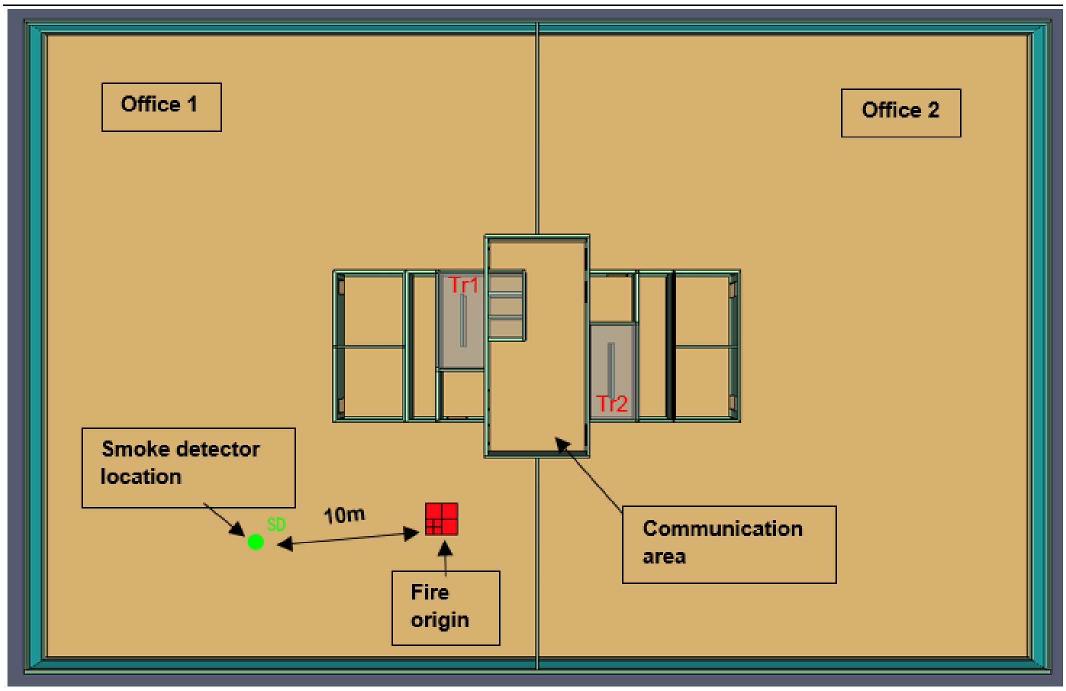
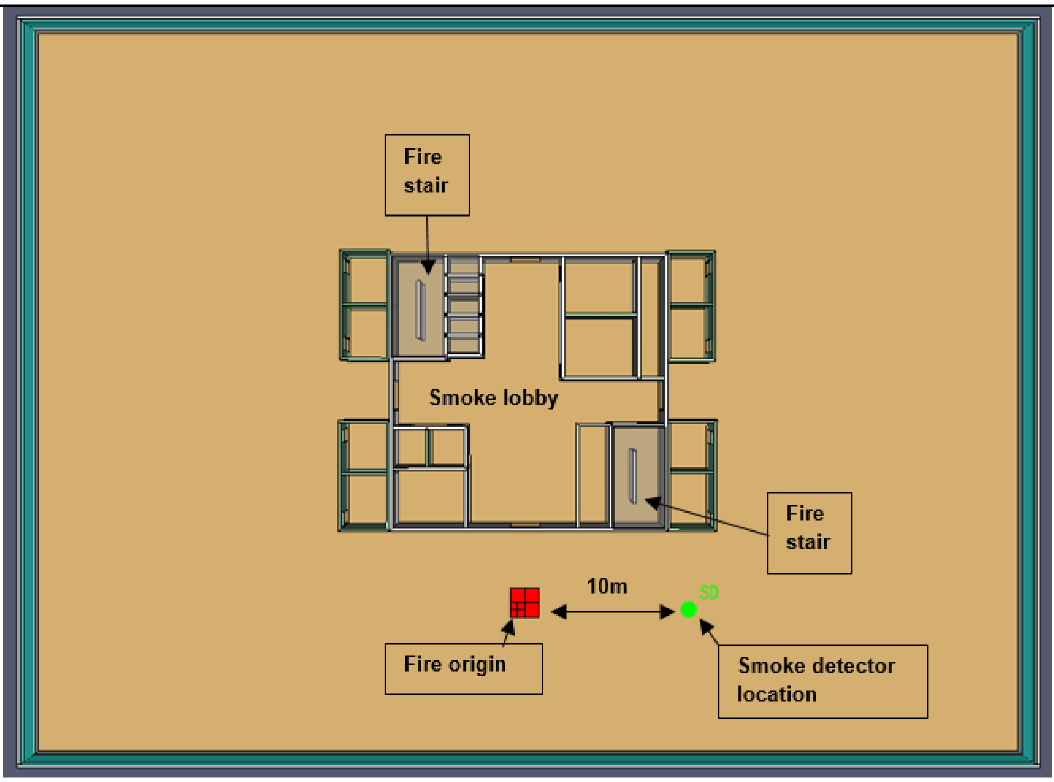
Swedish Scenario 1 (SS1) - Fire scenario description
In this scenario the fire has initiated on the 8th floor, located in the left-wing office area, adjacent to the egress route into the fire safe passage, part of the Tr1 staircase configuration (see Figure D4). The fire blocks the egress path into the Tr1 staircase for nearby occupants, as part of the sensitivity analysis. The fire scenario is assumed to originate from a faulty electrical component on an office desk. The fire is assumed to spread along the office desk surface, with dimension 2m x 2m. The faulty electrical component is assumed to ignite wood materials (red oak $CH_{1.7}O_{0.72}N$). The scenario is described as a serious fire sequence, with fast development and high heat release rate. The design fire parameters for this scenario are presented under Table D11, in the subsequent part below each fire scenario description.
 **Figure D4 - Layout presenting fire scenario 1 for the Swedish high-rise building, modelled in Pyrosim.**

Table D6 - Description of fire scenario 1 for the Australian high-rise building considered in this study.

Australian Scenario 1 (AS1) - Fire scenario description
In this scenario the fire has initiated on the 8th floor, located in the south office area, adjacent to the south entrance to the smoke lobby (see Figure D5). The fire blocks the egress path into the south entrance of the smoke lobby for nearby occupants, as part of the sensitivity analysis. The fire scenario is assumed to originate from a faulty electrical component on an office desk. The fire is assumed to spread along the office desk surface, with dimension 2m x 2m. The faulty electrical component is assumed to ignite wood materials (red oak $CH_{1.7}O_{0.72}N$). The scenario is described as a serious fire sequence, with fast development and high heat release rate. The design fire parameters for this scenario are presented under Table D11, in the subsequent part below each fire scenario description.
 **Figure D5 - Layout presenting fire scenario 1 for the Australian high-rise building, modelled in Pyrosim.**

10.1.2 Fire scenario 2

Table D7 - Description of fire scenario 2 for the Swedish high-rise building considered in this study.

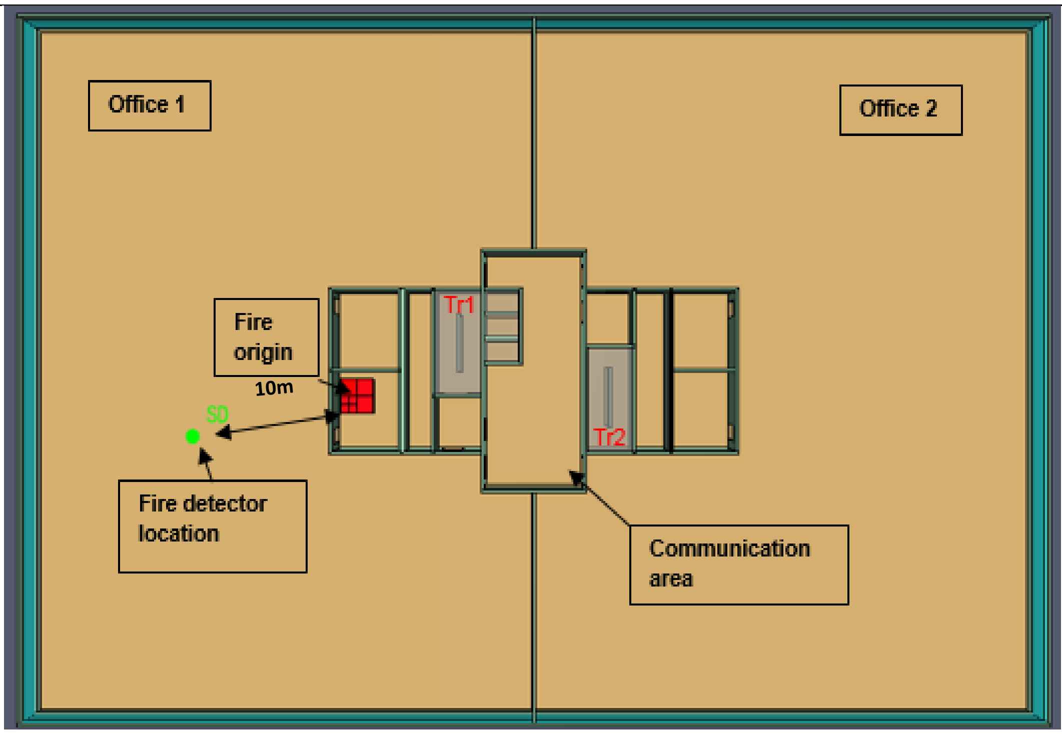
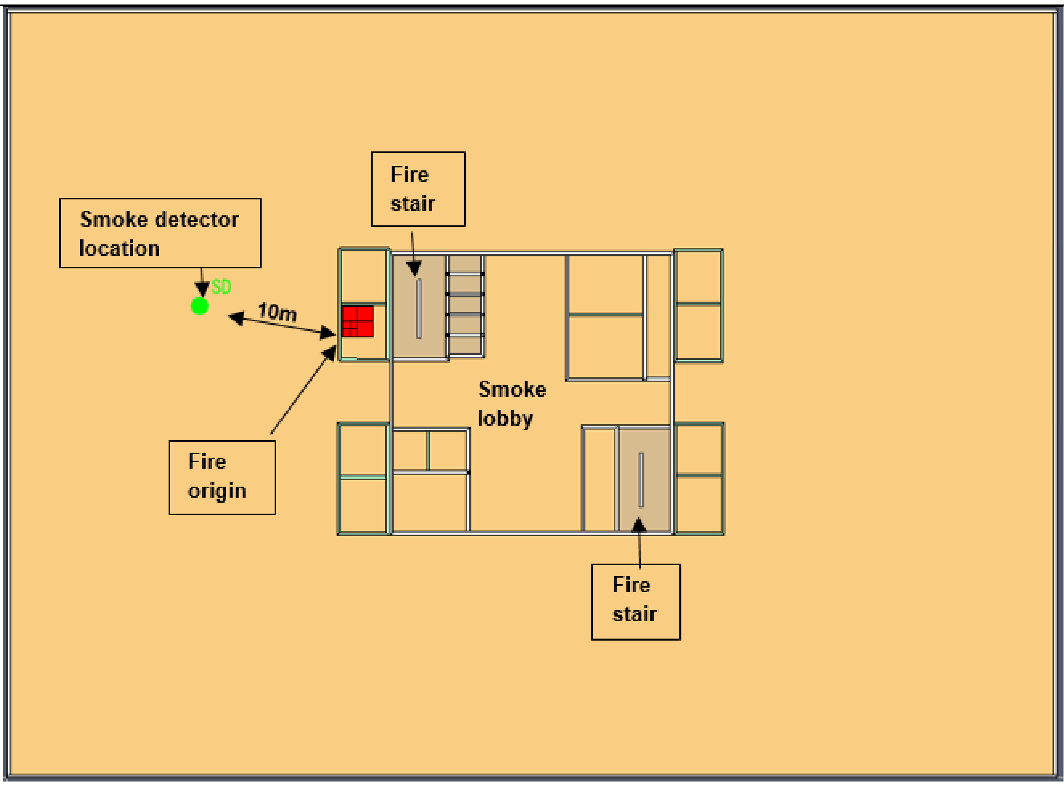
Swedish Scenario 2 (SS2) – Fire scenario description
This fire scenario is also initiated on the 8th floor, but unlike scenario 1 located in the sanitary compartment (WC) area serving the left office-wing (see Figure D6). This is argued from that this area is less likely to be occupied than respective office areas. The sanitary compartment is also located near the Tr1 egress route for the left-wing office occupants, as part of the sensitivity analysis. The fire scenario is assumed to have originated from a faulty electrical component used in the sanitary compartment, and is assumed to ignite wood materials (red oak $CH_{1.7}O_{0.72}N$). The fire is assumed to ignite and spread across a wooden bench located inside the area, with dimension 2m x 2m. The scenario is described as not an immediate hazard, but a potential worst-case, as the position can affect all occupants on the left-wing office floor. The occupants can also be assumed to be under the illusion of safety, since the fire is adjacent but not visual. The design fire parameters for this scenario are presented under Table D11, in the subsequent part below each fire scenario description.
 **Figure D6 - Layout presenting fire scenario 2 for the Swedish high-rise building, modelled in Pyrosim.**

Table D8 - Description of fire scenario 2 for the Australian high-rise building considered in this study.

Australian Scenario 2 (AS2) – Fire scenario description
This fire scenario is initiated on the 8th floor, located in the third sanitary compartment on the left office area, next to the left entrance into the smoke lobby (see Figure D7). This area is less likely to be occupied than the office area, but in correlation, just as connected to the whole floor level. Its position is also next to the left entrance to the smoke lobby, and has the potential to block the egress path, as part of the sensitivity analysis. The fire scenario is assumed to have originated from a faulty electrical component used in the area, and is assumed to ignite and spread across a wooden type construction with dimension 2mx2m, containing wood materials (red oak $CH_{1.7}O_{0.72}N$). The scenario is described as not an immediate hazard, but a potential worst-case, as the position can affect all occupants on the floor. The occupants can also be assumed to be under the illusion of safety, since the fire is adjacent but not visual. The design fire parameters for this scenario are presented under Table D11, in the subsequent part below each fire scenario description.
 **Figure D7 - Layout presenting fire scenario 2 for the Australian high-rise building, modelled in Pyrosim.**

10.1.3 Fire scenario 3

Table D9 - Description of fire scenario 3 for the Swedish high-rise building considered in this study.

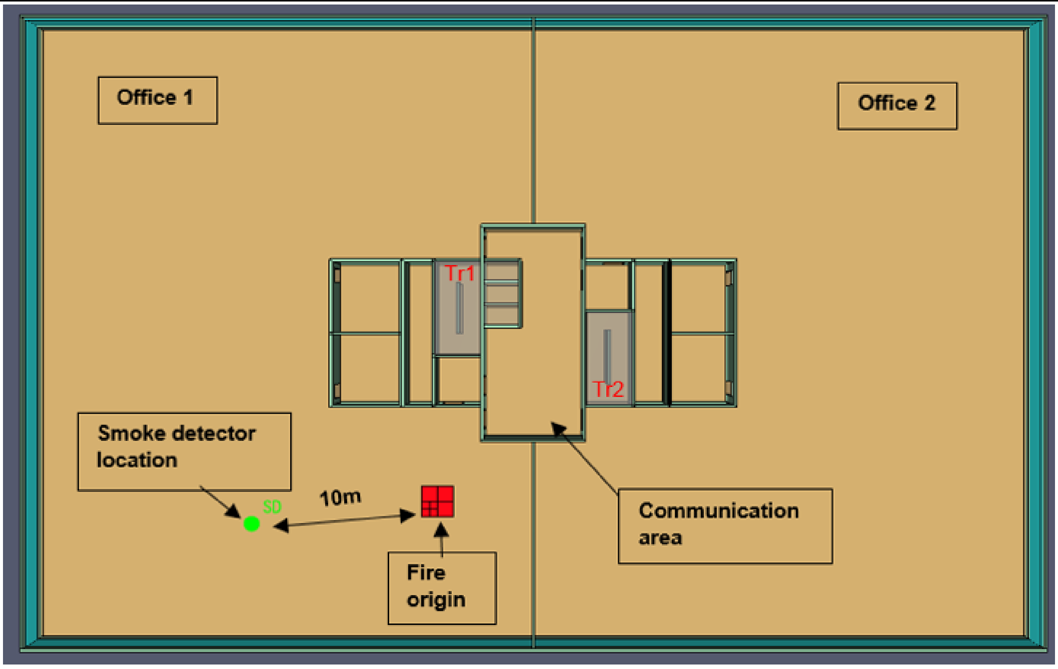
Swedish Scenario 3 (SS3) - Fire scenario description
This fire scenario is initiated on the 8th floor, located in the left-wing office area, adjacent to the egress route into the fire safe passage, part of the Tr1 staircase configuration (see Figure D8). This scenario is influenced by SS1, and simulates the fire blocking the egress path into the Tr1 staircase. It differs however from the smaller strain this scenario is meant to applicate to the building, as this scenario will reach a lower heat release rate and produce less quantity of soot and CO than the previous scenarios. However, this scenario shall be simulated with the assumption that the emergency elevators is unavailable. The fire is assumed to block the entrance to the fire safe passageway as part of the sensitivity analysis. The fire scenario is assumed to have originated from a faulty electrical component used in the left-wing office area, and is assumed to ignite wood materials (red oak $CH_{1.7}O_{0.72}N$). The fire will originate and spread across a wooden bench-sofa located in the office area, with dimension 1m x 1,6m. The scenario is described as not an immediate hazard, but developed during a period where following technical systems is unavailable. 1. The emergency elevators used to evacuate people with disabilities. The design fire parameters for this scenario are presented under Table D11, in the subsequent part below each fire scenario description.
 **Figure D8 - Layout presenting fire scenario 3 for the Swedish high-rise building, modelled in Pyrosim.**

Table D10 - Description of fire scenario 3 for the Australian high-rise building considered in this study.

Australian Scenario 3 (AS3) – Fire scenario description
This fire scenario is initiated on the 8th floor, located in the south office area, adjacent to the south entrance to the smoke lobby (see Figure D9). This scenario is influenced AS1, and is meant to simulate the fire blocking the egress path into south entrance to the smoke lobby for nearby occupants, as part of the sensitivity analysis. The fire scenario is also assumed to originate from a faulty electrical component on an office desk, and is assumed to spread across the office desk surface with dimension 1m x 1,6m. In comparison to AS1, are the strain derived from this scenario meant to be smaller. The faulty electrical component is assumed to ignite wood materials (red oak $CH_{1.7}O_{0.72}N$). The scenario is described as not an immediate hazard, but developed during a period where following technical systems is unavailable. 1. The automatic sprinkler system. The design fire parameters for this scenario are presented under Table D11, in the subsequent part below each fire scenario description.

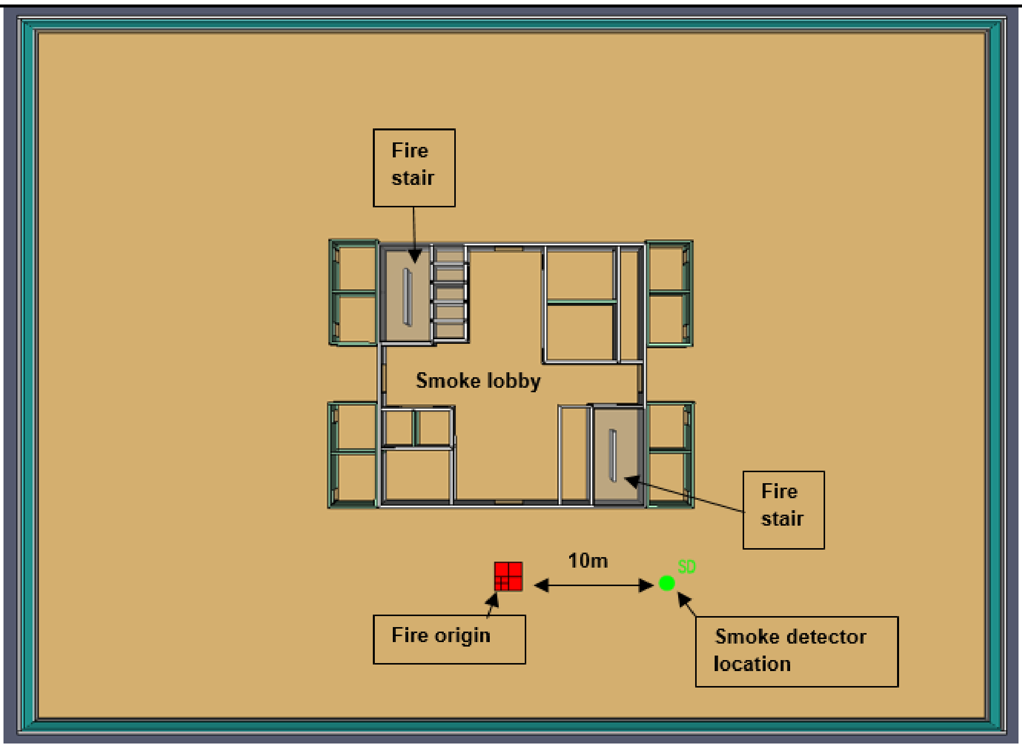



Figure D9 - Layout presenting fire scenario 3 for the Australian high-rise building, modelled in Pyrosim.

10.2 FDS modelling input

The design fire parameter for scenario 1-3 for each high-rise building considered in this study, is presented in Table D11.

Table D11 - Design fire characteristics for scenario 1-3 for the Swedish and Australian High-rise building evaluation.

Parameter	Value	Description	Reference
Fire type	Flaming fire	This was chosen since smouldering fire most likely would have limited impact on other occupants in other floor levels.	[41]
Reaction material	“Red Oak”	Chemical composition found in SFPE handbook, usage influenced by literature review.	[73] [41]
Fuel load	800 MJ/m^2	Value based on the occupancy value used in the fire safety concept for each building examined in this study.	[23]
Fire growth	T-squared	A medium t-squared was recommended for the type of occupancy used in this study.	[19]
Fire growth rate	0.012 kW/s^2	Value recommended in the Swedish guidelines.	[19]
HRR control	Max 5 MW	See section about the effect of sprinkler systems below this Table. The HRR for scenario 3 is prescribed as max 2 MW in the guidelines.	[19]
Radiative fraction	0.3	Used value from the literature review.	[41]
Soot yield	0.1 g/g	For scenario 1 and 2, soot yield for scenario 3 is 0.06 g/g. Values recommended in the guidelines.	[19]
CO production	0.1 g/g	For scenario 1 and 2, CO production for scenario 3 is 0.06 g/g. Values recommended in the guidelines.	[19]
CO_2 production	2.5 g/g	For scenario 1-3, values recommended in the guidelines.	[19]
Heat of combustion	16 MJ/kg	Value recommended in the guidelines. Heat of combustion for scenario 3 is specified as 20 MJ/kg in the guideline.	[19]

Values in Table D11 earlier for soot yield, and CO/CO_2 for fire scenario 3 shall be used for scenario 1-2 if the presence of an automatic sprinkler system is within the enclosure. If the expected HRR control during a discharge of a sprinkler system is max 5 MW, the HRR value shall be max 5 MW for 1 minute after discharge, thereafter within 1 minute be reduced to 1/3 of the MW effect for the remainder of the simulation [19].

The floor to slab height is in both high-rise buildings 3 m, and is derived from minimum ceiling height requirements in Sweden and Australia for respective 2.5 m and 2.4 m [4] [8]. However, have the office ceiling height been modelled as 3 m in both high-rise designs. This assumes that the false ceiling height of 0.5 m and 0.6 m is neglected away, which allows for a greater floor volume, than specified in the minimum requirements in both regulations. A false ceiling with openings could be assessed, but would require further revised modelling.

The location of the smoke detectors is conservatively assumed to be at the furthest point possible from each fire scenario, see Figure D4-D9, as a sensitivity analysis adjustment. Based on the Australian standard AS1670, the maximum distance between two detectors must not exceed 10.2 m, with measured obscuration of 5 %/m. [41] Similar requirements are found in the guidelines for fire detection systems SBF110:7, from the Swedish fire protection association, where maximum distance between two detectors is prescribed as 10m. [74]

10.3 FDS modelling validation

The quality and validation from outputs of FDS simulation, is strongly related to the simulation parameters, and whether the parameters used has been quality assured or not. Parameters concerning the fire, the combustion model, calculation simulation domain are important factors that must be validated prior to starting the simulations, in order to generate as accurate results as possible. [33] Hand calculation illustrating compliance with FDS modelling validation references, is presented in *Appendix H – Hand calculations*.

Since the guideline of BBRAD specifies details about the fire development, it becomes important that the parameters concerning the combustion efficiency of the fire is adopted into the simulations. Guidelines for the validation of the fire and its development are specified in the literature as following [33]:

- The dimensionless Heat Release Rate (HRR) Q^* should be between values of 0.3 to 2.5.

The dimensionless HRR Q^* describes how powerful the fire is in relation to its surface, and is calculated with following equation. FDS is created for simulations containing low speed flows. This requires the Q^* to be held within the above range for the model in FDS to apply. [33]

Equation D1 - Dimensionless Heat Release Rate Q*

$$\dot{Q}^* = \frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{gD} D^2} \qquad [33]$$

Where:

$\dot{Q}^*$	The dimensionless HRR
$\dot{Q}$	The fires HRR (kW)
$\rho_\infty c_p T_\infty$	Density (1.2 kg/m^3), heat capacity (1 kJ/kg/K) and temperature of air (293 K) [33]
g	Gravity (9.81 m/s^2)
D	Diameter of the fire (m)*

*The diameter of the fire in a circular shape.

Since the maximum heat release rate of the fire is pre-determined in the BBRAD as 5 MW for scenario 1-2, and 2 MW for scenario 3, the simulation must ensure that the dimensionless HRR is inside the intervals given above. As the fire development is assumed to reach the maximum value over time, the simulation must also ensure that dimensionless fire development is inside the interval throughout the simulation. [32] [33]

This creates some problems, since FDS calculates the fire development rate as a function of the surface, and a plotted parameter described as “Heat release rate per unit area” (HHRPUA). If the fire development shall be simulated as a function of time, must either the surface simulating the fire or the

HRRPUA change per unit of time. This subsequently means that the value of Q^* will be in constant change throughout the simulation. [33]

This is quality ensured by using the FDS function “TAU_Q”. This function regulates the HRRPUA value in accordance with a user specified time-line, and is used to simulate a more realistic fire spread effect development. The fire source used in each simulation shall be modelled using a number of fire cells, which will be activated at different times to mimic the t^2 fire growth. This enables the fire to be simulated as a function of the surface and HRR, and subsequently possible to maintain applicable values of the dimensionless HRR (Q*) throughout longer parts of the simulation. [32] [33]

Another parameter that needs to be quality assured is the grid resolution for each simulation. FDS solves continuity equation numerically for each control volume (grid cell). This leads to after each equation have been calculated, a residual term is left. The size of this residual term depends on the size of the cell, the larger the cell the greater the rest term [33]. [43]

Nysted [33] defines the characteristic fire diameter as a dimensionless number that describes the size of the fire with a dimensionless number. This number is strongly related to the HRR of the fire, and is given by following equation:

Equation D2 - Equation to obtain the dimensionless value of the characteristic fire diameter used in FDS.

$$D^* = \left(\frac{\dot{Q}}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{\frac{2}{5}} \qquad [33]$$

Where:

D^*	The characteristic fire diameter
$\dot{Q}$	The fires HRR (kW)
$\rho_\infty c_p T_\infty$	Density (1.2 kg/m^3), heat capacity (1 kJ/kg/K) and temperature of air (293 K) [33]
g	Gravity (9.81 m/s^2)

The effectiveness and reliability of a FDS simulation is thus dependant on the ratio between the characteristic fire diameter D* and the size of the grid cells δx. This subsequently means, that larger values of the ratio D*/δx, the more accurate calculation can be obtained by FDS [33]. In accordance with the FDS User’s Guide, shall the ratio of D*/δx be in a range of 10-20 in the near-field of the fire to obtain accurate values from the simulation. Nysted also states that at high room height (D*/H<0.5, where H is the room height (m)), should the ratio D*/δx be at least 15 [32] [33]. [43]

The simulation parameters used to conduct each fire simulation must validate the used grid cells in accordance with values given above. Each simulation must be able to quality assure the values obtained by the simulation domains. Table D12, presents the relation between recommended fire scenarios, and values used in FDS to satisfy the validation parameters discussed in this chapter. [43]

Table D12 - Quality assured parameters for each scenario analysis conducted in this report.

Scenario	Max HRR (MW)	HRRPUA (kW/m^2)	Growth rate (kW/s^2)	Fire source dimension (m^2)	$\dot{D}^*$(-)	$\dot{Q}^*$(-)				Grid cell size (m)				Room height (m)
						Min		Max		Fire source	Adjoining	Furthest away	Closed	
1	5	1252	0.012	4 (2mx2m)	1.8	0.6	0.5m x 0.5m	0.6	4m^2	0.1	0.2	0.4	1	3
2	5	1252	0.012	4 (2mx2m)	1.8	0.6	0.5m x 0.5m	0.6	4m^2	0.1	0.2	0.4	1	3
3	2	1250.6	0.012	1.6 (1mx1.6m)	1.3	0.75	0.4m x 0.25m	0.75	1.6m^2	0.1	0.2	0.4	1	3

Hand calculations made in accordance with this section is presented in *Appendix H – Hand calculation*.

