Automatic Fire Alarms – Response procedures

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Abstract
In this thesis, a risk analysis covering response procedures regarding fire alarms from automatic fire alarm systems is presented. Risk factors regarding current procedures in Iceland are identified, analyzed and discussed with regards to acceptance. The work results in a building classification model which classifies buildings/activities with regards to the response of the public services and private monitoring firms who service automatic fire alarm systems in Iceland.

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Summary

Automatic Fire Alarm Systems are important active fire protection measures, for initiating the evacuation of people from burning buildings as well as giving the Fire and Rescue Services more time of extinguishment actions whilst the fire is in a manageable state.

This work focuses on fire safety in socially vulnerable buildings with regards to these systems. Icelandic procedures regarding the response of alarms from automatic fire alarm systems are investigated as well as to some extent Scandinavian procedures. In Iceland, private companies service and monitor the automatic fire alarm systems which is not the case in other cities that were investigated in this work, as in those cities the Fire brigades themselves monitor the systems.

The methodology of risk management theory is the basis of this work as the aim is to find risk factors within current response procedures, analyze and evaluate those risk factors as well as reduce those risk factors.

Icelandic rules and regulations regarding the response to alarms from automatic fire alarm systems are not comprehensive enough to be valid as a work procedure for the Icelandic Fire and Rescue Services and the Private Monitoring Stations that monitor and service the systems. The fact that the time it takes the Private Monitoring Stations to investigate the genuineness of alarms, varies a lot and is not known to the full extent, calls for new procedures in the response to automatic fire alarms.

Various data is simulated to model the unmitigated fire growth time by using data from automatic fire alarm systems which should give the most accurate time of detection. As an illustrative project a model of the unmitigated fire growth time is created for both the procedures as they are today as well as a model of the unmitigated fire growth time is created assuming that the Public Alarm Control Center 112 would monitor these systems instead of private companies.

The model is then applied to a fictional fire scenario in a hospital ward and the difference in the response of alarms is investigated with regards to people being in critical conditions.

As a result, a Building Classification Model is introduced in trying to optimize the working procedures regarding alarms from automatic fire alarm systems aimed at the Fire and Rescue Services as well as the Private Monitoring Stations that service the systems.

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List of entities and various parties referred to in the report

BCM – Building Classification Model

CDFRS – Capital District Fire and Rescue Services

FRS – Fire and Rescue Services

ICA – Iceland Construction Authority

PMS – Private Monitoring Stations

112 – Public Alarm Control Center

AFA – Automatic Fire Alarm

AFAS – Automatic Fire Alarm System

FAD – Fire and Accident Database

UFGT – Unmitigated Fire Growth Time

1 Introduction

Automatic Fire Alarm Systems (AFAS) are amongst other things an essential part of fire protection in constructed facilities, firstly to initiate the evacuation of people and secondly for alarming the fire brigade. By using Probabilistic risk assessment (PRA), the reliability of fire protection systems can be analyzed in greater detail than by using prescriptive building codes as there are many probabilistic variables that contribute to the functionality of the systems. The reliability of fire protection systems is especially essential in controlling fires in larger buildings where situations are more challenging.

In Iceland about 1-2 % (Karlsson, 2010) of all fire alarms that the Capital Fire and Rescue Service (CDFRS) attend to are due to false alarms. This percentage is considered very low compared to some other countries. This percentage is for example around 30 % in Sweden (MSB, 2011). The percentage is low because of the service that Private Monitoring Stations (PMS) provide on AFAS. These firms deal with most of the alarms that the AFAS produce.

Even though this system has worked quite well (1-2 % false alarms in CDFRS callouts), there have been 3 counts of fatal injuries due to fires in the past two years where the fire alarm was first attended to by a PMS before calling the CDFRS. The problem at hand is therefore that although the small percentage of false CDFRS callouts is positive, the fact that fatal injuries have occurred raises the question whether the outcome would be different if the alarm was not first attended by a PMS but the public services, 112 and the CDFRS.

Currently in Iceland there is about 1700 mandatory AFAS set up by the PMS. As of today there are no specified procedures regarding delays in notifying the fire brigade when there is an alarm from an AFAS.

Various models are frequently used for fire safety engineering design. Typically, deterministic models assume that the AFAS operate correctly in all instances and seldom assume the fire brigades procedures and callout times which is a large factor in system functionality. A probability based model takes this further by considering the likelihood that these systems will not work and the subsequent consequences. As a result, by using a probabilistic assessment we can see the interaction between different fire protection systems.

1.1 Aim of the project

The aim of this work is to use the risk management methodology to identify possible risk scenarios that might be at hand with current work procedures regarding the monitoring of Automatic Fire Alarm Systems, aiming at buildings considered to be vulnerable from a societal point of view. To evaluate the level of risk, various strategies currently employed by the Fire Rescue Services (FRS) with regards to response procedures to automatic fire alarm systems are analyzed as well as various timelines regarding the alarm call-out time, the size of constructed facilities and other fire protection systems that are present. Also controlling/reducing the risk factors if necessary, by building a model that categorizes buildings with regards to the FRS response to fire alarms, i.e. when and when not should there be a delay in the fire brigades response to fire alarms. The model is built on this research on current working procedures regarding AFAS, fire protection measures, statistical analysis on empirical data from a PMS and the CDFRS as well as on a consequence model of a hospital ward and a new building regulation being introduced in Iceland.

1.2 Method

Firstly the methodology for reaching the aim of the project is determined. Risk analysis methods used will be qualitative as well as quantitative.

Probabilistic methods will be used to evaluate fire risk including simple statistical analysis, logic tree analysis and probability distributions.

Various data regarding CDFRS and PMS response times as well as floor area of facilities are analyzed in order to investigate the inter-dependence of these variables and to perform an analysis regarding optimal work procedures for the PMS and the FRS in order to reduce risks.

Data from different databases will be utilized in this study. Data and Databases are listed below:

- The Fire and Accident database, where every emergency call that the Fire and Rescue Service attend to relating fire is registered, including various time data.
- Data on all fire alarms registered with a Private Monitoring Station over a one year period and the associated response timelines.
- Data from the Icelandic Property registry where the floor area of buildings and facilities is registered as well as data from insurance companies on fire losses.

Evacuation calculations and computational fluid dynamic simulations will be carried out for a hospital building being planned in Reykjavik Iceland as an illustrative project as hospitals are considered vulnerable from a societal point of view.

A building classification model is introduced in this work which classifies buildings/activities with regards to the response of the PMS and the FRS following an alarm from an automatic fire alarm system. The classification model focuses on vulnerable buildings/activities but also builds a base for other buildings and activities.

1.3 Limitations

To allow an organised study of problem described above, some limitations must be made.

- For the most part, the analysis accounts for people safety and not environmental issues.
- The building subjects are buildings considered as socially vulnerable but not common buildings used as dwellings.
- As an illustrative project, a hospital building is studied and therefore other type of “industry” is not accounted for.

1.4 Structure of the thesis

Chapter 2 describes the general process of risk management and methods used in this work.

Chapter 3 presents a general overview of fire protection and fire safety design as well as contributing factors that lead to a fire hazard.

In Chapter 4, today´s procedures in Iceland regarding fire alarm systems are investigated and to some extent Scandinavian procedures as well.

In Chapter 5 a model is introduced of the unmitigated fire growth time involving the Capital District Fire and Rescue Services (CDFRS) and Private Monitoring Stations (PMS) response time, using data from automatic fire alarm systems (AFAS) and the fire and accident database (FAD).

Chapter 6 investigates the consequences of fire hazards by an illustrative project, where a hospital ward is analyzed with regards to a fire hazard.

Chapter 7 introduces a building classification model where buildings are categorized with respect to response procedures to automatic fire alarms.

Figure 1 below describes the structure of this project figuratively.

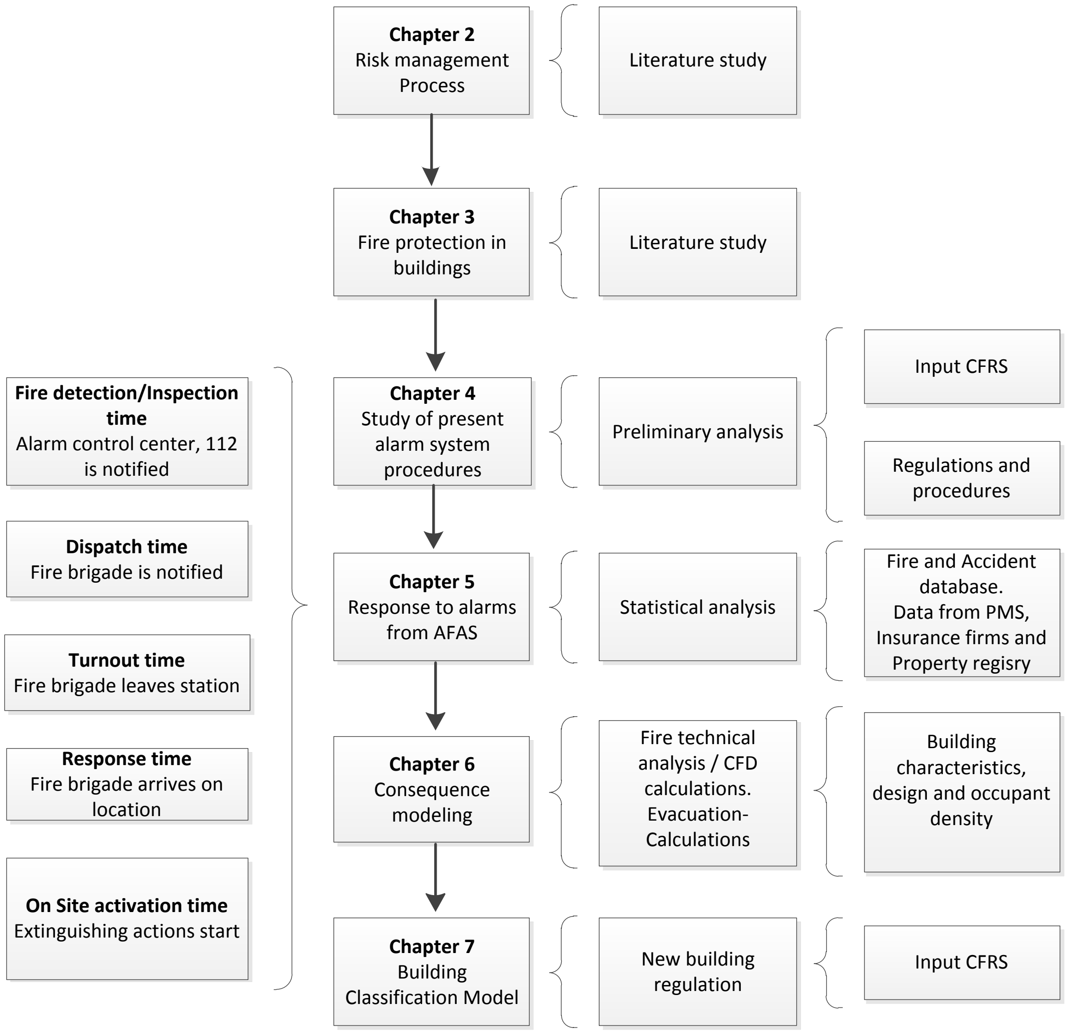

Figure 1 . Figurative structure of the thesis..

2 Risk management process

This chapter describes the risk management process. The theory presented should give an understanding of the central theories which underlie the result of the thesis. Figure 2 below based on international standard (IEC, 1995) shows the process graphically.

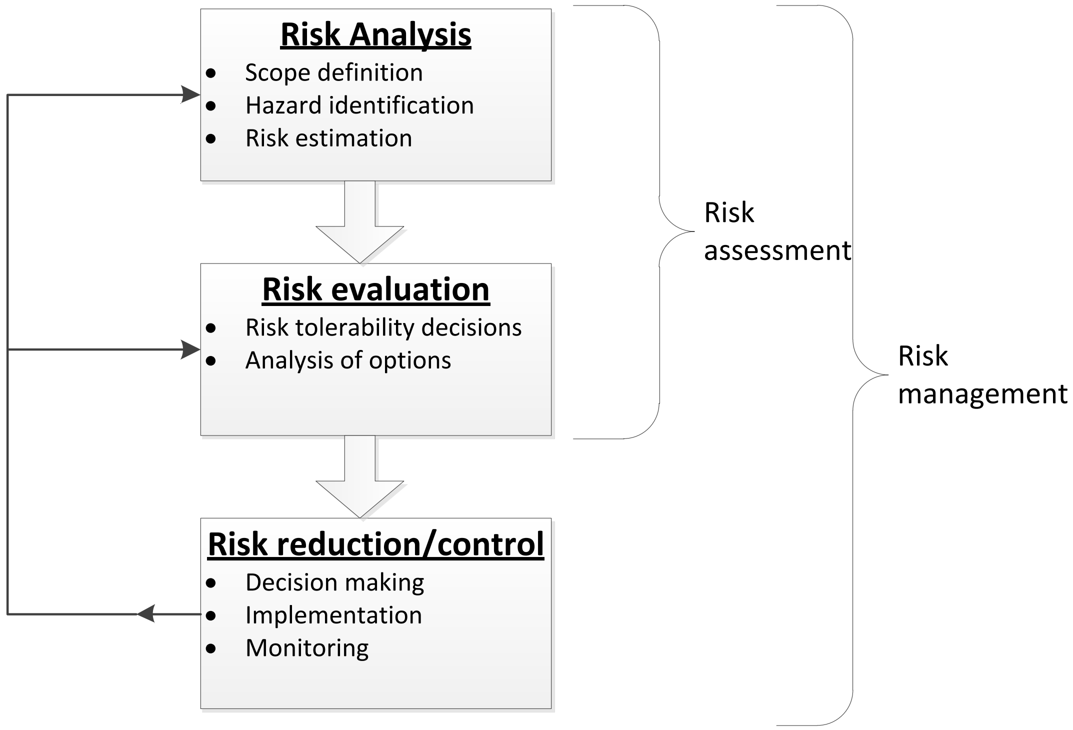

Figure 2 . The risk management process according to the International Electrotechnical Commission **(IEC, 1995)**

Before the management process is addressed, the term risk is defined.

There are numerous definitions of the word risk. Here the definition of the term risk by Kaplan and Garrick (1981) is used. It consists of asking the following three questions:

“What can happen? How likely is that to happen? If it does happen, what are the consequences?“

The answer to the first question gives a scenario of events which can be denoted by „S“, the second question then gives the likelyhood of that scenario happening „L“ and the third question represents the consequences „X“ if the scenarios at hand would occur. The risk is then the sum of all scenarios, the likelyhood of them happening and the consequences they can have.

The risk management process is then a systematic application of management policies, procedures and practices to the tasks of analyzing, evaluating and controlling risk. The process can be divided up to the three following steps as seen in Figure 2;

1. Risk analysis,
2. Risk evaluation and
3. Risk reduction/control.

The first step or the Risk analysis consists of determining the scope of the analysis being performed which leads to hazard identification and followed by an estimation of the risk. A number of methods can be used in the risk analysis depending on the circumstances and available resources.

The second step involves tolerability decisions and analysis of options, i.e. how much risk is tolerable and what options are available to minimize the risk factors. These two steps are generally referred to as a “Risk assessment”.

The third step is about making decisions and implementing them as well as monitoring as the risk management process is a systematic application.

The individual components Risk analysis, Risk evaluation and Risk reduction are discussed in more detail in Sections 2.1, 2.2 and 2.3.

2.1 Risk analysis

2.1.1 Scope

The first step of the risk analysis is to define the scope of the analysis and describe why the analysis is needed. The systems that will be analyzed shall be defined and limitations described. Questions need to be asked, examples below:

1. To what extent are false alarms compared to genuine fire alarms from automatic fire alarm systems (AFAS)?
2. What is the inspection time of the Private Monitoring Stations (PMS), servicing the AFAS?
3. Does the delayed time from ignition to the time the fire brigade is called have an impact on people’s safety?

The aim of this project is to answer these questions and more, first by identifying hazards.

2.1.2 Hazard identification and risk estimation

In the early stages of the analysis qualitative methods are most commonly used as a means of identifying possible hazards. Possible undesirable events are identified first and then analyzed separately. Subsequently possible improvements or preventive measures are formulated. An estimation of probability and consequences can be made in order to compare risks. Methods that are commonly used are Preliminary analysis, HazOp (Hazard and operability studies), What if? Analysis, checklists and text scale risk matrices (Nilsson, 2003).

When looking into the response to fire alarms from AFAS a preliminary analysis is used to look into the risk factors that are identified with the different callout timelines for the fire brigade. This is done with a literature study as well as interviewing people who work in the field at hand.

The preliminary analysis is then followed by more quantitative methods which are methods that involve numerical quantifications of both the probability of occurrence of a hazard and the consequence of that hazard or scenario. The multiplication of the numerical values of probability and consequence gives each scenario a numerical risk value. The calculation can either be deterministic or probabilistic. QRA (quantitative risk analysis) and PRA (probabilistic risk analysis) are both examples of such methods although the latter is more detailed.

Here, event trees are used to describe different events that can happen if for example systems fail or operate correctly giving a number of scenarios to work with. By using the event tree we are able to calculate the probability of each scenario. To some extent the probabilities are obtained by using probability distributions which help giving frequencies to each scenario. Brief overviews of methods used here are listed in the following Subsections.

2.1.3 Event tree analysis

An event tree analysis is a logic model which is presented graphically. The model is used to quantify outcomes of an initial event. Different scenarios can be set up with different probabilities and consequences, making it possible to give scenarios numerical risk values.

The event tree method used here involves the construction of an event tree of various fire scenarios subsequent to the initiation of a fire hazard. The purpose is to find possible outcomes from the initial event of a fire hazard. An example of an event tree is shown in Figure 3.

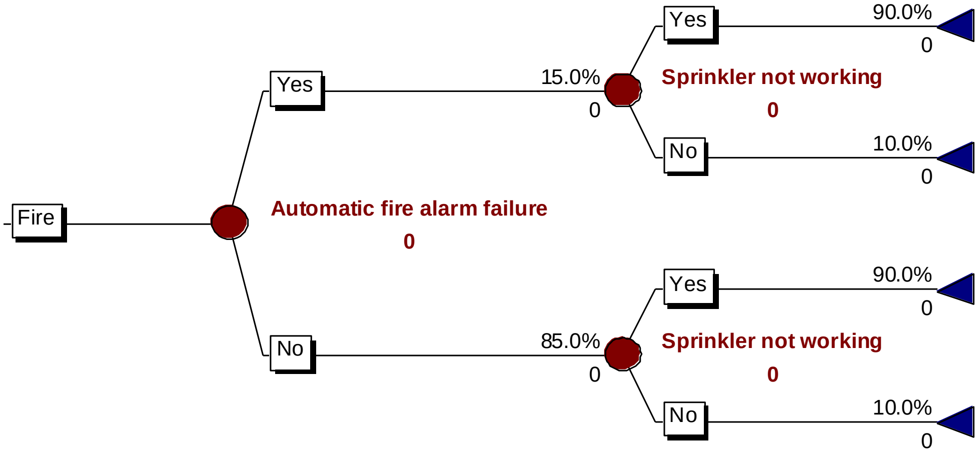

Figure 3 . Example of an Event tree.