10.3.1 Grid cell size and mesh boundaries

Mesh sizes is one of the most important parameters to consider when conducting a fire simulation in FDS/Pyrosim, and adapting the cells to fit the model can be problematic. It can therefore be necessary to use coarser or finer meshes (larger or smaller cell dimensions) in determined regions inside the model, in order to ensure the quality of the simulation results. When fluid transfers from a finer to coarser mesh size some of the information regarding the fluid property (example temperature, velocity, et.al.) is lost.

Due to capacity and time reducing reasons, it becomes desirable to choose as course as possible mesh resolution. At the same time it is desirable to obtain as realistic and accurate results as possible. A fine mesh resolution is therefore used in the fire area, as well as adjoining areas, with coarser mesh resolution further away from the fire area.

The mesh resolution chosen for all scenarios in the Swedish and Australian high-rise buildings are presented in Figure D10-D15. The Figures illustrates a horizontal view of the mesh resolution in the Pyrosim model. Mesh 1, 2, 3 and in some cases 4, represent areas with different mesh resolution, ranging from 1 being the finest and 3 or 4 the courses size. Table D13 to Table D18 presents the cell sizes used mesh category in accordance with respective Figure. The validation and quality assessment regarding the used cell size for each scenario is presented in Table D12 in previous section.

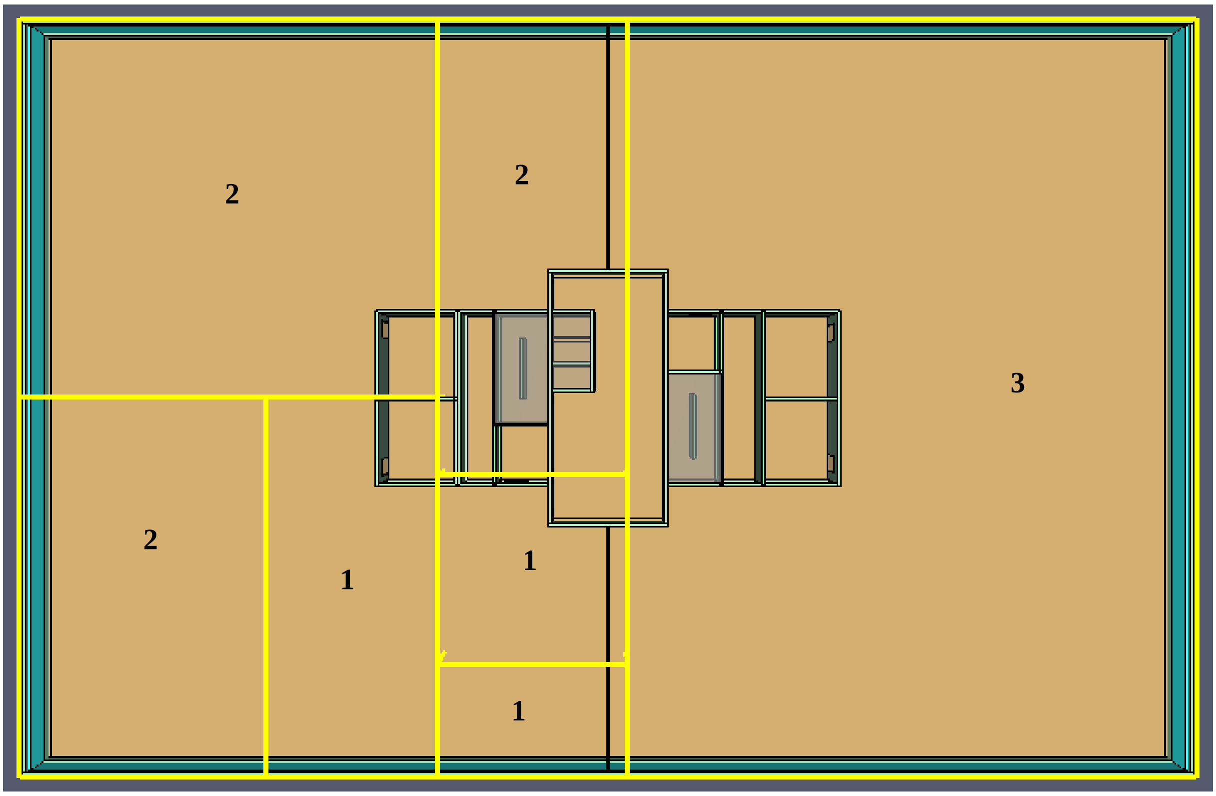


Figure D10 - Horizontal cut-out from the Pyrosim model of scenario 1 for the Swedish high-rise, illustrating the various meshes used as well as category of resolution (1-3) in accordance with Table D13

Table D13 - Mesh resolution of scenario 1 for the Swedish high-rise

Simulation ID	Cell size (m)			Description of cell resolution		
	Cat. 1	Cat. 2	Cat. 3	Cat.1	Cat. 2	Cat. 3
Scenario 1 - Sweden	0.1	0.2	1.0	Fine	Medium	Coarse

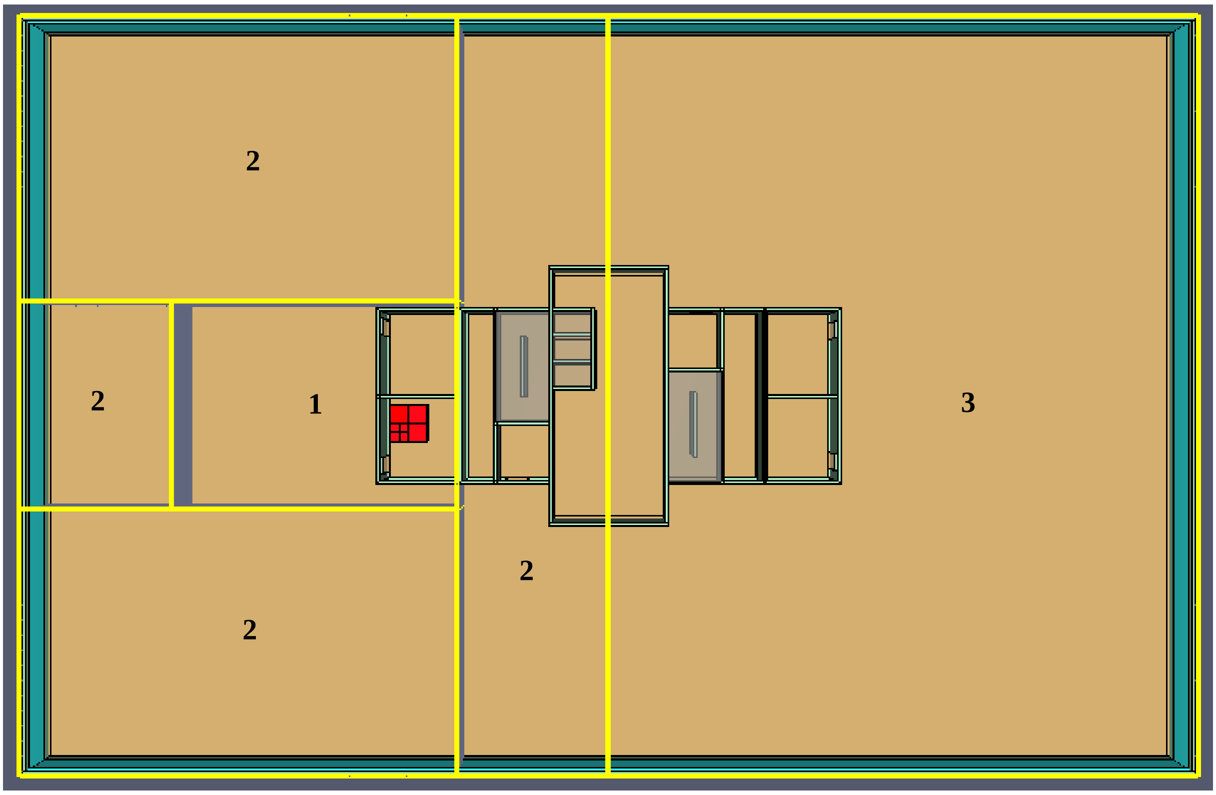


Figure D11 - Horizontal cut-out from the Pyrosim model of scenario 2 for the Swedish high-rise, illustrating the various meshes used as well as category of resolution (1-3) in accordance to Table D14.

Table D14- Mesh resolution of scenario 2 for the Swedish high-rise

Simulation ID	**Cell size (m)**			**Description of cell resolution**		
	Cat. 1	Cat. 2	Cat. 3	Cat.1	Cat. 2	Cat. 3
Scenario 2 - Sweden	0.1	0.2	1.0	Fine	Medium	Coarse

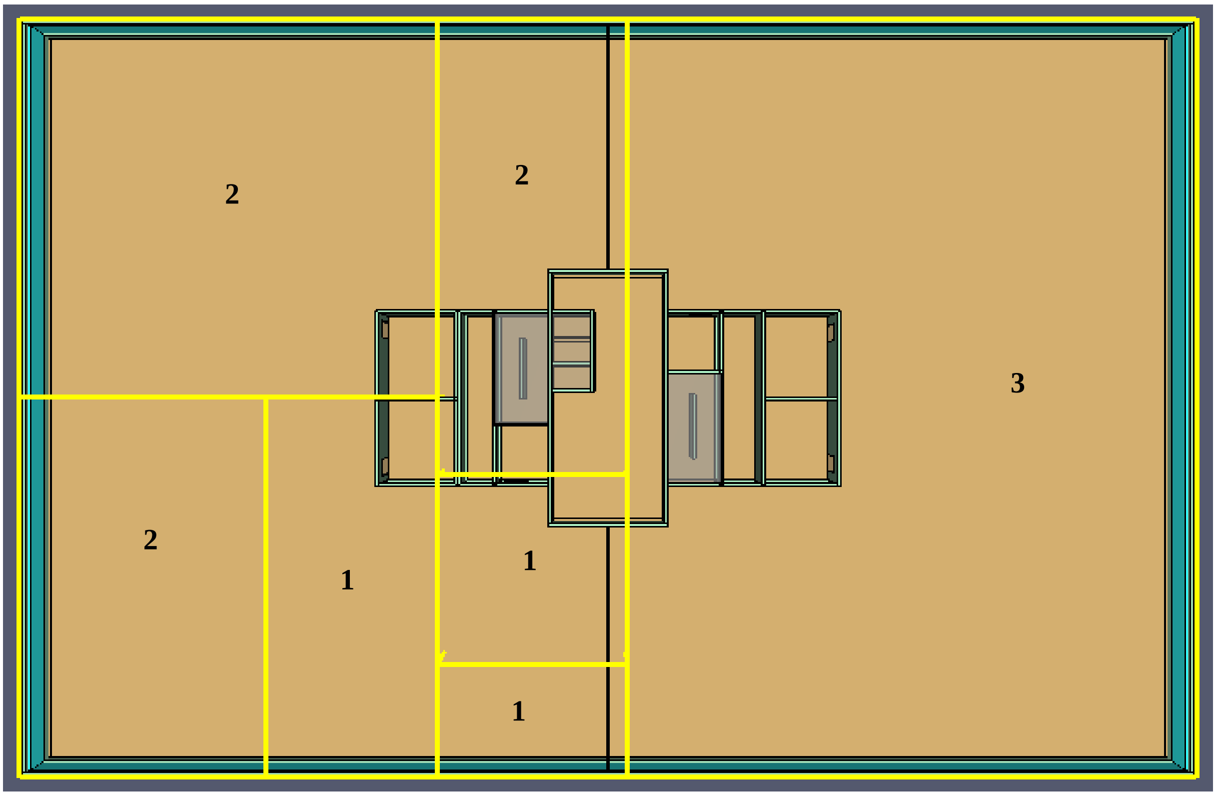


Figure D12 - Horizontal cut-out from the Pyrosim model of scenario 3 for the Swedish high-rise, illustrating the various meshes used as well as category of resolution (1-3) in accordance to Table D15.

Table D15 - Mesh resolution of scenario 3 for the Swedish high-rise

Simulation ID	**Cell size (m)**			**Description of cell resolution**		
	Cat. 1	Cat. 2	Cat. 3	Cat.1	Cat. 2	Cat. 3
Scenario 3 - Sweden	0.1	0.2	1.0	Fine	Medium	Coarse

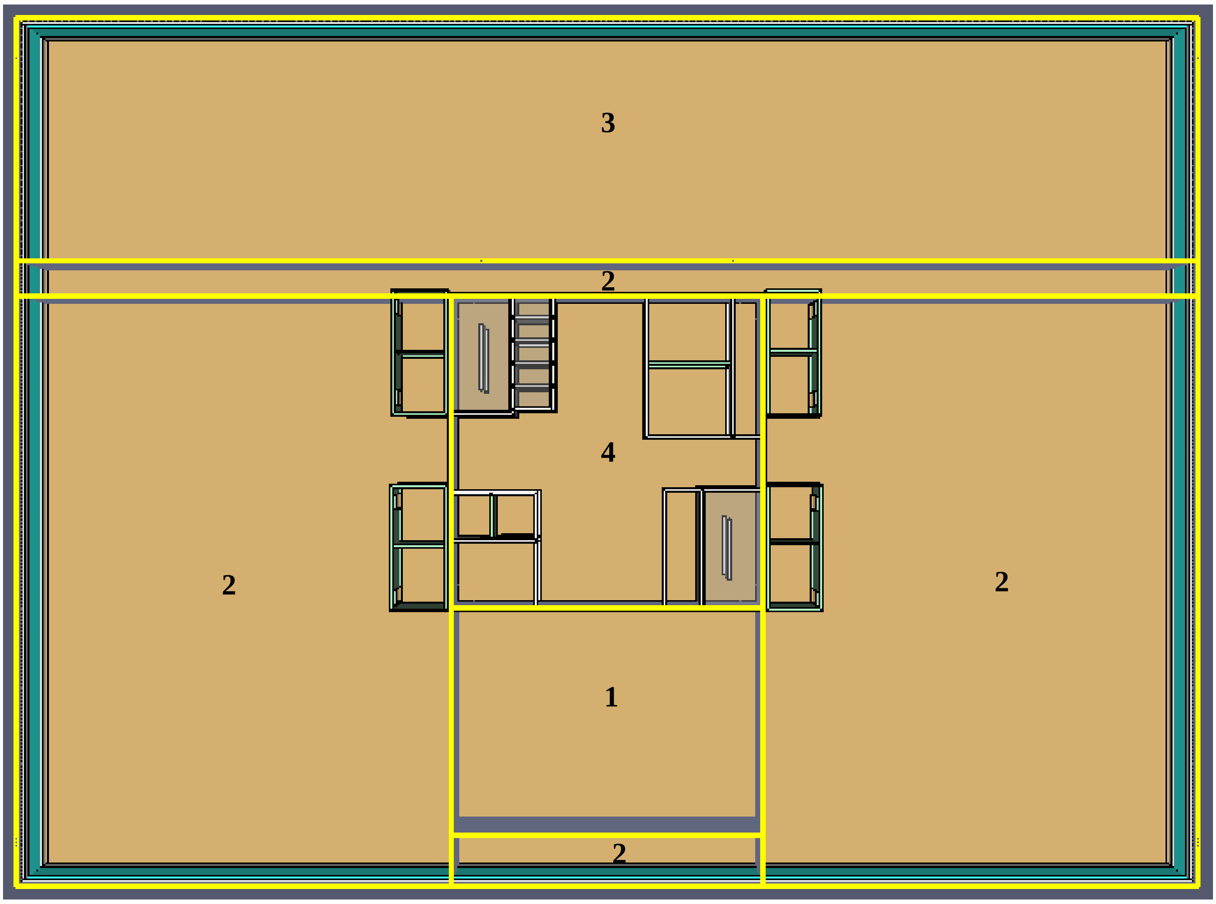


Figure D13 - Horizontal cut-out from the Pyrosim model of scenario 1 for the Australian high-rise, illustrating the various meshes used as well as category of resolution (1-4) in accordance to Table D16.

Table D16 - Mesh resolution of scenario 1 for the Australian high-rise

Simulation ID	**Cell size (m)**				**Description of cell resolution**			
	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat.1	Cat. 2	Cat. 3	Cat. 4
Scenario 1 - Australia	0.1	0.2	0.4	1.0	Fine	Medium	Medium/ Coarse	Coarse

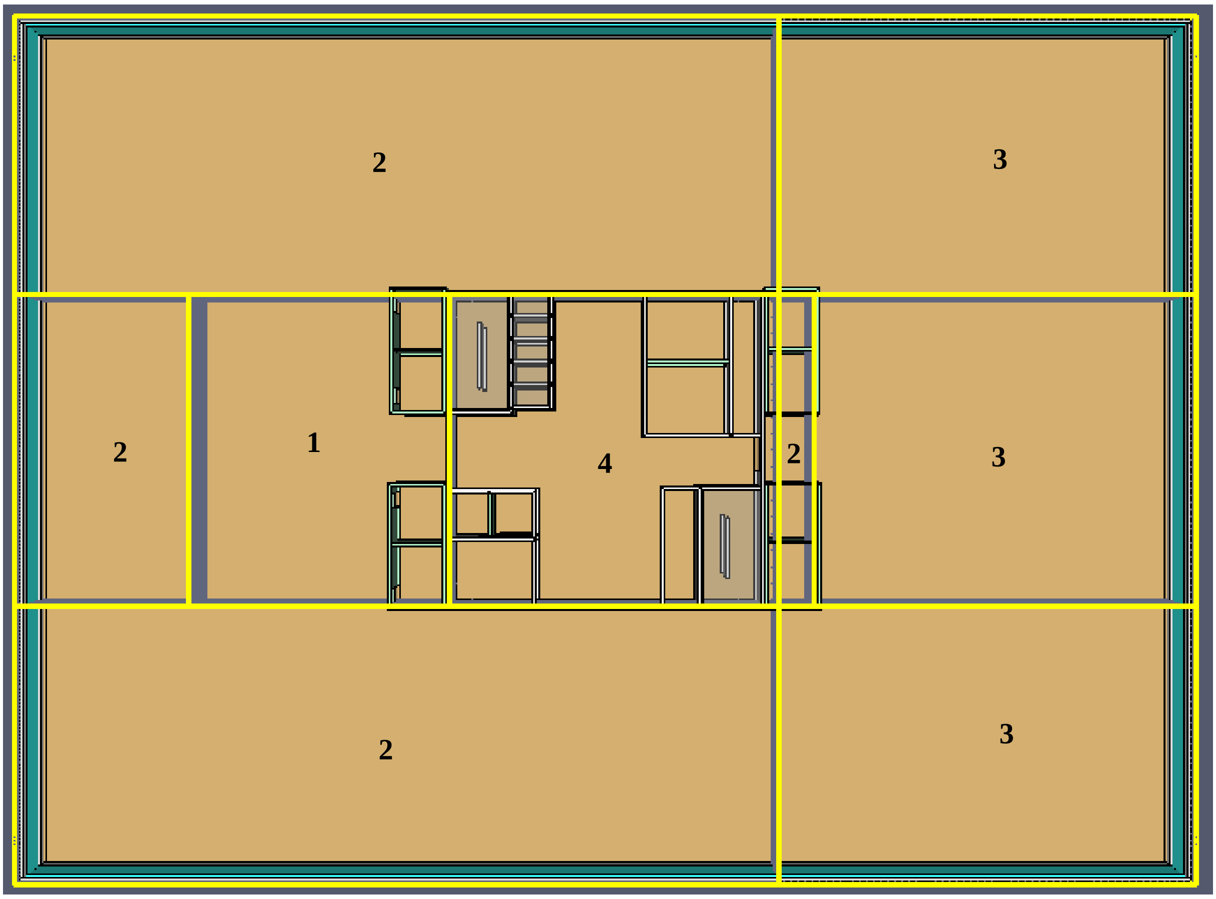


Figure D14 - Horizontal cut-out from the Pyrosim model of scenario 2 for the Australian high-rise, illustrating the various meshes used as well as category of resolution (1-4) in accordance to Table D17.

Table D17 - Mesh resolution of scenario 2 for the Australian high-rise

Simulation ID	**Cell size (m)**				**Description of cell resolution**			
	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat.1	Cat. 2	Cat. 3	Cat. 4
Scenario 2 - Australia	0.1	0.2	0.4	1.0	Fine	Medium	Medium/ Coarse	Coarse

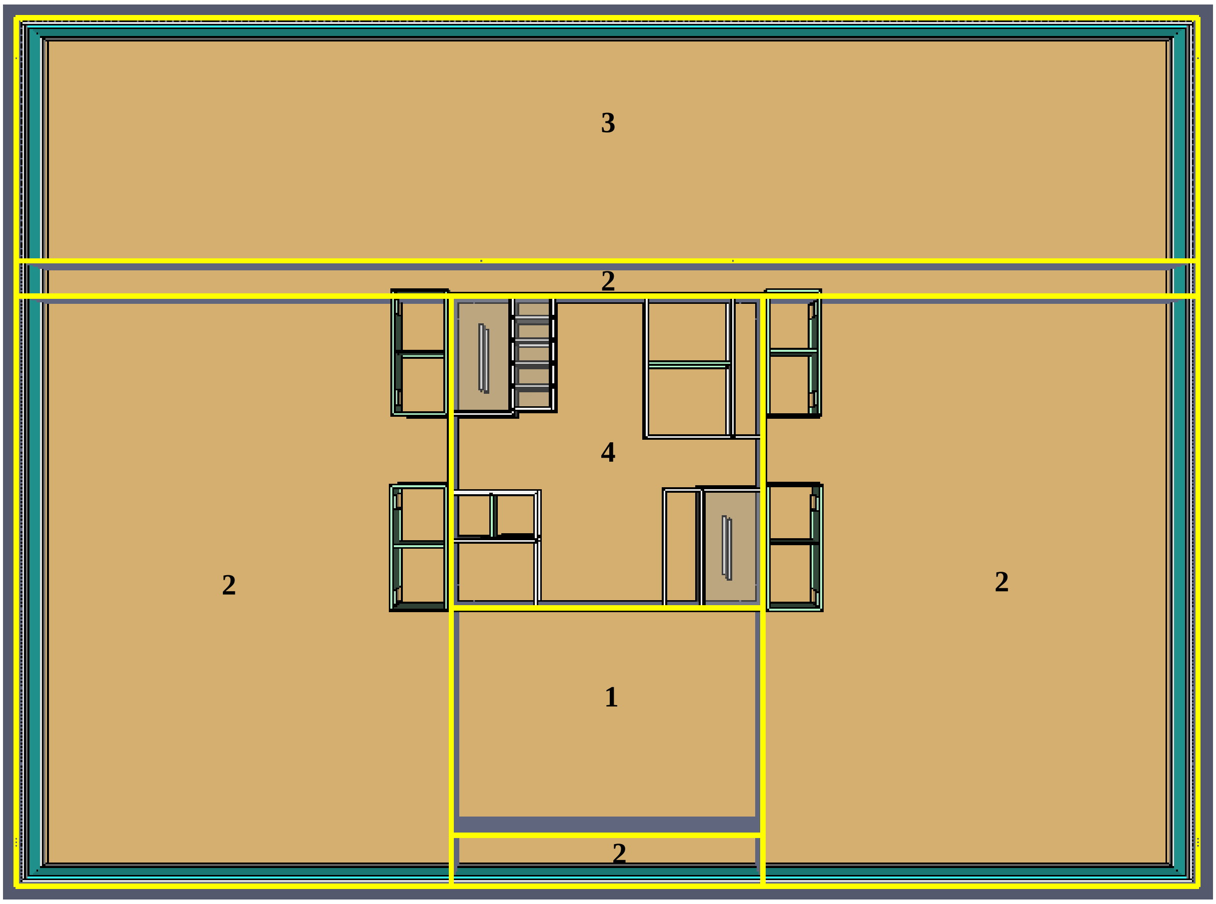


Figure D15 - Horizontal cut-out from the Pyrosim model of scenario 3 for the Australian high-rise, illustrating the various meshes used as well as category of resolution (1-4) in accordance to Table D18.

Table D18 - Mesh resolution of scenario 3 for the Australian high-rise

Simulation ID	**Cell size (m)**				**Description of cell resolution**			
	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat.1	Cat. 2	Cat. 3	Cat. 4
Scenario 3 - Australia	0.1	0.2	0.4	1.0	Fine	Medium	Medium/ Coarse	Coarse

10.4 FDS modelling results

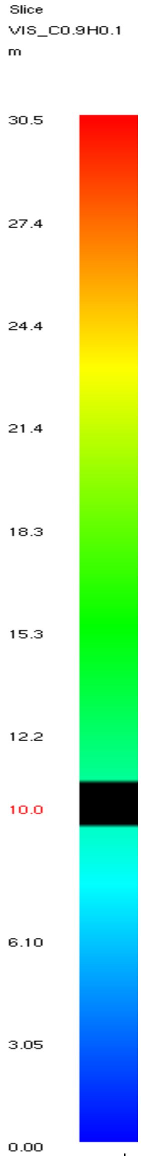
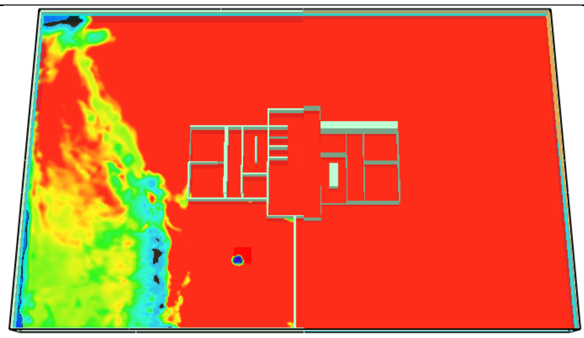
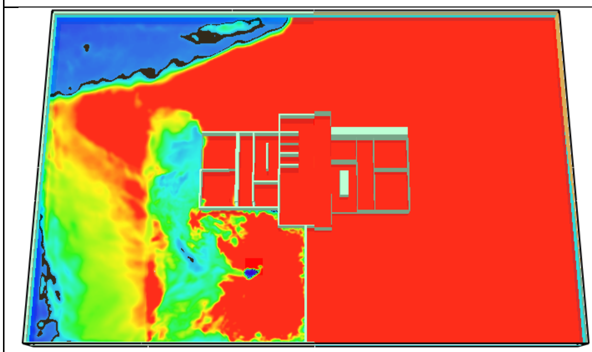
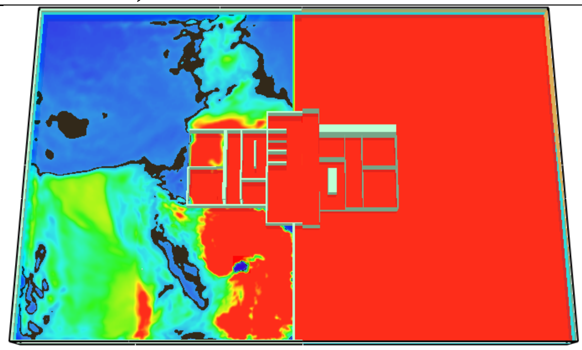
Following sections presents the simulation results for each fire scenario evaluated in this study. The Results only presents the tenability condition that first reached an untenable level for the floor occupants. This subsequently means that only the criteria used to determine the ASET value will be further elaborated in this report.

10.4.1 SS1 Visibility

Results from the first scenario shows that the smoke detector for SS1 activates at 45 s. This shall further be used as the Cue period (P_c) factor, further used to establish the egress simulation for SS1.

Table D19 presents the simulation results, and shows the visibility at 2 m above floor level. The scale on the right side of Table, shows the visibility level for each cut-out, and illustrates how the level falls below the acceptable value in the fire compartment. Reading from the scale, where red represents the highest visibility level, everything under black (10 m) is under acceptable level. Results show that the ASET criteria for the visibility level reaches 10 m around the evacuation routes at 260 s after ignition.

Table D19 - Simulation results for SS1 presenting the visibility level 2 m above the floor.

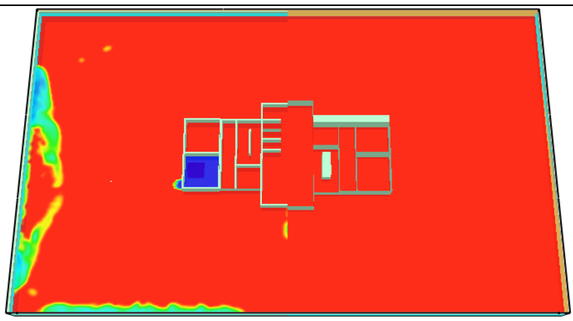
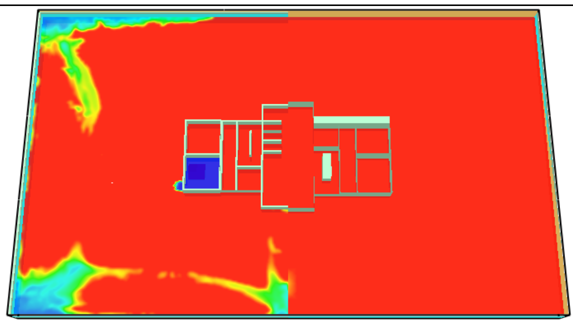
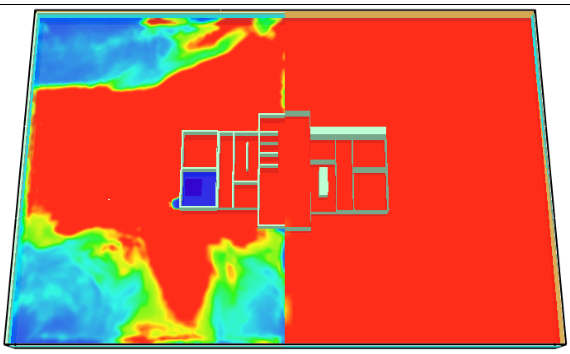
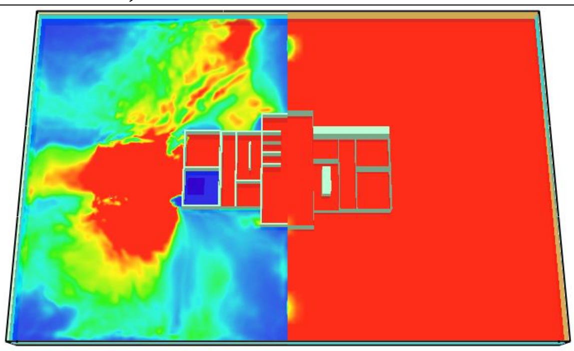
Scenario 1 – Sweden		
After 22 s	After 65 s	
		
After 141 s	After 175 s	
		
After 225 s	After 260 s, ASET is reached.	
		

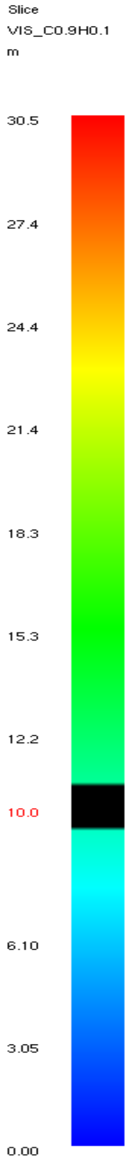
10.4.2 SS2 Visibility

Simulation results shows that the smoke detector for SS2 activates at 66 s, this shall further be used as the Cue period (P_c) factor further used to establish the egress simulation for SS2.

Table D20 presents the simulation results, and shows the visibility at 2 m above floor level. The scale on the right side of Table, shows the visibility level for each cut-out, and illustrates how the level falls below the acceptable value in the fire compartment. Reading from the scale, where red represents the highest visibility level, everything under black (10 m) is under acceptable level. Results show that the ASET criteria for the visibility level reaches 10 m around the evacuation routes at 267 s after ignition.

Table D20 - Simulation results for SS2 presenting the visibility level 2 m above the floor.

Scenario 2 – Sweden	
After 21 s	After 72 s
	
After 141 s	After 175 s
	
After 225 s	After 267 s, ASET is reached.
	

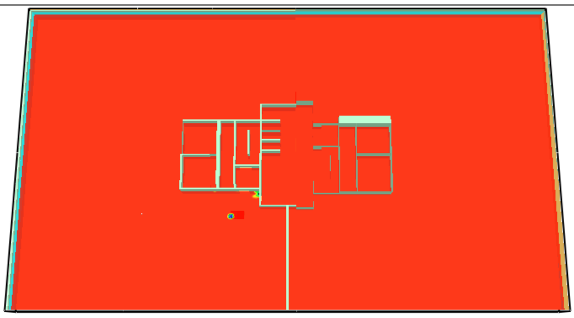
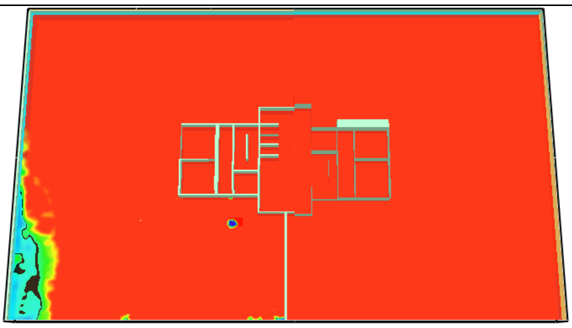
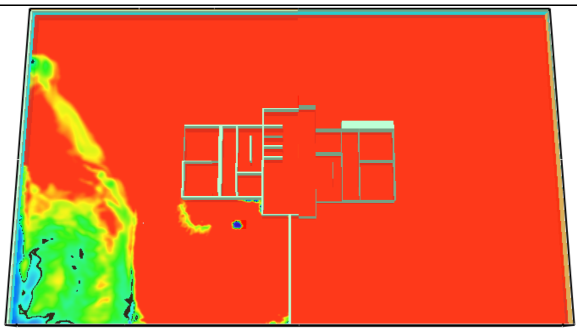
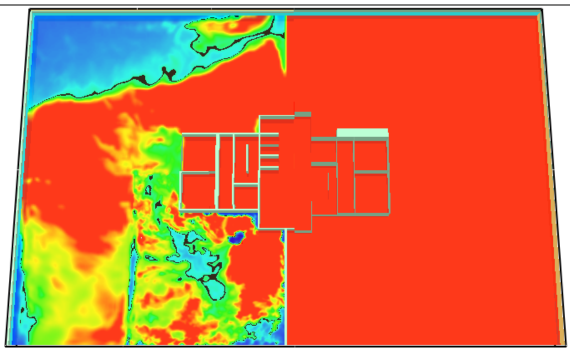
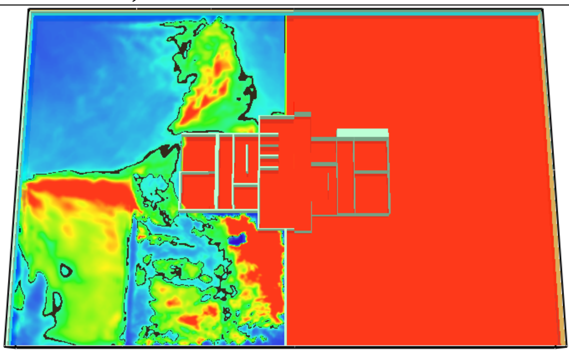


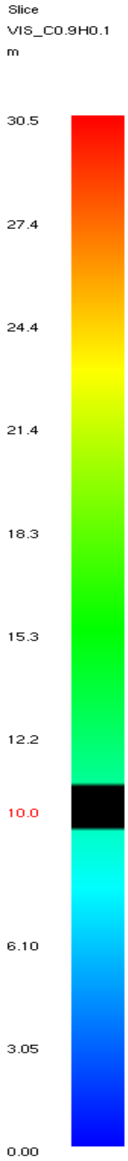
10.4.3 SS3 Visibility

Simulation results shows that the smoke detector for SS3 activates at 47 s, this shall further be used as the Cue period (P_c) factor further used to establish the egress simulation for SS3.

Table D21 presents the simulation results, and shows the visibility at 2 m above floor level. The scale on the right side of Table, shows the visibility level for each cut-out, and illustrates how the level falls below the acceptable value in the fire compartment. Reading from the scale, where red represents the highest visibility level, everything under black (10 m) is under acceptable level. Results show that the ASET criteria for the visibility level reaches 10 m around the evacuation routes at 272 s after ignition.

Table D21 - Simulation results for SS3 presenting the visibility level 2 m above the floor.

Scenario 3 – Sweden	
After 25 s	After 85 s
	
After 140 s	After 180 s
	
After 245 s	After 272 s, ASET is reached.
	

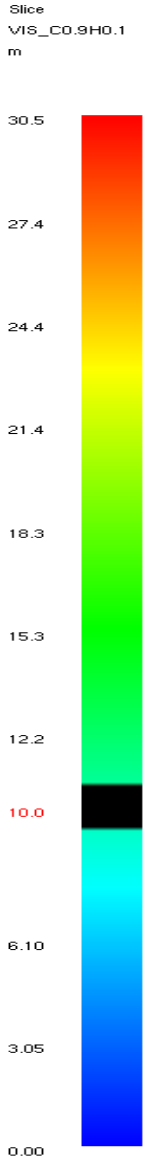
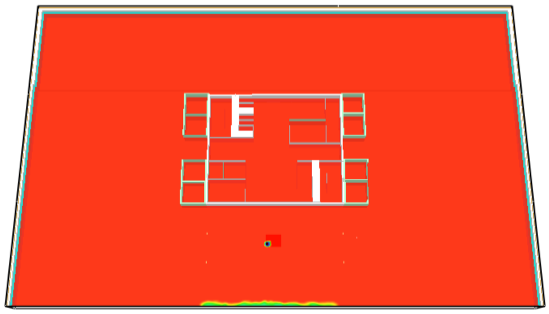
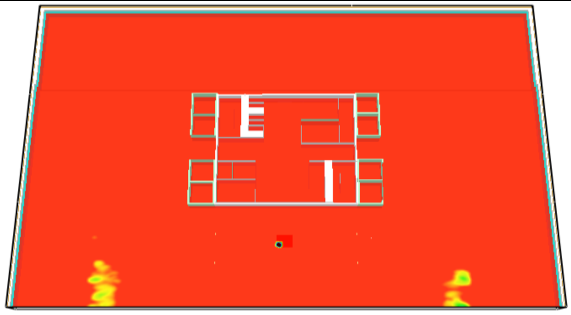
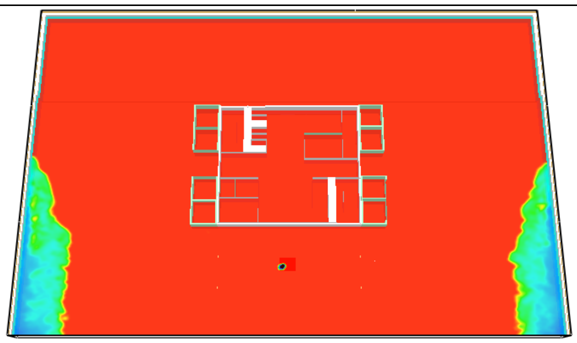
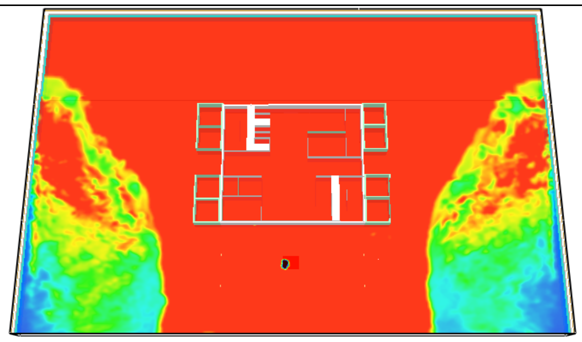
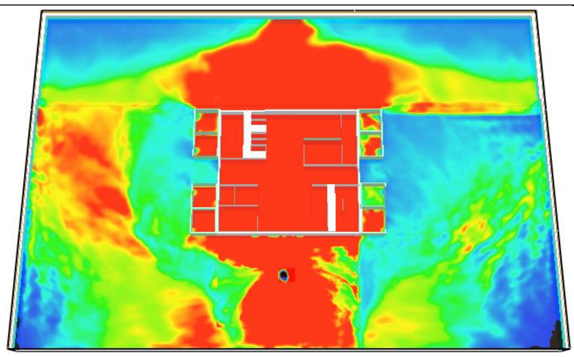
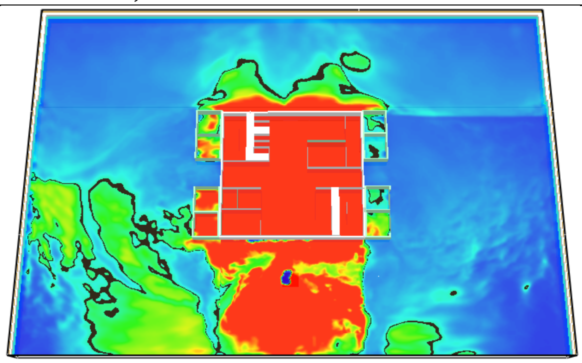


10.4.4 AS1 Visibility

Simulation results shows that the smoke detector for AS1 activates at 50 s, this shall further be used as the Cue period (P_c) factor further used to establish the egress simulation for AS1.

Table D22 presents the simulation results, and shows the visibility at 2 m above floor level. The scale on the right side of Table, shows the visibility level for each cut-out, and illustrates how the level falls below the acceptable value in the fire compartment. Reading from the scale, where red represents the highest visibility level, everything under black (10 m) is under acceptable level. Results show that the ASET criteria for the visibility level reaches 10 m around the evacuation routes at 350 s after ignition.

Table D22 - Simulation results for AS1 presenting the visibility level 2 m above the floor.

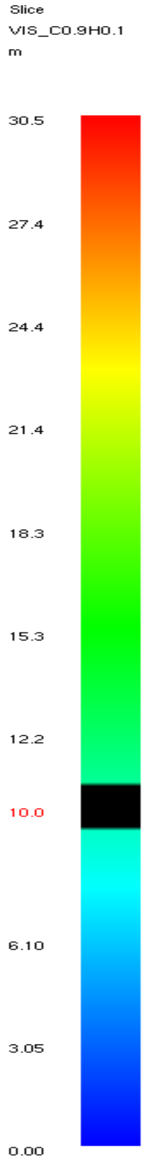
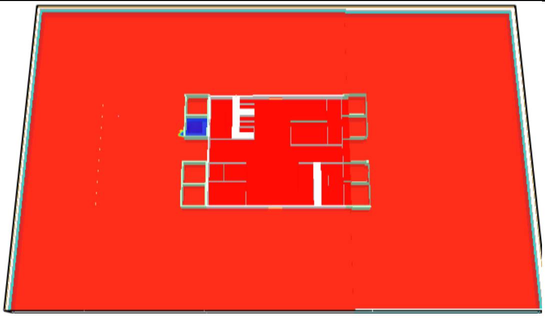
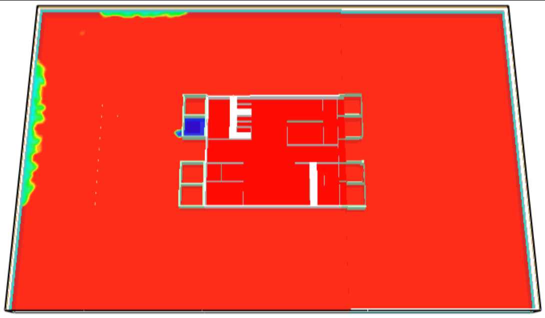
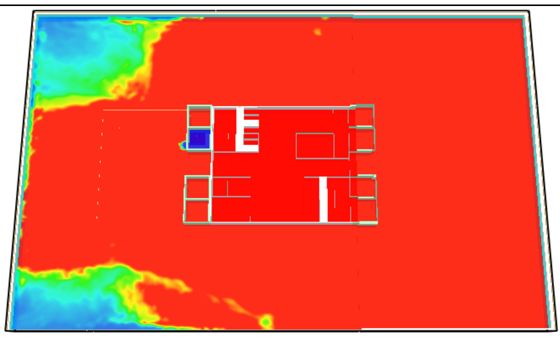
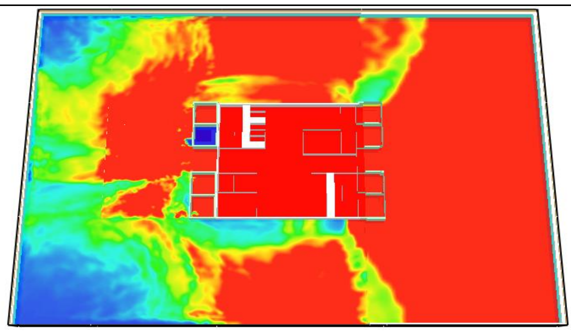
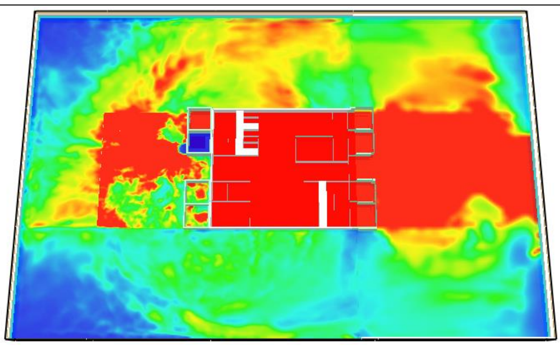
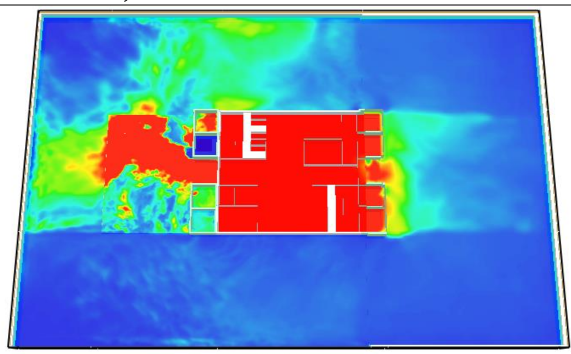
Scenario 1 – Australia		
After 50 s	After 100 s	
		
After 160 s	After 210 s	
		
After 310 s	After 360 s, ASET is reached.	
		

10.4.5 AS2 Visibility

Simulation results shows that the smoke detector for AS2 activates at 59 s, this shall further be used as the Cue period (P_c) factor further used to establish the egress simulation for AS2.

Table D23 presents the simulation results, and shows the visibility at 2 m above floor level. The scale on the right side of Table, shows the visibility level for each cut-out, and illustrates how the level falls below the acceptable value in the fire compartment. Reading from the scale, where red represents the highest visibility level, everything under black (10 m) is under acceptable level. Results show that the ASET criteria for the visibility level reaches 10 m around the evacuation routes at 440 s after ignition.

Table D23 - Simulation results for AS2 presenting the visibility level 2 m above the floor.

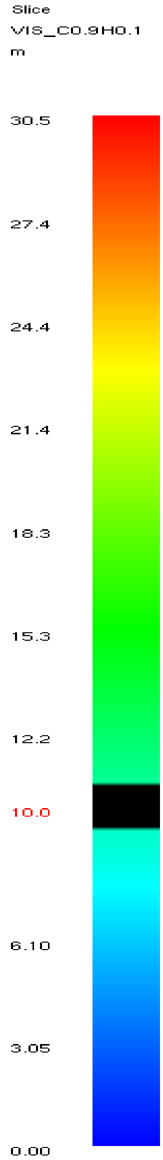
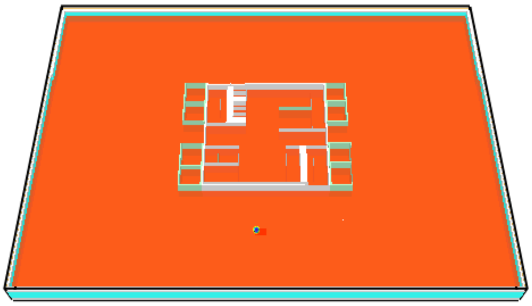
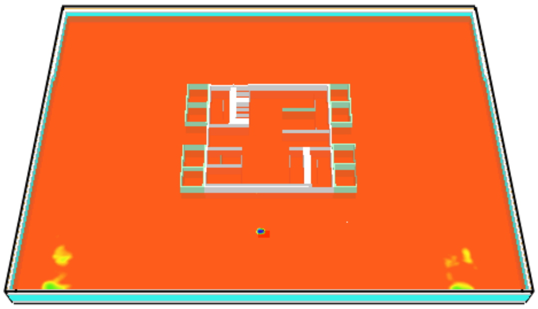
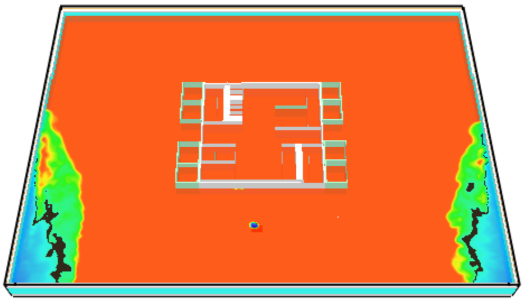
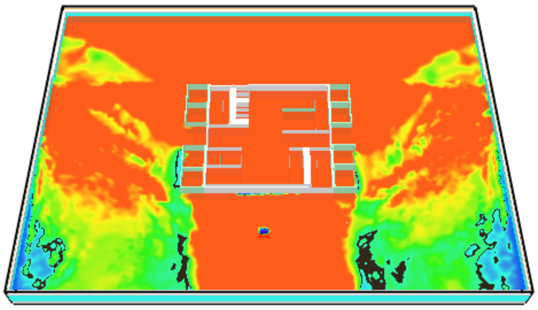
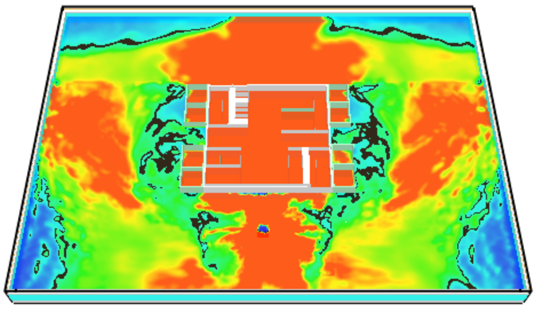
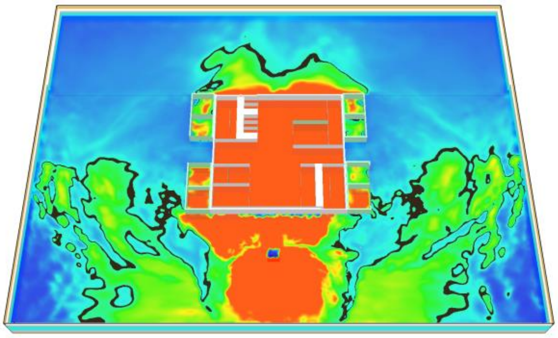
Scenario 2 – Australia		
After 50s	After 120s	
		
After 210s	After 285s	
		
After 370s	After 467s, ASET is reached.	
		

10.4.6 AS3 Visibility

Simulation results shows that the smoke detector for AS3 activates at 60 s, this shall further be used as the Cue period (P_c) factor further used to establish the egress simulation for AS3.

Table D24 presents the simulation results, and shows the visibility at 2 m above floor level. The scale on the right side of Table, shows the visibility level for each cut-out, and illustrates how the level falls below the acceptable value in the fire compartment. Reading from the scale, where red represents the highest visibility level, everything under black (10 m) is under acceptable level. Results show that the ASET criteria for the visibility level reaches 10 m around the evacuation routes at 375 s after ignition.

Table D24 - Simulation results for AS3 presenting the visibility level 2 m above the floor.

Scenario 3 – Australia		
After 60s	After 130s	
		
After 190s	After 250s	
		
After 310s	After 375s, ASET is reached.	
		

11 Egress simulation

To determine the Required Safe Egress Time (RSET), the use of an egress simulator software Pathfinder shall be used. This section presents the framework used to prepare and conduct the egress simulations, and later the subsequent results, extracted from the simulations.

The RSET value used in this analysis shall comprise of the following occupant movement parameters:

- RSET = Cue period (P_c) + Response period (P_r) + Delay period (P_d) + Movement period (P_m) [40]

Table D25 presents a summarization on how each parameter shall be obtained in this section.

Table D25 - Occupant movement parameters *[19]*

RSET VARIABLE	OCCUPANTS CAN SEE THE FIRE/SMOKE	OCCUPANTS CANNOT SEE THE FIRE/SMOKE
CUE PERIOD (P_C)	30 s	Based on the calculated detection time from the FDS simulations.
RESPONSE AND DELAY PERIOD ($P_R + P_D$) BASED ON VALUES GIVEN IN THE BBRAD	30 s	1 minute
MOVEMENT PERIOD (P_M)	See section 11.4 *"Evacuation modelling input"*.	

The cue period (P_c) is explained as the time from ignition to a detection system detect the fire and alarms the occupants. This parameter is determined by the smoke alarm detection time and shall be obtained by the fire scenario simulations.

The pre-movement time (Response period (P_r) + Delay period (P_d)) of 30 s, for occupants observing the fire is considered reasonable, as the occupants will be familiar with the egress routes and can see the smoke. The open floor layout (see *Appendix A – Building design layout* for floor layout design for each high-rise building) will enable most of the floor occupants to see the smoke, triggering a faster decision-making process to evacuate. [41]

The movement period (P_m) will be determined through egress simulations, using the egress simulator *Pathfinder* computer model, with movement parameters from BBRAD.

11.1 Pathfinder modelling

To assess RSET vs ASET correlation for every fire scenario evaluated in this analysis, each scenario shall be assessed, using the computational evacuation software Pathfinder. Pathfinder can be described as an agent based egress simulator, which uses steering behaviour to model the occupant motion, and consists of three modules. [41]

1. Graphical user interface.
2. The simulator.
3. 3D result viewer.

Pathfinder provides, much like Pyrosim, tools to build a 3D model of the building to be analysed. The exit system to be evaluated, and people are then added inside the modelled building. Evacuation is then simulated, with features that considers every person to act as an individual person, leading to that each simulated occupant follows a unique process of egress. [41]

The movement of each agent can be simulated in the model using two methods, either 1) the SFPE mode, and 2) Steering mode. SFPE mode uses the assumptions and calculations presented in the SFPE handbook of Fire Protection Engineering. [42] The steering mode is based on Reynolds steering model, and is more dependent on collision avoidance and occupant interaction. [42] As mentioned earlier in section 3.4.5., in the main document, this study will use the steering based model to simulate the occupant evacuation.

Both Swedish and Australian regulation have legislating requirements for emergency and firefighting lifts. Pathfinder support lifts operation in egress mode operations, and is based on guidelines in *Using*

Elevators in Fires [41]. As both building considered in this study has emergency elevators included in their fire safety concept, and the Swedish guidelines for analytical dimensions prescribes the use of emergency elevators in egress simulation, this feature will be further implemented in all egress simulations. [19]

11.2 Evacuation strategy

The aim of the egress simulation software shall be to assess the total egress time with respect of zone evacuation.

The evacuation method of “zone evacuation” has been selected due to the large relation between number of occupants, and available egress routes within each high-rise building. An immediate total evacuation could also be assessed. However, due to the exceeding number of occupants per floor level, implementing such procedure would only lead to queuing to enter the stairs, as well as congestion inside each stair configuration. Zoned evacuation priorities the floor in danger, including adjoining floors to evacuate first, and aims at decreasing queuing time in the egress paths. [27]

Zone evacuation will therefore be the evacuation strategy further used in this study, and further implemented in the egress simulation.

11.3 Egress scenario descriptions

This risk analysis will consist and simulate six different evacuation simulation with different combination, depending on the specifics of the evaluated fire scenario. The location of the fire, as well as objective of each scenario will vary depending on the design scenario specifics. The egress simulation needs therefore to be revised, to simulate the intendent scenario as accordingly to the specifics as possibly. In all scenarios, the primary egress strategy shall be to evacuate through the stairs closest to the agent, to the ground level. As each building consists of emergency elevators as part of fire safety features, people with disability will be modelled to evacuate by these, to the discharge floor at the ground level.

Each building considered in this study have been represented in Pathfinder in accordance with the design layout presented in *Appendix A* (see Figure D16 and D17).

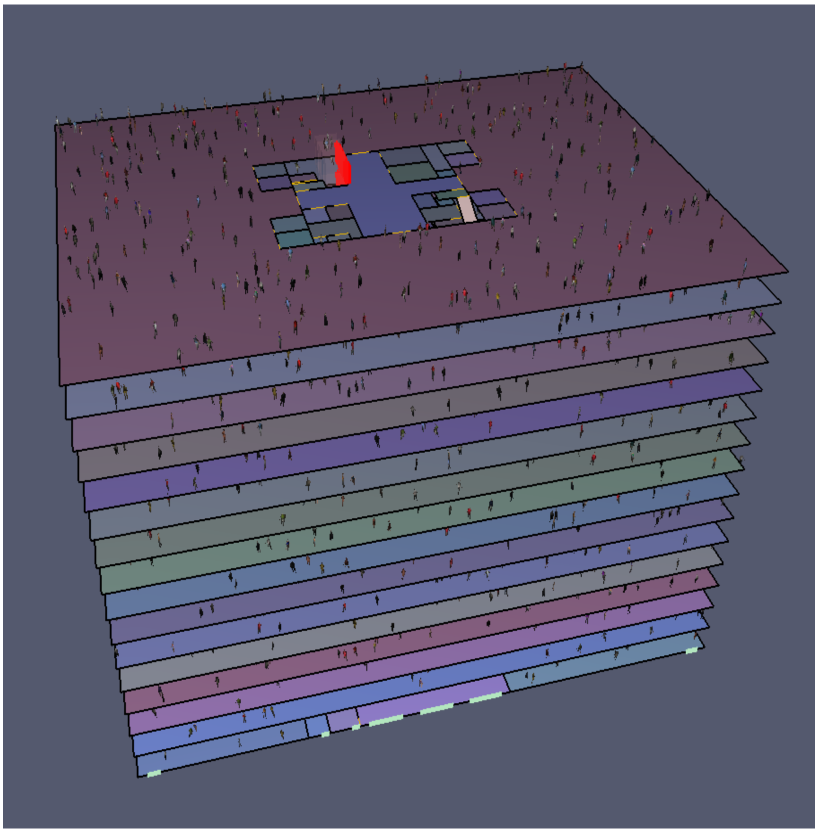


Figure D16 - Model of the Australian high-rise building used to simulate scenario AS1-3 in Pathfinder.