2.1.4 Probability distributions

The elements considered here as random variables are associated with the performance of the Fire and Rescue Services (FRS) and the Private Monitoring Stations (PMS). These elements are various timelines which begin with an alarm from an automatic fire alarm system until the FRS start extinguishment actions. A probability distribution assigns a probability to random variables and here the distribution is considered continuous, i.e. having a probability density function.

The distribution considered here with regards to the various response timelines of the PMS and FRS is the gamma distribution which is widely used in risk analysis modeling and has been used for modeling time distributions of fire brigades (Tillander, 2004). The gamma density function is given by (Ross, 2000):

$$f(t) = \beta^{\alpha} \frac{1}{\Gamma(\alpha)} t^{\alpha-1} e^{-\beta t}$$

where α is the shape parameter of the distribution, β the scale parameter of the distribution and $\Gamma(\alpha)$ is the gamma function. The Gamma density function is fitted visually to the observations built on empirical data from the PMS and the FRS.

2.2 Risk evaluation

To be able to conclude whether or not risks concerning the project at hand are acceptable, the risk factors need to be evaluated. Are the risks acceptable, negligible or tolerable? In addition, the question of tolerability must be addressed, i.e. who is the risk tolerable to?

Risk can be categorized by the nature of consequences being investigated. The most frequently used risk measures are individual risk and societal risk. The societal risk measure is the main concern of this work as the quantitative risk analysis results in a level of risk and therefore the individual risk measure is only briefly discussed in the following chapter as a means of showing the difference between the two.

2.2.1 Individual risk

The impact on individuals because of possible hazards is termed individual risk. A common form of the presentation of individual risk is by using risk contour plots and individual risk profiles which is a plot of individual risk as a function of distance from a risk source. The contours connect points of equal individual risk of fatality over a specific period. (American Institute of Chemical Engineers, 2000).

Average individual risk can be calculated using historical data as number of fatalities/year divided by the number of people exposed to a certain hazard. The measure is then expressed as the likelihood of injury/year an individual is exposed to, unaffected by time of day. The individual risk measure does however not completely describe scenarios where a single hazard could affect many people as it defines the risk to a single person in the vicinity of a hazard. These scenarios are addressed by using the societal risk measure, described below.

2.2.2 Societal risk

The societal risk is a measure of impact on the general public as major hazards can affect many people. As described by the (American Institute of Chemical Engineers, 2000), societal risk addresses the number of people who might be affected by hazardous incidents. It is usually represented with an F-N curve which stands for Frequency of accidents vs Number of fatalities. The representation shows in a cumulative way the expected annual frequency of the number of casualties caused by a hazardous event.

The societal risk measure gives more detailed information about the risk factor than the individual risk as it presents how many fatalities can be expected every year from a single event which the individual risk measure does not. This societal risk measure makes it easier to define tolerable risk criteria for different activities as different scenarios give different levels of risk to be evaluated.

Here, the number of fatalities is not used in the F-N curve, but a time axis, which shows the number of people exposed to critical conditions in a burning building depending on the effectiveness of fire alarm systems and the reflex time of the fire brigade.

2.3 Risk reduction

When the risk assessment has been performed, possible interventions can be made. If the risk is not acceptable, there is a need for some intervention actions to lower the risk level to the extent it becomes acceptable. Choosing the alternative which leads to smallest risk is not always reasonable with regards to cost so rational decisions are important. An example of that is if the fire brigade would go to all alarms from AFAS, resulting in vast majority of costly false callouts. Here a categorization of building structures will be introduced as an attempt of reducing the risk of fire hazards as well as costly callouts of the Fire brigades. Chapter 3 discusses the issue of fire protection in buildings in a general way

3 Fire protection in buildings

In this chapter the focus is on fire protection in buildings. The development of building constructions is constantly changing with different architecture and building materials resulting in more complex buildings where the subject of fire safety becomes more demanding. The following sections discuss the purpose of fire safety design and the approaches that can be used to reach acceptable levels of fire safety.

3.1 Fire safety design

The fire safety design process aims to provide safety to occupants of buildings and prevent property losses. The design process involves the use of fire protection measures to control fire and smoke scenarios as well as ensure safe evacuation of people out of a burning building. The objective of the fire design is described by (Rasbash, 1984) as one or all of the following:

1. Loss prevention.
2. Safety of individuals
3. Prevention of societal hurt and concern

Loss prevention can be confined to buildings, building contents, processes etc. where the losses can be expressed financially direct or indirect (Rasbash, 1984).

Safety of individuals can be expressed as the number of casualties that may arise, following a fire in a building and is closely related to the term individual risk, seen in Section 2.2 where specific individuals are of concern.

Prevention of societal hurt and concern implies the effort of reducing the likelihood of large number of fatalities/injuries resulting from a fire incident which could have great social impact. This aspect is often referred to a societal risk as described above, and is the main cause for most public legislation on fire safety (Rasbash, 1984).

With regards to building and fire safety, there has been a worldwide tendency in recent decades to facilitate a transition from prescribed to performance-based building regulations. The prescriptive way of designing involves the use of direct quantitative demands, recommendations in guideline documents, standards and building codes.

Generally, building codes provide either prescriptive demands or performance demands.
With performance based design the focus on design decisions is based on demand and performance requirements of the proposed structure. Below a short summary of the two methodologies is shown.

3.1.1 Prescriptive approach

As the name implies the approach of construction design is based on prescribed material issued by appropriate authorities. The method is widely used and cost effective in standard buildings. Although when building projects become larger and more complex the prescriptive design solutions can get costly and in some cases no prescriptive solutions are available. That is why it is sometimes necessary to deviate from prescriptive design with analytical or performance based methods as described in next Subsection 3.1.2.

3.1.2 Performance based approach

During the last two decades there has been an effort in many parts of the world to move from prescriptive demands in building regulations toward an increased use of performance-based demands. A very useful report on the transition from prescriptive to performance based building codes in 14 different counties around the globe was presented by the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) recently (Meachham, 2010).

Regulatory agencies of all types, and in many parts of the world, began to reconsider the traditional prescriptive approach to regulations, seeking ways to clarify the intent of regulation, reduce regulatory burden, and encourage innovation without compromising the levels of performance delivered. This gave rise to the consideration of functional, objective-based or performance-based approaches to the regulation.

Designing with performance based approach, statistical determination is important as factors related to fire safety in concerning constructions are quantified. The probability of a hazardous event is evaluated based on relevant data. The goal is to show that the probability of a hazardous event is acceptably low. There are mainly two procedures to be considered, that is deterministic or probabilistic procedures (BSI, 2003).

With a deterministic analysis the probability of a hazard happening is not accounted for and the approach is to describe the hazard in terms of the consequences. In a deterministic analysis, the set of circumstances that will lead to a single outcome are evaluated. Thus, the design will be either acceptable or not. (Tillander, 2004)

With a probabilistic analysis the probability of an unwanted event and subsequent consequences are based on past data. The main objective is to show that the probability of an occurrence of an unwanted event is acceptably low (BSI, 2003). Primarily, the aim is to use this approach whenever possible but sometimes the lack of statistical data prevents that from being possible. In that case the two procedures, deterministic and probabilistic methods can be applied together (Tillander, 2004).

The combination of the two can be done by looking at a fully defined fire as being deterministic whereas some input variables are assumed probabilistic. This combination strategy has been termed risk based fire safety engineering and has been used to analyze uncertainties in deterministic models. (Tómasson & et al, 2008).

A probabilistic analysis as a part of a performance based fire design takes into account that risk is a function of both consequences and the frequency of a fire hazard happening. Not all fires turn into a major hazard and therefore the term “Fire hazard” is the topic of following Section.

3.2 Fire hazard

The aim of Fire Safety Engineering is to prevent fire hazards. Therefore it is important to know what factors contribute to the development of a hazardous fire. These factors according to (Yung, 2008) consist of five major events that contribute to the development of a hazardous fire scenario. These events are:

1. Fire ignition
2. Fire growth
3. Smoke spread
4. Failure of occupants to evacuate
5. Failure of fire brigade response

The following discussion gives an overview of these five factors.

3.2.1 Fire ignition

The first event addresses fire ignition. Fire can be ignited in numerous ways, from burning cigarettes to faulty electrical outlets etc. There is no absolute solution to the ignition of fires but the use of fire persistent building materials is a good fire prevention measure as well as the education of staff or inhabitants of a building being considered.

3.2.2 Fire growth

The second event addresses fire growth. Fire growth as well as fire ignition depends on many factors, such as fuel type, building geometry, ventilation, furniture etc. The main concern is the development of flashover which means the spread of fire beyond area of origin. Fire protection measures include construction barriers, such as fire walls, doors, windows and active systems such as automatic fire alarm and sprinkler systems to contain the fire and reduce risk.

3.2.3 Smoke spread

The third event addresses smoke spread. A fire causes smoke to spread throughout a building through corridors and other means resulting in blocked egress routes to other locations in a building as it impacts the visibility of the occupants, staff or others in the building. It also carries dangerous gases which people may inhale. Active fire protection measures include smoke control systems, ventilation and self-closing doors to name a few.

3.2.4 Failure of occupants to evacuate

The forth event addresses the failure of evacuation. Failure to evacuate is mainly caused by smoke spread to egress routes and intense heat in the building. An effective way of preventing these scenarios is the use of smoke detectors which raises alarm before conditions become critical for evacuation. Other protection measures include protected escape routes, evacuation training, refuge areas etc.

3.2.5 Failure of fire brigade response

The fifth event is the failure of fire brigade to response in time. This event concerns all the other events as a successful intervention of the fire brigade minimizes the danger of the other four events.

This study places special emphasis on this factor which could result in failure to rescue trapped occupants and controlling the fire. But what factors influence the successful response and rescue efforts of the fire brigade? The main factors include:

1. Capable staff at the placement of fire
2. Active fire protection systems / Automatic fire alarms systems
3. Distance to fire stations
4. Adequate crew and equipment

Factors 1 and 2 have great impact on the notification of the fire brigade and factors 3 and 4 influence the success or failure of the extinguishment operations on site.

3.3 Fire protection systems as fire barriers

The categories of fire protection are mainly two; passive fire protection and active fire protection. The goal of passive fire protection is to contain fires or slow down fire spread by using fire resistant walls, doors, and windows etc. which are approved by building codes.

The main focus of this work is however on active fire protection systems which are systems that require a certain amount of motion and response in order to work. The active fire protection systems considered in this work are automatic fire alarm systems which are described in greater detail in the following subsection.

3.3.1 Automatic fire alarm systems (AFAS)

Building fires can be detected very soon after ignition by inhabitants, guests or staff at the building at hand. The factors contributing to short detection time include general alertness of people and distance to the ignition source. If people are not alert, for example during the night when sleeping, a fire can grow undetected despite of close presence to the ignition source. In addition, not being close to the ignition source can prolong the time of detection.

Reliable fire detection is therefore very important in all constructed buildings, firstly for initiating the evacuation of people from hazardous environment and secondly as a means to initiate fire extinguishment. The main focus here is on alarms from mandatory automatic fire alarm systems but not on domestic smoke and heat detectors.

AFAS are designed to detect fires by monitoring changes in the environment such as smoke increase in the atmosphere. These systems are intended to notify building occupants in the case of an unwanted fire. As described by (Smith, 1994), the principal function of fire detection systems is identified as the notification of anti-fire agents of the probability of an unwanted fire.

Another description of Automatic fire alarm systems by (Jones & Bukowski, 2001) claims that the aim of installing such equipment is to enable people to identify the location of a fire quickly and accurately and to indicate the status of emergency equipment of fire safety functions that might affect the safety of occupants in a fire situation. Since time is of the essence in occupant evacuation, automatic detectors are normally required in building regulations to provide early detection (Yung, 2008).

The probability of fire spread or large fire scenarios can both be reduced by early detection or early discovery. Also, as stated by (Baldwin, 1971) the probability of fires that start during the night and become large could be reduced by two-thirds if early detection is available.

Numbers published in Fire statistics United Kingdom 1991 (Ramachandran, 1998) show that 67 % of occupant building fires are confined to items first ignited if the fire is discovered by smoke alarms and only 0,2 % spread beyond the building of ignition. On the other hand, if smoke alarms are not installed, 36 % of fires would be confined to items first ignited and 2,5 % would spread beyond the building of ignition, see graphically in Figure 4.

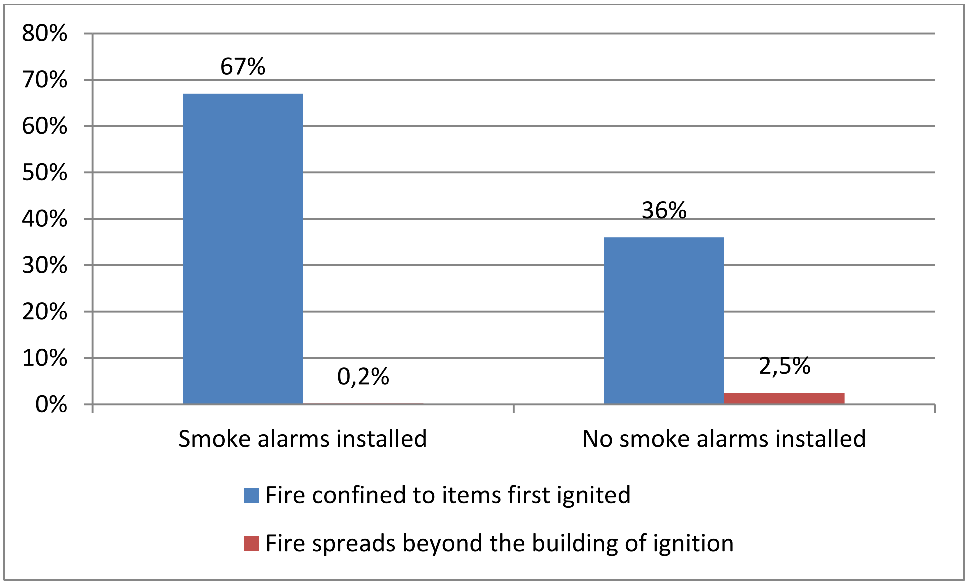

Figure 4 . Fire confinement and spread frequency with and without smoke alarms. **(Ramachandran, 1998)**

The numbers also show that for dwellings the probability of a fire being confined to items first ignited is 68 % if there is functional fire alarm system present and 41 % if there is no such system in place, as seen in Figure 5.

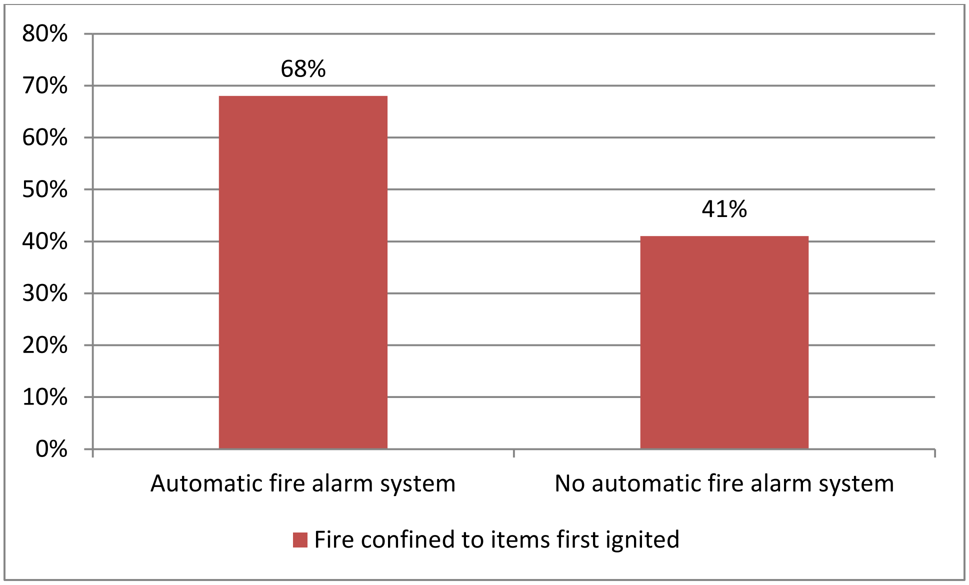

Figure 5 . Fire confinement with and without fire alarm systems. **(Ramachandran, 1998)**

Although these numbers apply for dwellings and not public buildings where an AFAS is required, they provide a good indication of the functionality of fire alarm systems.

3.3.2 Operational reliability of automatic fire alarm systems

The reliability of AFAS can be divided into different elements, including operational reliability and performance reliability (Bukowski, 1999). The difference between the two is that operational reliability provides a measure of the probability that an AFAS will function as intended, when needed. The performance reliability is a measure of how reliable the system is under specific conditions. As described by (Bukowski, 1999), the former is a reliability measure of the components of a system or the system as a whole whereas the latter is a measure of the system design for a certain or a number of fire scenarios. Performance reliability is very dependent on the operational reliability as even though systems are adequately designed according to circumstances, they will not work if they do not operate.

The operational reliability is considered from here on, as the purpose of this study is not to look into different designs of systems.

A fire alarm system can be looked at as a multiple entry "pump" as described by (Nyyssönen, Rajakko, & Rahkonen, 2005). If one detector dos not respond, there is often another response from a neighboring detector, like a pump, which is fed from several independent inlets. However, the operational reliability is difficult to assess because of the numerous systems on the market making it hard to find statistical data on how many detectors respond to a single fire. As an alternative, (Nyyssönen, Rajakko, & Rahkonen, 2005) propose a fault tree through an "OR" gate assessing a failure of fire detection and alarm.

The fault tree seen in Figure 6 describes six subsystems. From left these subsystems are; detector failure, failure of alarm system component, signal communication subsystem failure, failure in auxiliary control subsystems, power supply failure and failures resulting in false alarms.