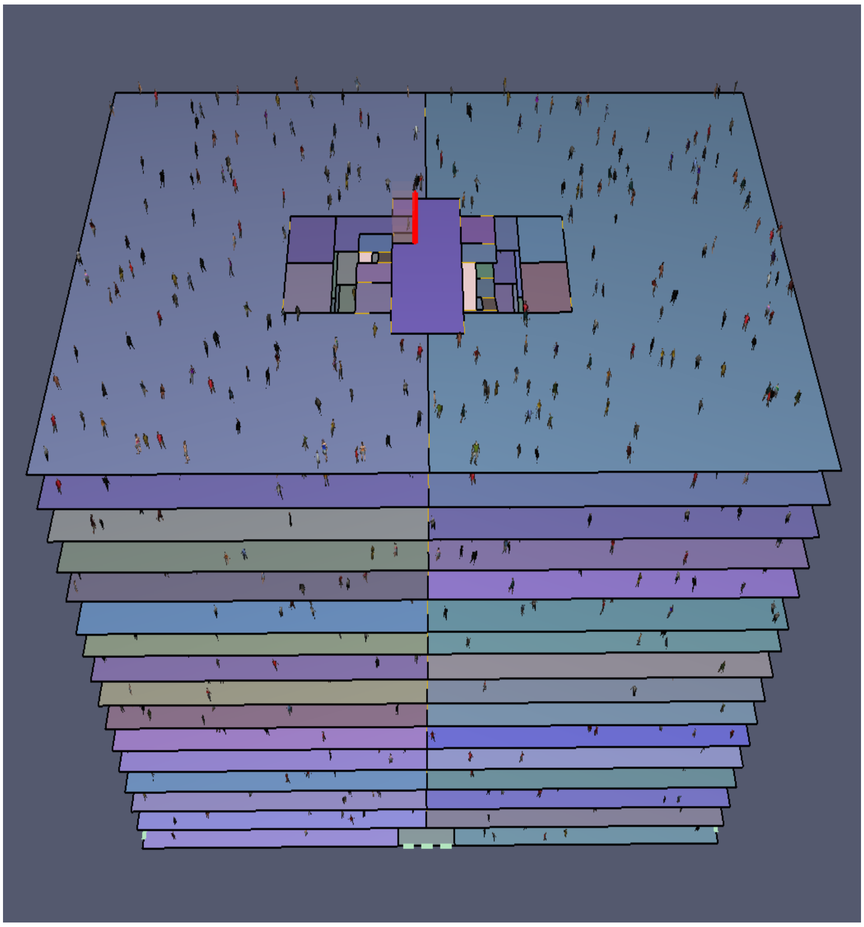


Figure D17 - Model of the Swedish high-rise building used to simulate SS1-3 in Pathfinder

The geometry and number of agents representing their respective building is modelled in line with the description described in the main body of this study, as well as previous sections in this analysis. Table D26-D31, presents the different egress modelling scenarios, in accordance with the intention, and specifics of design fire scenario.

The Swedish high-rise can in accordance with the fire safety concept accommodate a total of 3561 occupants, with each floor containing 223 people. The ground floor can only accommodate 216 occupants, due to less office space available. The Pathfinder model of the Swedish building however, contains 3576 occupants. With each floor accommodating 224 people, except the ground floor, to evenly distribute the numbers of occupants on each office area. This will be the most conservatory value to be used in each simulation, and will test the robustness of the building design. The Australian high-rise is modelled with the number of occupants specified earlier in this report.

People with reduced mobility has been takin into account in both high-rise buildings, and represents 6 % of the people on each floor. The Swedish and Australian buildings accommodates a total 224 people and 286 people with reduced mobility respectively. The BBRAD specifies that at least 1% of the total number of occupants must be modelled with reduced mobility in public places, but do not provide any guideline for office use. The selection of 6 % is conservative, and taken into account due to the sensitivity analysis. These are modelled with reduced physical properties in correlation with the standard office occupant modelled in this study (see Table D32).

The emergency elevators within the Swedish and Australian high-rise have been modelled in accordance with the building design layouts in *Appendix A – Building design layout*. Input values (e.g. acceleration and holding capacity) and function of the elevators used in this risk assessment, has been in accordance with standard values programmed into the Pathfinder software.

11.3.1 Egress scenario 1

Table D26 - Egress scenario description for SS1

Building design	**People using the stair configurations [%]**	**People using the emergency elevators [%]**	**Floor level subjected to the scenario. [Floor/16]**
Swedish	94	6	8/16

In this scenario (see Figure D18), the fire is placed in order to block the egress path for the left-wing office occupants into the Tr1 staircase configuration (red "X" in the Figure). With the primary evacuation route blocked by the fire, the left-wing office occupants must either evacuate through the fire compartmental boundaries (1), and into the communication area to reach the Tr1 or Tr2 configurations. Alternatively evacuate a longer distance around the central core of the building into the communication area (2), prior to evacuating through either the Tr1 or Tr2 staircase, to ground level.

In this scenario it is assumed that 94 % of each floor consists of occupants with standard agent physic, and evacuate through either of the Tr1 or Tr2 configuration, until they reach the ground floor and evacuate the building. 6 % of the population of each floor is counted as people with reduced mobility, and modelled with reduced horizontal speed. These occupants shall be simulated with egress path leading to the emergency elevator to safely evacuate the building.

The egress modelling parameters for this scenario are presented in Table D32 in following part.

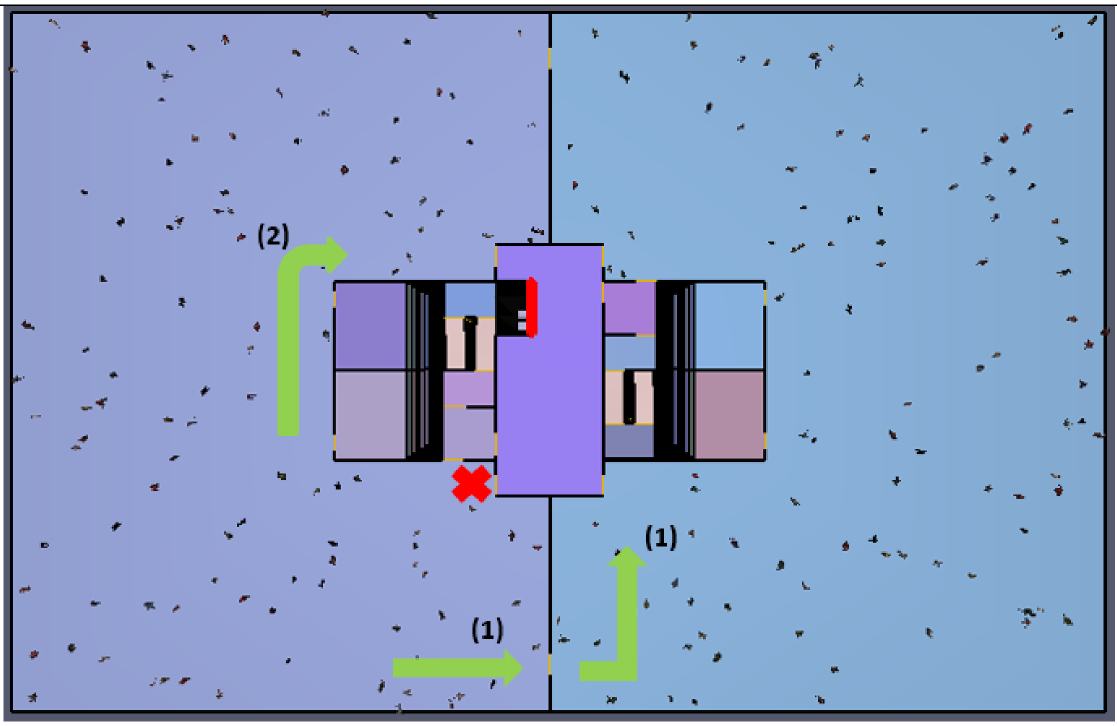


Figure D18 - Egress strategy interpretation SS1

Table D27 - Egress scenario description for AS1

Building design	People using the stair configurations [%]	People using the emergency elevators [%]	Floor level subjected to the scenario. [Floor/16]
Australian	94	6	8/16

In this scenario (see Figure D19), the fire is placed in order to block the egress path into the south entrance of the smoke lobby for the agents assumed to have their office station in the south area. With the primary evacuation route blocked by the fire (red "X" in the Figure), the south office occupants must evacuate a longer distance round the central core of the building into either the west or east entrance to the smoke lobby. Prior to evacuating through either fire safe staircase configuration, to the ground level and evacuate through the exits.

This scenario assumes that 94% of each floor consists of occupants with standard agent physic, and will evacuate through either of the fire safe staircases, until they reach the ground floor and evacuate the building. 6% of the population of each floor is counted as people with reduced mobility, and modelled with reduced horizontal speed. These occupants shall be simulated with egress path leading to the emergency elevator to safely evacuate the building.

The egress modelling parameters for this scenario are presented under Table D32, in the subsequent part below each egress scenario description.

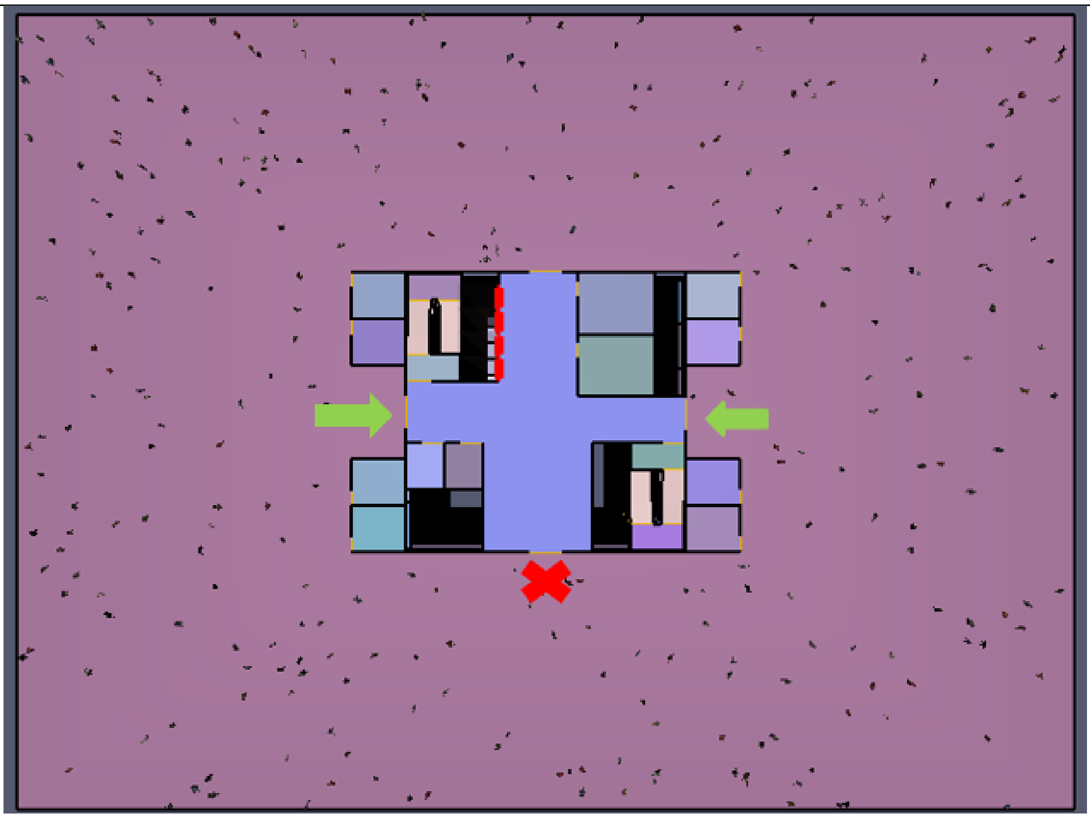


Figure D19 - Egress strategy interpretation AS1

11.3.2 Egress scenario 2

Table D28 - Egress scenario description for SS2

Building design	**People using the stair configurations [%]**	**People using the emergency elevators [%]**	**Floor level subjected to the scenario. [Floor/16]**
Swedish	94	6	8/16

In this scenario (see Figure D20), the fire is placed in the sanitary compartment adjacent to the left-wing office occupants. In comparison to scenario 1, is all evacuation routes now available for the occupants. The agents are thereby modelled to evacuate in accordance to the primary and secondary evacuation plan described in the fire safety concept.

In this scenario it is assumed that 94% of each floor consists of occupants with standard agent physic, and evacuate through either of the Tr1 or Tr2 configuration, until they reach the ground floor and evacuate the building. 6% of the population of each floor is counted as people with reduced mobility, and modelled with reduced horizontal speed. These occupants shall be simulated with egress path leading to the emergency elevator to safely evacuate the building.

The egress modelling parameters for this scenario are presented in Table D32, in following part.

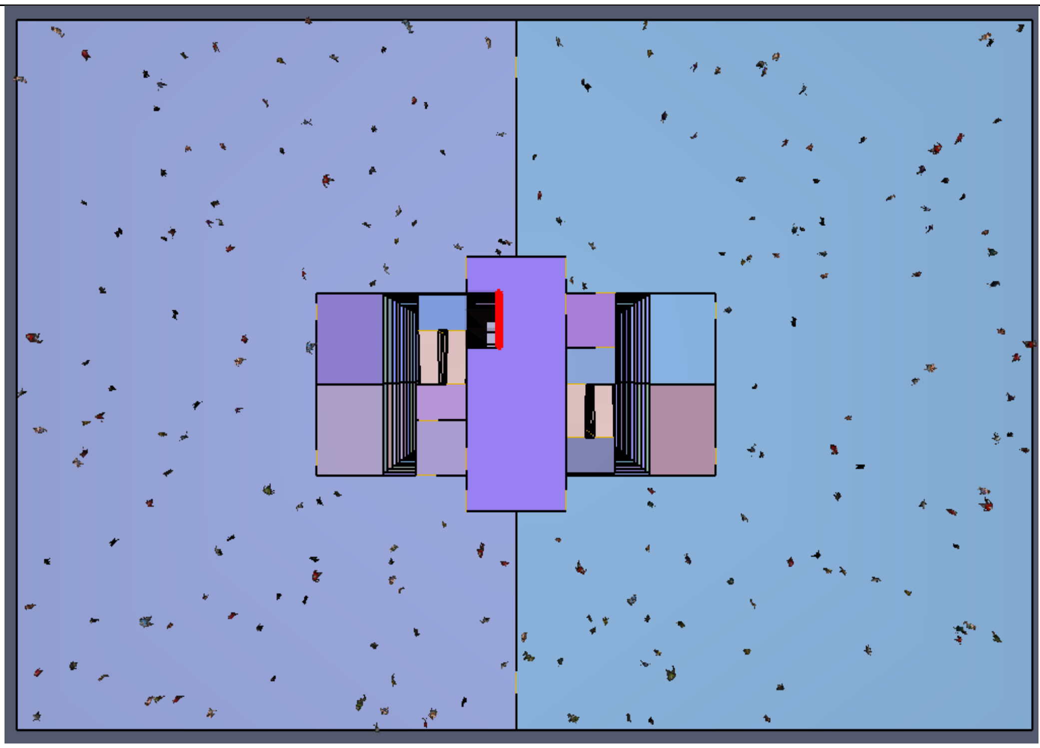


Figure D20 - Egress strategy interpretation SS2

Table D29 - Egress scenario description for AS2

Building design	**People using the stair configurations [%]**	**People using the emergency elevators [%]**	**Floor level subjected to the scenario. [Floor/16]**
Australian	94	6	8/16

In this scenario (see Figure D21), the fire is placed in the sanitary compartment to the nearest left of the west entrance to the smoke lobby. In comparison to scenario 1, is all evacuation routes available for the occupants. The agents are thereby modelled to evacuate in accordance to the primary and secondary evacuation plan described in the fire safety concept.

In this scenario it is assumed that 94% of each floor consists of occupants with standard agent physic, and evacuate through either of the fire safe staircase configuration, until they reach the ground floor and evacuate the building. 6% of the population of each floor is counted as people with reduced mobility, and modelled with reduced horizontal speed. These occupants shall be simulated with egress path leading to the emergency elevator to safely evacuate the building.

The egress modelling parameters for this scenario are presented in Table D32, in following part.

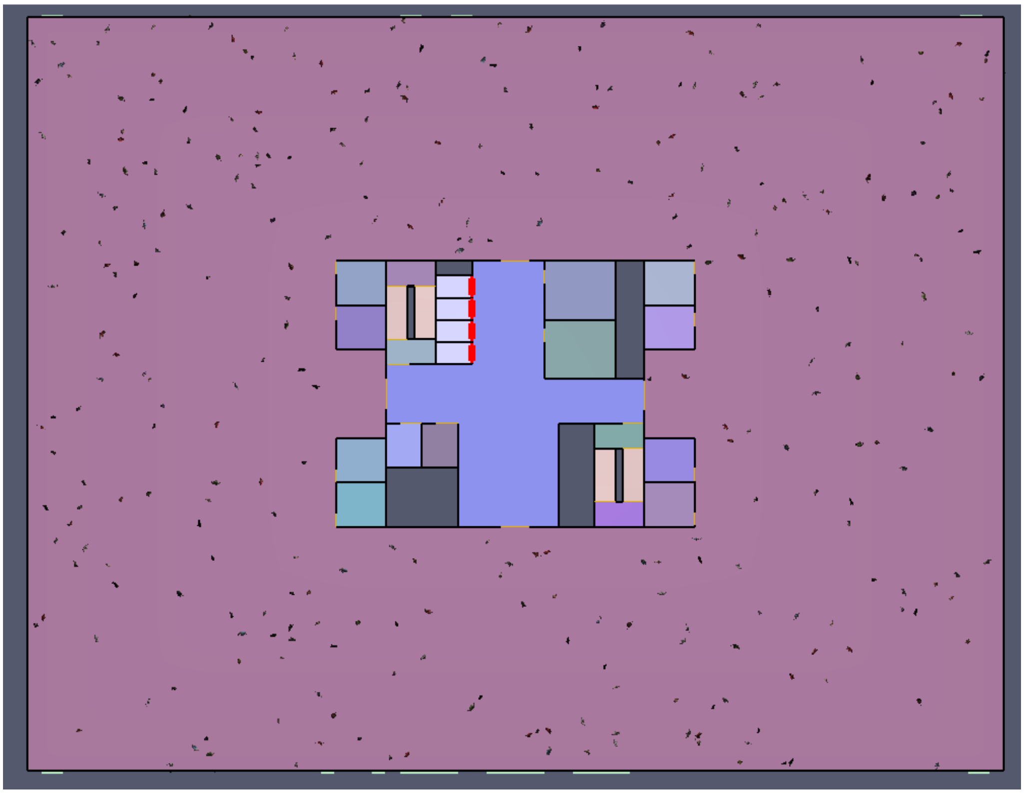


Figure D21 - Egress strategy interpretation AS2

11.3.3 Egress scenario 3

Table D30 - Egress scenario description for SS3

Building design	**People using the stair configurations [%]**	**People using the emergency elevators [%]**	**Floor level subjected to the scenario. [Floor/16]**
Swedish	100	0	8/16

In this scenario (see Figure D22), the fire is placed in order to block the egress path for the left-wing office occupants into the Tr1 staircase configuration (red “X” in the Figure). With the primary evacuation route blocked by the fire, the left-wing office occupants must either evacuate through the fire compartmental boundaries (1), and into the communication area to reach the Tr1 or Tr2 configurations. Alternatively evacuate a longer distance around the central core of the building into the communication area (2), prior to evacuating through either the Tr1 or Tr2 staircase, to ground level.

This scenario assumes in comparison to scenario 1, that the emergency elevators are malfunctioning as part of the sensitivity analysis (orange “X” blocking the entrance to the elevators). This means that all agents must evacuate through either of the stair configurations. The simulation shall still consist of agent characteristics in accordance with 94% standard modelled physic, and 6% of each floor as people with reduced mobility.

The egress modelling parameters for this scenario are presented in Table D32, in following part

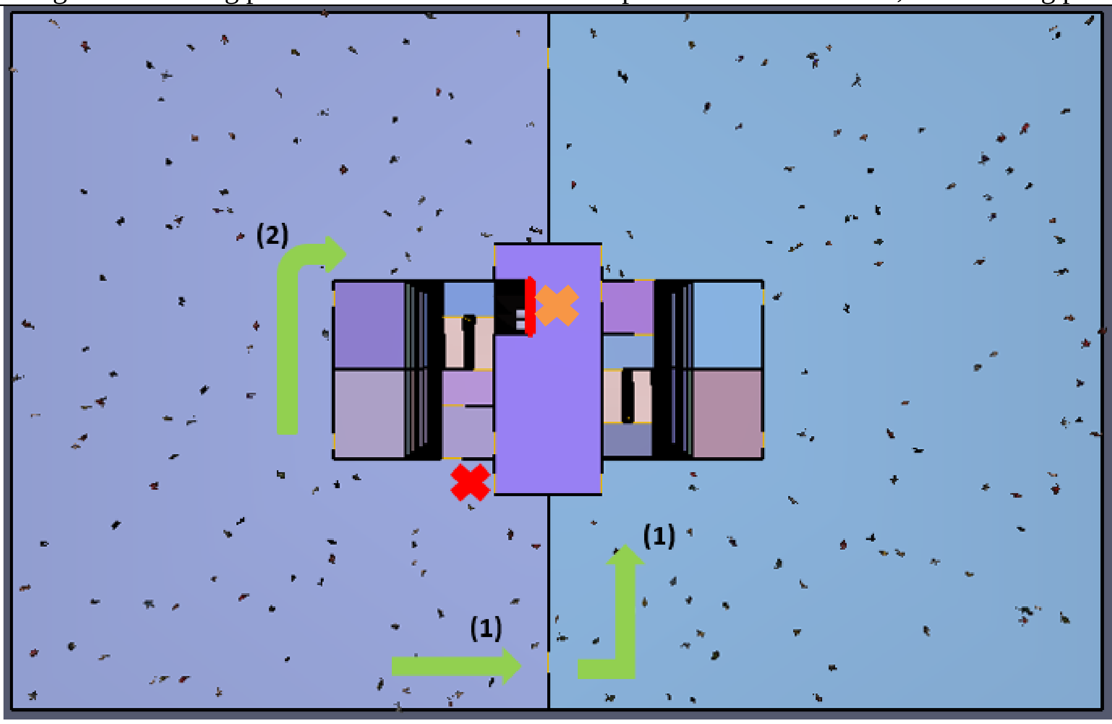


Figure D22 - Egress strategy interpretation SS3

Table D31 - Egress scenario description for AS3

Building design	People using the stair configurations [%]	People using the emergency elevators [%]	Floor level subjected to the scenario. [Floor/16]
Australian	94	6	8/16

In this scenario (see Figure D23), fire is placed in order to block the egress path for the office occupants assumed to have their office station in the south area. With the primary evacuation route blocked by the fire (red "X" in the Figure), the south office occupants must evacuate a longer distance round the central core of the building into either the west or east entrance to the smoke lobby. Prior to evacuating through either fire safe staircase, to the ground level and evacuate through the exits.

This scenario assumes in comparison to scenario 1, that the sprinkler system is malfunctioning as part of the sensitivity analysis. In this scenario it is assumed that 94 % of each floor consists of occupants with standard agent physic, and evacuate through either of the fire safe staircase configuration, until they reach the ground floor and evacuate the building. 6% of the population of each floor is counted as people with reduced mobility, and modelled with reduced horizontal speed. These occupants shall be simulated with egress path leading to the emergency elevator to safely evacuate the building.

The egress modelling parameters for this scenario are presented in Table D32, in following part

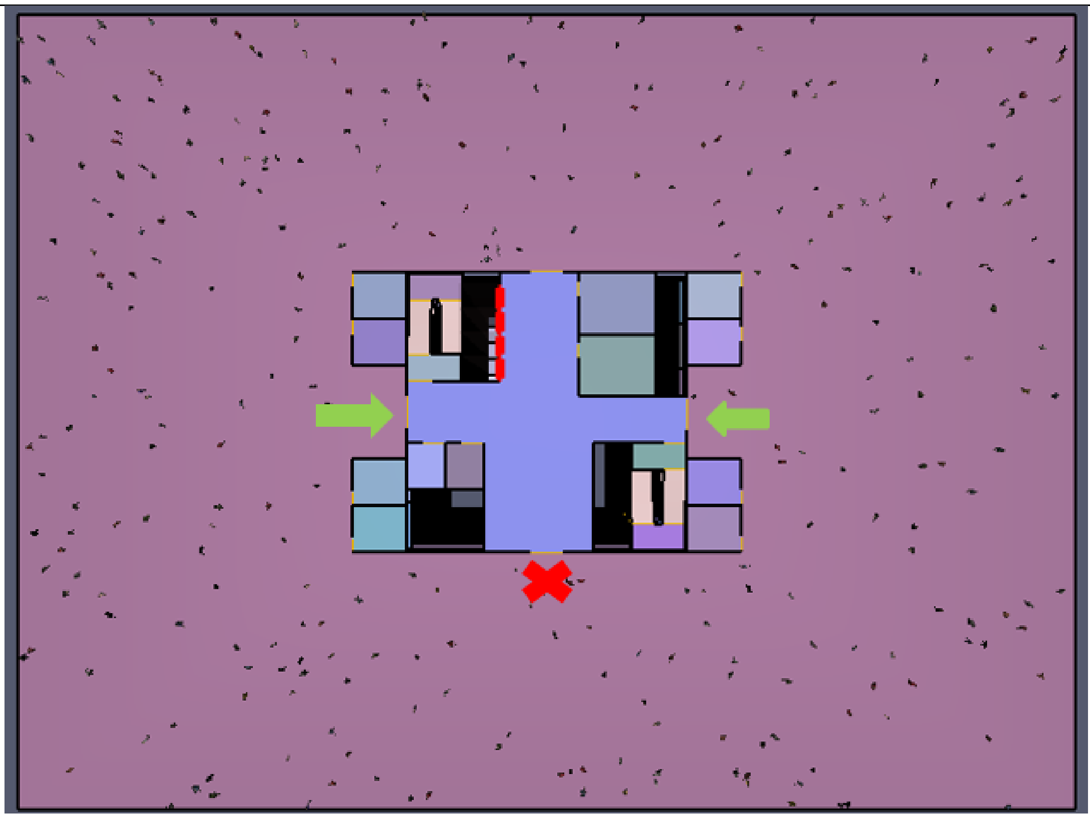


Figure D23 - Egress strategy interpretation AS3

11.4 Evacuation modelling input

In this risk analysis shall the evacuation time be defined as the time for occupants to reach a position of safety, with respect from their point of origin. This position of safety is a place which the occupants can reach trough the established egress routes.

The fire safe passages, each staircase configuration, behind fire compartmental boundaries and the outside area shall be considered positions of safety for the Swedish high-rise building. Position of safety in the Australian high-rise building are the smoke lobby, each staircase configuration, the fire safe passage and the outside area.

The egress modelling parameters for scenario 1-3 for each high-rise building considered in this study, is presented in Table D32.

Table D32 - Pathfinder egress simulation input parameters

DESIGN EGRESS SCENARIO PARAMS

	Parameter	Value	Comment
OCCUPANT CHARACTERISTICS	Cue period (P_c).	30 s	For agent located at a position at viewing distance to the fire.
	Cue period (P_c).	Depending on smoke detector activation time.	Agents not seeing the fire, value obtained by the FDS simulation.
	Pre-movement time (Response period (P_r) + Delay period (P_d)).	30 s	For agents near and at a viewing distance of the fire. 60 s for agents not seeing the fire.
	Walking speed on horizontal surfaces.	Min: 0.6m/s Max: 1.5m/s	Values for a standard agent as specified in the guidelines. [19]
	Walking speed along sloping planes.	Min: 0.5m/s Max: 0.75m/s	Values for a standard agent as specified in the guidelines. [19]
	Walking speed on horizontal surfaces.	Min: 0.4m/s Max: 1m/s	Values for agents with reduced mobility as specified in the guidelines. [19]
	Walking speed along sloping planes.	Min: 0.33m/s Max: 0.5m/s	Values for agents with reduced mobility as specified in the guidelines. [19]
	Shoulder width.	0.4558m	Standard value used in the software. [42]
EVACUATION MODE	Zoned evacuation.	2 floors at a time.	After pre-movement time: - The occupants at the 8th- 9th floor begin evacuate the building. - 1 level above and 1 level below at every 4 minutes interval.
	Occupant load.	Refers to Table 2 in this report.	
SIMULATION MODE	This study will use the steering based model to simulate the occupant evacuation.		

11.5 Pathfinder modelling results

Following sections presents the simulation results for each egress scenario evaluated in this study. The results are presented in forms of cut-outs, with descriptions, from key moments in the evacuation simulation.

11.5.1 SS1

The Pathfinder simulation results at the floor of origin of the fire scenario, level 8 are shown in Figure D25. The RSET value for SS1 is 226 s. Other Pathfinder simulation results from SS1 are summarised in Table D33.

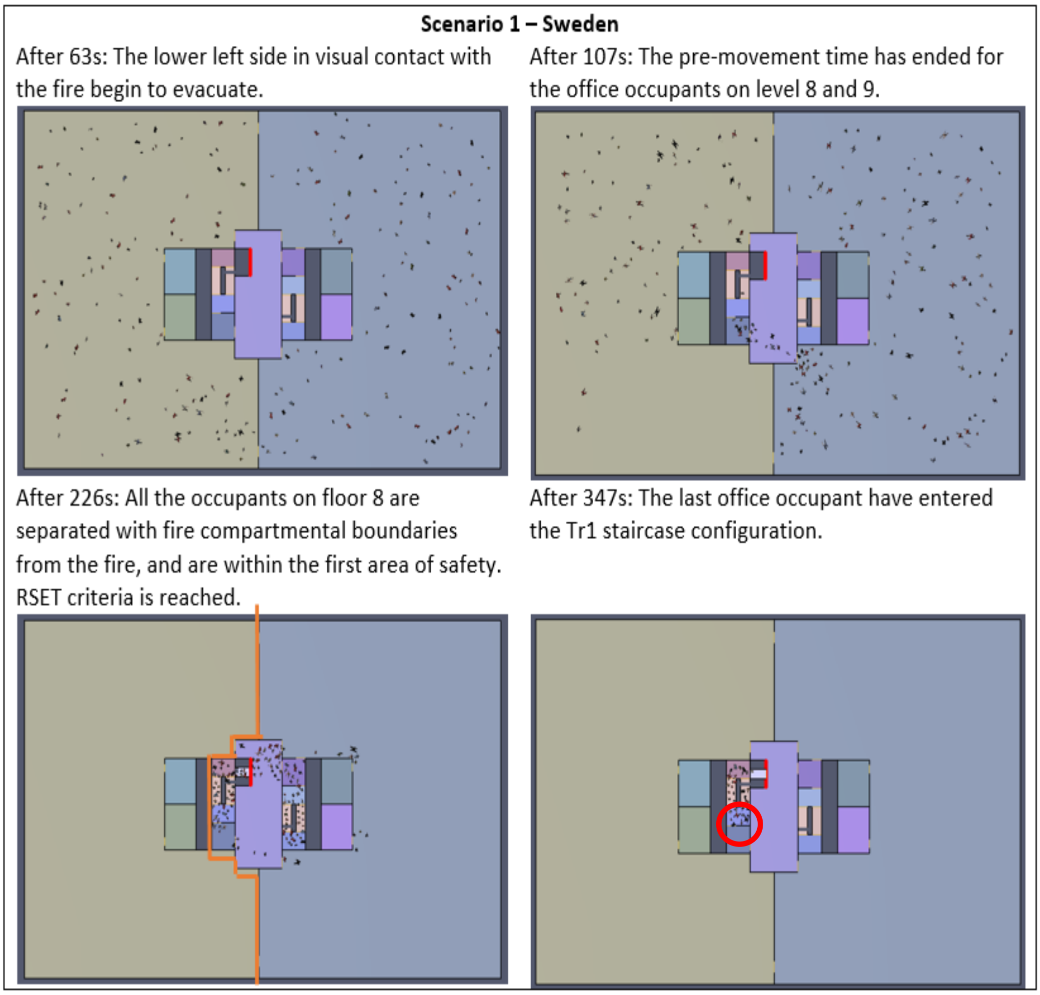


Figure D25 - Visual overview of key moments in egress scenario SS1 (floor of fire origin)

Table D33 - Pathfinder results from egress simulation SS1

Specifics	Time (s)
Last occupants from level 16 to walk pass level 8 (floor of fire origin).	2119
All occupants from ground to level 16 to evacuate out of the building.	2284

11.5.2 SS2

The Pathfinder simulation results at the floor of origin of the fire scenario, level 8 are shown in Figure D26. The RSET value for SS2 is 280 s. Other Pathfinder simulation results from SS2 are summarised in Table D34.

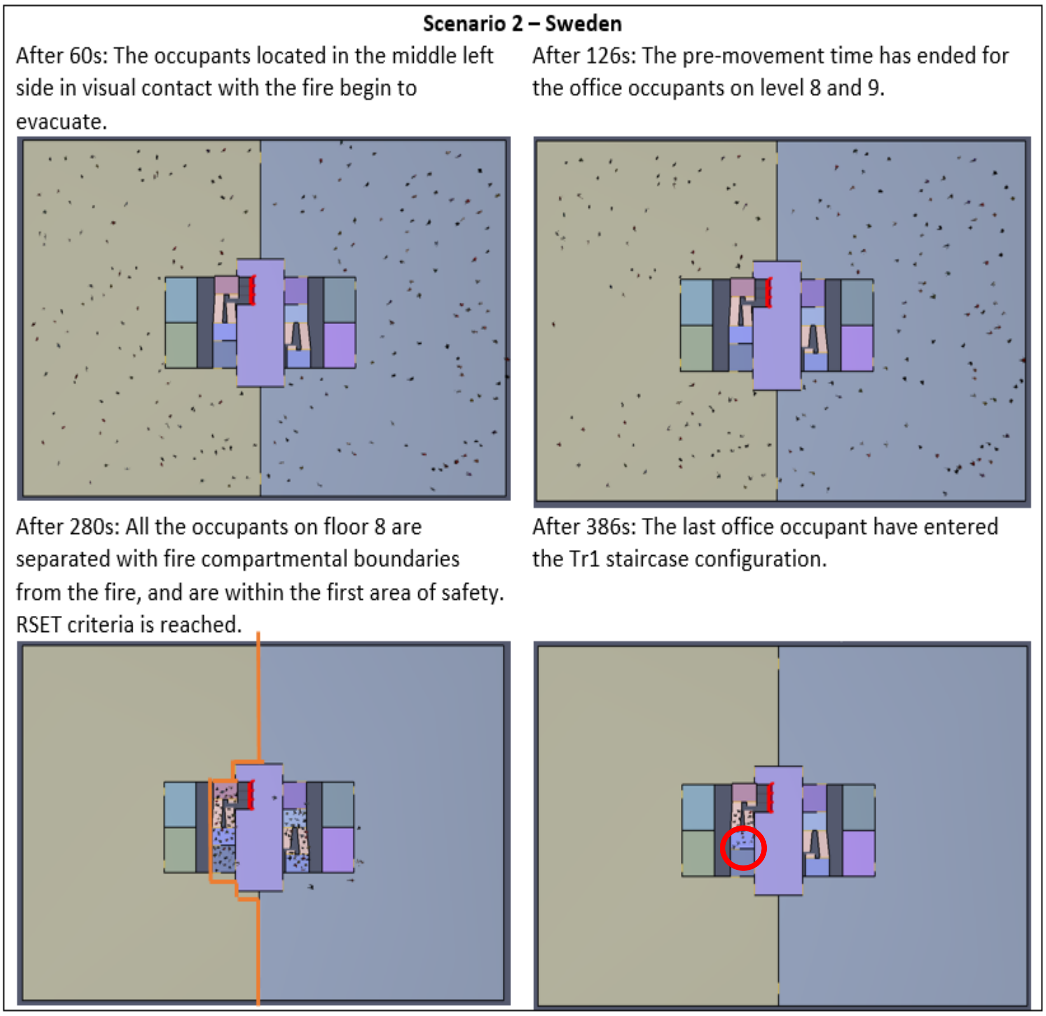


Figure D26 - Visual overview of key moments in egress scenario SS2 (floor of fire origin)

Table D34 - Pathfinder results from egress simulation SS2

Specifics	Time (s)
Last occupants from level 16 to walk pass level 8 (floor of fire origin).	2135
All occupants from ground to level 16 to evacuate out of the building.	2308

11.5.3 SS3

The Pathfinder simulation results at the floor of origin of the fire scenario, level 8 are shown in Figure D27. The RSET value for SS3 is 210 s. Other Pathfinder simulation results from SS3 are summarised in Table D35.

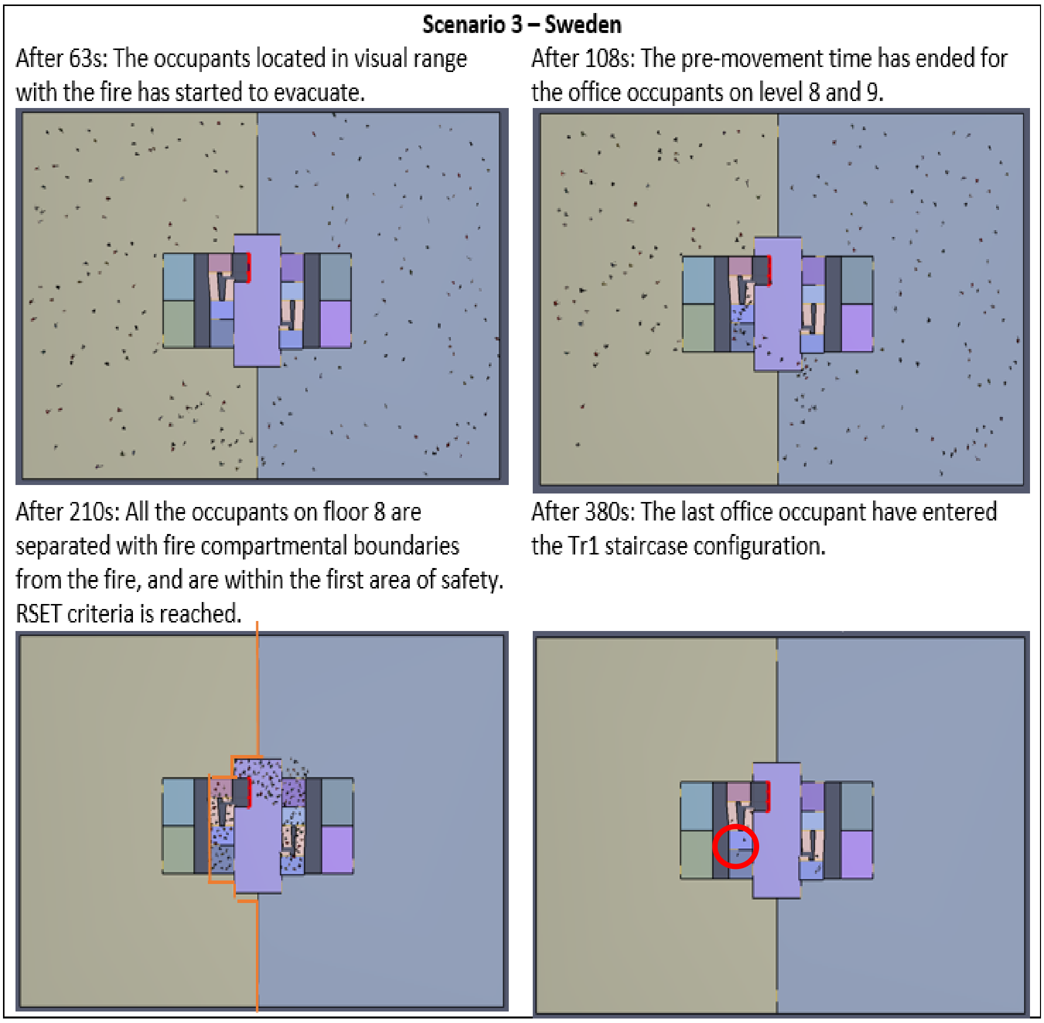


Figure D27 - Visual overview of key moments in egress scenario SS3 (floor of fire origin)

Table D35 - Pathfinder results from egress simulation SS3

Specifics	**Time (s)**
Last occupants from level 16 to walk pass level 8 (floor of fire origin).	2160s
All occupants from ground to level 16 to evacuate out of the building.	2363s

11.5.4 AS1

The Pathfinder simulation results at the floor of origin of the fire scenario, level 8 are shown in Figure D28. The RSET value for AS1 is 208 s. Other Pathfinder simulation results from AS1 are summarised in Table D36.

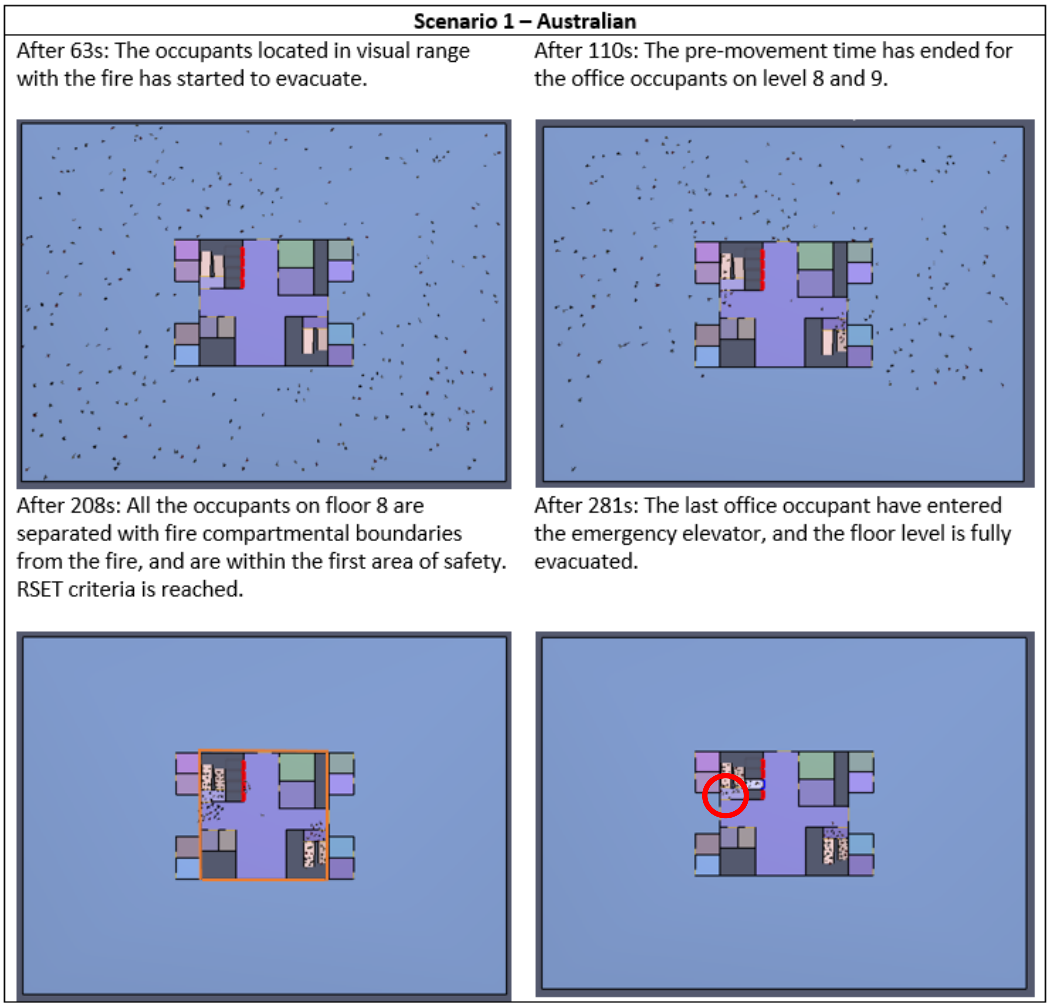


Figure D28 - Visual overview of key moments in egress scenario AS1 (floor of fire origin)

Table D36 - Pathfinder results from egress simulation AS1

Specifics	**Time (s)**
Last occupants from level 16 to walk pass level 8 (floor of fire origin).	2106
All occupants from ground to level 16 to evacuate out of the building.	2325

11.5.5 AS2

The Pathfinder simulation results at the floor of origin of the fire scenario, level 8 are shown in Figure D29. The RSET value for AS2 is 201 s. Other Pathfinder simulation results from AS2 are summarised in Table D37.

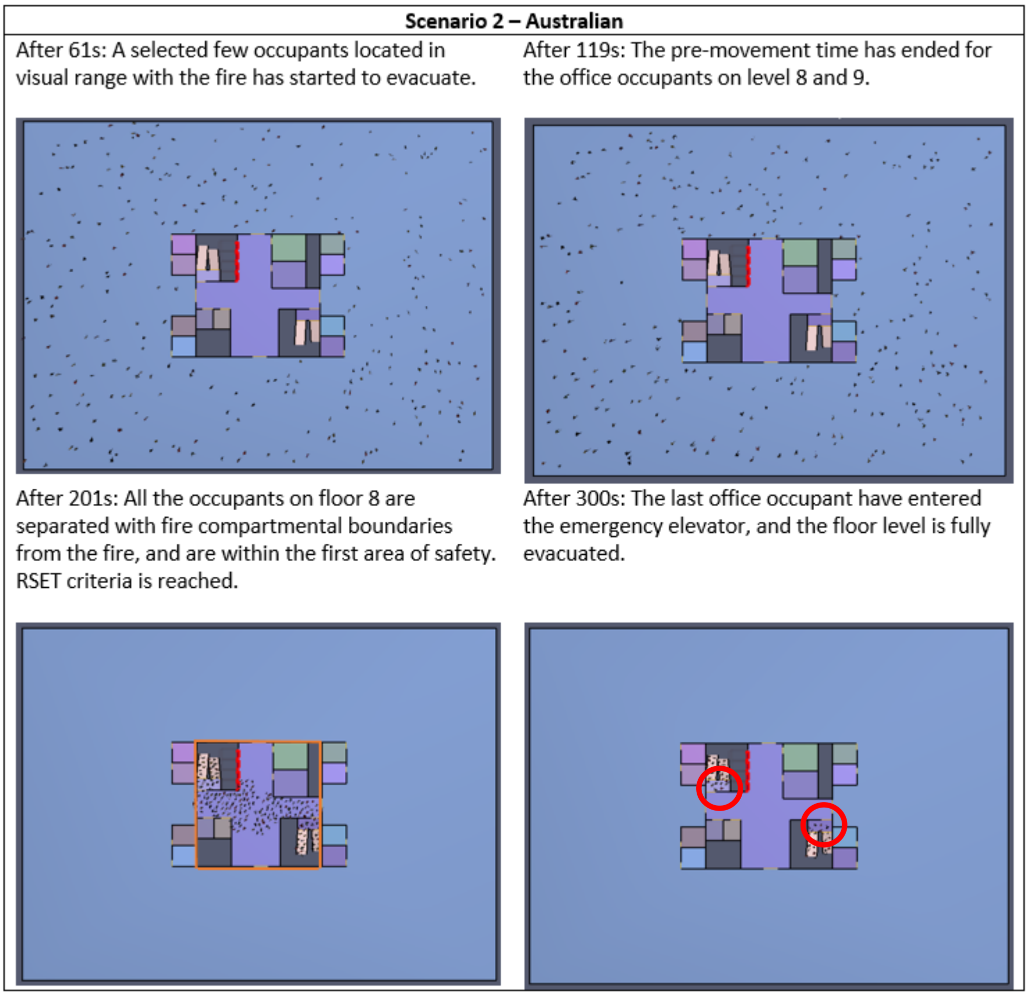


Figure D29 - Visual overview of key moments in egress scenario AS2 (floor of fire origin)

Table D37 - Pathfinder results from egress simulation AS2

Specifics	**Time (s)**
Last occupants from level 16 to walk pass level 8 (floor of fire origin).	2116s
All occupants from ground to level 16 to evacuate out of the building.	2334s

11.5.6 AS3

The Pathfinder simulation results at the floor of origin of the fire scenario, level 8 are shown in Figure D30. The RSET value for AS3 is 225 s. Other Pathfinder simulation results from AS3 are summarised in Table D38.

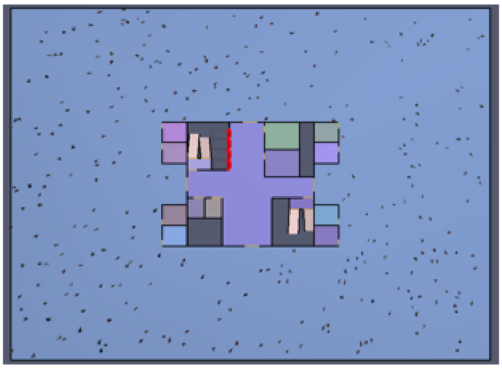
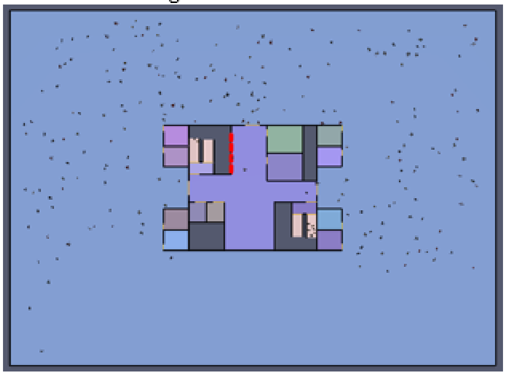
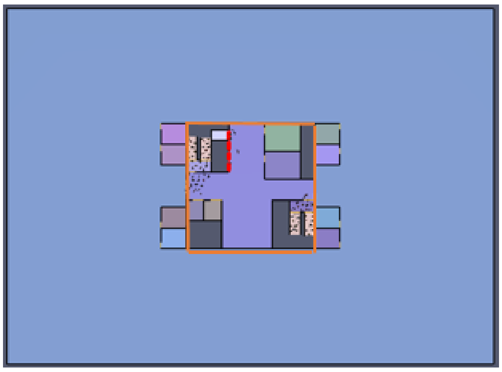
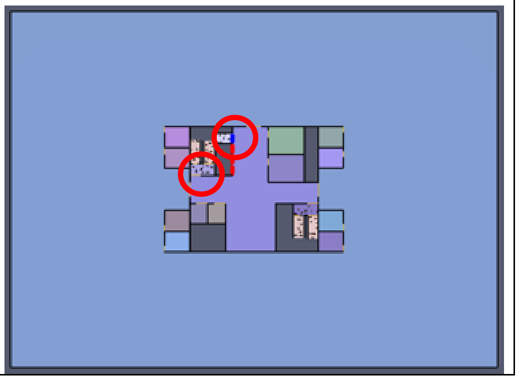
Scenario 3 – Australian	
After 60s: Occupants located in visual range with the fire has started to evacuate.	After 122s: The pre-movement time has ended for the office occupants on level 8 and 9, and they have started evacuating.
	
After 225s: All the occupants on floor 8 are separated with fire compartmental boundaries from the fire, and are within the first area of safety. RSET criteria is reached.	After 252s: The last office occupants have entered the emergency elevator and the fire safe stairway configurations, and the floor level is seconds from fully evacuated.
	

Figure D30 - Visual overview of key moments in egress scenario AS3 (floor of fire origin)

Table D38 - Pathfinder results from egress simulation AS3

Specifics	**Time (s)**
Last occupants from level 16 to walk pass level 8 (floor of fire origin).	2118
All occupants from ground to level 16 to evacuate out of the building.	2324

12 Risk analysis

The results obtained from the FDS and Pathfinder simulations are collated for evaluation in this section. The results are presented as histograms, illustrating the required and available safe egress time in relation to a time axis. The choice of histograms was made to better facilitate an understanding over the time sequence required, and available, until untenable condition prevailed in the office area.

The scenario results will be presented in accordance with their respective building. This allows for better visualization of the fire safety level of the buildings when subjected to various fire scenarios. This due to the different strains of stress each scenarios is designed to implement of the construction.

The tenability conditions used as metrics in this risk analysis to measure the conditions in the office environment, and time for the ASET criteria to occur, have been extracted from BBRAD [19] and is presented in Table D4 in this report. The RSET criteria was measured in accordance with simulated time for all the office occupants to reach a position of safety. Positions of safety and egress modelling input is presented in section 11.4 *Evacuation modelling input.*

It should be mentioned prior to the presentation of the results, that each scenario parameter used in the simulations have been subjected to a sensitivity analysis, with the intent of establishing, and subjecting each analysis object towards the "worst credible scenarios". The sensitivity analysis have been executed by implementing, and establishing scenario sequences that will subject the design towards a higher level of stress. Parameter or sequence altered to make the results more robust and conservative, is mentioned throughout the report.

12.1 Swedish high-rise building

The performance of the Swedish high-rise building, in accordance to the RSET vs ASET principle, is presented in the histograms (Figure D31-D33).

Figure D31 presents the results from the "worst case scenario" SS1. From the illustration it can be noticed that the time for all occupants of the 8th floor to reach a position of safety, is less than the time for untenable condition to occur, with a safety factor of 34 s.

The FDS fire- and Pathfinder egress simulation results illustrated in the histogram for SS1, shows that the Swedish high-rise building provides a satisfactory level of safety for its occupants in scenario 1.

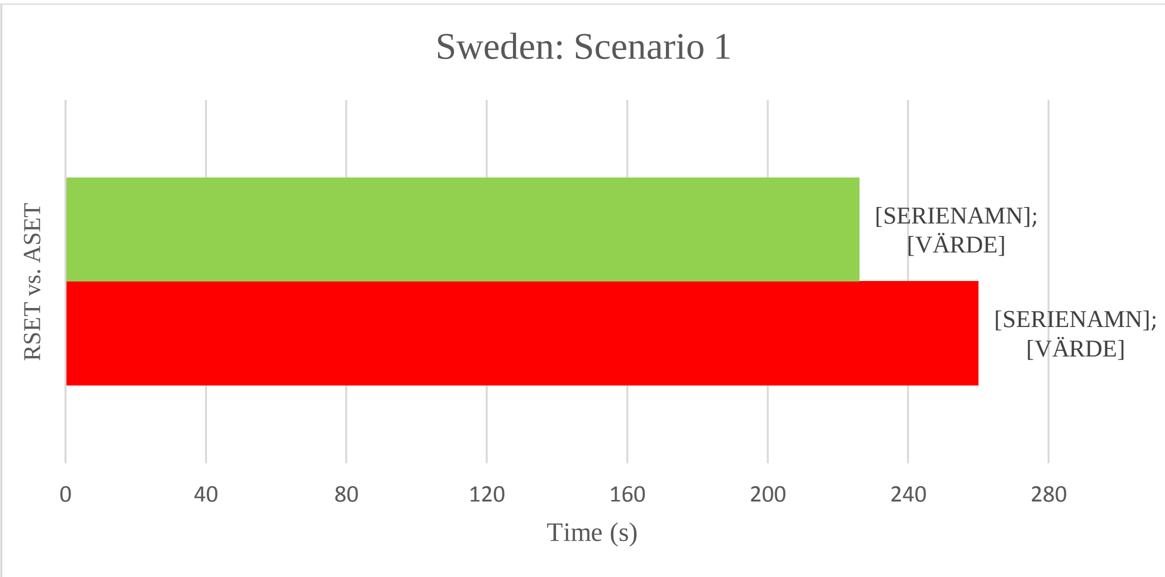


Figure D31 - Histogram illustrating the required and available safe egress time for SS1

Figure D32 presents the results derived from the fire and egress simulation SS2. From the histogram it can be noticed that the time available to evacuate the office premise, is less than time required to evacuate by 13 s. This shows that the evacuating occupants will be subjected to endangering condition, with an unacceptable risk of fatality in SS2.

The presentation of the results clearly visualize an unacceptable level of safety for the office occupants during the sequence of events evaluated in SS2.

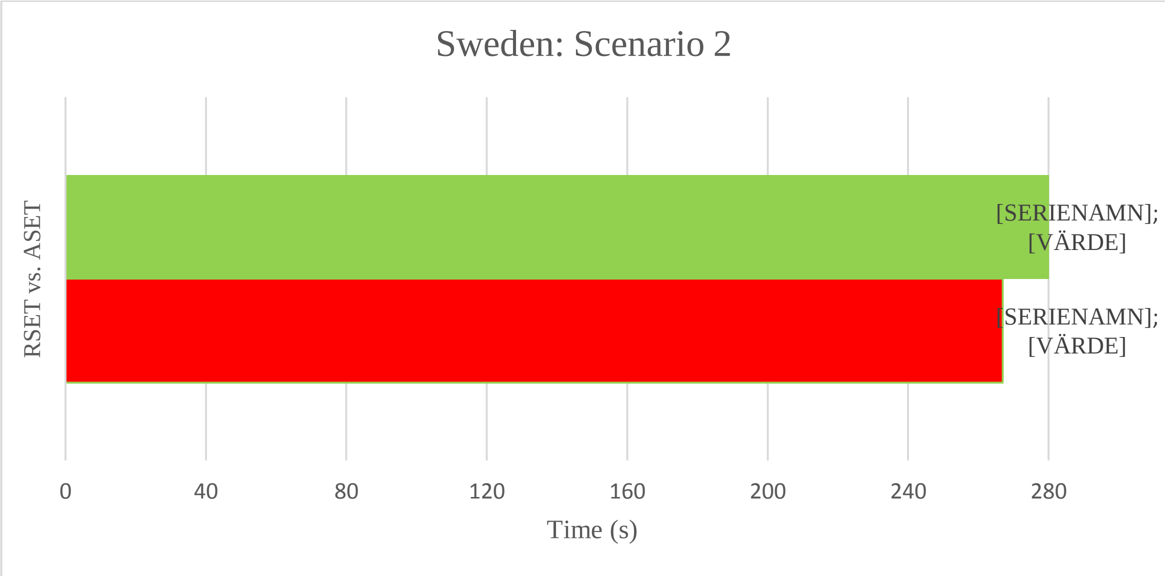


Figure D32 - Histogram illustrating the required and available safe egress time for SS2

The results from the fire- and evacuation simulations for SS3 is illustrated in Figure D33. The histogram shows that the office occupants required 210 s to reach a position of safety, with a safety factor of 62 s (272 s after ignition) available before the office reached untenable conditions.

The histogram clearly shows that the Swedish building design provides a satisfactory level of safety for its occupants, when subjected to the sequence of events in scenario 3.