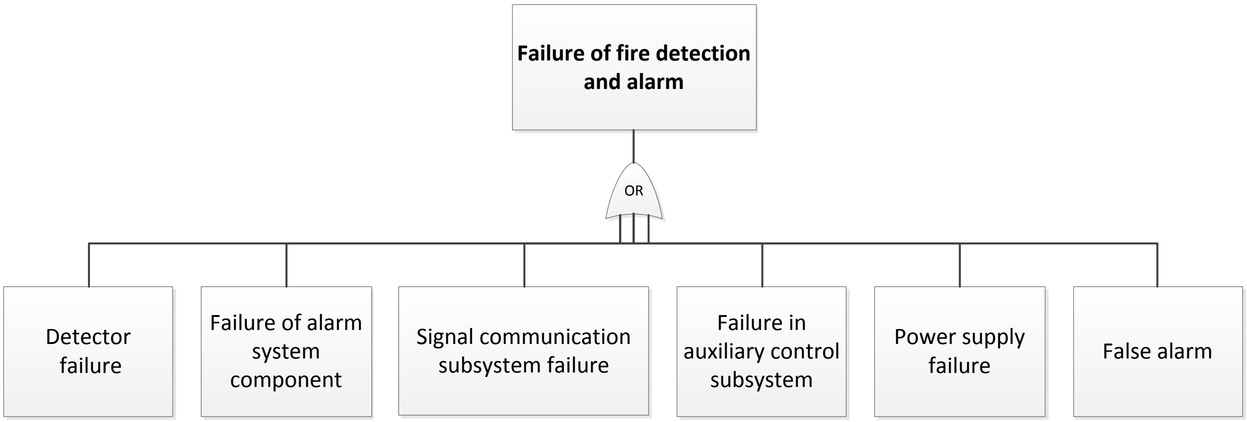

Figure 6 . Fault tree for the failure of fire detection and alarm.

Each of these six subunits can be divided further down. This tree is for demonstration of dependencies, and not strictly a fault tree in mathematical sense, since the number of components in various branches or even within a branch are not the same. Once some numerical values of component or subsystem performance are available, approximate real fault trees can be built.

Although statistical data on subunits are hard to find, literature of various kinds provides information on the reliability of AFAS. The British Standards (BSI, 2003) for example, give information on different detectors, alarm boxes, wiring and sounders.

Another issue with the AFAS is false alarms to the FRS. The system might be working properly, detecting smoke from a pot on the stove and raising an alarm resulting in a callout of the fire brigade which arrives on the scene but no fire has occurred as the inhabitants have put out the fire/smoke without contacting anyone. This can be costly and is discussed in greater detail in the following Subsection.

3.3.3 False alarms

Many lives have been saved along with gained economical savings because of AFAS that detect fire in its early stages. The fact is however that the majority of all alarms from these systems are not genuine fire alarms i.e. false alarms. In Sweden 97 % of alarms from automatic fire alarm systems are false alarms (Hjort, 2005). The minority of these alarms are attended to by the FRS as many occur when people are at the location of the alarm and can stop it. However the consequences of frequent false alarms can cause:

- Reduced respect for fire alarm systems in general and genuine alarms.
- Fire brigades spend time, energy and money in vain.
- Can be dangerous for people as unnecessary evacuations are carried out
- Whilst fire brigades are following false alarms they are not present if there are real fire incidents elsewhere.
- False alarms are costly and cause production delays within companies where false alarms are frequent.

In the USA and Sweden, false alarms are mainly triggered by burnt food, welding, hot steam, dust exposure, and problems with heating, ventilation and air conditioning systems. (Hjort, 2005) (Durso JR, 2011)

Unnecessary alarms cause inconvenience both for the owners of the systems as well as fire brigades.

In Figure 7 a graph is shown where the Reykjavik´s Capital District Fire and Rescue Services (CDFRS) attended a callout where there was an alarm from an alarm system but no fire to fight. As seen in the figure there is a rise in the alarms in 2009 as it comprises only of January 2009.

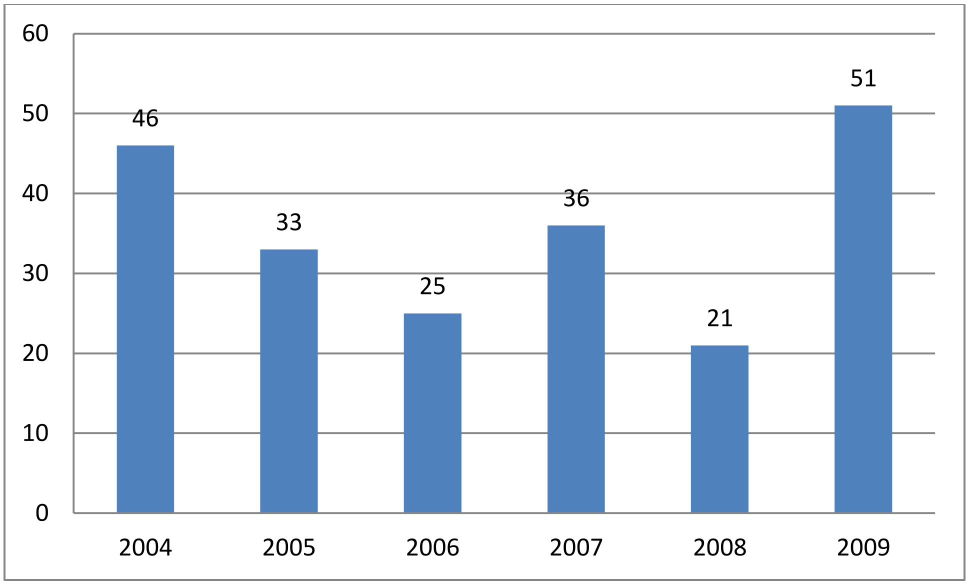

Figure 7 . Number of false alarms callouts for the CDFRS. The number in 2009 is only for January.

The rise of false alarm callouts in January 2009 is not known to the full extent but it was a factor in triggering this work.
Although there are a number of false callouts every year for the CDFRS the number of false alarms are about 2 % of all callouts (Karlsson, 2010).

According to Swedish statistics (MSB, 2011), 30 % of the Swedish fire brigades interventions in 2010 were due to false alarm from AFAS. In the U.S.A, in 2008, one out of ten calls that the U.S. fire brigades responded to were false alarms or 10 % in total. (Karter Jr, 2009)

The difference in statistics might be because of the number of systems between different countries and communities, different procedures within countries and communities, whether or not the fire brigade responds to all callouts or if there is a security firm that attends to the alarms beforehand.

The Icelandic authorities want to keep the percentage of false alarm callouts as low as possible without affecting safety levels as can be the case if there is a delay in the FRS reflex time due to genuine alarms.

The main type of calls that the CDFRS or 112 receive are live calls from persons but also calls about alarms from AFAS from the companies that monitor them, the Private Monitoring Stations (PMS). Icelandic procedures and CDFRS callouts are discussed in more detail in Chapters 4 and 5.

False alarms from AFAS are usually classed as being due to “apparatus”, although this can often be subdivided into categories (Mott MacDonald, 2008) such as:

- Poor design of the system (e.g. siting inappropriate detectors in kitchens)
- Poor management (e.g. hot work close to detectors without appropriate safeguards)

- Poor maintenance of system (e.g. ignoring persistent “false” alarms rather than fixing the problem)

The benefits of reducing falls alarms are numerous, both for the “business” sector as well as for Fire and Rescue Services(FRS) in general as listed by (Mott MacDonald, 2008) in Table 1:

Table 1: Benefits of reducing false alarms

Benefits of reducing false alarm rates
To business
Reduced business disruption through fewer evacuations and stoppages
Reduction in casualties due to improved response to fire alarms due to greater likelihood that they are true
Reduced impact to business from retained fire-fighters responding to calls
To Fire and Rescue Services
Releases resources for training and community and statutory fire safety tasks.
Ability to place resources on standby as a strategic resource in the event of a serious incident
Fewer Road Traffic Collisions
Cashable savings, especially in the case of retained fire fighters
Increased availability of appliances for attending other emergency calls
Reduction of problematic call out workload in a small number of “busy” fire stations.

It is of importance for stakeholders domestically and internationally to reduce false and costly alarms to gain the benefits mentioned above. The U.K. (Chief Fire Officers Association, 2008) has stated that “It is essential that a consistent national approach to reducing false alarms and unwanted fire signals is developed”. Icelandic procedures and CDFRS callouts are discussed in more detail in Chapters 4 and 5.

3.4 Summary

In this chapter we have reviewed the basic factors contributing to a fire hazard as well as different fire safety design methodologies. We have found that an AFAS is an important part of fire protection, especially for initiating the evacuation of people from burning buildings as well as giving the CDFRS more time of extinguishment actions whilst the fire is still manageable. However, we have also found that a lot of the callouts, due to AFAS are because of false alarms. We have to some extent shown that this is an international problem which needs attendance.

The aim and objective of the regulations on AFAS set by the ICA (Iceland Construction Authority) and the ÍST EN 54 standard (Icelandic Standards, 2002), is to ensure that AFAS are designed, installed and maintained in such a manner that any fire incident is detected early so the safe evacuation of people is not put to risk and fire extinguishment can start before the fire has started to spread considerable.

By reducing the number of false alarms by safe design and a proper reaction practices the use of AFAS proof a valuable asset in fire safety.

In Chapter 4, present alarm system procedures are introduced as a means of identifying risks that might be at hand with today´s practice in the response to AFA.

4 Study of present alarm systems procedures

The response procedures regarding automatic fire alarm systems have been analyzed both nationally and to some extent internationally. As a means of this work, the study of international responses was partly carried out by the Icelandic CDFRS as they sent a questionnaire to the fire brigades of the Scandinavian countries to get information on the working procedures regarding alarms from automatic fire alarm systems first hand.

4.1 Icelandic procedures

The legislation that governs the requirements of fire protection in buildings is the Building Regulation nr. 441/1998 issued by the Environmental authorities of Iceland (Ministry of the Environment, 2006). The regulation mainly consists of prescriptive codes regarding the construction of buildings and other constructions. It describes for example where automatic fire alarms systems as well as sprinkler systems are mandatory measures of fire protection. Article 161 in the regulation states that fire alarm systems shall be in accordance with ÍSTN EN 54 and the rules of the Icelandic Construction Authority (ICA).

According to these Icelandic regulations, all Automatic fire alarm systems shall be connected to a certified Private Monitoring Station (PMS) that receives the alarms and contacts the Public Alarm Control Center (112) if necessary. The 112 then alarms the fire brigade. These PMS are the service providers of the AFAS and have a permit from the ICA to conduct their business. Figure 8 shows the AFA process graphically. The PMS have their own home station in the capital district area where they monitor the AFAS and send out security guards if the monitoring team thinks it is necessary for investigating the cause of alarm.

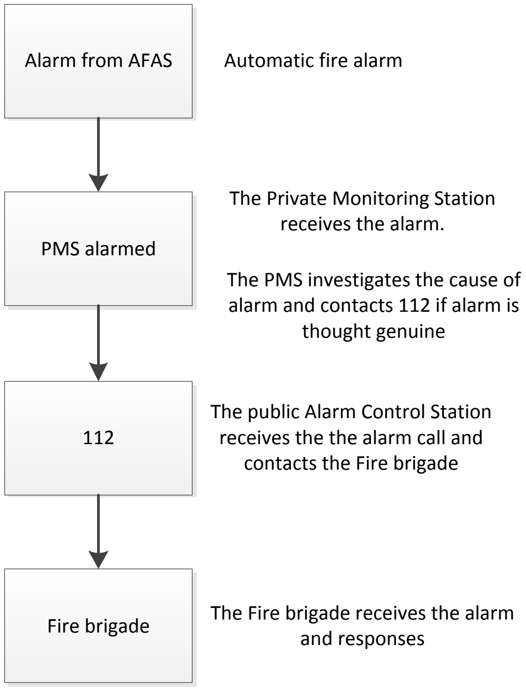

Figure 8 . Current Icelandic working procedures with regards to the response to AFA.

This procedure aims to maximize the efficiency of the fire brigades by making sure that the callout of the fire brigade is due to genuine alarm but not a false alarm. However, this procedure can lengthen the reflex time of the fire brigade if there is an actual fire to be fought, which delivers ground for this study.

Currently there is about 1700 mandatory AFAS set up by the PMS. As of today there are no specified procedures regarding delays in notifying the fire brigade when there is an alarm from an AFAS.

Hospitals are considered vulnerable buildings where fire alarm systems are mandatory as patients in hospitals in a lot of cases do not have the capability to evacuate a burning building as well as a “production stop” can cause a lot of harm for the society. Below, Figure 9 shows the ratio of CDFRS callouts with respect to building category where there was an alarm from an AFAS. (Data retrieved from the Fire and Accident Database (FAD)).

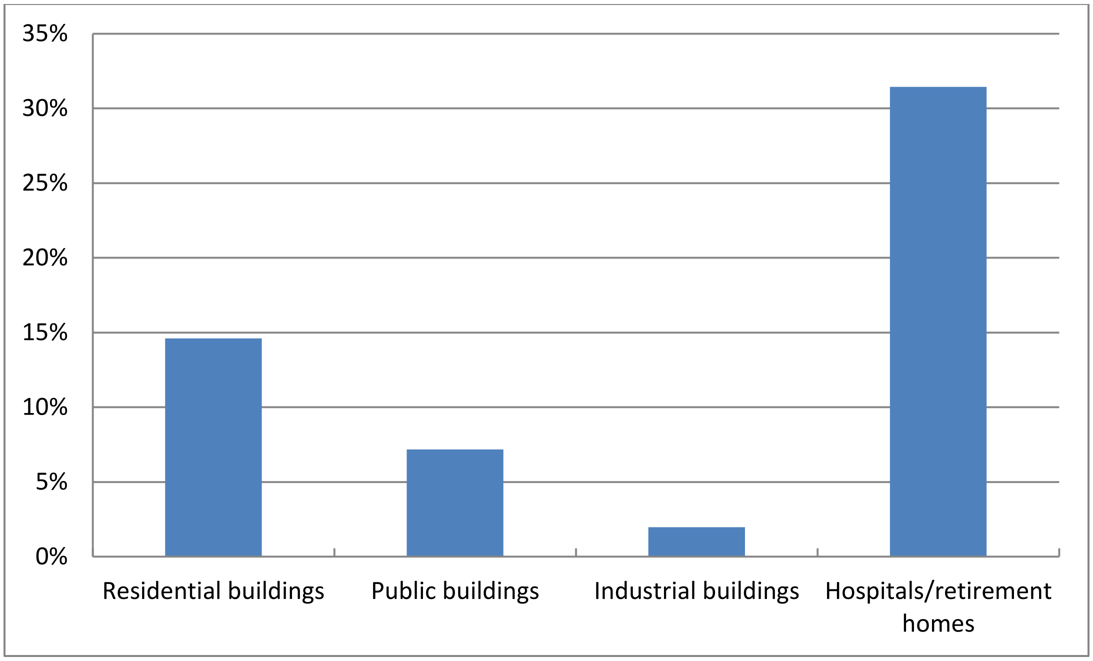

Figure 9 . Callouts of the CDFRS due to AFAS with regards to building category.

As the figure shows, the vast majority comes from hospitals and retirement homes which delivers ground for the illustrative study in Chapter 6.

4.2 International procedures

When looking into international rules and regulations as well as procedures regarding the response to alarms from AFAS, it was found that there are many different procedures within states and cities of the countries investigated. It was therefore decided as mentioned earlier to work with a questionnaire which the CDFRS sent to the Fire Brigades of Copenhagen in Denmark, Stockholm and Gothenburg in Sweden and Oslo in Norway.

The questionnaire consisted of six questions which all were related to the response to a fire alarm from an AFAS. The six questions are listed below:

1. Are there any delays allowed in the regulations and procedures between an alarm from a mandatory fire alarm system and the callout of the fire brigade?
2. If delays are allowed, what rules apply on the handling of the alarm? Which criteria need to be in place in order for the delay to be allowed and which demands on procedures do the private monitoring stations need to fulfill (if private monitoring stations deal with the alarm).
3. Are buildings and companies classified with reference to permissible delays in callouts and is there a difference in the handling of alarms with respect the time of day?
4. Is there a monetary charge for a fire brigade callout due to a false alarm?
5. If there is a charge for false alarms, what is the amount charged? And is the charge permitted by the laws and regulations?
6. Who is charged? The owner of the system or the user of the system.

The answer to the first question was "yes" in all concerning cities, i.e. there is a delay permitted in the callout of the fire brigade. This is interesting as in the Icelandic legislation, there is no time interval given for a delayed response of the fire brigade.

The answer to the second question was somewhat similar between concerning cities as the Fire brigades monitor the AFAS in all cities and maximum delay is 10 minutes in Copenhagen, Stockholm and Gothenburg but the delay it is negotiable in Oslo. This procedure is fundamentally different in Iceland as Private Monitoring Stations (PMS) monitor the AFAS.

The third question concerning building/activity classification regarding AFA delays, no answer came from Copenhagen and Oslo but in Stockholm and Gothenburg there is not a special categorization but different between activities and staff on site. The answers regarding different handling of alarms with respect to time of day, there is a different handling in Copenhagen, Gothenburg and Oslo but no answer came from Stockholm regarding this matter. The different handling is though not necessary because of time of day but also due to number of staff on site of alarm. These answers are somewhat similar to the CDFRS procedures in Iceland as currently the response to AFA is not according to different buildings or activities.

The answer to the fourth and fifth question was interesting as in all cities; there is a monetary charge for callouts due to false alarms which is not the case in Iceland. The amount is different between cities as was expected but in Copenhagen and Stockholm the charge is permitted by law whereas in Oslo the charge is not by legislative but no answer came from Gothenburg regarding that matter.

The answer to the sixth question regarding who is charged for false callouts the answer was the same in Stockholm, Gothenburg and Oslo, where the person/company which signed the monitoring contract is charged. I Copenhagen it is the owner of the system who is charged.

As seen above, the answers were quite different but had some things in common within each country. What was of most interest, in all the cities considered was that the FRS monitors the AFAS. Also in all cases, delay is permitted in response to AFA as well as all the fire brigades charge for unnecessary callouts. In Appendix 1, all the answers are shown as they came from the fire brigades.

The main difference between the procedures in the above cities and countries and Iceland is that the Icelandic FRS does not monitor the AFAS. Also there is no charge made by the Icelandic FRS in the case of unnecessary callouts or false alarms. The service and monitoring of the AFAS is carried out as mentioned earlier by private monitoring stations (PMS) that have been certified by the ICA. The time it takes these PMS to inspect and analyze the reasons for AFA varies a lot as there is not a legislative time limit in place in Icelandic regulations covering AFAS. In fact the regulations do not allow for any delay, but due to impracticality and cost of such a procedure, it has become a de-facto. The PMS have their own dispatch/control stations which receive alarms from AFAS and deal with them by phone or by arriving on scene to investigate the cause of alarm. They do not have any traffic priority as the FRS have, making their travel time longer than the Fire brigades.

4.3 Summary

Icelandic rules and regulations regarding the response to an alarm from an AFAS are not comprehensive enough to be valid as a work procedure for the Icelandic FRS and the PMS that monitor and service the AFAS. The fact that the timeline it takes the PMS to investigate the genuineness of alarms, varies a lot and is not known to the full extent, calls for new procedures in the response to AFA.

We have found that in the case of an actual fire alarmed by an AFAS, the FRS do not respond until they have had notice from the PMS (given that people at burning site have not called 112), making the fire growth time longer resulting in increased risk of injury or death. This is not allowed by the regulations, but has become de-facto procedure, without necessary regulatory support and consequence assessment.

There needs to be a clear understanding between involved parties on procedures regarding alarms from these systems in order to minimize risks to the public.

In Chapter 5, a model of the unmitigated fire growth time is introduced where data from the PMS and FAD is analyzed. The purpose is to look into different callouts and analyze the timelines to see where and how current procedures can be improved in order to minimize risks to the public.

5 Response to Automatic Fire Alarms

In this chapter our aim is to investigate callouts of the CDFRS with regards to AFAS. We want to see the extent of incoming alarms from AFAS as well as different timelines regarding callouts due to AFAS. We shall discuss the extent of false alarms and the different callout timelines as well as the time difference if the FRS would monitor the AFAS instead of the PMS. In Section 5.1 we discuss the unmitigated fire growth time (UFGT). A model is introduced which takes into account data from the PMS and their service of AFA systems.

5.1 Unmitigated Fire Growth Time (UFGT) model

The time it takes from the ignition of fire until the fire brigade starts fire extinguishment actions, the UFGT can be modeled as seen in Figure 10 (Tómasson & et al, 2008)

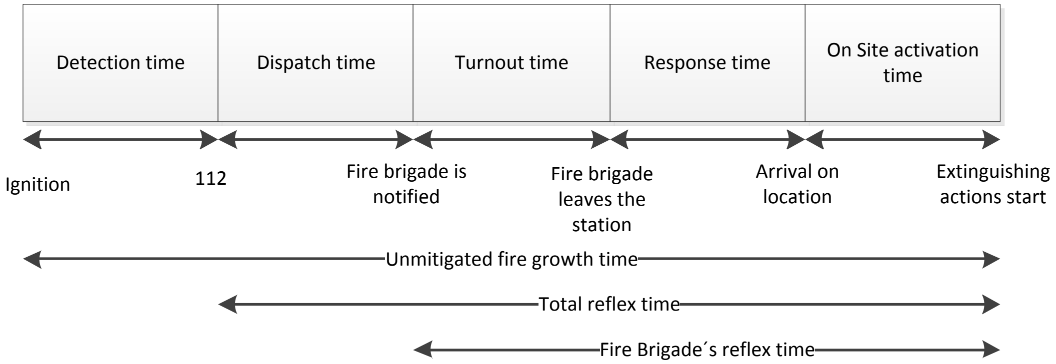

Figure 10 . Time line of the unmitigated fire growth time

Figure 10 describes the total time from ignition of fire to the time the fire fighters start extinguishment actions. The time interval is divided into a timeline of five main parts, namely:

1. Detection time: The time from the ignition of fire until the Public Alarm Control Center (112) is notified.
2. The dispatch time: The time which it takes the 112 to notify the fire brigade.
3. The Turnout time: The time it takes the fire brigade to leave the home station.
4. Response time: The time it takes the fire brigade to transport to the hazard location.
5. On-site activation time: The time it takes the fire brigade to start extinguishment actions.

The first part of the interval in Figure 10, Detection time, is an uncertain variable as it does not describe to the full extent the actual ignition time, but the time when someone or something acknowledges a fire and contacts the 112.

Here, we want to build a model to simulate the UFGT using AFAS data. By doing that we should get a more detailed time of ignition, making the model of UFGT more accurate. A graphical description of the model is given in Figure 11.

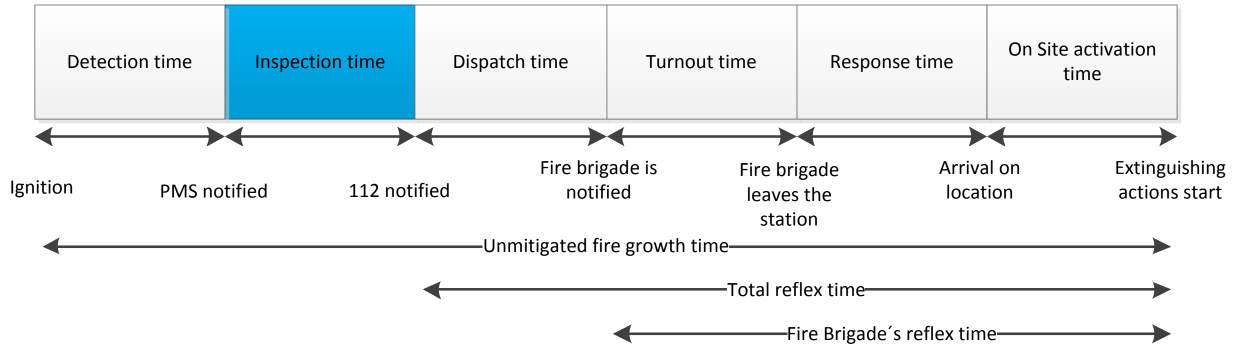

Figure 11 . Time line of the unmitigated fire growth time with regards to automatic fire alarms

Figure 11 describes the UFGT, taking into account the total reflex time of the public services, 112 and the FRS as well as the PMS and their inspection time (blue in Figure 11) before calling the 112. With given information on the mode of detection (AFAS), placement of detection etc., the perimeter of the detection time can be minimized and increase the accuracy of the model.

To build the model and get information on different timelines, time related data is needed. In Section 5.2 relevant data and data sources are introduced. In Sections 5.3-5.8 the, individual parts of the UFGT model are discussed.

5.2 Relevant data

The time at which the 112 is notified of fire alarms has been recorded for a number of years. The ICA keeps a database where these emergency callouts are registered and stored. The main role of this Fire and Accident database (FAD) is to gather together in one centralized database information about emergency callouts from all the Icelandic Fire brigades. By doing this, statistical information is gathered on various emergency callouts which can be used to organize the Fire brigades better and by that, improve the service to the general public.

This data is vital for modeling the Total reflex time of the public services, the 112 and the FRS. In the following Subsection 5.2.1, the FAD is introduced and in Subsection 5.2.2 and 5.2.3 data from the Icelandic property registry and insurance companies is investigated in order to see where fire alarms are coming from. The data retrieved from the PMS to investigate the time of detection and inspection is introduced in Subsection 5.2.4.

5.2.1 The Fire and Accident Database (FAD)

In the database various information about the causes of fires and accidents are registered along with the reactions of the concerning fire brigade. Every fire brigade in Iceland registers in the database and all of them can access their own files but the ICA has access to all files within the database. In the database, information about all emergency callouts that the Icelandic FRS attends to is registered.

In this work the focus is on the Capital and the surrounding communities. Therefore data that concerns the CDFRS is of most importance and was filtered out to be utilized in this work

Below in Figure 12, it can be seen that the CDFRS attends to various callouts and about 40% are related to fires according to the database for the years 2008-2009.

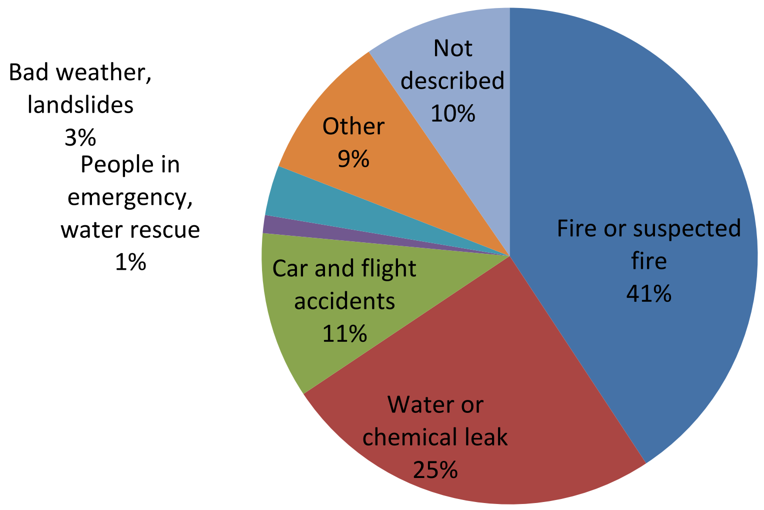

Figure 12 . Callout types of the CDFRS

As seen in Figure 12, the CDFRS attend to many different callouts which makes it even more valuable not to be spending time on costly false fire alarms.

As seen in Figure 9 in Section 4.1 the callouts due to AFAS are shown but if we look further into all building fire callouts, we see that over 60 % are in residential buildings as is shown in Figure 13 below. The figure shows the proportion of CDFRS actual building fire callouts but does not take into account the number of buildings within each category which is of course the highest in residential buildings.

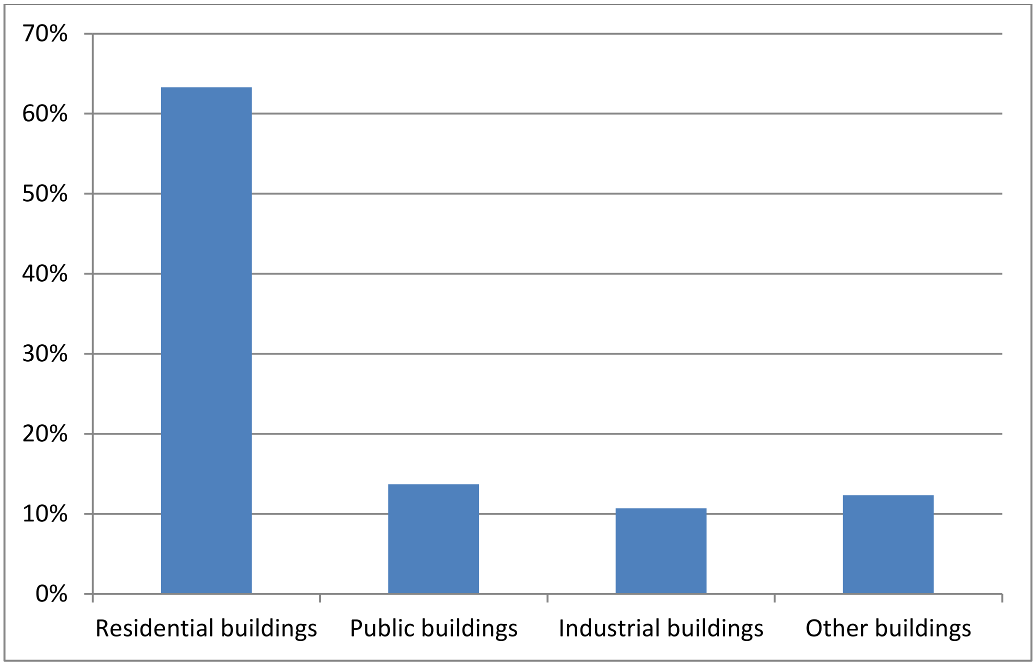

Figure 13 . Types of buildings in building fire callouts.

This work focuses on building fire data and therefore all other information not regarding building fires is for the most part left out when the timelines of UGFT and reflex time was investigated.

Information and data gathered from the database includes dates of building fire incidents, various timelines regarding the response, from the time that the Public Alarm Control Center (112) is notified until the time that the extinguishing action ends, along with the building fire address and the type of building that is on fire.

In Table 2 below the datasheet that the Fire brigades use to register building fires is presented.

Table 2: Fire brigade registration form for building fires.

Location		
Name of the fire brigade	Captain	Prioraty (1, 2, 3 or 4)
Street address	Postal code	Community
Callout to own community	Callout to contracted community	Callout to community without contract
Alarm to manager in another community	Helping another community	

Type of building				
Single family dwelling	Rowhouse/Duet	Block of flats	Summerhouse	Open area
General buildings (what kind of building?)		Industrial building (what kind?)		Other (what?)

Time registration	Date	Time	**Fireman ID**	Vehicl nr	**Injured**	Num of injured	Number of toxics
Alarm to 112					Minor		
Alarm to FRS					Alot		
First vehicle left					Dead		
Arrive at location							
Rescue efforsts begun							
Rescue of valuables begun							
Rescue efforts completed							

FRS actions		
Smoke diving, nr of smokedivers		
Total man hours		
Callout equipment failure?	No	Yes, because of?
Equipment failure?		
Callout delays?		

Description

The database was used to get information on all callouts of the CDFRS for the years 2007-2010. The data was then filtered as mentioned above to get as relevant data as possible.

If there are callouts related to fire incidents the callouts are registered as “fire in buildings”. It does not matter if the alarm comes from people or automatic fire alarm systems. Although, if there are callouts due to automatic fire alarm systems but no fire, they are registered as such. These callouts were investigated to see the extent of callouts of the CDFRS due to AFAS and no fire to fight the data was filtered specially.

The result was a total of 404 callouts where there was an alarm from an AFAS but no fire to fight. 95 % of these callouts were registered as “Alarm system, no fire” The rest or 5 % were due to water leakage or not described. In many of these cases the CDFRS was cancelled before arriving at location.

5.2.2 Data from the Icelandic Property registry database

Iceland Property Registry (Registers Iceland, 2012) is responsible for collecting, processing, storing and publishing real estate data such as market data, which is used by central and local government institutions, real estate brokers and the financial sector.

Iceland Property Registry analyses and publishes data on the real estate market, based on registered property sales data, which have been collected since 1980. The data was collected to see where the majority of CDFRS callouts lie. All callouts of the CDFRS in 2008 due to fire in buildings were retrieved from the FAD and analyzed with reference to the size of the constructions on fire. Below in Figure 31 the proportion of the CDFRS callouts vs the square meter of buildings is shown.

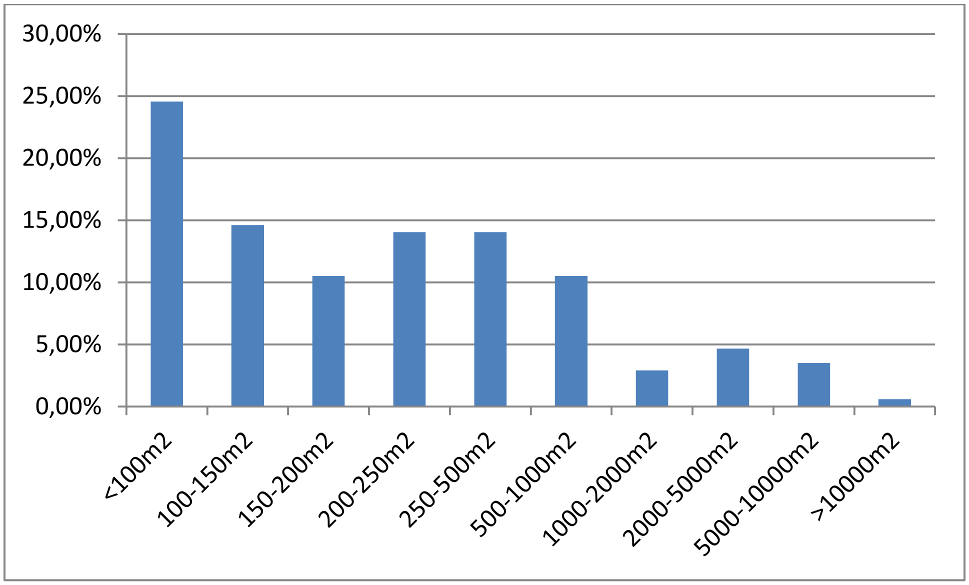

Figure 14 .CDFRS callout rate with regards to the size of constructions

As seen in Figure 14, the majority of the CDFRS callouts are to buildings less than 100 m^2 which indicates that most callouts are to residential housing confirming what was found in Subsection 5.2.1 and consistent with the findings of (Tillander, 2004). However, we have to bear in mind that these proportions do not take into account the number of buildings/apartments within each size category which could give a completely different scenario. Figure 14 mainly shows that most callouts are to a smaller housing (< 100 m^2)

5.2.3 Data collection from insurance companies

To estimate economic losses in building fires it is necessary to gather data on monetary losses regarding fire incidents. In this work the four main insurance companies of Iceland were contacted to get information about losses that were related to fire incidents in 2008. The data that was gathered from the insurance companies included all incidents that were fire related in but as before, this work aims to look at building fires in particular and therefore the data that was not related to building fires was filtered out. Below in Figure 15 the insurance premiums paid out by the insurance companies and the CDFRS callouts with respect to size of constructions is shown.

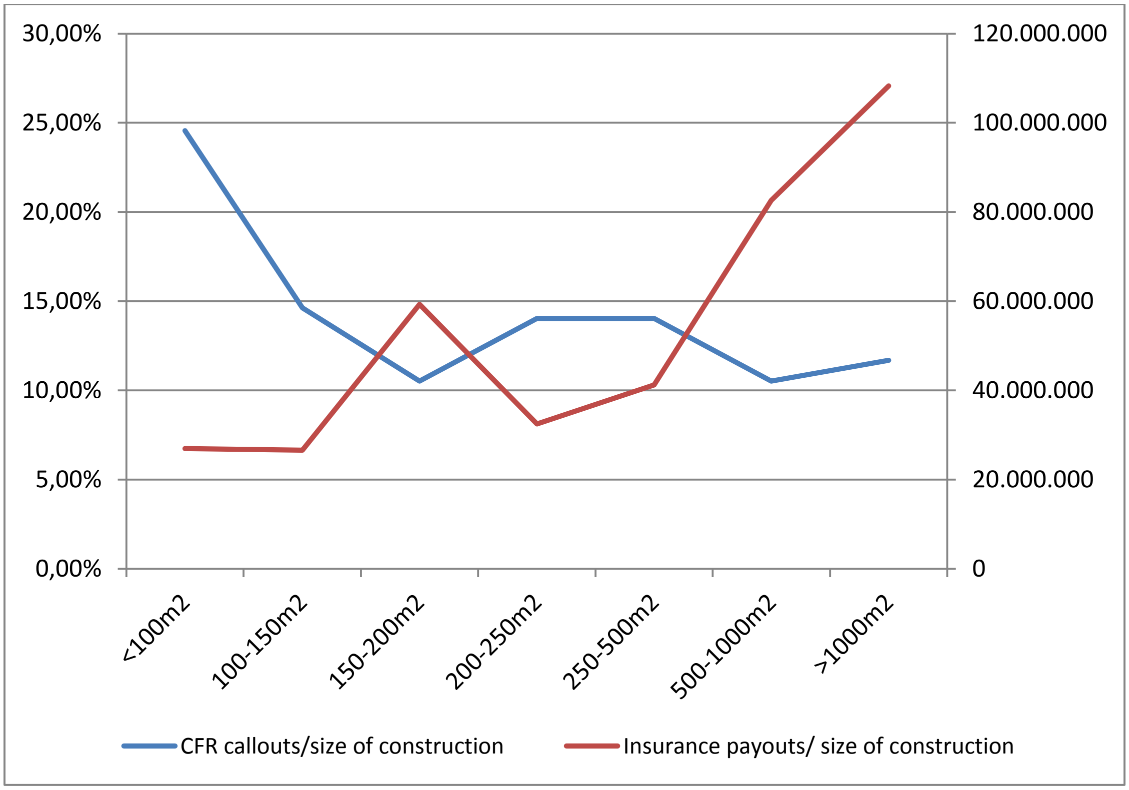

Figure 15 .CDFRS callout rates and paid out paid monetary losses by insurance companies with regards to construction sizes.