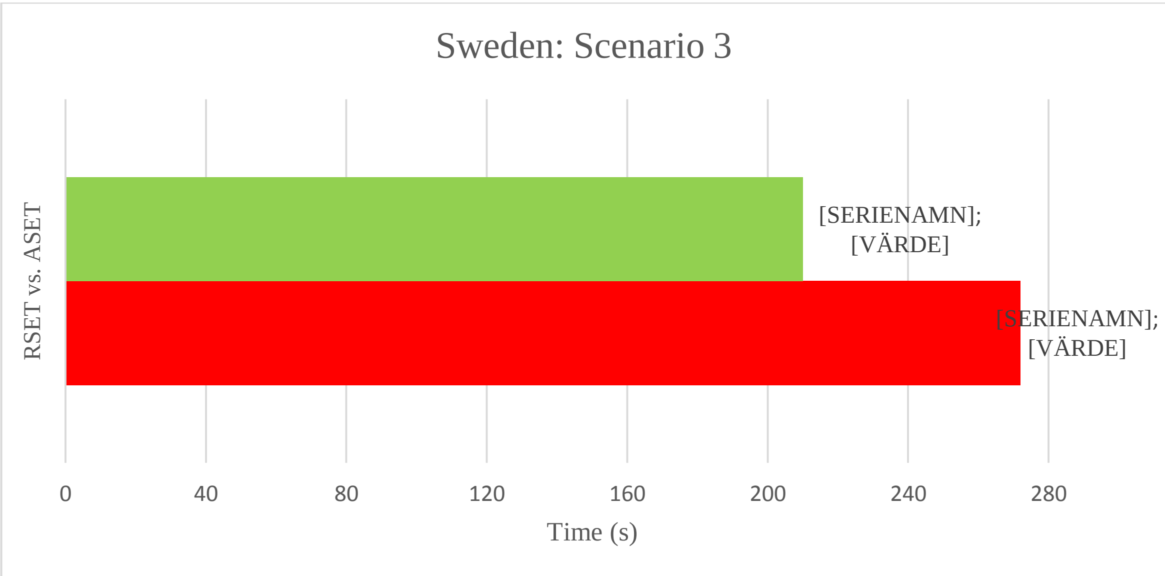


Figure D33 - Histogram illustrating the required and available safe egress time for SS3

12.2 Australian high-rise building

The performance of the Australian high-rise building, in accordance to the RSET vs ASET principle, is presented in the histograms (Figure D34-D36).

Results from the fire- and evacuation simulation AS1 is illustrated in Figure D34. The histogram shows that the office occupants required 208 s to reach a position of safety, with a safety factor of 152 s (360 s after ignition) available before the office reached untenable conditions.

The FDS fire- and Pathfinder egress simulation results illustrated in the histogram for AS1, clearly shows that the Australian high-rise building provides a satisfactory level of safety for its occupants in scenario 1.

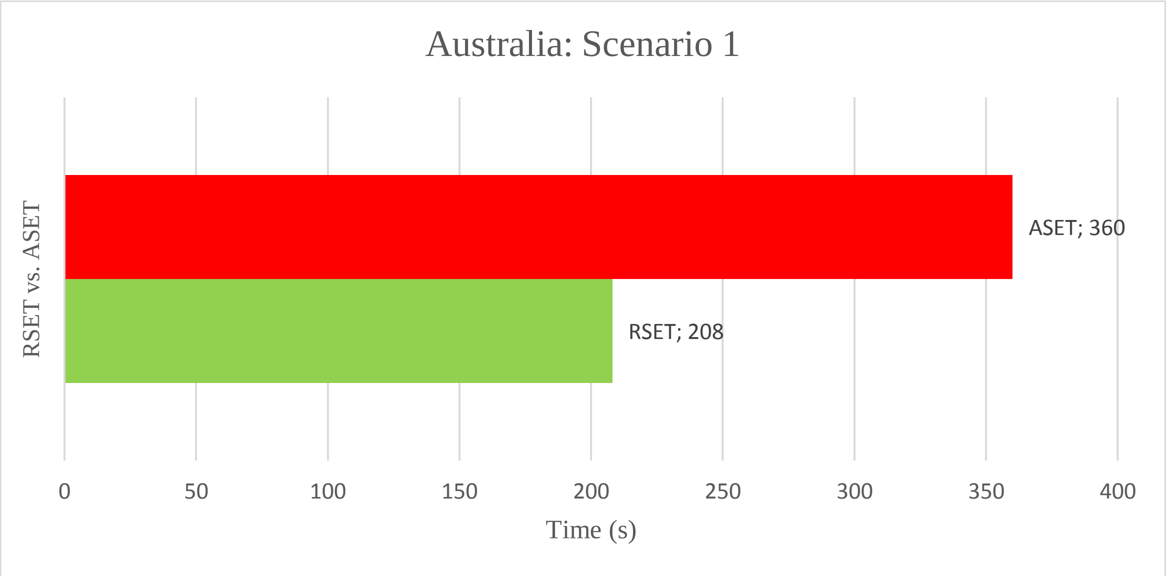


Figure D34 - Histogram illustrating the required and available safe egress time for AS1

The performance of the Australian high-rise when subjected to scenario AS2 is illustrated in Figure D35. The results shows that the office occupants required 201 s to reach a position of safety, with a safety margin of 266 s (467 s after ignition) before the office premise reach an untenable condition.

The simulation results presented in the histogram clearly illustrates that the Australian high-rise building provided a satisfactory level of safety for its occupants in scenario 2.

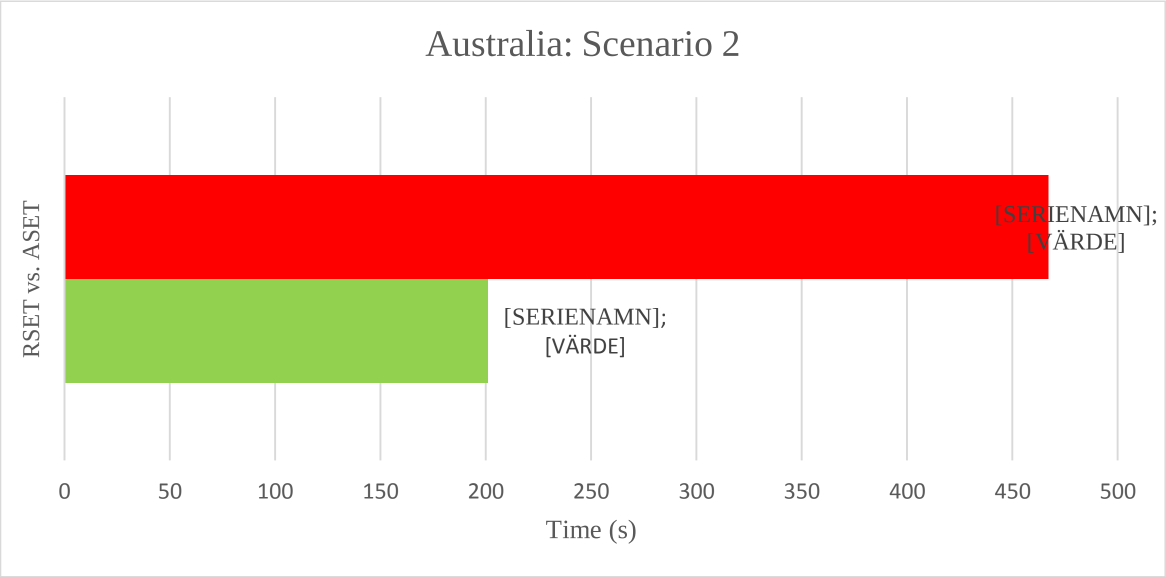


Figure D35 - Histogram illustrating the required and available safe egress time for AS2

The performance of the Australian high-rise in scenario sequence AS3 is illustrated in Figure D36. The results shows that the office occupants required approximately 225 s to reach a position of safety, with a safety margin of 150 s (375 s after ignition) before the office premise reach an untenable condition.

The simulation results presented in the histogram clearly illustrates that the Australian high-rise building provided a satisfactory level of safety for its occupants in scenario 3.

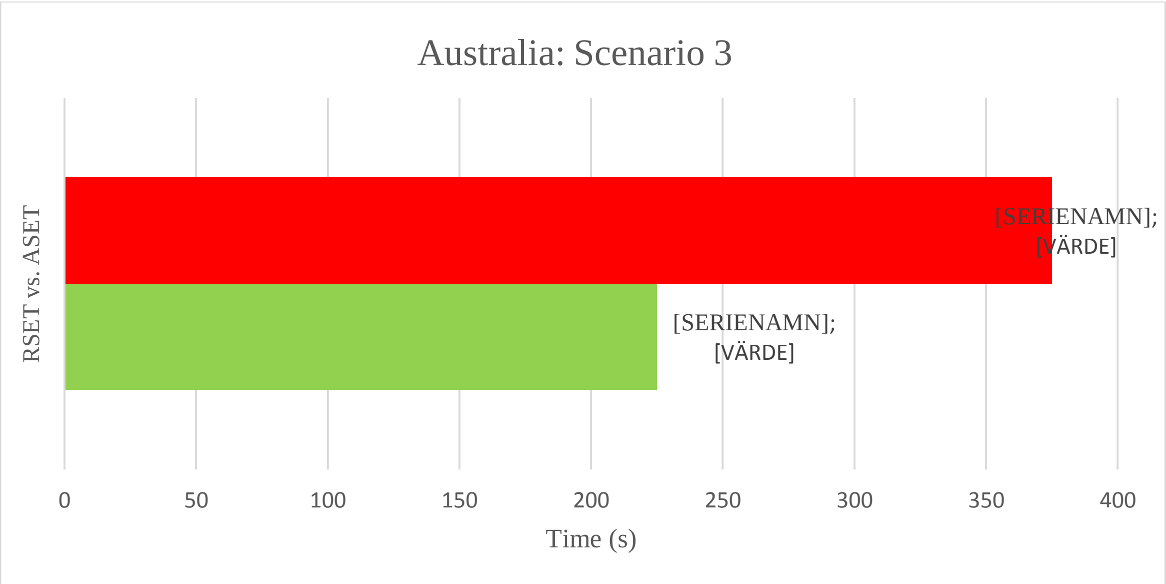


Figure D36 - Histogram illustrating the required and available safe egress time for AS3

15. Appendix E – Pathfinder model setup

This chapter provides the characteristics of the model case geometry for the Swedish and Australian high-rise building. Information regarding floor numbering, floor height and inter-distance between floors for both high-rise buildings is provided from Table E1 and Table E2.

It must be mentioned in accordance with following tables that Pathfinder models each floor as a flat surface. The floor-to-floor distance of 3.17 m and 3.22 m was used to include the thickness of each floor slab in the total height of the building, as specified in respective *Appendix B-C*.

Table E1 - Characteristics of the Swedish high-rise model, floor description from floor 1 to 16.

Description	Floor	Height (m)	Floor to floor distance (m)
High-rise floor with office use	16th	47.55	-
High-rise floor with office use	15th	44.38	3.17
High-rise floor with office use	14th	41.21	3.17
High-rise floor with office use	13th	38.04	3.17
High-rise floor with office use	12th	34.87	3.17
High-rise floor with office use	11th	31.7	3.17
High-rise floor with office use	10th	28.53	3.17
High-rise floor with office use	9th	25.36	3.17
High-rise floor with office use	8th	22.19	3.17
Low-rise floor with office use	7th	19.02	3.17
Low-rise floor with office use	6th	15.85	3.17
Low-rise floor with office use	5th	12.68	3.17
Low-rise floor with office use	4th	9.51	3.17
Low-rise floor with office use	3rd	6.34	3.17
Low-rise floor with office use	2nd	3.17	3.17
Ground floor with office use	1st	0	3.17

Table E2 - Characteristics of the Australian high-rise model, floor description from floor 1 to 16.

Description	Floor	Height (m)	Floor to floor distance (m)
High-rise floor with office use	16th	48.3	-
High-rise floor with office use	15th	45.08	3.22
High-rise floor with office use	14th	41.86	3.22
High-rise floor with office use	13th	38.64	3.22
High-rise floor with office use	12th	35.42	3.22
High-rise floor with office use	11th	32.2	3.22
High-rise floor with office use	10th	28.98	3.22
High-rise floor with office use	9th	25.76	3.22
High-rise floor with office use	8th	22.54	3.22
Low-rise floor with office use	7th	19.32	3.22
Low-rise floor with office use	6th	16.10	3.22
Low-rise floor with office use	5th	12.88	3.22
Low-rise floor with office use	4th	9.66	3.22
Low-rise floor with office use	3rd	6.44	3.22
Low-rise floor with office use	2nd	3.22	3.22
Ground floor with office use	1st	0	3.22

16. Appendix F – Pyrosim/FDS model code script

16.1. Swedish scenario 1

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&OBST XB=0.0,0.17,0.17,39.83,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx017y40
&OBST XB=61.83,62.0,0.17,39.83,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx017y40
&OBST XB=61.83,62.0,0.17,39.83,0.87,2.67, RGB=51,255,255, SURF_ID='Glass'/ Windowx017y40
&OBST XB=61.83,62.0,0.17,39.83,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx017y40
&OBST XB=30.915,31.085,26.83,39.83,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandcellindelning 2
&OBST XB=30.915,31.085,0.17,13.17,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandcellindelning
&OBST XB=27.83,34.17,13.17,13.34,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ kommunikations vägg S
&OBST XB=27.83,28.0,13.34,26.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg V
&OBST XB=34.0,34.17,13.34,26.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg Ö
&OBST XB=27.83,34.17,26.66,26.83,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg N
&OBST XB=26.36,26.53,19.96,23.19,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ trappuppgång vägg mitten
&OBST XB=24.89,27.83,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång N
&OBST XB=24.89,25.06,18.66,24.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång V
&OBST XB=24.89,27.83,18.49,18.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång S
&OBST XB=24.89,25.06,15.49,18.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss vägg V
&OBST XB=24.89,27.83,15.32,15.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss S
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&OBST XB=34.17,37.11,21.32,21.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg S
&OBST XB=34.17,37.11,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Obstruction
&OBST XB=36.94,37.11,15.49,21.32,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg Ö
&OBST XB=35.47,35.64,16.79,20.19,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg Mitten
&OBST XB=36.94,37.11,21.49,24.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss2 vägg Ö
&OBST XB=34.17,37.11,15.32,15.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss2 vägg S
&OBST XB=39.34,43.11,19.905,20.075,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ WCvägg1
&OBST XB=18.72,23.06,19.905,20.075,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ WCvägg2
&OBST XB=0.0,62.0,0.0,40.0,3.17,3.5, COLOR='INVISIBLE', SURF_ID='Concrete wall'/ Roof
&OBST XB=24.0,26.0,8.0,10.0,0.17,0.5, SURF_ID='INERT'/ Obstruction
&OBST XB=23.0,23.2,16.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.0,25.0,24.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=24.8,25.0,16.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.1,23.2,15.5,16.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.1,25.1,15.3,15.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=24.9,25.1,15.5,16.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=39.0,43.0,24.0,25.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=39.0,43.0,15.0,15.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=39.0,39.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=43.0,43.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=37.0,39.0,24.0,25.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=37.0,39.0,15.0,15.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=37.0,37.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=39.0,39.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=18.8,22.0,24.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.8,18.8,20.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.7,18.9,15.5,20.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.7,22.0,15.3,15.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.0,23.0,24.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.8,23.0,16.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.0,23.1,15.3,15.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.9,23.1,15.5,16.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2

&HOLE XB=30.1,30.27,20.52,21.62,0.17,2.27/ Hole
&HOLE XB=30.1,30.27,21.9326,23.0326,0.17,2.27/ Hole
&HOLE XB=30.1,30.27,23.3566,24.4566,0.17,2.27/ Hole
&HOLE XB=25.39,26.59,15.32,15.49,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss
&HOLE XB=27.83,28.0,13.84,15.04,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuSV
&HOLE XB=35.41,36.61,24.49,24.66,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss2
&HOLE XB=34.0,34.17,13.84,15.04,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuSÖ
&HOLE XB=27.83,28.0,15.98,17.19,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss/kommu
&HOLE XB=25.39,26.89,18.49,18.66,0.17,2.17, CTRL_ID='CTRL1'/ DörrTr1
&HOLE XB=35.11,36.61,21.32,21.49,0.17,2.17, CTRL_ID='CTRL1'/ DörrTr2
&HOLE XB=34.0,34.17,24.86,26.06,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-SlussNÖ
&HOLE XB=34.0,34.17,22.79,23.99,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-slussNÖ
&HOLE XB=27.83,28.0,24.96,26.16,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuNV
&HOLE XB=43.11,43.28,23.09,23.99,0.17,2.17/ WC1-toa1
&HOLE XB=43.11,43.28,15.99,16.89,0.17,2.17/ WC1-toa2
&HOLE XB=18.72,18.89,23.26,24.16,0.17,2.17/ WC2-toa1
&HOLE XB=18.72,18.89,15.82,16.72,0.17,2.17/ WC2-toa2
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&HOLE XB=30.915,31.085,35.33,36.83,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-brandcell2
&HOLE XB=28.0,30.1,20.52,24.49,3.17,3.52/ Hole
&HOLE XB=25.0,27.8,18.6,24.4,3.1,3.52/ Hole
&HOLE XB=34.0,37.0,15.0,21.0,2.5,3.6/ Hole

&VENT SURF_ID='Burner3.3', XB=25.0,26.0,9.0,10.0,0.5,0.5, RGB=255,7,19/ Vent3.3
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&VENT SURF_ID='Burner3.1', XB=25.0,26.0,8.0,9.0,0.5,0.5, RGB=255,7,19/ Vent3.1
&VENT SURF_ID='Burner2.3', XB=24.5,25.0,8.5,9.0,0.5,0.5, RGB=255,7,19/ Vent2.3
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&VENT SURF_ID='burner', XB=24.0,24.5,8.0,8.5,0.5,0.5, RGB=255,7,19/ Vent1
&VENT SURF_ID='OPEN', XB=25.06,27.83,18.66,24.49,3.5,3.5/ Tr1
&VENT SURF_ID='OPEN', XB=34.17,36.94,15.49,21.32,3.5,3.5/ Tr2
&VENT SURF_ID='OPEN', XB=28.0,30.1,20.52,24.49,3.5,3.5/ Hissar

&ISOF QUANTITY='TEMPERATURE', VALUE=80.0/
&ISOF QUANTITY='VISIBILITY', VALUE=10.0/

&SLCF QUANTITY='TEMPERATURE', PBZ=1.7/
&SLCF QUANTITY='VISIBILITY', PBZ=1.9/
&SLCF QUANTITY='VISIBILITY', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='AEROSOL VOLUME FRACTION', SPEC_ID='CARBON DIOXIDE', PBZ=2.0/
&SLCF QUANTITY='AEROSOL VOLUME FRACTION', SPEC_ID='OXYGEN', PBZ=2.0/
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='SOOT', PBZ=1.9/
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&SLCF QUANTITY='AEROSOL VOLUME FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ=2.0/

&TAIL /
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16.2. Swedish scenario 2

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Scenario2modidierad.fds
Generated by PyroSim - Version 2014.2.0807
2018-maj-08 15:24:06

-------------User Section (not generated by PyroSim)-------------
--------------------PyroSim-generated Section--------------------

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&MESH ID='Mesh1-a-a-b-a-b', IJK=150,110,40, XB=8.0,23.0,14.0,25.0,-0.5,3.5/
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&MESH ID='Mesh1-b', IJK=31,40,4, XB=31.0,62.0,0.0,40.0,-0.5,3.5/
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    H=1.7,
    O=0.72,
    CO_YIELD=0.1,
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    QUANTITY='CHAMBER OBSCURATION',
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    BETA_E=-0.7,
    ALPHA_C=0.8,
    BETA_C=-0.9/
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&DEVC ID='SMOKE LAYER', QUANTITY='LAYER HEIGHT', XB=4.0,4.0,5.0,5.0,0.17,3.0/
&DEVC ID='SMOKE LAYER01', QUANTITY='LAYER HEIGHT', XB=29.3765,29.3765,3.68065,3.68065,-0.185503,2.6445/
&DEVC ID='SMOKE LAYER02', QUANTITY='LAYER HEIGHT', XB=2.65228,2.65228,36.1963,36.1963,-0.134358,2.69564/

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&MATL ID='CONCRETE',
    FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
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    CONDUCTIVITY=1.8,
    DENSITY=2280.0/