Figure 15 shows the rate of callouts of the CDFRS with regards to the size of constructions as well as paid out premiums by the Insurance companies. As mentioned above the majority of callouts is in smaller housing whereas, the insurance claims are smallest in building less than 100 m^2 but gradually increase with the size of the construction.

5.2.4 Data retrieved from PMS

To be able to get the most accurate time of detection, data was needed from the PMS that service and monitor the AFAS. In Iceland there are mainly two firms that monitor and service AFAS. Filtered building fire data from the FAD covering 2008-2010 was sent to these firms and a request was made to get all of the alarms coming from AFAS over a one year period.

One PMS answered the call and presented data for the years 2008-2010 which was used to compare with the FAD data in order to investigate UFGT. Also all alarms from AFAS over a one year period, ranging from the middle of 2009-2010 was received from the same PMS which was used to investigate the time of fire detection as well as look into the inspection time of the PMS.

The dataset covering all alarms over a one year period gives a good indication of the extent of alarms coming from AFAS as well as false alarms.

In total there were 16000 cases over the one year period which needed attendance by the PMS. The data shows that the vast majority of alarms are processed over the phone by the PMS as only 20 % or 3159 cases required a PMS security guard to be sent on scene to investigate the cause of alarm. (Figure 16)

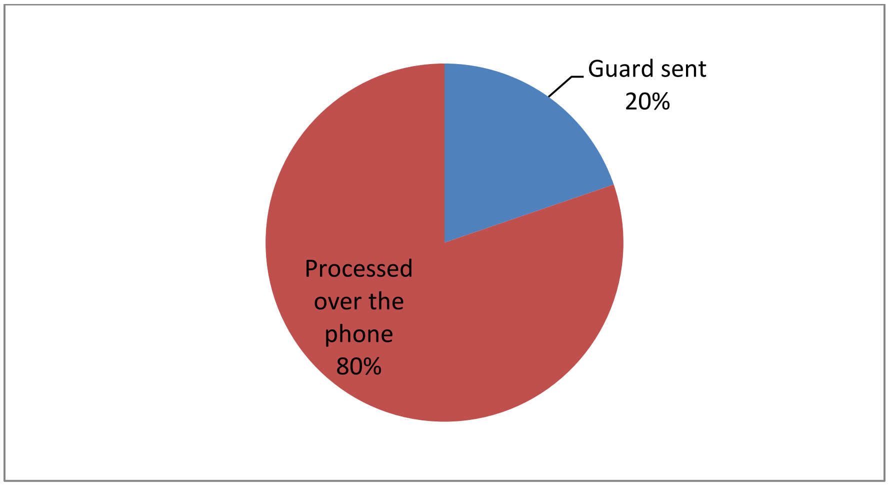

Figure 16 . Most of AFA processed over the phone by the PMS.

Looking at the same dataset to investigate the cause of alarm, it can be seen that only a small percentage of the alarms are registered as genuine alarms. Out of 3159 callouts where a security guard is sent on scene, most are revoked and only about 2 % are registered as genuine alarms. The types of callouts are described graphically in Figure 17 below.

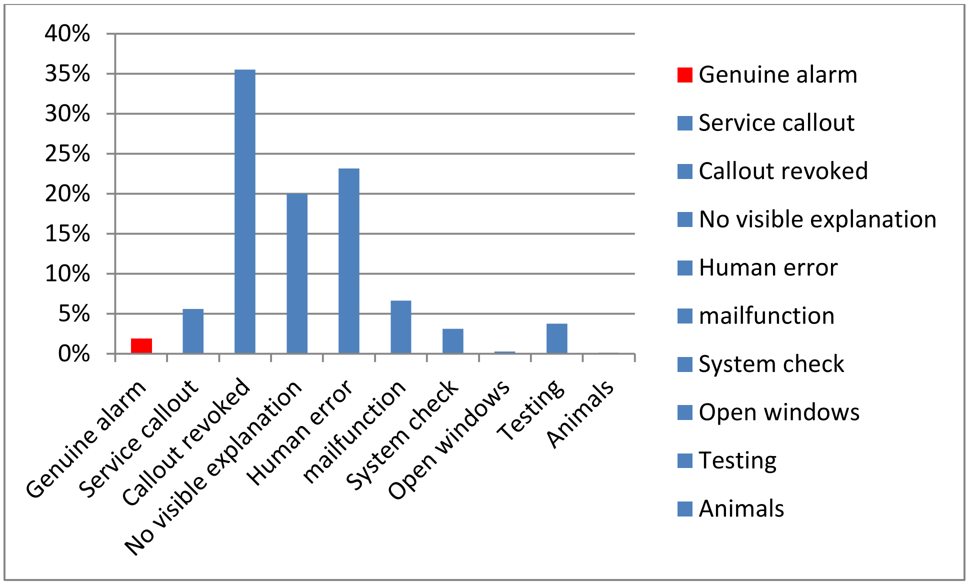

Figure 17 . Type of callouts due to AFA as registered by the PMS.

As seen in Figure 17 a number of explanations are registered as reasons for the rest of the callouts. Animals and open windows comprise to about 0,03 % of all the callouts registered which implies a motion sensor but not a smoke alarm.

The 2 % of callouts, registered as genuine alarms are a total of 60 cases over a one year period between the middle of 2009-2010. In Section 5.3 this one year dataset is investigated further with regards to detection time.

5.3 Detection time

The Detection time is here referred to as the time of detection i.e. timing of incoming alarms from the AFAS, as that is the mode of detection we are interested in. The dataset covering all alarms over a one year period, described in the above Subsection 5.2.4 was used to investigate timing of all alarms as well as genuine alarms and alarms thought to be from mandatory AFAS.

Below an analysis of all AFA which needed attendance according to one PMS is presented with regards to time of day.

As mentioned in the previous subsection there was a total of 3159 cases where the PMS assumed that there was a need of sending a PMS security guard on scene to check the cause of alarm. Looking into these alarms it can be seen that the majority of alarms happen during daytime as seen in Figure 18 below which shows the timing of 3159 alarms from AFAS.

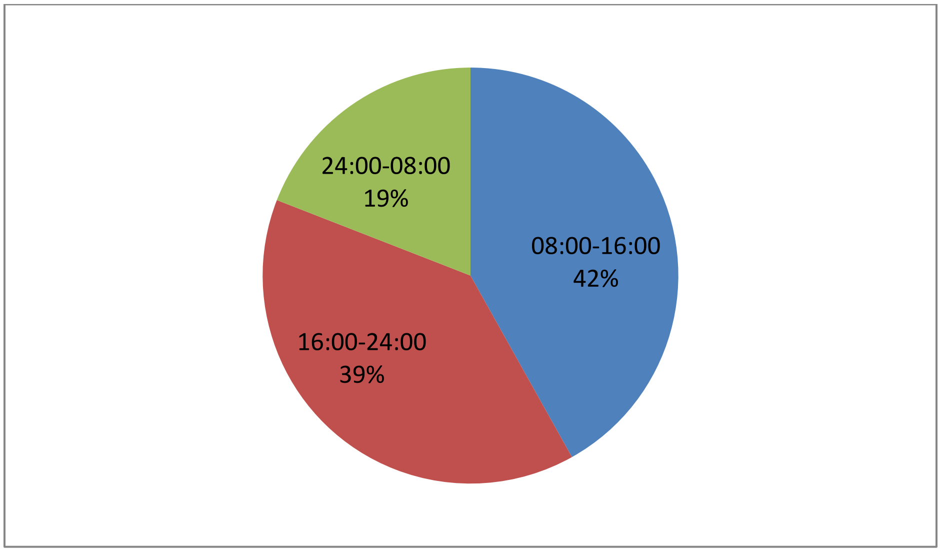

Figure 18 . Timing of the AFA alarms.

As seen in Figure 18, less than 20 % of alarm cases happen from midnight through 8 in the morning. Although as mentioned, the vast minority of these alarms are registered as genuine alarms by the PMS.

When the 2 % of cases registered as genuine alarms are investigated further it can be seen that the timing of those alarms mostly arise after work hours as seen in Figure 19 and only 30 % of alarms occur between 08:00 – 16:00.

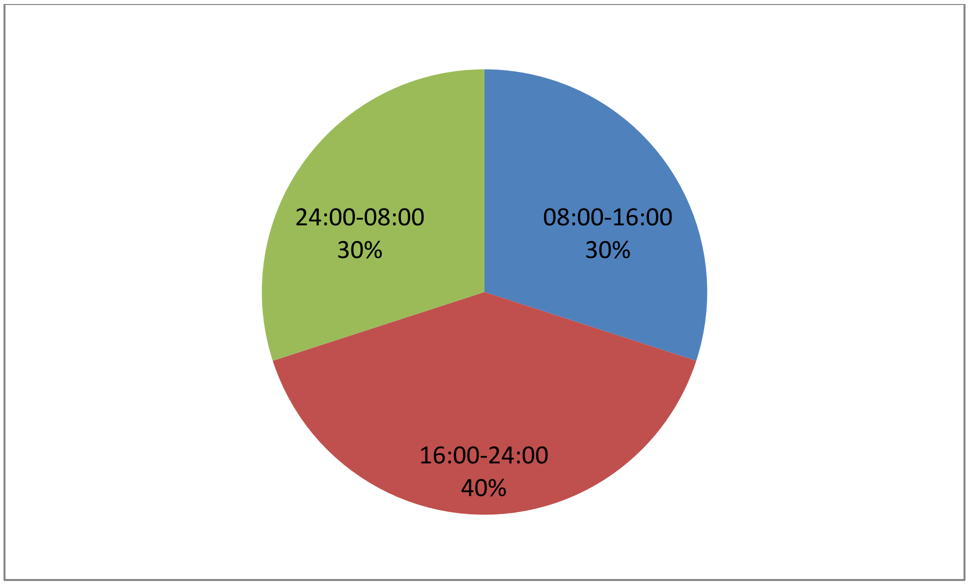

Figure 19 . Timing of alarms registered as genuine.

The data presented in Figure 19 indicates that the most common time of detection of alarms registered as genuine by the PMS is “out of office” hours. Below, in Figure 20 the type of buildings where registered genuine alarms occur is listed.

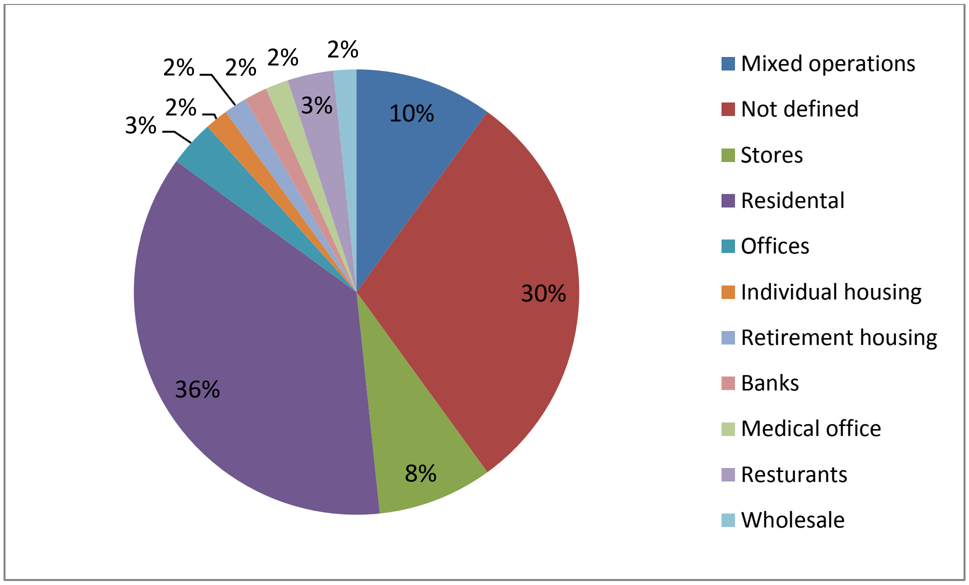

Figure 20 . Location of genuine alarms.

As seen in Figure 20, the majority of alarms registered as genuine by the PMS are coming from residential housing having a fire alarm systems or a motion censored anti-theft system which can be triggered by smoke.

The data indicates that the alarms come from all kinds of housing and business and not especially from mandatory AFAS in public buildings. However, this data gives good indication on the extent of false alarms from these AFAS as well as the timing of alarms. The most common timing of detection was between the hours of 16:00-24:00.

To be able to investigate the timing of alarms from mandatory AFAS the dataset of 3159 alarms where the PMS sent a security guard on scene of alarm, needed to be filtered.

First, all alarms coming from homes and individuals were filtered out. Secondly, as seen in Figure 20, the “Not defined” location of alarms account for about 30 % of all alarms. To get a realistic analysis of these alarms the data was filtered with regards to postal numbers. As a result, the postal numbers where the vast majority of housing is residential was filtered out.

In addition the alarms registered as “tests” and “service calls” were filtered out. The results, after filtering a total of 1076 alarms were left to be investigated further.

Out of 1076 alarms, there were 883 instances where a PMS security guard is registered on the site of alarm. 33 of those alarms are registered as genuine alarms or just about 4%.

When the filtered 1076 alarms are investigated with regards to time of detection it can be seen that about 60 % of alarms arise after typical working hours from 08:00-16:00. Below in Figure 21 the timing of filtered AFA is shown.

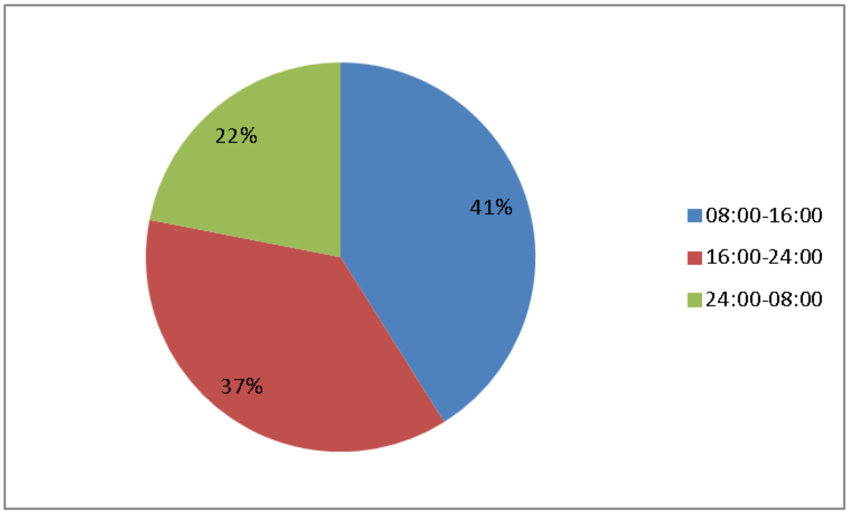

Figure 21 . Timing of all AFA from mandatory AFAS.

When the genuine alarms (33 alarms) are investigated with regards to time of detection it can be seen that 70 % of alarms arise after typical working hours from 08:00-16:00. Below in Figure 22 the timing of alarms registered as genuine by the PMS is shown.

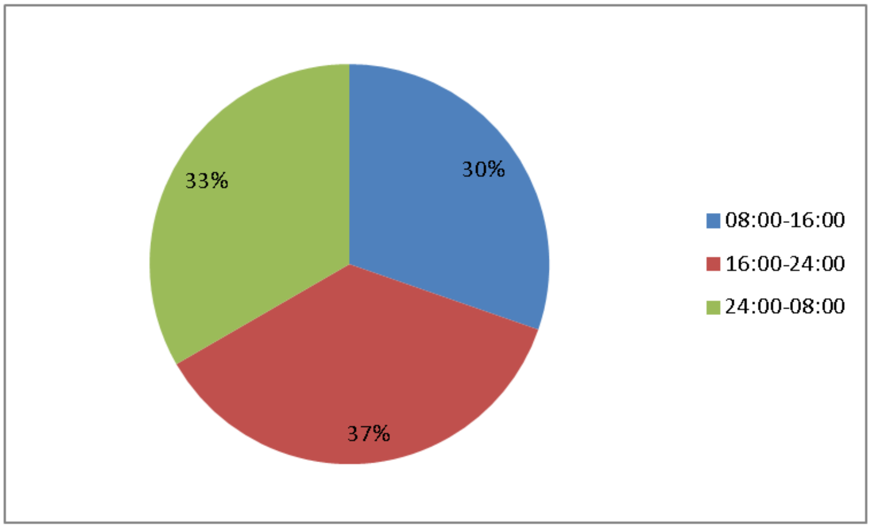

Figure 22 . Timing of filtered AFA alarms with regards to genuine alarms.

As before with all alarms, the most frequent time of detection from mandatory AFAS is after typical working hours. In Section 5.4, the responses to these callouts are investigated further as to be able to model the UFGT, information on the PMS inspection time is of essence.

5.4 Inspection time

Here, the Inspection time is described as the timeline from when an AFAS alarms until a security guard from a PMS is on the scene of alarm and contacts the 112. The dataset covering one year and retrieved from the PMS does not include the actual time when the 112 is called. As a result the assumption is made that, in the case of genuine fire incidents the contact to 112 occurs when the PMS security guard is on fire scene.

The investigated inspection time is based on data from one PMS. In order to look closely in to the timeline of inspection time, the interval has been divided up to the following two timelines:

- Private Monitoring Station dispatch time (PMS dispatch time) and
- Private Monitoring Station response time (PMS response time).

Figuratively, the Inspection time seen in Figure 11, is divided as seen in Figure 23 below.

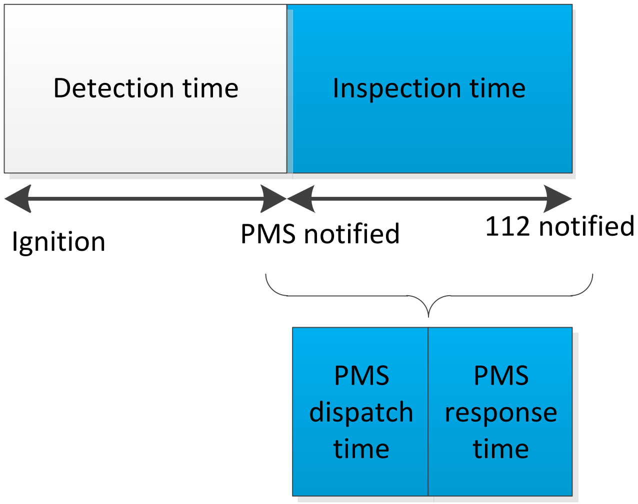

Figure 23 . Inspection time divided to PMS dispatch time and PMS response time

5.4.1 PMS dispatch time

The PMS dispatch time is the time interval from, when an AFAS alarms the control center of the PMS until the PMS decides to send out a security guard to check the reason of alarm. Here the callouts of most interest are the callouts that arise because of mandatory AFAS. As a result, the filtered alarms where a PMS security guard was sent on scene to investigate the cause of alarm as described in Section 5.3 is of most use. In total the investigated alarms comprises of 1076 fire alarms where a security guard was sent on scene of alarm.

The fact that a lot of callouts are revoked does not affect the dispatch time in any way as the time interval shows the time it takes the control station of the PMS to assign a security guard to an alarm.

In figure 24, the density function of the PMS dispatch time is presented. The Gamma density function introduced in subsection 2.1.4 has been fitted visually to the observations. The gamma function parameters in the figure are $\alpha = 2$ and $\beta = 1{,}25$.

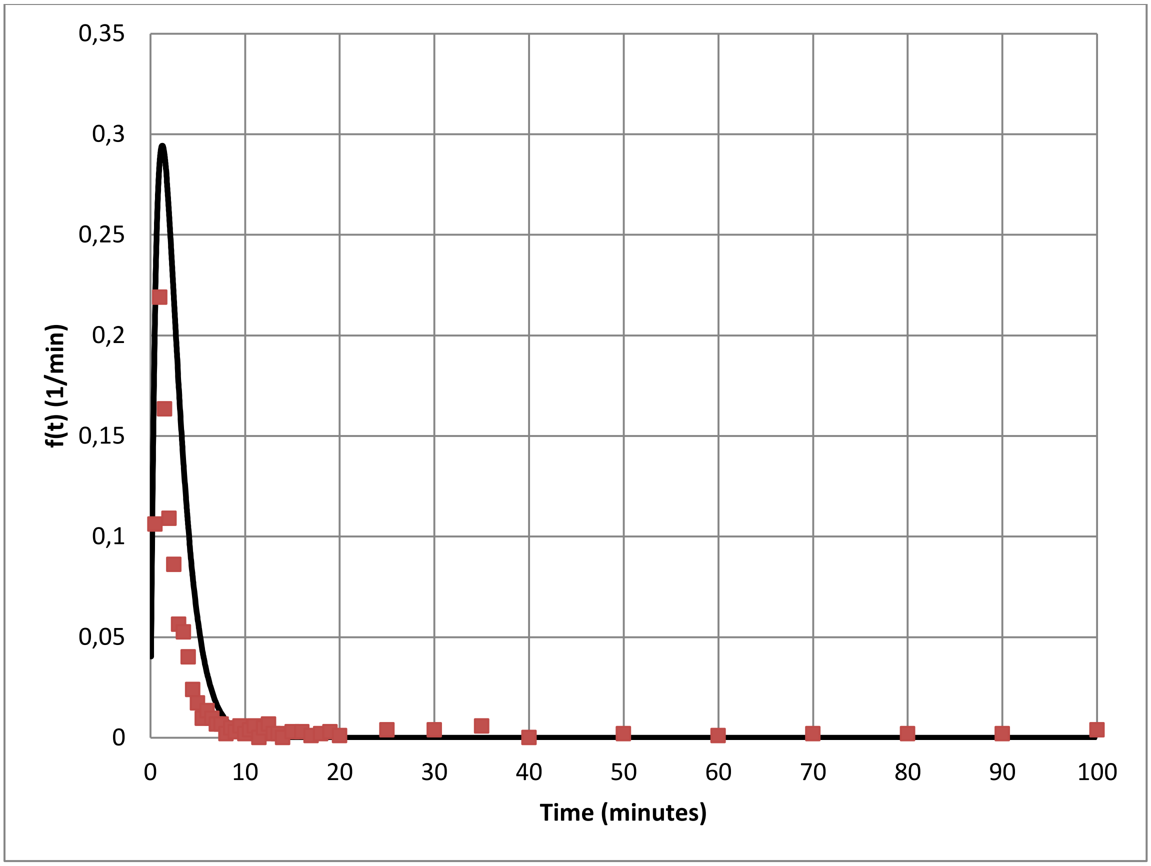

Figure 24 . The time distribution of the PMS dispatch time and the Gamma density function (black line).

Figure 24 describes the time distribution of the PMS dispatch time along with the Gamma density function. The calculated mean value of the PMS dispatch time is 3,67 minutes.

5.4.2 PMS response time

The PMS response time is the time interval from when a security guard is registered to investigate an alarm until the security guard reaches the fire alarm destination. The PMS security guards do not have a priority in the traffic as the Fire brigades, however the PMS have a number of security guards driving around which means that sometimes they are quick on alarm scene and sometimes not as they do not necessarily need to go from their home station as the Fire brigades usually do.

The dataset used to investigate the PMS response time is described in Section 5.3. The data of most interest, regards the response to mandatory AFAS and as mentioned, there were 883 instances of 1076 where a PMS security guard was registered on the site of alarm coming from a system thought to be mandatory. These 883 callouts were analyzed and fitted to a distribution.

In figure 25, the density function of the PMS response time is presented. The Gamma density function has been fitted visually to the observations. The gamma function parameters in the figure are $\alpha = 1,3495$ and $\beta = 6,6887$.

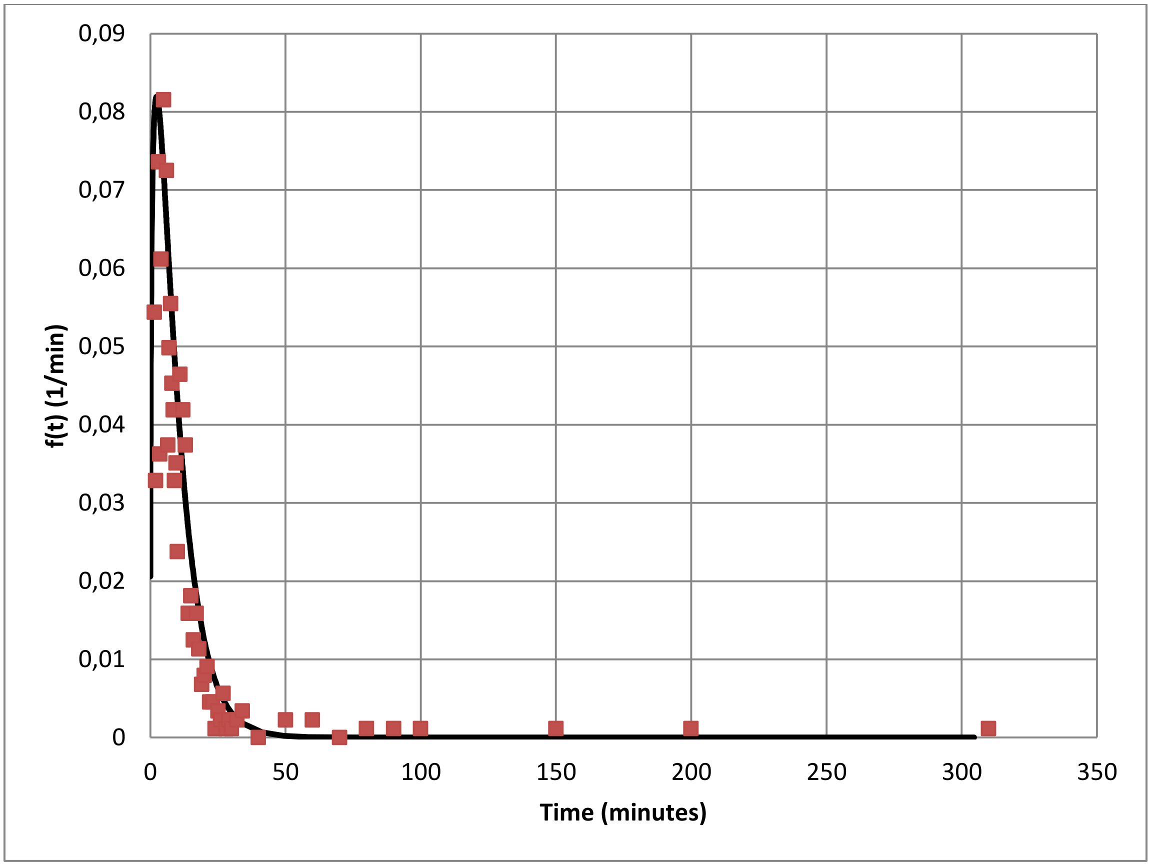

Figure 25 . The time distribution of the PMS response time and the Gamma density function (black line).

Figure 25 describes the time distribution of the PMS response time along with the Gamma density function. The calculated mean value of the PMS response time is 8,67 minutes.

Now we can put together a reasonable accurate distribution for the Inspection time interval by combining the two timelines of dispatch and response time of the PMS. The time distribution of the PMS Inspection time is presented in Figure 26 where the Gamma density function has been fitted visually to the observations. The gamma function parameters in the figure are $\alpha = 2$ and $\beta = 8$.

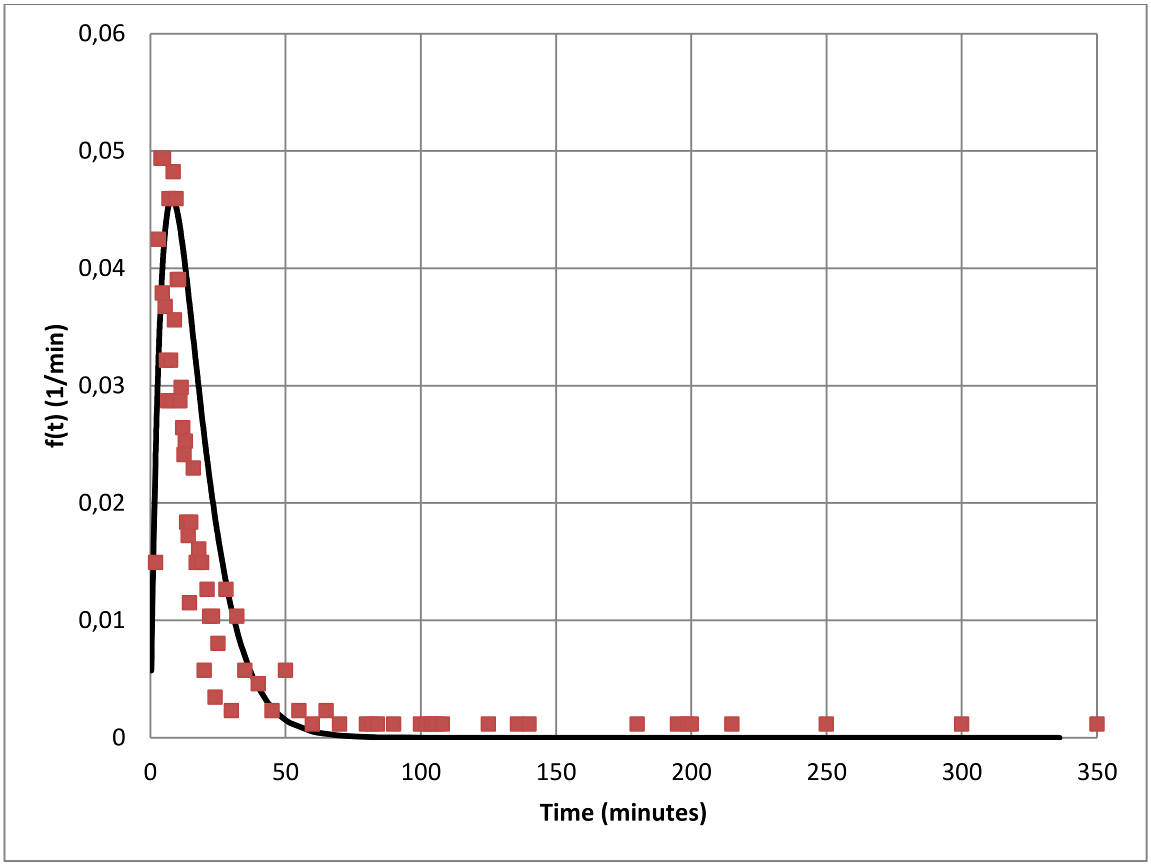

Figure 26 . The time distribution of the PMS Inspection time and the Gamma density function (black line).

Figure 26 describes the time distribution of the PMS Inspection time along with the Gamma density function. The calculated mean value of the PMS response time is around 12,2 minutes.

It has to be kept in mind that the data used is registered by the PMS itself and does not describe the exact timing of contacting the 112. As a result the FAD where all registered calls to the 112 was investigated to look into the genuine alarm callouts of the CDFRS. First, the timelines following the Inspection time in Figure 11 are investigated, beginning with the Dispatch time of the Public Alarm Control Center 112.

5.5 Dispatch time – 112

The dispatch time is the time from when the Public Alarm Control Center (112) is notified until the Fire brigade is notified. This time is highly dependent on technology and a well trained staff. The dispatch time has been recorded for many years by the 112 and here it is retrieved from the FAD for further analysis. The dataset retrieved here consists of all callouts of the CDFRS from 2008-2010 regarding building fire, suspicion of fire in a building and callouts registered as fire alarm system callouts. The total number of retrieved callouts was 848. These callouts were analyzed and used to fit a distribution. In Figure 27, the density function of the 112 Dispatch time is presented. The Gamma density function has been fitted visually to the observations. The gamma function parameters in the figure are α = 1,6511 and β = 1,0356

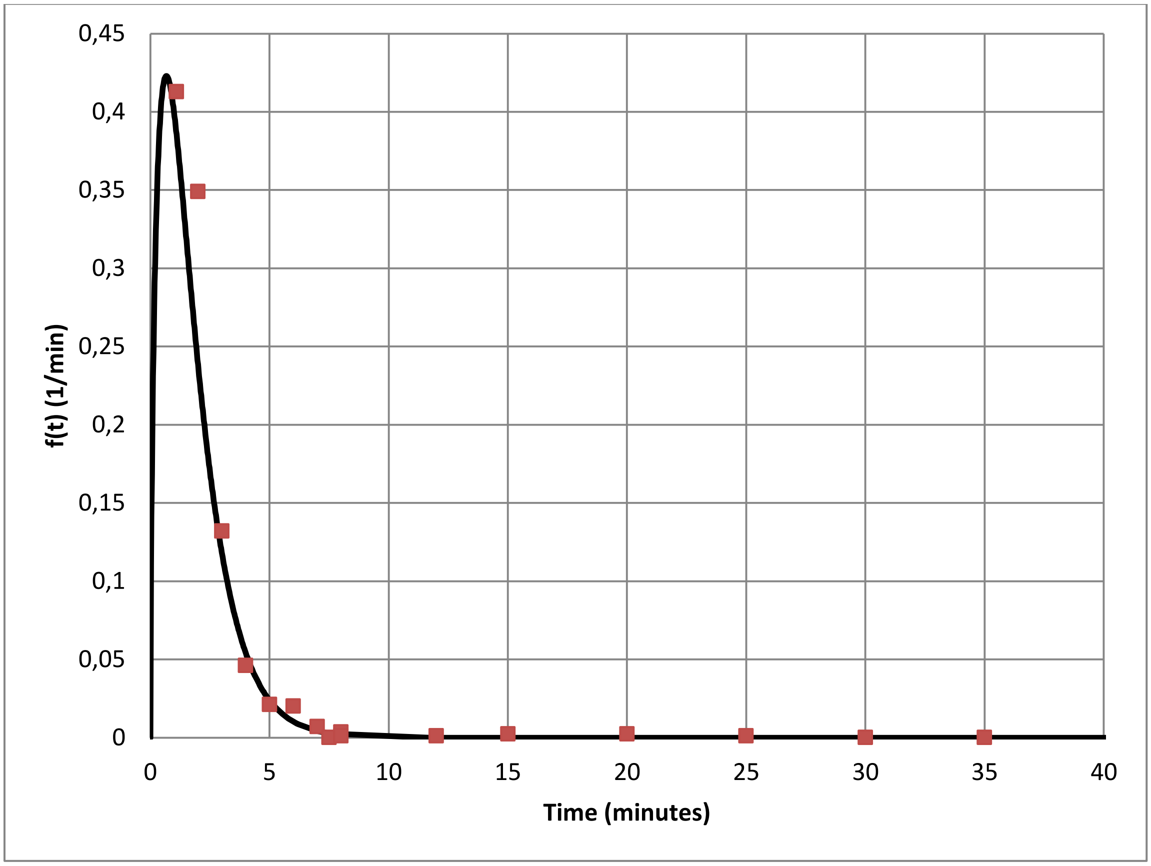

Figure 27 . The time distribution of the 112 Dispatch time and the Gamma density function (black line).

Figure 27 describes the time distribution of the 112 Dispatch time along with the Gamma density function. The calculated mean value of the 112 Dispatch time is around 1,7 minutes. The dispatch time here is higher here than what was found in a high rise building study (Tómasson & et al, 2008). The reason could be a smaller datasets used here as this data only covers building fires whereas the high rise study investigated all alarms that the 112 received for the years 2005-2007.