&SURF ID='INERT3',
    RGB=195,161,102/
&SURF ID='Concrete wall',
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    MATL_MASS_FRACTION(1,1)=1.0,
    THICKNESS(1)=0.17/
&SURF ID='Glass',
    RGB=51,255,255/
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    HRRPUA=1252.0,
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&RAMP ID='Burner3.3_RAMP_Q', T=560.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=646.0, F=1.0/
&RAMP ID='Burner3.3_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner3.2',
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&RAMP ID='Burner3.2_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner3.1',
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&RAMP ID='Burner2.1_RAMP_Q', T=220.0, F=1.0/
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&SURF ID='burner',
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&OBST XB=28.0,30.1,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg1
&OBST XB=28.0,30.1,23.12,23.29,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg2
&OBST XB=28.0,30.1,21.72,21.92,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg3
&OBST XB=28.0,30.1,20.35,20.52,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg4
&OBST XB=30.1,30.27,20.35,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hisstak
&OBST XB=0.0,62.0,0.0,0.17,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx62y017
&OBST XB=0.0,62.0,0.0,0.17,0.87,2.67, RGB=51,255,255, SURF_ID='Glass'/ Windowx62y017
&OBST XB=0.0,62.0,0.0,0.17,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx62y017
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&OBST XB=0.0,0.17,0.17,39.83,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx017y40
&OBST XB=0.0,0.17,0.17,39.83,0.87,2.67, RGB=51,255,255, SURF_ID='Glass'/ Windowx017y40
&OBST XB=0.0,0.17,0.17,39.83,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx017y40
&OBST XB=61.83,62.0,0.17,39.83,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx017y40
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&OBST XB=61.83,62.0,0.17,39.83,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx017y40
&OBST XB=30.915,31.085,26.83,39.83,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandcellindelning 2
&OBST XB=30.915,31.085,0.17,13.17,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandcellindelning
&OBST XB=27.83,34.17,13.17,13.34,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ kommunikations vägg S
&OBST XB=27.83,28.0,13.34,26.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg V
&OBST XB=34.0,34.17,13.34,26.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg Ö
&OBST XB=27.83,34.17,26.66,26.83,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg N
&OBST XB=26.36,26.53,19.96,23.19,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ trappuppgång vägg mitten
&OBST XB=24.89,27.83,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång N
&OBST XB=24.89,25.06,18.66,24.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång V
&OBST XB=24.89,27.83,18.49,18.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång S
&OBST XB=24.89,25.06,15.49,18.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss vägg V
&OBST XB=24.89,27.83,15.32,15.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss S
```

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&OBST XB=34.17,37.11,21.32,21.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg S
&OBST XB=34.17,37.11,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Obstruction
&OBST XB=36.94,37.11,15.49,21.32,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg Ö
&OBST XB=35.47,35.64,16.79,20.19,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg Mitten
&OBST XB=36.94,37.11,21.49,24.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss2 vägg Ö
&OBST XB=34.17,37.11,15.32,15.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss2 vägg S
&OBST XB=39.34,43.11,19.905,20.075,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ WCvägg1
&OBST XB=18.72,23.06,19.905,20.075,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ WCvägg2
&OBST XB=0.0,62.0,0.0,40.0,3.17,3.5, COLOR='INVISIBLE', SURF_ID='Concrete wall'/ Roof
&OBST XB=19.0,21.0,17.5,19.5,0.17,0.49, SURF_ID='INERT'/ Obstruction
&OBST XB=23.0,23.2,15.4,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.0,25.0,24.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=24.8,25.0,15.4,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.2,24.8,15.4,15.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=39.0,43.0,24.0,25.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=39.0,43.0,15.0,15.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=39.0,39.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=43.0,43.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=37.0,39.0,24.0,25.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=37.0,39.0,15.0,15.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=37.0,37.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=39.0,39.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=18.7,18.9,15.5,24.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.7,23.0,15.3,15.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.7,23.0,24.5,24.7,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.9,23.0,15.5,24.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=23.0,23.0,15.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2

&HOLE XB=30.1,30.27,20.52,21.62,0.17,2.27/ Hole
&HOLE XB=30.1,30.27,21.9326,23.0326,0.17,2.27/ Hole
&HOLE XB=30.1,30.27,23.3566,24.4566,0.17,2.27/ Hole
&HOLE XB=25.39,26.59,15.32,15.49,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss
&HOLE XB=27.83,28.0,13.84,15.04,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuSV
&HOLE XB=35.41,36.61,24.49,24.66,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss2
&HOLE XB=34.0,34.17,13.84,15.04,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuSÖ
&HOLE XB=27.83,28.0,15.99,17.19,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss/kommu
&HOLE XB=25.39,26.89,18.49,18.66,0.17,2.17, CTRL_ID='CTRL1'/ DörrTr1
&HOLE XB=35.11,36.61,21.32,21.49,0.17,2.17, CTRL_ID='CTRL1'/ DörrTr2
&HOLE XB=34.0,34.17,24.86,26.06,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-SlussNÖ
&HOLE XB=34.0,34.17,22.79,23.99,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-slussNÖ
&HOLE XB=27.83,28.0,24.96,26.16,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuNV
&HOLE XB=43.11,43.28,23.09,23.99,0.17,2.17/ WC1-toa1
&HOLE XB=43.11,43.28,15.99,16.89,0.17,2.17/ WC1-toa2
&HOLE XB=18.72,18.89,23.26,24.16,0.17,2.17/ WC2-toa1
&HOLE XB=18.72,18.89,15.82,16.72,0.17,2.17/ WC2-toa2
&HOLE XB=30.915,31.085,3.17,4.67,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-brandcell
&HOLE XB=30.915,31.085,35.33,36.83,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-brandcell2
&HOLE XB=28.0,30.1,20.52,24.49,3.17,3.52/ Hole
&HOLE XB=25.0,27.8,18.6,24.4,3.1,3.52/ Hole
&HOLE XB=34.0,37.0,15.0,21.0,2.5,3.6/ Hole

&VENT SURF_ID='Burner3.3', XB=20.0,21.0,18.5,19.5,0.5,0.5, RGB=255,7,19/ Vent3.3
&VENT SURF_ID='Burner3.2', XB=20.0,21.0,17.5,18.5,0.49,0.49, RGB=255,7,19/ Vent3.2
&VENT SURF_ID='Burner3.1', XB=19.0,20.0,18.5,19.5,0.5,0.5/ Vent3.1
&VENT SURF_ID='Burner2.3', XB=19.5,20.0,18.0,18.5,0.5,0.5, RGB=255,7,19/ Vent2.3
&VENT SURF_ID='Burner2.2', XB=19.5,20.0,17.5,18.0,0.5,0.5, RGB=255,7,19/ Vent2.2
&VENT SURF_ID='Burner2.1', XB=19.0,19.5,18.0,18.5,0.5,0.5, RGB=255,7,19/ Vent2.1
&VENT SURF_ID='burner', XB=19.0,19.5,17.5,18.0,0.5,0.5, RGB=255,7,19/ Vent
&VENT SURF_ID='OPEN', XB=25.06,27.83,18.66,24.49,3.5,3.5/ Tr1
&VENT SURF_ID='OPEN', XB=34.17,36.94,15.49,21.32,3.5,3.5/ Tr2
&VENT SURF_ID='OPEN', XB=28.0,30.1,20.52,24.49,3.5,3.5/ Hissar

&ISOF QUANTITY='TEMPERATURE', VALUE=80.0/
&ISOF QUANTITY='VISIBILITY', VALUE=10.0/

&SLCF QUANTITY='TEMPERATURE', PBZ=1.7/
&SLCF QUANTITY='VISIBILITY', PBZ=1.9/
&SLCF QUANTITY='VISIBILITY', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='CARBON DIOXIDE', PBZ=2.0/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', PBZ=2.0/
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ=2.0/

&TAIL /
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16.3. Swedish scenario 3

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Scenario3.fds
Generated by PyroSim - Version 2014.2.0807
2018-feb-20 11:22:26

-------------User Section (not generated by PyroSim)-------------

--------------------PyroSim-generated Section--------------------

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&DUMP RENDER_FILE='Scenario3.ge1', DT_RESTART=300.0/

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&MESH ID='Mesh1-a-a-a-b', IJK=90,200,40, XB=13.0,22.0,0.0,20.0,-0.5,3.5/
&MESH ID='Mesh1-a-a-b', IJK=110,100,20, XB=0.0,22.0,20.0,40.0,-0.5,3.5/
&MESH ID='Mesh1-a-b-a', IJK=100,60,40, XB=22.0,32.0,0.0,6.0,-0.5,3.5/
&MESH ID='Mesh1-a-b-b-a', IJK=100,100,40, XB=22.0,32.0,6.0,16.0,-0.5,3.5/
&MESH ID='Mesh1-a-b-b-b', IJK=50,120,20, XB=22.0,32.0,16.0,40.0,-0.5,3.5/
&MESH ID='Mesh1-b', IJK=30,40,4, XB=32.0,62.0,0.0,40.0,-0.5,3.5/

&REAC ID='Red oak',
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    C=1.0,
    H=1.7,
    O=0.72,
    CO_YIELD=0.06,
    SOOT_YIELD=0.06,
    HEAT_OF_COMBUSTION=2.0E4/

&PROP ID='Cleary Ionization I1',
    QUANTITY='CHAMBER OBSCURATION',
    ALPHA_E=2.5,
    BETA_E=-0.7,
    ALPHA_C=0.8,
    BETA_C=-0.9/
&DEVC ID='THCP', QUANTITY='THERMOCOUPLE', XYZ=25.2,12.4,2.1/
&DEVC ID='THCP01', QUANTITY='THERMOCOUPLE', XYZ=25.2,12.4,1.8/
&DEVC ID='THCP02', QUANTITY='THERMOCOUPLE', XYZ=25.2,12.4,1.5/
&DEVC ID='THCP03', QUANTITY='THERMOCOUPLE', XYZ=25.2,12.4,1.2/
&DEVC ID='THCP04', QUANTITY='THERMOCOUPLE', XYZ=25.2,12.4,0.9/
&DEVC ID='SD', PROP_ID='Cleary Ionization I1', XYZ=14.4812,12.1735,3.0/
&DEVC ID='SMOKE LAYER', QUANTITY='LAYER HEIGHT', XB=4.0,4.0,5.0,5.0,0.17,3.0/
&DEVC ID='SMOKE LAYER01', QUANTITY='LAYER HEIGHT', XB=29.3765,29.3765,3.68065,3.68065,-0.185503,2.6445/
&DEVC ID='SMOKE LAYER02', QUANTITY='LAYER HEIGHT', XB=2.65228,2.65228,36.1963,36.1963,-0.134358,2.69564/

&CTRL ID='CTRL1', FUNCTION_TYPE='ALL', LATCH=.FALSE., INITIAL_STATE=.TRUE., INPUT_ID='latch'/
&CTRL ID='latch', FUNCTION_TYPE='ALL', LATCH=.TRUE., INPUT_ID='SD'/

&MATL ID='CONCRETE',
    FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
    SPECIFIC_HEAT=1.04,
    CONDUCTIVITY=1.8,
    DENSITY=2280.0/

&SURF ID='INERT3',
    RGB=195,161,102/
&SURF ID='Concrete wall',
    MATL_ID(1,1)='CONCRETE',
    MATL_MASS_FRACTION(1,1)=1.0,
    THICKNESS(1)=0.17/
&SURF ID='Glass',
    RGB=51,255,255/
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    COLOR='RED',
    HRRPUA=1254.6,
    RAMP_Q='Burner3.3_RAMP_Q'/
&RAMP ID='Burner3.3_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=290.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=409.0, F=1.0/
&RAMP ID='Burner3.3_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner3.1',
    COLOR='RED',
    HRRPUA=1254.6,
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&RAMP ID='Burner3.1_RAMP_Q', T=0.0, F=0.0/
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&RAMP ID='Burner3.1_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner3.2',
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    HRRPUA=1254.6,
    RAMP_Q='Burner3.2_RAMP_Q'/
&RAMP ID='Burner3.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=205.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=290.0, F=1.0/
&RAMP ID='Burner3.2_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner2.3',
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    HRRPUA=1254.6,
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&RAMP ID='Burner2.3_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner2.1',
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    HRRPUA=1254.6,
    RAMP_Q='Burner2.1_RAMP_Q'/
&RAMP ID='Burner2.1_RAMP_Q', T=0.0, F=0.0/
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&RAMP ID='Burner2.1_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner2.2',
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    HRRPUA=1254.6,
    RAMP_Q='Burner2.2_RAMP_Q'/
&RAMP ID='Burner2.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=100.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=140.0, F=1.0/
&RAMP ID='Burner2.2_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='burner',
    COLOR='RED',
    HRRPUA=1254.6,
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&OBST XB=0.0,62.0,0.0,40.0,0.0,0.17, SURF_ID='INERT3'/ Floor
&OBST XB=28.0,30.1,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg1
&OBST XB=28.0,30.1,23.12,23.29,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg2
&OBST XB=28.0,30.1,21.72,21.92,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg3
&OBST XB=28.0,30.1,20.35,20.52,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hissvägg4
&OBST XB=30.1,30.27,20.35,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Hisstak
&OBST XB=0.0,62.0,0.0,0.17,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx62y017
&OBST XB=0.0,62.0,0.0,0.17,0.87,2.67, RGB=51,255,255, SURF_ID='Glass'/ Windowx62y017
&OBST XB=0.0,62.0,0.0,0.17,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx62y017
&OBST XB=0.0,62.0,39.83,40.0,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx62y40
&OBST XB=0.0,62.0,39.83,40.0,0.87,2.67, RGB=51,255,255, SURF_ID='Glass'/ Windowx62y40
&OBST XB=0.0,62.0,39.83,40.0,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx62x40
&OBST XB=0.0,0.17,0.17,39.83,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx017y40
&OBST XB=0.0,0.17,0.17,39.83,0.87,2.67, RGB=51,255,255, SURF_ID='Glass'/ Windowx017y40
&OBST XB=0.0,0.17,0.17,39.83,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx017y40
&OBST XB=61.83,62.0,0.17,39.83,0.17,0.87, RGB=146,202,166, SURF_ID='Concrete wall'/ Wallx017y40
&OBST XB=61.83,62.0,0.17,39.83,0.87,2.67, RGB=51,255,255, SURF_ID='Glass'/ Windowx017y40
&OBST XB=61.83,62.0,0.17,39.83,2.67,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Himlingx017y40
&OBST XB=30.915,31.085,26.83,39.83,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandcellindelning 2
&OBST XB=30.915,31.085,0.17,13.17,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandcellindelning
&OBST XB=27.83,34.17,13.17,13.34,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ kommunikations vägg S
&OBST XB=27.83,28.0,13.34,26.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg V
&OBST XB=34.0,34.17,13.34,26.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg Ö
&OBST XB=27.83,34.17,26.66,26.83,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Kommunikations vägg N
&OBST XB=26.36,26.53,19.96,23.19,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ trappuppgång vägg mitten
&OBST XB=24.89,27.83,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång N
&OBST XB=24.89,25.06,18.66,24.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång V
&OBST XB=24.89,27.83,18.49,18.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Vägg trappuppgång S
&OBST XB=24.89,25.06,15.49,18.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss vägg V
&OBST XB=24.89,27.83,15.32,15.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss S
&OBST XB=34.17,37.11,21.32,21.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg S
&OBST XB=34.17,37.11,24.49,24.66,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Obstruction
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&OBST XB=36.94,37.11,15.49,21.32,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg Ö
&OBST XB=35.47,35.64,16.79,20.19,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Trappuppgång2 vägg Mitten
&OBST XB=36.94,37.11,21.49,24.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss2 vägg Ö
&OBST XB=34.17,37.11,15.32,15.49,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ Brandsluss2 vägg S
&OBST XB=39.34,43.11,19.905,20.075,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ WCvägg1
&OBST XB=18.72,23.06,19.905,20.075,0.17,3.17, RGB=146,202,166, SURF_ID='Concrete wall'/ WCvägg2
&OBST XB=0.0,62.0,0.0,40.0,3.17,3.5, COLOR='INVISIBLE', SURF_ID='Concrete wall'/ Roof
&OBST XB=24.4,26.0,11.8832,12.8832,0.17,0.49, SURF_ID='INERT'/ Obstruction
&OBST XB=23.1,23.2,15.5,16.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.1,25.1,15.3,15.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=24.9,25.1,15.5,16.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.0,23.2,16.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=23.0,25.0,24.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=24.8,25.0,16.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft
&OBST XB=39.0,43.0,24.0,25.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=39.0,43.0,15.0,15.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=39.0,39.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=43.0,43.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ WC
&OBST XB=37.0,39.0,24.0,25.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=37.0,39.0,15.0,15.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=37.0,37.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=39.0,39.0,15.0,24.0,0.5,3.5, RGB=146,202,166, SURF_ID='Concrete wall'/ Shaft2
&OBST XB=18.7,18.9,15.5,20.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.7,22.0,15.3,15.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.8,22.0,24.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=18.8,18.8,20.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.0,23.1,15.3,15.5,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.9,23.1,15.5,16.0,0.2,3.2, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.0,23.0,24.4,24.6,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2
&OBST XB=22.8,23.0,16.0,24.4,0.1,3.1, RGB=146,202,166, SURF_ID='Concrete wall'/ WC2

&HOLE XB=30.1,30.27,20.52,21.62,0.17,2.27/ Hole
&HOLE XB=30.1,30.27,21.9326,23.0326,0.17,2.27/ Hole
&HOLE XB=30.1,30.27,23.3566,24.4566,0.17,2.27/ Hole
&HOLE XB=25.39,26.59,15.32,15.49,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss
&HOLE XB=27.83,28.0,13.84,15.04,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuSV
&HOLE XB=35.41,36.61,24.49,24.66,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss2
&HOLE XB=34.0,34.17,13.84,15.04,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuSÖ
&HOLE XB=27.83,28.0,15.98,17.19,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-sluss/kommu
&HOLE XB=25.39,26.89,18.49,18.66,0.17,2.17, CTRL_ID='CTRL1'/ DörrTr1
&HOLE XB=35.11,36.61,21.32,21.49,0.17,2.17, CTRL_ID='CTRL1'/ DörrTr2
&HOLE XB=34.0,34.17,24.86,26.06,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-SlussNÖ
&HOLE XB=34.0,34.17,22.79,23.99,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-slussNÖ
&HOLE XB=27.83,28.0,24.96,26.16,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-komuNV
&HOLE XB=43.11,43.28,23.09,23.99,0.17,2.17/ WC1-toa1
&HOLE XB=43.11,43.28,15.99,16.89,0.17,2.17/ WC1-toa2
&HOLE XB=18.72,18.89,23.26,24.16,0.17,2.17/ WC2-toa1
&HOLE XB=18.72,18.89,15.82,16.72,0.17,2.17/ WC2-toa2
&HOLE XB=30.915,31.085,3.17,4.67,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-brandcell
&HOLE XB=30.915,31.085,35.33,36.83,0.17,2.17, CTRL_ID='CTRL1'/ Dörr-brandcell2
&HOLE XB=28.0,30.1,20.52,24.49,3.17,3.52/ Hole
&HOLE XB=34.0,37.0,15.0,21.0,2.5,3.6/ Hole
&HOLE XB=25.0,27.8,18.6,24.4,3.1,3.52/ Hole

&VENT SURF_ID='Burner3.3', XB=25.2,26.0,12.3832,12.8832,0.5,0.5/ Vent3.3
&VENT SURF_ID='Burner3.1', XB=24.4,25.2,12.3832,12.8832,0.5,0.5, RGB=255,7,19/ Vent3.1
&VENT SURF_ID='Burner3.2', XB=25.2,26.0,11.8832,12.3832,0.5,0.5/ Vent3.2
&VENT SURF_ID='Burner2.3', XB=24.8,25.2,12.1332,12.3832,0.5,0.5, RGB=255,7,19/ Vent2.3
&VENT SURF_ID='Burner2.1', XB=24.4,24.8,12.1332,12.3832,0.5,0.5, RGB=255,7,19/ Vent2.1
&VENT SURF_ID='Burner2.2', XB=24.8,25.2,11.8832,12.1332,0.5,0.5, RGB=255,7,19/ Vent2.2
&VENT SURF_ID='burner', XB=24.4,24.8,11.8832,12.1332,0.5,0.5, RGB=255,7,19/ Vent
&VENT SURF_ID='OPEN', XB=25.06,27.83,18.66,24.49,3.5,3.5/ Tr1
&VENT SURF_ID='OPEN', XB=34.17,36.94,15.49,21.32,3.5,3.5/ Tr2
&VENT SURF_ID='OPEN', XB=28.0,30.1,20.52,24.49,3.5,3.5/ Hissar

&ISOF QUANTITY='TEMPERATURE', VALUE=80.0/
&ISOF QUANTITY='VISIBILITY', VALUE=10.0/

&SLCF QUANTITY='TEMPERATURE', PBZ=1.7/
&SLCF QUANTITY='VISIBILITY', PBZ=1.9/
&SLCF QUANTITY='VISIBILITY', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ=2.0/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', PBZ=2.0/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='CARBON DIOXIDE', PBZ=2.0/
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='SOOT', PBZ=1.9/
&TAIL /
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16.4. Australian scenario 1

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Scenario1.fds
Generated by PyroSim - Version 2014.2.0807
2018-feb-20 13:27:57

&HEAD CHID='Scenario1'/
&TIME T_END=1000.0/
&DUMP RENDER_FILE='Scenario1.ge1', DT_RESTART=300.0/

&MESH ID='Mesh01-a-b-b-a', IJK=18,18,4, XB=25.0,43.0,16.0,34.0,0.0,4.0/
&MESH ID='Mesh01-b-a', IJK=340,10,20, XB=0.0,68.0,34.0,36.0,0.0,4.0/
&MESH ID='Mesh01-b-b', IJK=170,35,10, XB=0.0,68.0,36.0,50.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-b-merged-a', IJK=90,15,20, XB=25.0,43.0,0.0,3.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-b-merged-b', IJK=180,130,40, XB=25.0,43.0,3.0,16.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-a-merged', IJK=125,170,20, XB=0.0,25.0,0.0,34.0,0.0,4.0/
&MESH ID='Mesh01-a-a-b-b', IJK=125,170,20, XB=43.0,68.0,0.0,34.0,0.0,4.0/

&REAC ID='red oak',
    FUEL='REAC_FUEL',
    C=1.0,
    H=1.7,
    O=0.72,
    CO_YIELD=0.06,
    SOOT_YIELD=0.06,
    HEAT_OF_COMBUSTION=1.6E4/

&PROP ID='Cleary Ionization I1',
    QUANTITY='CHAMBER OBSCURATION',
    ALPHA_E=2.5,
    BETA_E=-0.7,
    ALPHA_C=0.8,
    BETA_C=-0.9/
&DEVC ID='SD', PROP_ID='Cleary Ionization I1', XYZ=44.6882,10.5,3.0/
&DEVC ID='LAYER', QUANTITY='LAYER HEIGHT', XB=4.98605,4.98605,10.7188,10.7188,0.22,3.17/
&DEVC ID='LAYER01', QUANTITY='LAYER HEIGHT', XB=4.98605,4.98605,44.5988,44.5988,0.22,3.17/
&DEVC ID='LAYER02', QUANTITY='LAYER HEIGHT', XB=60.0728,60.0728,10.7188,10.7188,0.22,3.17/
&DEVC ID='LAYER03', QUANTITY='LAYER HEIGHT', XB=60.0728,60.0728,44.5988,44.5988,0.22,3.17/
&DEVC ID='THCP', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,2.1/
&DEVC ID='THCP01', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,1.8/
&DEVC ID='THCP02', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,1.5/
&DEVC ID='THCP03', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,1.2/
&DEVC ID='THCP04', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,0.9/
&DEVC ID='LAYER04', QUANTITY='LAYER HEIGHT', XB=33.697,33.697,6.61937,6.61937,0.22,3.17/

&CTRL ID='CTRL1', FUNCTION_TYPE='ALL', LATCH=.FALSE., INITIAL_STATE=.TRUE., INPUT_ID='latch'/
&CTRL ID='latch', FUNCTION_TYPE='ALL', LATCH=.TRUE., INPUT_ID='SD'/

&MATL ID='CONCRETE',
    FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
    SPECIFIC_HEAT=1.04,
    CONDUCTIVITY=1.8,
    DENSITY=2280.0/

&SURF ID='Concrete walls',
    COLOR='GRAY 80',
    MATL_ID(1,1)='CONCRETE',
    MATL_MASS_FRACTION(1,1)=1.0,
    THICKNESS(1)=0.22/
&SURF ID='INERT2',
    RGB=195,161,102/
&SURF ID='concrete wall thinner',
    RGB=146,202,166,
    MATL_ID(1,1)='CONCRETE',
    MATL_MASS_FRACTION(1,1)=1.0,
    THICKNESS(1)=0.17/
&SURF ID='Burner3.3',
    COLOR='RED',
    HRRPUA=1252.0,
    RAMP_Q='Burner3.3_RAMP_Q'/
&RAMP ID='Burner3.3_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=560.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=646.0, F=1.0/
&RAMP ID='Burner3.3_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner3.3_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner3.3_RAMP_Q', T=1000.0, F=0.3/
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&SURF ID='Burner3.2',
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     HRRPUA=1252.0,
     RAMP_Q='Burner3.2_RAMP_Q'/
&RAMP ID='Burner3.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=455.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=560.0, F=1.0/
&RAMP ID='Burner3.2_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner3.2_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner3.2_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner3.1',
     COLOR='RED',
     HRRPUA=1252.0,
     RAMP_Q='Burner3.1_RAMP_Q'/
&RAMP ID='Burner3.1_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.1_RAMP_Q', T=320.0, F=0.0/
&RAMP ID='Burner3.1_RAMP_Q', T=455.0, F=1.0/
&RAMP ID='Burner3.1_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner3.1_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner3.1_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner2.3',
     COLOR='RED',
     HRRPUA=1252.0,
     RAMP_Q='Burner2.3_RAMP_Q'/
&RAMP ID='Burner2.3_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.3_RAMP_Q', T=220.0, F=0.0/
&RAMP ID='Burner2.3_RAMP_Q', T=320.0, F=1.0/
&RAMP ID='Burner2.3_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner2.3_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner2.3_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner2.2',
     COLOR='RED',
     HRRPUA=1252.0,
     RAMP_Q='Burner2.2_RAMP_Q'/
&RAMP ID='Burner2.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=220.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=320.0, F=1.0/
&RAMP ID='Burner2.2_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner2.2_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner2.2_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner2.1',
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     HRRPUA=1252.0,
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&RAMP ID='Burner2.1_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.1_RAMP_Q', T=160.0, F=0.0/
&RAMP ID='Burner2.1_RAMP_Q', T=220.0, F=1.0/
&RAMP ID='Burner2.1_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner2.1_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner2.1_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='burner',
     COLOR='RED',
     HRRPUA=1252.0,
     RAMP_Q='burner_RAMP_Q'/
&RAMP ID='burner_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='burner_RAMP_Q', T=160.0, F=1.0/
&RAMP ID='burner_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='burner_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='burner_RAMP_Q', T=1000.0, F=0.3/

&OBST XB=0.0,0.22,0.22,49.78,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ window-west
&OBST XB=0.0,68.0,0.0,0.22,0.22,0.92, SURF_ID='Concrete walls'/ Wall-south
&OBST XB=0.0,68.0,0.0,0.22,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ Window-south
&OBST XB=0.0,68.0,0.0,0.22,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof- south
&OBST XB=0.0,0.22,0.22,49.78,0.22,0.92, SURF_ID='Concrete walls'/ Wall-west
&OBST XB=0.0,0.22,0.22,49.78,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof- west
&OBST XB=67.78,68.0,0.22,49.78,0.22,0.92, SURF_ID='Concrete walls'/ wall-east
&OBST XB=67.78,68.0,0.22,49.78,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ window-east
&OBST XB=67.78,68.0,0.22,49.78,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof-east
&OBST XB=0.0,68.0,49.78,50.0,0.22,0.92, SURF_ID='Concrete walls'/ wall-north
&OBST XB=0.0,68.0,49.78,50.0,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ window-north
&OBST XB=0.0,68.0,49.78,50.0,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof-north
&OBST XB=0.0,68.0,0.0,50.0,0.0,0.22, SURF_ID='INERT2'/ Floor
&OBST XB=0.0,68.0,0.0,50.0,3.22,4.0, COLOR='INVISIBLE', SURF_ID='INERT'/ roof
&OBST XB=27.2,27.37,20.0,22.5834,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-Acc Wc
&OBST XB=26.6,26.82,28.6,32.4,0.22,3.44, SURF_ID='Concrete walls'/ Wall-staircase1
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&OBST XB=40.98,41.2,17.6,21.1,0.22,3.44, SURF_ID='Concrete walls'/ wall-staircase2
&OBST XB=36.389,41.2366,30.049,30.219,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-wc1
&OBST XB=21.3958,25.0,19.45,19.65,0.22,2.97, SURF_ID='concrete wall thinner'/ wall-wc2
&OBST XB=21.6699,25.0,30.7281,30.8981,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-Wc3
&OBST XB=43.3924,46.2244,30.7657,30.9357,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-wc4
&OBST XB=32.75,34.75,9.5,11.5,0.22,0.49, SURF_ID='INERT'/ Obstruction
&OBST XB=43.2,43.4,34.0,34.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=43.2,46.4,34.2,34.4,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=46.2,46.4,34.0,34.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=43.2,43.4,27.2,34.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=43.2,46.4,27.0,27.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=46.2,46.4,27.2,34.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=24.8,25.0,15.8,20.0,0.2,3.4, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=25.0,30.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=25.0,30.0,20.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=25.0,25.0,16.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=30.0,30.0,16.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=25.0,30.0,15.8,16.0,0.2,3.4, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=41.2,43.2,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=41.0,43.0,26.0,26.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=41.0,43.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=41.0,41.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=43.0,43.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=43.0,43.2,25.8,34.0,0.2,3.4, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=43.4,46.4,19.6,19.8,0.2,3.4, SURF_ID='concrete wall thinner'/ Wall-wc5
&OBST XB=24.8,25.0,19.8,22.8,0.2,3.4, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=25.0,30.0,20.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=25.0,30.0,23.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=25.0,25.0,20.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=30.0,30.0,20.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=39.0,40.0,16.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway2
&OBST XB=40.0,43.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway2
&OBST XB=40.0,43.0,23.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway2
&OBST XB=43.0,43.2,15.8,23.0,0.2,3.4, SURF_ID='Concrete walls'/ stairway2
&OBST XB=39.4,43.0,15.8,16.0,0.2,3.4, SURF_ID='Concrete walls'/ stairway2
&OBST XB=24.8,28.6,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ stairway1
&OBST XB=24.8,25.0,27.0,34.0,0.2,3.4, SURF_ID='Concrete walls'/ stairway1
&OBST XB=28.0,29.0,27.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway1
&OBST XB=25.0,28.0,27.0,27.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway1
&OBST XB=39.0,40.0,16.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=37.0,39.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=37.0,39.0,23.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=37.0,37.0,16.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=37.2,39.6,15.8,16.0,0.2,3.5, SURF_ID='Concrete walls'/ shaft4
&OBST XB=28.4,31.0,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=28.0,29.0,33.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=29.0,31.0,33.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=29.0,31.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=31.0,31.0,33.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=28.0,29.0,28.0,31.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=28.0,29.0,32.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=28.0,31.0,27.0,28.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=28.0,31.0,31.0,32.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=29.0,31.0,29.0,29.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=29.0,31.0,30.0,30.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=29.0,31.0,33.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=31.0,31.0,28.0,31.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=31.0,31.0,32.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=21.4,21.6,34.0,34.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=21.4,24.8,34.2,34.4,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=24.6,24.8,34.0,34.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=21.4,21.6,27.2,34.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=24.6,24.8,27.0,34.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=21.6,24.6,27.2,27.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=36.2,41.4,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ WC1
&OBST XB=36.0,41.0,26.0,26.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=36.0,41.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=36.0,36.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=41.0,41.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=24.8,43.2,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=24.8,25.0,15.8,34.0,0.2,3.4, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=25.0,43.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=25.0,43.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=25.0,25.0,16.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=43.0,43.0,16.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=43.0,43.2,15.8,34.0,0.2,3.4, SURF_ID='Concrete walls'/ smoke lobby
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&OBST XB=25.0,43.0,15.8,16.0,0.2,3.5, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=43.2,43.4,16.0,23.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=43.2,46.4,15.8,16.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=43.2,46.6,23.0,23.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=46.2,46.4,16.0,16.4,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=46.4,46.6,22.6,23.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=46.4,46.4,16.4,22.6,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=21.4,21.6,16.0,23.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc3
&OBST XB=21.4,24.8,15.8,16.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc3
&OBST XB=24.6,24.8,16.0,23.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc3
&OBST XB=21.6,24.6,23.0,23.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc3

&HOLE XB=21.3958,21.5658,16.0037,16.8952,0.22,2.22/ Door-Wc3-1
&HOLE XB=21.3722,21.5668,21.6077,22.4992,0.22,2.22/ Door-Wc3-2
&HOLE XB=21.4999,21.6699,27.7929,28.6844,0.22,2.22/ Door-Wc2-1
&HOLE XB=21.4999,21.6699,33.0982,34.02,0.22,2.22/ Door-Wc2-2
&HOLE XB=46.2974,46.4957,15.944,16.803,0.22,2.22/ Door-Wc5-1
&HOLE XB=46.3245,46.4991,21.4965,22.4071,0.22,2.22/ Door-Wc5-2
&HOLE XB=46.22,46.3933,27.6962,28.5922,0.22,2.22/ Door-Wc4-1
&HOLE XB=46.1992,46.3933,32.9928,33.8975,0.22,2.22/ Door-Wc4-2
&HOLE XB=24.78,25.02,23.78,25.78,0.22,2.72, CTRL_ID='CTRL1'/ Door-Lobby entrance W
&HOLE XB=42.98,43.22,23.78,25.78,0.22,2.72, CTRL_ID='CTRL1'/ Door- Lobby entrance E
&HOLE XB=32.7933,34.7911,33.9731,34.22,0.22,2.72, CTRL_ID='CTRL1'/ Door-Lobby entrance N
&HOLE XB=32.78,34.78,15.78,16.01,0.22,2.92, CTRL_ID='CTRL1'/ Door-Lobby entrance S
&HOLE XB=24.9,26.5,27.08,27.3,-0.1,2.92/ Door-staircase1
&HOLE XB=41.5,43.1,22.6837,22.92,-0.1,2.92/ Door-staircase2
&HOLE XB=24.9,26.1,22.5398,22.7599,-0.1,2.22/ Door-Acc Wc1
&HOLE XB=28.5387,29.6347,22.5446,22.7646,-0.1,2.22/ Door-Acc Wc2
&HOLE XB=30.74,30.96,31.58,32.68,-0.1,2.77/ Elevator door-firefighting
&HOLE XB=30.74,30.96,30.2397,31.3397,-0.1,2.72/ Elevator door- passanger
&HOLE XB=30.74,30.96,28.9069,30.0009,-0.1,2.72/ Elevator door- firefighting2
&HOLE XB=30.74,30.96,27.5682,28.6682,-0.1,2.72/ Elevator door- passanger2
&HOLE XB=36.169,36.39,26.0,26.9,-0.1,2.22/ Door-wc1-1
&HOLE XB=36.168,36.389,32.6252,34.1,-0.1,2.22/ Door-wc1-1
&HOLE XB=28.64,30.74,27.5682,34.1,3.22,4.1/ Hole
&HOLE XB=24.9,28.42,27.3482,34.1,3.22,4.1/ Hole
&HOLE XB=39.58,43.1,15.9,22.7,3.22,4.1/ Hole

&VENT SURF_ID='OPEN', XB=25.0,28.42,27.3,34.0,4.0,4.0/ Opening-Stairway1
&VENT SURF_ID='OPEN', XB=28.64,30.74,27.5682,34.0,4.0,4.0/ Opening-Elevators
&VENT SURF_ID='OPEN', XB=39.58,43.0,16.0,22.7,4.0,4.0/ Opening-Stairway2
&VENT SURF_ID='Burner3.3', XB=33.75,34.75,10.5,11.5,0.5,0.5/ Vent3.3
&VENT SURF_ID='Burner3.2', XB=33.75,34.75,9.5,10.5,0.5,0.5/ Vent3.2
&VENT SURF_ID='Burner3.1', XB=32.75,33.75,10.5,11.5,0.5,0.5/ Vent3.1
&VENT SURF_ID='Burner2.3', XB=33.25,33.75,10.0,10.5,0.5,0.5/ Vent2.3
&VENT SURF_ID='Burner2.2', XB=33.25,33.75,9.5,10.0,0.5,0.5/ Vent2.2
&VENT SURF_ID='Burner2.1', XB=32.75,33.25,10.0,10.5,0.5,0.5/ Vent2.1
&VENT SURF_ID='burner', XB=32.75,33.25,9.5,10.0,0.5,0.5/ Vent

&ISOF QUANTITY='TEMPERATURE', VALUE=80.0/
&ISOF QUANTITY='VISIBILITY', VALUE=10.0/

&SLCF QUANTITY='TEMPERATURE', PBZ=1.7/
&SLCF QUANTITY='VISIBILITY', PBZ=1.9/
&SLCF QUANTITY='VISIBILITY', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='AEROSOL VOLUME FRACTION', SPEC_ID='CARBON DIOXIDE', PBZ=2.0/
&SLCF QUANTITY='AEROSOL VOLUME FRACTION', SPEC_ID='OXYGEN', PBZ=2.0/
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='AEROSOL VOLUME FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ=2.0/

&TAIL /
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16.5. Australian scenario 2

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Scenario2.fds
Generated by PyroSim - Version 2014.2.0807
2018-feb-20 13:36:53

&HEAD CHID='Scenario2'/
&TIME T_END=1000.0/
&DUMP RENDER_FILE='Scenario2.ge1', DT_RESTART=300.0/
&MISC RESTART=.TRUE./
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&MESH ID='Mesh01-a-b-a-a', IJK=50,90,20, XB=0.0,10.0,16.0,34.0,0.0,4.0/
&MESH ID='Mesh01-a-b-a-b', IJK=150,180,40, XB=10.0,25.0,16.0,34.0,0.0,4.0/
&MESH ID='Mesh01-b-a', IJK=220,80,20, XB=0.0,44.0,34.0,50.0,0.0,4.0/
&MESH ID='Mesh01-a-b-b-b-a', IJK=10,90,20, XB=44.0,46.0,16.0,34.0,0.0,4.0/
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&MESH ID='Mesh01-a-b-b-b-b', IJK=55,45,10, XB=46.0,68.0,16.0,34.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-merged-b', IJK=60,40,10, XB=44.0,68.0,0.0,16.0,0.0,4.0/
&MESH ID='Mesh01-b-b', IJK=60,40,10, XB=44.0,68.0,34.0,50.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-merged-a', IJK=220,80,20, XB=0.0,44.0,0.0,16.0,0.0,4.0/

&REAC ID='red oak',
    FUEL='REAC_FUEL',
    C=1.0,
    H=1.7,
    O=0.72,
    CO_YIELD=0.06,
    SOOT_YIELD=0.06,
    HEAT_OF_COMBUSTION=1.6E4/

&PROP ID='Cleary Ionization I1',
    QUANTITY='CHAMBER OBSCURATION',
    ALPHA_E=2.5,
    BETA_E=-0.7,
    ALPHA_C=0.8,
    BETA_C=-0.9/
&DEVC ID='SD', PROP_ID='Cleary Ionization I1', XYZ=12.4747,30.697,3.0/
&DEVC ID='LAYER', QUANTITY='LAYER HEIGHT', XB=4.98605,4.98605,10.7188,10.7188,0.22,3.17/
&DEVC ID='LAYER01', QUANTITY='LAYER HEIGHT', XB=4.98605,4.98605,44.5988,44.5988,0.22,3.17/
&DEVC ID='LAYER02', QUANTITY='LAYER HEIGHT', XB=60.0728,60.0728,10.7188,10.7188,0.22,3.17/
&DEVC ID='LAYER03', QUANTITY='LAYER HEIGHT', XB=60.0728,60.0728,44.5988,44.5988,0.22,3.17/
&DEVC ID='THCP', QUANTITY='THERMOCOUPLE', XYZ=22.7,29.7,2.1/
&DEVC ID='THCP01', QUANTITY='THERMOCOUPLE', XYZ=22.7,29.7,1.8/
&DEVC ID='THCP02', QUANTITY='THERMOCOUPLE', XYZ=22.7,29.7,1.5/
&DEVC ID='THCP03', QUANTITY='THERMOCOUPLE', XYZ=22.7,29.7,1.2/
&DEVC ID='THCP04', QUANTITY='THERMOCOUPLE', XYZ=22.7,29.7,0.9/
&DEVC ID='LAYER04', QUANTITY='LAYER HEIGHT', XB=33.697,33.697,6.61937,6.61937,0.22,3.17/

&CTRL ID='CTRL1', FUNCTION_TYPE='ALL', LATCH=.FALSE., INITIAL_STATE=.TRUE., INPUT_ID='latch'/
&CTRL ID='latch', FUNCTION_TYPE='ALL', LATCH=.TRUE., INPUT_ID='SD'/

&MATL ID='CONCRETE',
    FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
    SPECIFIC_HEAT=1.04,
    CONDUCTIVITY=1.8,
    DENSITY=2280.0/

&SURF ID='Concrete walls',
    COLOR='GRAY 80',
    MATL_ID(1,1)='CONCRETE',
    MATL_MASS_FRACTION(1,1)=1.0,
    THICKNESS(1)=0.22/
&SURF ID='INERT2',
    RGB=195,161,102/
&SURF ID='concrete wall thinner',
    RGB=146,202,166,
    MATL_ID(1,1)='CONCRETE',
    MATL_MASS_FRACTION(1,1)=1.0,
    THICKNESS(1)=0.17/
&SURF ID='Burner3.3',
    COLOR='RED',
    HRRPUA=1252.0,
    RAMP_Q='Burner3.3_RAMP_Q'/
&RAMP ID='Burner3.3_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=560.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=646.0, F=1.0/
&RAMP ID='Burner3.3_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner3.3_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner3.3_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner3.2',
    COLOR='RED',
    HRRPUA=1252.0,
    RAMP_Q='Burner3.2_RAMP_Q'/
&RAMP ID='Burner3.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=455.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=560.0, F=1.0/
&RAMP ID='Burner3.2_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner3.2_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner3.2_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner3.1',
    COLOR='RED',
    HRRPUA=1252.0,
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&RAMP ID='Burner3.1_RAMP_Q', T=320.0, F=0.0/
&RAMP ID='Burner3.1_RAMP_Q', T=455.0, F=1.0/
&RAMP ID='Burner3.1_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner3.1_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner3.1_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner2.3',
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    HRRPUA=1252.0,
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&RAMP ID='Burner2.3_RAMP_Q', T=0.0, F=0.0/
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&RAMP ID='Burner2.3_RAMP_Q', T=320.0, F=1.0/
&RAMP ID='Burner2.3_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner2.3_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner2.3_RAMP_Q', T=1000.0, F=0.3/
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    HRRPUA=1252.0,
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&RAMP ID='Burner2.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=220.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=320.0, F=1.0/
&RAMP ID='Burner2.2_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner2.2_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner2.2_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='Burner2.1',
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    HRRPUA=1252.0,
    RAMP_Q='Burner2.1_RAMP_Q'/
&RAMP ID='Burner2.1_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.1_RAMP_Q', T=160.0, F=0.0/
&RAMP ID='Burner2.1_RAMP_Q', T=220.0, F=1.0/
&RAMP ID='Burner2.1_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='Burner2.1_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='Burner2.1_RAMP_Q', T=1000.0, F=0.3/
&SURF ID='burner',
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    HRRPUA=1252.0,
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&RAMP ID='burner_RAMP_Q', T=160.0, F=1.0/
&RAMP ID='burner_RAMP_Q', T=706.0, F=1.0/
&RAMP ID='burner_RAMP_Q', T=766.0, F=0.3/
&RAMP ID='burner_RAMP_Q', T=1000.0, F=0.3/

&OBST XB=0.0,0.22,0.22,49.78,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ window-west
&OBST XB=0.0,68.0,0.0,0.22,0.22,0.92, SURF_ID='Concrete walls'/ Wall-south
&OBST XB=0.0,68.0,0.0,0.22,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ Window-south
&OBST XB=0.0,68.0,0.0,0.22,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof- south
&OBST XB=0.0,0.22,0.22,49.78,0.22,0.92, SURF_ID='Concrete walls'/ Wall-west
&OBST XB=0.0,0.22,0.22,49.78,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof- west
&OBST XB=67.78,68.0,0.22,49.78,0.22,0.92, SURF_ID='Concrete walls'/ wall-east
&OBST XB=67.78,68.0,0.22,49.78,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ window-east
&OBST XB=67.78,68.0,0.22,49.78,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof-east
&OBST XB=0.0,68.0,49.78,50.0,0.22,0.92, SURF_ID='Concrete walls'/ wall-north
&OBST XB=0.0,68.0,49.78,50.0,0.92,2.72, RGB=54,249,240, SURF_ID='INERT'/ window-north
&OBST XB=0.0,68.0,49.78,50.0,2.72,3.22, SURF_ID='Concrete walls'/ elevated roof-north
&OBST XB=0.0,68.0,0.0,50.0,0.0,0.22, SURF_ID='INERT2'/ Floor
&OBST XB=0.0,68.0,0.0,50.0,3.22,4.0, COLOR='INVISIBLE', SURF_ID='INERT'/ roof
&OBST XB=27.2,27.37,20.0,22.5834,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-Acc Wc
&OBST XB=26.6,26.82,28.6,32.4,0.22,3.44, SURF_ID='Concrete walls'/ Wall-staircase1
&OBST XB=40.98,41.2,17.6,21.1,0.22,3.44, SURF_ID='Concrete walls'/ wall-staircase2
&OBST XB=36.389,41.2366,30.049,30.219,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-wc1
&OBST XB=21.3958,25.0,19.45,19.65,0.22,2.97, SURF_ID='concrete wall thinner'/ wall-wc2
&OBST XB=21.6699,25.0,30.7281,30.8981,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-Wc3
&OBST XB=43.3924,46.2244,30.7657,30.9357,0.22,3.44, SURF_ID='concrete wall thinner'/ Wall-wc4
&OBST XB=21.7,23.7,28.7,30.7,0.22,0.49, SURF_ID='INERT'/ Obstruction
&OBST XB=46.0,46.4,27.2,27.2,0.4,3.6, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=46.4,46.4,27.2,34.0,0.4,3.6, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=44.0,46.4,34.4,34.4,0.4,3.6, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=46.4,46.4,34.0,34.4,0.4,3.6, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=44.0,46.0,27.0,27.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=43.2,43.4,34.0,34.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=43.2,44.0,34.2,34.4,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc5
```

```
&OBST XB=43.0,44.0,27.0,27.0,0.0,3.0, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=43.0,43.0,27.0,34.0,0.0,3.0, SURF_ID='concrete wall thinner'/ Wc5
&OBST XB=24.8,25.0,16.0,20.0,0.2,3.4, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=24.8,30.0,15.8,16.0,0.2,3.4, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=25.0,30.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=25.0,30.0,20.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=25.0,25.0,16.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=30.0,30.0,16.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft2
&OBST XB=41.2,43.2,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=41.0,43.0,26.0,26.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=41.0,43.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=41.0,41.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=43.0,43.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft1
&OBST XB=46.0,46.4,19.6,19.6,0.4,3.6, SURF_ID='concrete wall thinner'/ Wall-wc5
&OBST XB=44.0,46.0,19.6,19.8,0.2,3.4, SURF_ID='concrete wall thinner'/ Wall-wc5
&OBST XB=43.0,44.0,20.0,20.0,0.0,3.0, SURF_ID='concrete wall thinner'/ Wall-wc5
&OBST XB=24.8,25.0,19.8,22.8,0.2,3.4, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=25.0,30.0,20.0,20.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=25.0,30.0,23.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=25.0,25.0,20.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=30.0,30.0,20.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ WC-acc
&OBST XB=39.4,43.2,15.8,16.0,0.2,3.4, SURF_ID='Concrete walls'/ stairway2
&OBST XB=39.0,40.0,16.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway2
&OBST XB=40.0,43.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway2
&OBST XB=40.0,43.0,23.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway2
&OBST XB=43.0,43.0,16.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway2
&OBST XB=24.8,25.0,27.1,34.0,0.2,3.4, SURF_ID='Concrete walls'/ stairway1
&OBST XB=24.8,28.6,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ stairway1
&OBST XB=28.0,29.0,27.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway1
&OBST XB=25.0,28.0,27.0,27.0,0.0,3.0, SURF_ID='Concrete walls'/ stairway1
&OBST XB=37.2,39.6,15.8,16.0,0.2,3.4, SURF_ID='Concrete walls'/ shaft4
&OBST XB=39.0,40.0,16.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=37.0,39.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=37.0,39.0,23.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=37.0,37.0,16.0,23.0,0.0,3.0, SURF_ID='Concrete walls'/ shaft4
&OBST XB=28.4,31.0,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=28.0,29.0,33.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=29.0,31.0,33.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=29.0,31.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=31.0,31.0,33.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ Shaft3
&OBST XB=28.0,29.0,28.0,31.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=28.0,29.0,32.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=28.0,31.0,27.0,28.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=28.0,31.0,31.0,32.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=29.0,31.0,29.0,29.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=29.0,31.0,30.0,30.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=29.0,31.0,33.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=31.0,31.0,28.0,31.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=31.0,31.0,32.0,33.0,0.0,3.0, SURF_ID='Concrete walls'/ Obstruction
&OBST XB=21.5,21.7,27.3,34.0,0.2,3.5, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=21.5,24.8,27.1,27.3,0.2,3.5, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=24.6,24.8,27.3,34.0,0.2,3.5, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=21.4,21.6,34.0,34.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=21.4,24.8,34.2,34.4,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=24.6,24.8,34.0,34.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc2
&OBST XB=36.2,41.4,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ WC1
&OBST XB=36.0,41.0,26.0,26.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=36.0,41.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=36.0,36.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=41.0,41.0,26.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ WC1
&OBST XB=24.8,25.0,16.0,34.0,0.2,3.5, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=24.8,43.2,15.8,16.0,0.2,3.4, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=24.8,43.2,34.0,34.2,0.2,3.4, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=25.0,43.0,16.0,16.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=25.0,43.0,34.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=25.0,25.0,16.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=43.0,43.0,16.0,34.0,0.0,3.0, SURF_ID='Concrete walls'/ smoke lobby
&OBST XB=46.0,46.4,22.8,23.2,0.4,3.6, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=46.4,46.4,16.0,22.8,0.4,3.6, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=44.0,46.0,23.0,23.2,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=44.0,46.4,15.6,16.0,0.4,3.6, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=43.2,44.0,15.8,16.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=43.0,44.0,23.0,23.0,0.0,3.0, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=43.0,43.0,16.0,23.0,0.0,3.0, SURF_ID='concrete wall thinner'/ Wc4
&OBST XB=21.4,21.6,16.0,22.9,0.2,3.5, SURF_ID='concrete wall thinner'/ Wc3
&OBST XB=21.4,24.8,22.9,23.1,0.2,3.5, SURF_ID='concrete wall thinner'/ Wc3
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&OBST XB=24.6,24.8,16.0,22.9,0.2,3.5, SURF_ID='concrete wall thinner'/ Wc3
&OBST XB=21.4,24.8,15.8,16.0,0.2,3.4, SURF_ID='concrete wall thinner'/ Wc3

&HOLE XB=21.3958,21.5658,15.99,16.8952,0.22,2.22/ Door-Wc3-1
&HOLE XB=21.3722,21.5668,21.6077,22.4992,0.22,2.22/ Door-Wc3-2
&HOLE XB=21.4999,21.6699,27.7929,28.6844,0.22,2.22/ Door-Wc2-1
&HOLE XB=21.4999,21.6699,33.0982,34.01,0.22,2.22/ Door-Wc2-2
&HOLE XB=46.2974,46.4957,15.944,16.803,0.22,2.22/ Door-Wc5-1
&HOLE XB=46.3245,46.4991,21.4965,22.4071,0.22,2.22/ Door-Wc5-2
&HOLE XB=46.22,46.3933,27.6962,28.5922,0.22,2.22/ Door-Wc4-1
&HOLE XB=45.96,46.3933,32.9928,34.04,0.22,2.22/ Door-Wc4-2
&HOLE XB=24.78,25.01,23.78,25.78,0.22,2.72, CTRL_ID='CTRL1'/ Door-Lobby entrance W
&HOLE XB=43.0,43.22,23.78,25.78,-0.1,2.72, CTRL_ID='CTRL1'/ Door- Lobby entrance E
&HOLE XB=32.7933,34.7911,33.9731,34.22,0.22,2.72, CTRL_ID='CTRL1'/ Door-Lobby entrance N
&HOLE XB=32.78,34.78,15.78,16.02,0.22,2.92, CTRL_ID='CTRL1'/ Door-Lobby entrance S
&HOLE XB=24.9,26.5,27.08,27.3,-0.1,2.92/ Door-staircase1
&HOLE XB=41.5,43.0,22.6837,22.92,-0.1,2.92/ Door-staircase2
&HOLE XB=24.9,26.1,22.5398,22.7599,-0.1,2.22/ Door-Acc Wc1
&HOLE XB=28.5387,29.6347,22.5446,22.7646,-0.1,2.22/ Door-Acc Wc2
&HOLE XB=30.74,30.96,31.58,32.68,-0.1,2.77/ Elevator door-firefighting
&HOLE XB=30.74,30.96,30.2397,31.3397,-0.1,2.72/ Elevator door- passanger
&HOLE XB=30.74,30.96,28.9069,30.0009,-0.1,2.72/ Elevator door- firefighting2
&HOLE XB=30.74,30.96,27.5682,28.6682,-0.1,2.72/ Elevator door- passanger2
&HOLE XB=36.169,36.39,26.0,26.9,-0.1,2.22/ Door-wc1-1
&HOLE XB=36.168,36.389,32.6252,34.1,-0.1,2.22/ Door-wc1-1
&HOLE XB=28.64,30.74,27.5682,34.1,3.22,4.1/ Hole
&HOLE XB=24.9,28.42,27.3482,34.1,3.22,4.1/ Hole
&HOLE XB=39.58,43.0,15.9,22.7,3.22,4.1/ Hole

&VENT SURF_ID='OPEN', XB=25.0,28.42,27.3,34.0,4.0,4.0/ Opening-Stairway1
&VENT SURF_ID='OPEN', XB=28.64,30.74,27.5682,34.0,4.0,4.0/ Opening-Elevators
&VENT SURF_ID='OPEN', XB=39.58,43.0,16.0,22.7,4.0,4.0/ Opening-Stairway2
&VENT SURF_ID='Burner3.3', XB=22.7,23.7,29.7,30.7,0.5,0.5/ Vent3.3
&VENT SURF_ID='Burner3.2', XB=22.7,23.7,28.7,29.7,0.5,0.5/ Vent3.2
&VENT SURF_ID='Burner3.1', XB=21.7,22.7,29.7,30.7,0.5,0.5/ Vent3.1
&VENT SURF_ID='Burner2.3', XB=22.2,22.7,29.2,29.7,0.5,0.5/ Vent2.3
&VENT SURF_ID='Burner2.2', XB=21.7,22.2,29.2,29.7,0.5,0.5/ Vent2.2
&VENT SURF_ID='Burner2.1', XB=22.2,22.7,28.7,29.2,0.5,0.5/ Vent2.1
&VENT SURF_ID='burner', XB=21.7,22.2,28.7,29.2,0.5,0.5/ Vent

&ISOF QUANTITY='TEMPERATURE', VALUE=80.0/
&ISOF QUANTITY='VISIBILITY', VALUE=10.0/

&SLCF QUANTITY='TEMPERATURE', PBZ=1.7/
&SLCF QUANTITY='VISIBILITY', PBZ=1.9/
&SLCF QUANTITY='VISIBILITY', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='CARBON DIOXIDE', PBZ=2.0/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='OXYGEN', PBZ=2.0/
&SLCF QUANTITY='MASS FRACTION', SPEC_ID='SOOT', PBZ=1.9/
&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ=2.0/
&TAIL /
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16.6. Australian scenario 3

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Scenario3.fds
Generated by PyroSim - Version 2014.2.0807
2018-feb-26 16:21:01

&HEAD CHID='Scenario3'/
&TIME T_END=1000.0/
&DUMP RENDER_FILE='Scenario3.ge1', DT_RESTART=300.0/

&MESH ID='Mesh01-a-b-b-a', IJK=18,18,4, XB=25.0,43.0,16.0,34.0,0.0,4.0/
&MESH ID='Mesh01-b-a', IJK=340,10,20, XB=0.0,68.0,34.0,36.0,0.0,4.0/
&MESH ID='Mesh01-b-b', IJK=170,35,10, XB=0.0,68.0,36.0,50.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-b-merged-a', IJK=90,15,20, XB=25.0,43.0,0.0,3.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-b-merged-b', IJK=180,130,40, XB=25.0,43.0,3.0,16.0,0.0,4.0/
&MESH ID='Mesh01-a-a-a-a-merged', IJK=125,170,20, XB=0.0,25.0,0.0,34.0,0.0,4.0/
&MESH ID='Mesh01-a-a-b-b', IJK=125,170,20, XB=43.0,68.0,0.0,34.0,0.0,4.0/

&REAC ID='red oak',
    FUEL='REAC_FUEL',
    C=1.0,
    H=1.7,
    O=0.72,
    CO_YIELD=0.06,
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     SOOT_YIELD=0.06,
     HEAT_OF_COMBUSTION=2.0E4/

&PROP ID='Cleary Ionization I1',
     QUANTITY='CHAMBER OBSCURATION',
     ALPHA_E=2.5,
     BETA_E=-0.7,
     ALPHA_C=0.8,
     BETA_C=-0.9/
&DEVC ID='SD', PROP_ID='Cleary Ionization I1', XYZ=44.6882,10.5,3.0/
&DEVC ID='LAYER', QUANTITY='LAYER HEIGHT', XB=4.98605,4.98605,10.7188,10.7188,0.22,3.17/
&DEVC ID='LAYER01', QUANTITY='LAYER HEIGHT', XB=4.98605,4.98605,44.5988,44.5988,0.22,3.17/
&DEVC ID='LAYER02', QUANTITY='LAYER HEIGHT', XB=60.0728,60.0728,10.7188,10.7188,0.22,3.17/
&DEVC ID='LAYER03', QUANTITY='LAYER HEIGHT', XB=60.0728,60.0728,44.5988,44.5988,0.22,3.17/
&DEVC ID='THCP', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,2.1/
&DEVC ID='THCP01', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,1.8/
&DEVC ID='THCP02', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,1.5/
&DEVC ID='THCP03', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,1.2/
&DEVC ID='THCP04', QUANTITY='THERMOCOUPLE', XYZ=33.75,10.5,0.9/
&DEVC ID='LAYER04', QUANTITY='LAYER HEIGHT', XB=33.697,33.697,6.61937,6.61937,0.22,3.17/

&CTRL ID='CTRL1', FUNCTION_TYPE='ALL', LATCH=.FALSE., INITIAL_STATE=.TRUE., INPUT_ID='latch'/
&CTRL ID='latch', FUNCTION_TYPE='ALL', LATCH=.TRUE., INPUT_ID='SD'/

&MATL ID='CONCRETE',
     FYI='NBSIR 88-3752 - ATF NIST Multi-Floor Validation',
     SPECIFIC_HEAT=1.04,
     CONDUCTIVITY=1.8,
     DENSITY=2280.0/

&SURF ID='Concrete walls',
     COLOR='GRAY 80',
     MATL_ID(1,1)='CONCRETE',
     MATL_MASS_FRACTION(1,1)=1.0,
     THICKNESS(1)=0.22/
&SURF ID='INERT2',
     RGB=195,161,102/
&SURF ID='concrete wall thinner',
     RGB=146,202,166,
     MATL_ID(1,1)='CONCRETE',
     MATL_MASS_FRACTION(1,1)=1.0,
     THICKNESS(1)=0.17/
&SURF ID='Burner3.3',
     COLOR='RED',
     HRRPUA=1254.6,
     RAMP_Q='Burner3.3_RAMP_Q'/
&RAMP ID='Burner3.3_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=290.0, F=0.0/
&RAMP ID='Burner3.3_RAMP_Q', T=409.0, F=1.0/
&RAMP ID='Burner3.3_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner3.2',
     COLOR='RED',
     HRRPUA=1254.6,
     RAMP_Q='Burner3.2_RAMP_Q'/
&RAMP ID='Burner3.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=290.0, F=0.0/
&RAMP ID='Burner3.2_RAMP_Q', T=409.0, F=1.0/
&RAMP ID='Burner3.2_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner3.1',
     COLOR='RED',
     HRRPUA=1254.6,
     RAMP_Q='Burner3.1_RAMP_Q'/
&RAMP ID='Burner3.1_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner3.1_RAMP_Q', T=205.0, F=0.0/
&RAMP ID='Burner3.1_RAMP_Q', T=290.0, F=1.0/
&RAMP ID='Burner3.1_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner2.3',
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     HRRPUA=1254.6,
     RAMP_Q='Burner2.3_RAMP_Q'/
&RAMP ID='Burner2.3_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.3_RAMP_Q', T=140.0, F=0.0/
&RAMP ID='Burner2.3_RAMP_Q', T=205.0, F=1.0/
&RAMP ID='Burner2.3_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner2.2',
     COLOR='RED',
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      HRRPUA=1254.6,
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&RAMP ID='Burner2.2_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=140.0, F=0.0/
&RAMP ID='Burner2.2_RAMP_Q', T=205.0, F=1.0/
&RAMP ID='Burner2.2_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='Burner2.1',
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      HRRPUA=1254.6,
      RAMP_Q='Burner2.1_RAMP_Q'/
&RAMP ID='Burner2.1_RAMP_Q', T=0.0, F=0.0/
&RAMP ID='Burner2.1_RAMP_Q', T=100.0, F=0.0/
&RAMP ID='Burner2.1_RAMP_Q', T=140.0, F=1.0/
&RAMP ID='Burner2.1_RAMP_Q', T=1000.0, F=1.0/
&SURF ID='burner',
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&HOLE XB=30.74,30.96,30.2397,31.3397,-0.1,2.72/ Elevator door- passanger
&HOLE XB=30.74,30.96,28.9069,30.0009,-0.1,2.72/ Elevator door- firefighting2
&HOLE XB=30.74,30.96,27.5682,28.6682,-0.1,2.72/ Elevator door- passanger2
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&HOLE XB=24.9,28.42,27.3482,34.1,3.22,4.1/ Hole
&HOLE XB=39.58,43.1,15.9,22.7,3.22,4.1/ Hole
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&VENT SURF_ID='OPEN', XB=39.58,43.0,16.0,22.7,4.0,4.0/ Opening-Stairway2
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&SLCF QUANTITY='VOLUME FRACTION', SPEC_ID='CARBON MONOXIDE', PBZ=2.0/
&TAIL /
```