5.6 Turnout time – Fire brigade

The turnout time represents the time from which the Fire brigade is contacted, until a fire team leaves the station. There are a lot of factors that contribute to a fast turnout time as described by (Tómasson & et al, 2008), the design of the fire station, time of day, risk of simultaneous alarms and the availability of fire fighters play a key role in a successful turnout time. The same dataset as was used for the dispatch time was used to simulate the turnout time of the CDFRS. In Figure 28, the density function of the Turnout time is presented. The Gamma density function has been fitted visually to the observations. The gamma function parameters in the figure are α = 2,9875 and β = 0,53216

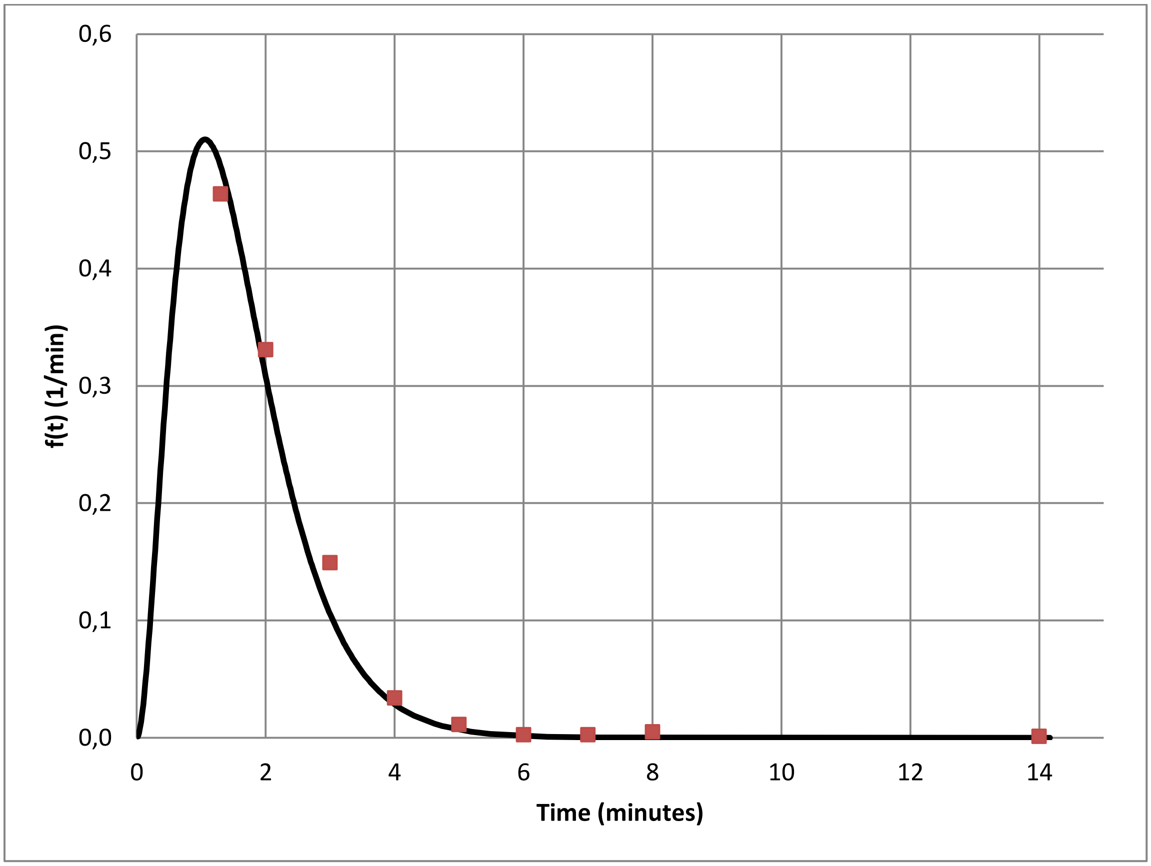

Figure 28 . The time distribution of the Fire brigade Turnout time and the Gamma density function (black line).

Figure 28 describes the time distribution of the Turnout time along with the Gamma density function. The calculated mean value of the Turnout time is around 1,5 minutes.

5.7 Response time – Fire brigade

The response time of the Fire brigade is the time from when the first rescue vehicles leave the Fire station until they reach the site of the fire hazard at hand. The Fire brigades have priority in the traffic and therefore they are in most cases faster on site than the PMS that service the AFAS. The same dataset that was used for analyzing the Dispatch and Turnout time was used to simulate the Response time of the CDFRS. In Figure 29, the density function of the Response time is presented. The Gamma density function has been fitted visually to the observations. The gamma function parameters in the figure are α = 4,8318 and β = 1,2271.

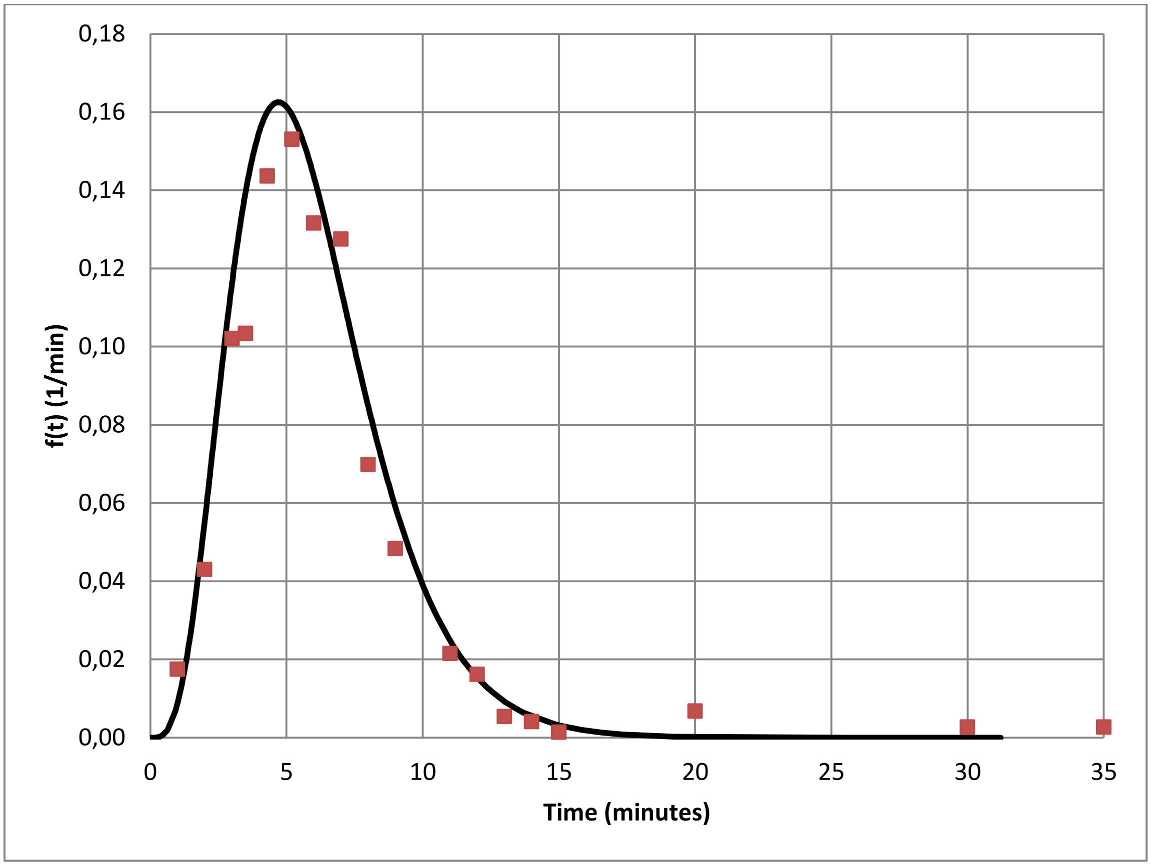

Figure 29 . The time distribution of the Fire brigade Response time and the Gamma density function (black line).

Figure 29 describes the time distribution of the Response time along with the Gamma density function. The calculated mean value of the Response time is around 5,2 minutes.

5.8 On-site activation time – Fire brigade

The On-site activation time is the time it takes the Fire brigade to start extinguishment and rescue actions after having arrived on the scene of fire. This time is highly dependent on building design as height and size of the building plays a key role as well as fire protection measures with regards to water intakes and fire hydrants. The same dataset as was used in the above sections was used to simulate the On-site activation time. In Figure 30, the density function of the On-site activation time is presented. The Gamma density function has been fitted visually to the observations. The gamma function parameters in the figure are $\alpha = 4$ and $\beta = 0{,}4$.

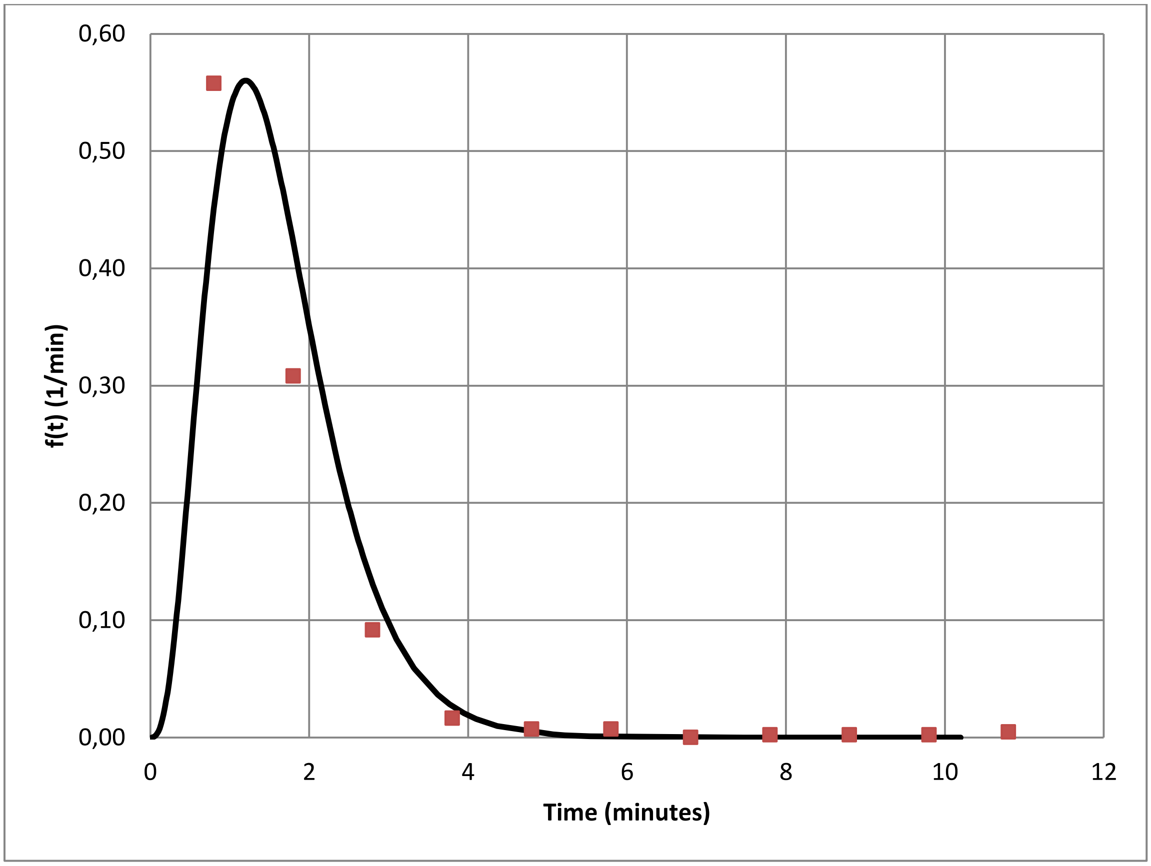

Figure 30 . The time distribution of the Fire brigade On-site activation time and the Gamma density function (black line).

Figure 30 describes the time distribution of the On-site activation time along with the Gamma density function. The calculated mean value of the On-site activation time is around 1 minute.

5.9 Data validation

As mentioned in Section 5.4, the analyzes of the PMS Inspection time was carried out by data retrieved and registered by the PMS. To investigate the validity of that data, information from the FAD has been filtered and compared to the data retrieved from the PMS.

Out of 848 building fire callouts that the CDFRS attended to during the years 2008-2010, 69 of them were also responded to by the PMS. By looking into these callouts, the Inspection time of the PMS can be analyzed with regards to actual fire scenarios, registered by the Public Alarm Control Center 112.

Of the 69 callouts that were investigated by a PMS, there were 14 instances where the 112 had already received a warning about a fire hazard before the PMS even had received an alarm.

The cause can depend on many factors, most likely, AFAS malfunction or the fact that people tend to call the 112 if they smell smoke or detect fire by other means.

In addition when looking into the same dataset i.e. the 69 callouts where the PMS was involved, the 112 had been notified by other means in 29 cases before being contacted by the PMS or in about 42 % of the cases.

The sample of 55 callouts where the PMS contacted the 112 because of a building fire was analyzed and fitted to a distribution. In Figure 31, the density function of the Inspection time is presented. The Gamma density function has been fitted visually to the observations. The gamma function parameters in the figure are $\alpha = 4,7$ and $\beta = 1,3$.

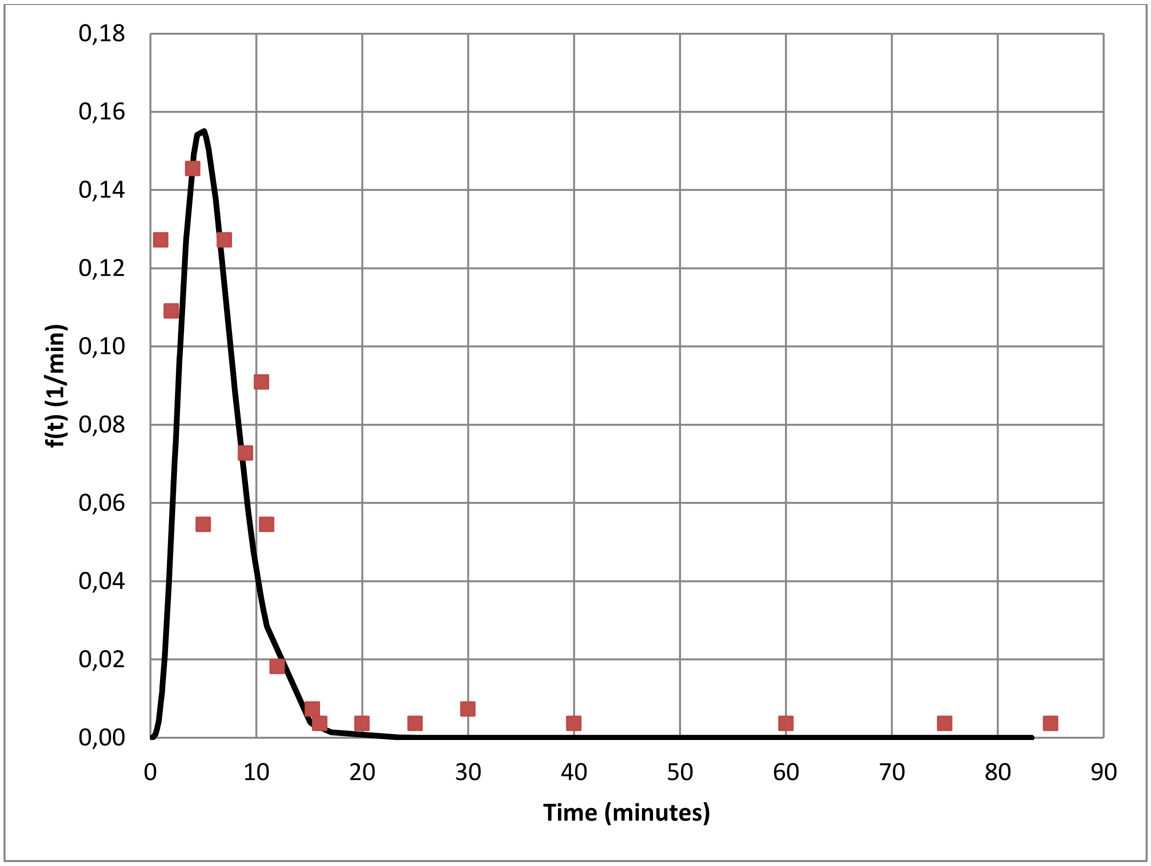

Figure 31 . The time distribution of the PMS Inspection time with regards to actual fire scenarios and the Gamma density function (black line)..

Figure 31 describes the time distribution of the Inspection time of the PMS with regards to actual fires as registered by the 112, along with the Gamma density function. The calculated mean value of the Inspection time is around 12 minutes.

We can now compare the Inspection time data from Section 5.4 with the above data and see that the average Inspection time registered by the PMS is around 12 minutes over a one year period and consistent with the analyzed callouts of the CDFRS in the years 2008-2010.

5.10 UFGT- Delay vs No Delay

Now we can model the UFGT where inspection time intervals of the PMS are included and compare the results with the UFGT assuming no delay in calling the 112 i.e. assuming the 112 would monitor the AFAS without a middleman responding to alarms beforehand.

In Figure 32, the UFGT when assuming no delay in the calling of 112 is presented. The Gamma density function has been fitted visually to the data. The gamma function parameters in the figure are α = 7,9107 and β = 1,3041.

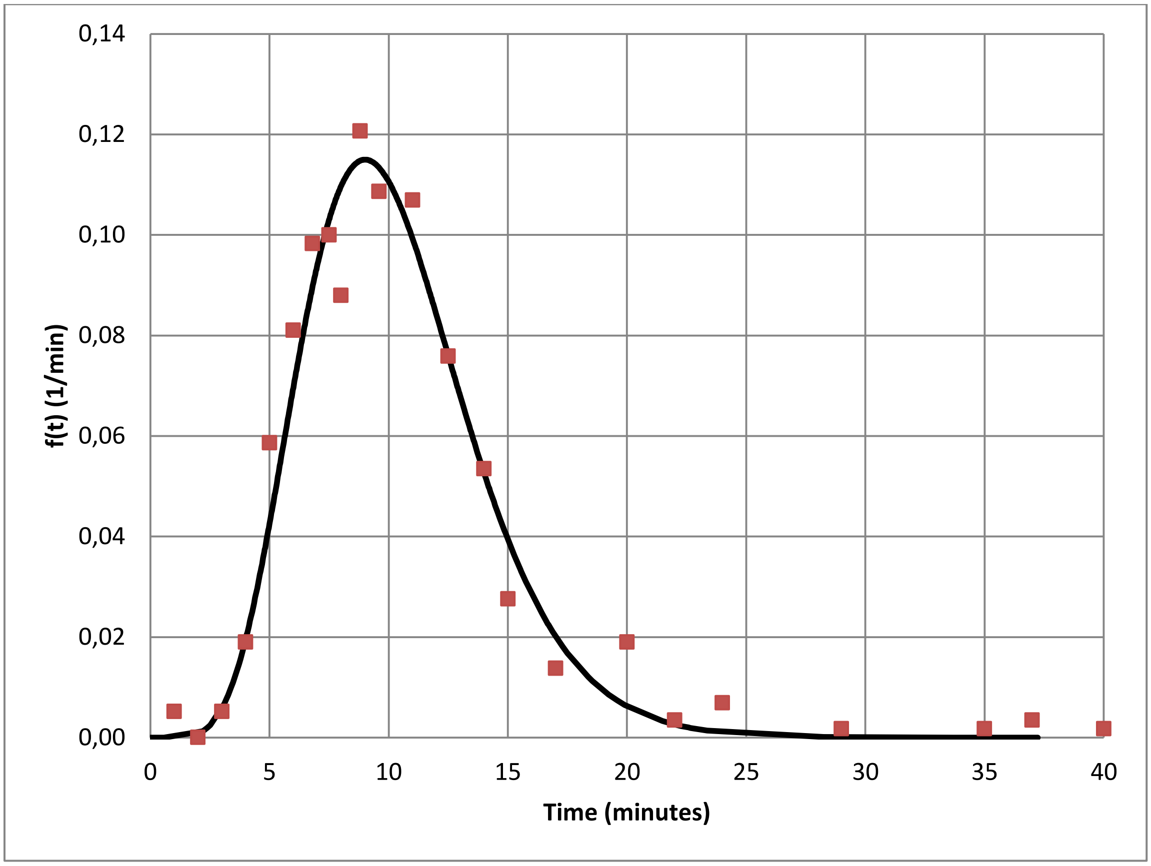

Figure 32 . The time distribution of the UFGT assuming that 112 monitors the AFAS and the Gamma density function (black line).