17. Appendix H – Hand calculations

This chapter presents the hand calculations made prior to the fire simulations as a part of the FDS modelling validation.

17.1. Area of the burner:

$$A_{fire\ scenario\ 1\ and\ 2} = 2\ m\ x\ 2\ m = 4m^2$$
$$A_{fire\ scenario\ 3} = 1.6\ m\ x\ 1\ m = 1.6\ m^2$$

17.2. Fire diameter, D:

The fire is assumed circular, diameter of the fire is then calculated by following steps.

$$A_{cirkel} = \left(\frac{\pi}{4}\right) x\ D^2$$

$$D = \sqrt{\frac{4\ x\ A}{\pi}}$$

$$D_{fire\ scenario\ 1\ and\ 2} = \sqrt{\frac{4\ x\ 4\ m^2}{\pi}} = 2.256\ m$$

$$D_{fire\ scenario\ 3} = \sqrt{\frac{4\ x\ 1.6}{\pi}} = 1.42\ m$$

17.3. Characteristic HRR, Q*:

$$\dot{Q}^* = \frac{\dot{Q}}{\rho_\infty\ x\ c_p\ x\ T_\infty\ x\ \sqrt{g\ x\ D}\ x\ D^2}$$

$$\dot{Q}^*_{fire\ scenario\ 1\ and\ 2} = \frac{5000\ kW}{1.2\frac{Kg}{m^3}\ x\ 1.0\frac{kJ}{kgK}\ x\ 293\ K\ x\ \sqrt{9.81\frac{m}{s^2} x\ 2.256\ m}\ x\ 2.256\ m^2} = 0.59$$

OK, FDS user guide specifies values between 0.3 and 2.5

$$\dot{Q}^*_{fire\ scenario\ 3} = \frac{2000\ kW}{1.2\frac{Kg}{m^3}\ x\ 1.0\frac{kJ}{kgK}\ x\ 293\ K\ x\ \sqrt{9.81\frac{m}{s^2} x\ 1.42\ m}\ x\ 1.42\ m^2} = 0.75$$

OK, FDS user guide specifies values between 0.3 and 2.5

17.4. Characteristic fire diameter, D*:

$$D^* = \left(\frac{Q}{\rho_\infty\ x\ c_p\ x\ T_\infty\ x\ \sqrt{g}}\right)^{\frac{2}{5}}$$

$$D^*_{fire\ scenario\ 1\ and\ 2} = \left(\frac{5000\ kW}{1.2\frac{Kg}{m^3}\ x\ 1.0\frac{kJ}{kgK}\ x\ 293\ K\sqrt{9.81\frac{m}{s^2}}}\right)^{\frac{2}{5}} = 1.8\ m$$

$$D^*_{fire\ scenario\ 3} = \left(\frac{2000\ kW}{1.2\frac{Kg}{m^3}\ x\ 1.0\frac{kJ}{kgK}\ x\ 293\ K\sqrt{9.81\frac{m}{s^2}}}\right)^{\frac{2}{5}} = 1.27\ m$$

17.5. Relationship, D*/H:

Fire scenario 1 and 2: $\frac{D^*}{H} = \frac{1.8\ m}{3\ m} = 0.6$

Fire scenario 3: $\frac{D^*}{H} = \frac{1.27\ m}{3\ m} = 0.42$

17.6. Relationship D*/dx:

Table H1 - Relationship between the characteristic fire diameter and cell size used in Pyrosim

	dx = 0.1 m	**dx = 0.2 m**	**dx =0.4 m**	**dx = 1 m**
	D*/dx			
Swedish fire scenario 1 and 2	18	9	-	1.8
Swedish fire scenario 3	12.7	6.35	-	1.27
Australian scenario 1 and 2	18	9	4.5	1.8
Australian scenario 3	12.7	6.35	3.175	1.27

These values are OK. In accordance with the FDS User's Guide, shall the ratio of D*/δx be in a range of 10-20 in the near-field of the fire to obtain accurate values from the simulation. Nysted also states that at high room height (D*/H<0.5, where H is the room height (m)), should the ratio D*/δx be at least 15 [32] [33].