Figure 32 describes the time distribution of UFGT assuming that the 112 would monitor alarms from AFAS along with the Gamma density function. The calculated mean value of the UFGT is around 9 minutes.

In Figure 33, the UFGT when assuming a delay in the calling of 112 is presented. The Gamma density function has been fitted visually to the data. The gamma function parameters in the figure are α = 3 and β 2,8.

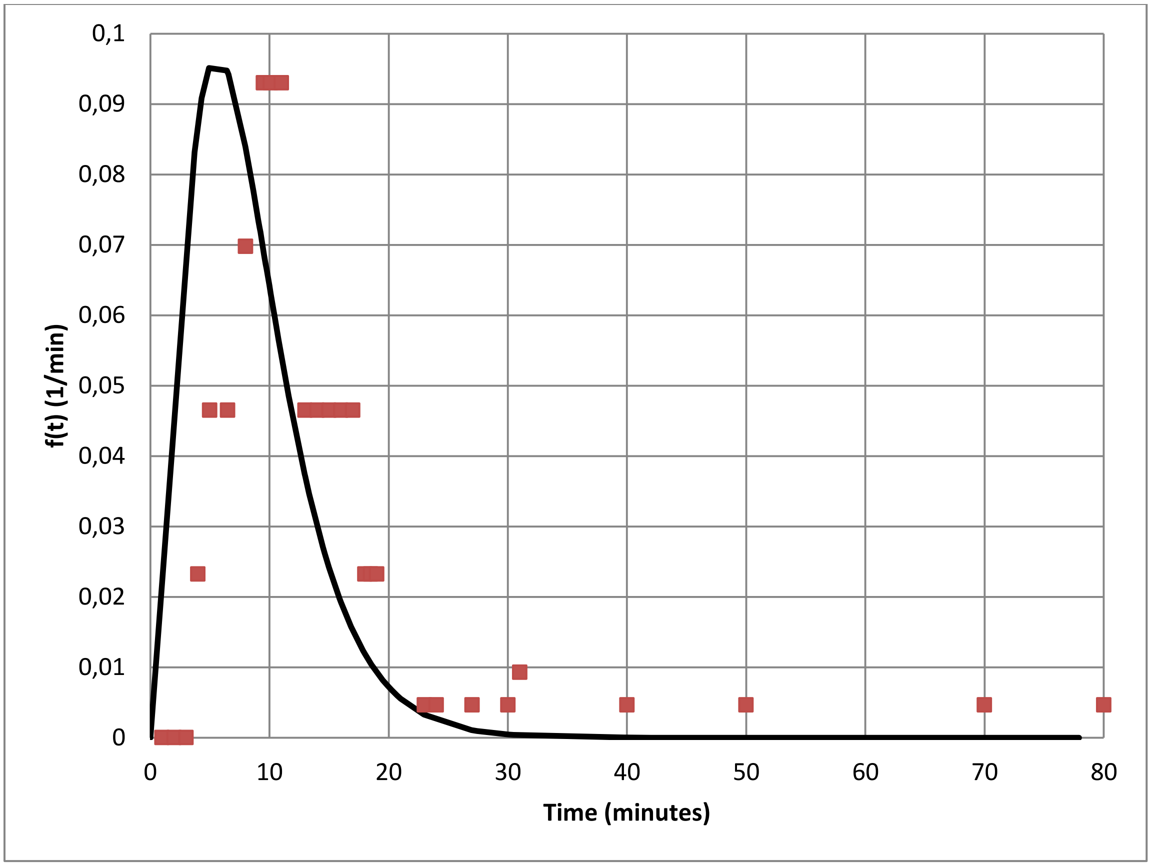

Figure 33 . The time distribution of the UFGT assuming current working procedures where PMS monitor AFAS and the Gamma density function (black line).

Figure 33 describes the time distribution of UFGT assuming current working procdures regarding alarms from AFAS along with the Gamma density function. The calculated mean value of the UFGT is around 17,5 minutes.

As seen in above figures there is a significant difference in the UFGT depending on whether there is a delay in the response of the Fire brigade to an alarm from an AFAS or not. We can say that Figure 32 represents the situation where all alarms from the AFA systems would go through the Public Alarm Control Center 112 and Figure 33 represents today’s procedures.

Of course the dataset where there is no delay is much larger as it takes into account all the fire callouts 2008-2010 whereas the delay dataset only accounts for the cases where there was an alarm where the PMS was involved. However, this gives a good indication of time differences as shown when compared with the timelines in Section 5.4 where inspection data from a PMS covering one year period was investigated.

5.11 Summary

In Chapter 5 we have discussed the UFGT with regards to different responses to alarms from AFAS. We have seen that the extent of alarms coming from AFAS is vast and most are not genuine fire alarms which need the interference of the FRS.

The UFGT has been divided into different timelines with regards to the response of PMS, 112 and the CDFRS. We have found that current working procedures regarding AFA can increase the UFGT in the case of an actual fire hazard. However if assuming the 112 and FRS would monitor the AFAS the extent of false and costly alarms would increase significantly, making the Total reflex time of the public services to genuine fire alarms uncertain.

We have seen that on average the inspection time of the PMS is around 12 minutes. If we assume that critical conditions arise after 15 minutes in a certain building, there is a 95 % probability of the CDFRS arriving before that time if the 112 monitors the AFAS compared to 55,6 % if assuming the inspection of a PMS beforehand.

Of course, the timing of critical conditions is not a constant and therefore in Chapter 6, the topic of discussion is consequence modeling. We want to know what consequences this difference in UFGT time can have in an actual fire scenario. In addition we want to use the model to help the FRS to organize their working procedures regarding AFA response and improve their service to the general public.

6 Consequence modeling

In this chapter we want to investigate what impact the delayed response of the CDFRS discussed in the above chapter has on actual fire hazards. We want to know if there is a reason of changing current working procedures regarding FRS callouts from AFAS in order to minimize the risk of harm to people. To do this, a fire scenario has been created, event trees defined and consequences estimated for a hospital building being designed in Reykjavík Iceland.

The analysis is simplified as its main purpose is to look into different CDFRS responses regarding a fire hazard. The main concern of the analysis is the effect a delayed response of the CDFRS has on people's safety at the hospital. The model is built up with a risk analysis approach using data and methodology from the above chapters as well as methods introduced by (Frantzich, 1997) and (Olsson, 1999). The analysis is meant as an illustrative object to build a basis for clear working procedures with regards to automatic fire alarm systems. In Section 6.1 the concerned building is described in more detail.

6.1 Reykjavík university hospital

The building considered here is a five story Treatment Center building with a basement. The focus is on one ward at the second floor of the Treatment Center. The ward chosen is the ward where infectious diseases are treated as well as it plays a role in treating recovering patients. In Figure 34 below a schematic outline of the ward can be seen along with the rest of the second floor of the Treatment Center.

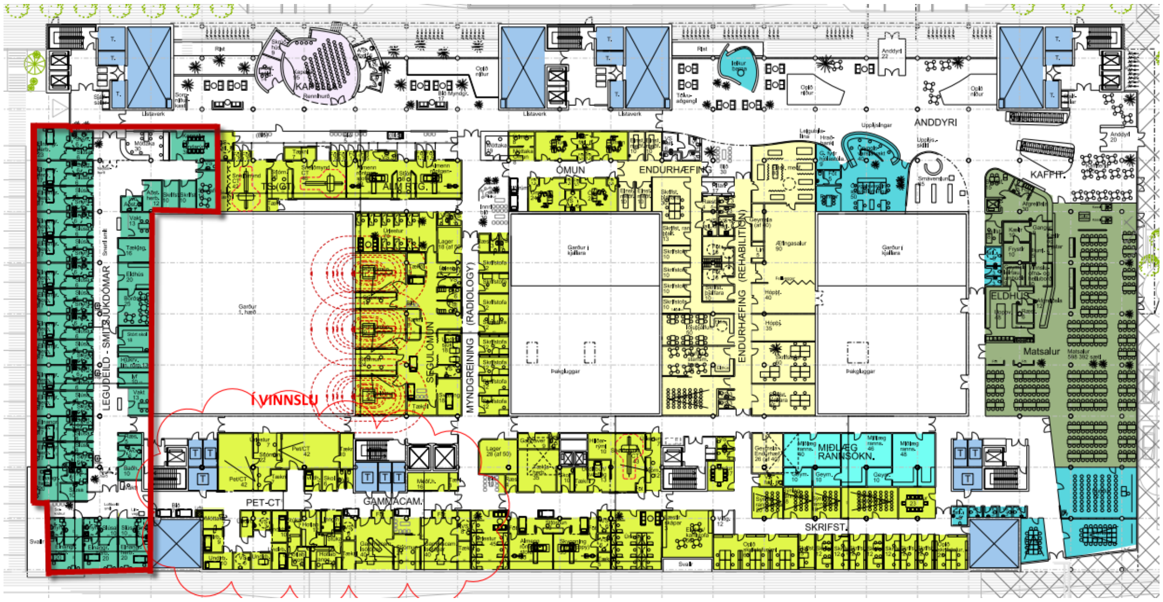

Figure 34 . An overview of the second floor of the Treatment Center. Marked with red is the considered ward

The ward has 17 nursing rooms, most about 30 m^2 in size. The ward also contains offices, staffroom, kitchen, dining room and other smaller rooms. The total size of the ward is about 1200 m^2. Open spaces and hallways are around 290 m^2 (white color in Figure 35). A more detailed look of the ward of infectious diseases and recovering patents is shown in Figure 35 below.

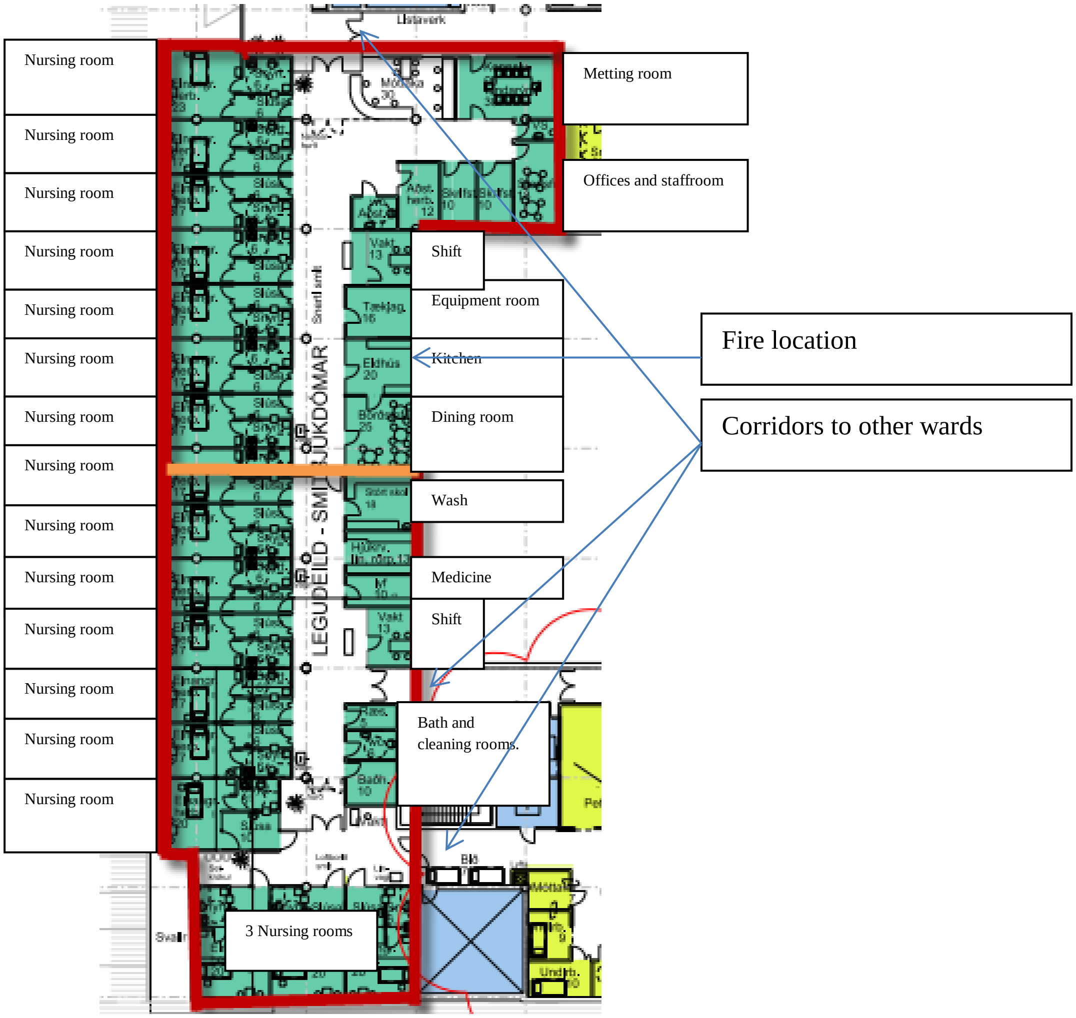

Figure 35 . A detailed view of the ward considered

The goal is to set up a fire scenario inside the ward and investigate the consequences with regards to people's safety inside the ward as well as outside of it. The consequences are measured with regards to visibility and heat. The area around the ward that was considered is around 4.800 m^2. The exact number of patients in the ward and outside of it is not certain but believed to be 14-18 at the ward and 120-150 outside the ward, in other parts of the second floor. Staff numbers at the ward and outside of it are assumed 10 and 57 during the day and 5 and 28 during the night. To begin with the placement of fire ignition was considered. According to an NFPA study (Flynn, 2009) the leading area of fire origin in hospital structures is the kitchen or cooking area. With that in mind, the ignition source was chosen to be in the kitchen. In Figure

35, the fire location is shown as well as corridors leading to and from the ward. In Section 6.2 the events that can lead to critical conditions at the ward and adjacent corridors are discussed.

6.2 Events

In this Section the Event tree is used to calculate and compare risks in the case of a fire hazard. The tree consists of a number of events, although the scope of events has been simplified in order to keep the focus on the subject at hand. Most of the events are questions which can be answered by a “yes” or a “no”. If the answer is “Yes” the result is usually a worse outcome but if the answer is “no”, the result is a better outcome. There are mainly two trees considered, having the same event characteristics but different probabilities with respect to UFGT and the response of the CDFRS, resulting in different scenarios. A third tree is considered as well to investigate a smaller area closer to the fire source. The initial event is of course a fire starting in the building. The following events considered here are related to the following topics:

- Fire during the day or night?
- Does the AFAS raise alarm?
- Do people put out the fire or is it self-extinguishing?
- Does the Sprinkler put out the fire? and
- Is the CDFRS on site before critical conditions arise?

The first tree under consideration does not include the last topic concerning the arrival of the CDFRS as its purpose is to investigate critical conditions vs. evacuation time closer to the fire. The result of that tree is then combined with two identical event trees where the only difference between them was the arrival time of the CDFRS. Below the above listed topics are described shortly.

Fire starting?

The likelihood of a fire starting is calculated with the following equation (BSI, 2003):

$$F_i=aA_b^{\,b}$$

Where “a” and “b” are constants for different types of buildings and A is the square meters of the building considered. Here, we are looking at a hospital building, meaning a = 0,0007 and b = 0,74 according to (BSI, 2003). By using the square meters of the ward of infectious diseases and recovery, 1200 m^2, the results are approx. 0,14 fire incidents per year.

Timing of fire (Day/Night)?

The timing of fire is considered to happen during the evening/night with 60 % probability and during the morning/midday with 40 % probability which is in line with findings in Section 5.3 regarding genuine alarms from AFAS and an NFPA study (Flynn, 2009).

Automatic fire alarm system working?

The fire alarm system connected to the PMS is considered to work with an 85 % probability, which is in the lower limit of the sources considered (BSI, 2003) (Richard W. Bukowski, 1993). The AFA system also influences the probability of alarm reaching people in the building as a whole as the AFAS in the building are interconnected.

Do people put out fire or is it self-extinguishing?

If a fire incident arises in the ward, it is expected to be put out by staff or be self-extinguishing with a 90 % probability if the AFAS raises alarm and 80 % if it does not, which is a conservative assessment as the many employees will work at the ward.

Does the sprinkler put out the fire?

The sprinkler system of the hospital is expected to work as intended in 90 % of the cases, consistent with British standards (BSI, 2003) and (Nystedt, 2011).

Is the CDFRS on site before critical conditions arise?

Critical conditions arise at different times throughout the ward and adjacent corridors as will be discussed in Section 6.3.

It is assumed that critical conditions arise when visibility or temperature overcome defined limits in and outside of the ward in question, affecting more people than within the ward itself. Critical conditions outside the ward arise after approx. 11 minutes assuming a worst case scenario. Using the probability distributions found in Chapter 5 the probability of the CDFRS arriving before that time is approx. 79 % if there is no delay in responding to the AFAS and approx. 36 % if there is a delay in response of the AFAS. If the AFAS does not raise an alarm, the same probability applied for the timing of CDFRS arrival, 50 %.

A more detailed look into the events leading to critical conditions are shown in Appendix 2 where the Event trees are shown for the different scenarios, Section 6.3 discusses the chosen fire scenario and circumstances leading to critical conditions.

6.3 Fire scenario

A CFD (Computational Fluid Dynamics) code, FDS (Fire Dynamics Simulator) (McGrattan, McDermott, Hostikka, & Floyd, 2010) was used to create the fire scenario. The FDS software is specially developed for fire modeling and is today one of the most widely used software programs in fire protection engineering around the world.

The second floor of the hospital treatment building was set up in FDS with emphasis on the ward considered. The ignition origin was as mentioned above in the kitchen of the ward. The chosen fire scenario is a fast αt^2 $(\alpha=0,047)$ fire with a heat release rate per unit area (HRPUA) of 350 kW/m^2 (Karlsson & Quintiere, 1999).

The results from the CFD simulations are compared to critical conditions that might arise during a fire. The critical thresholds are exceeded when (LTH, Brandskyddslaget & Brandteknik vid LTH, 2005):

- People are subject to temperatures higher than 80 °C.
- The visibility is less than 10 meters.

Below in Figure 36 the model is shown. Simplifications have been made on other parts than the ward of infectious diseases and recovery as the purpose is to see whether or not the visibility or temperature becomes critical at corridors adjacent to the concerned ward.

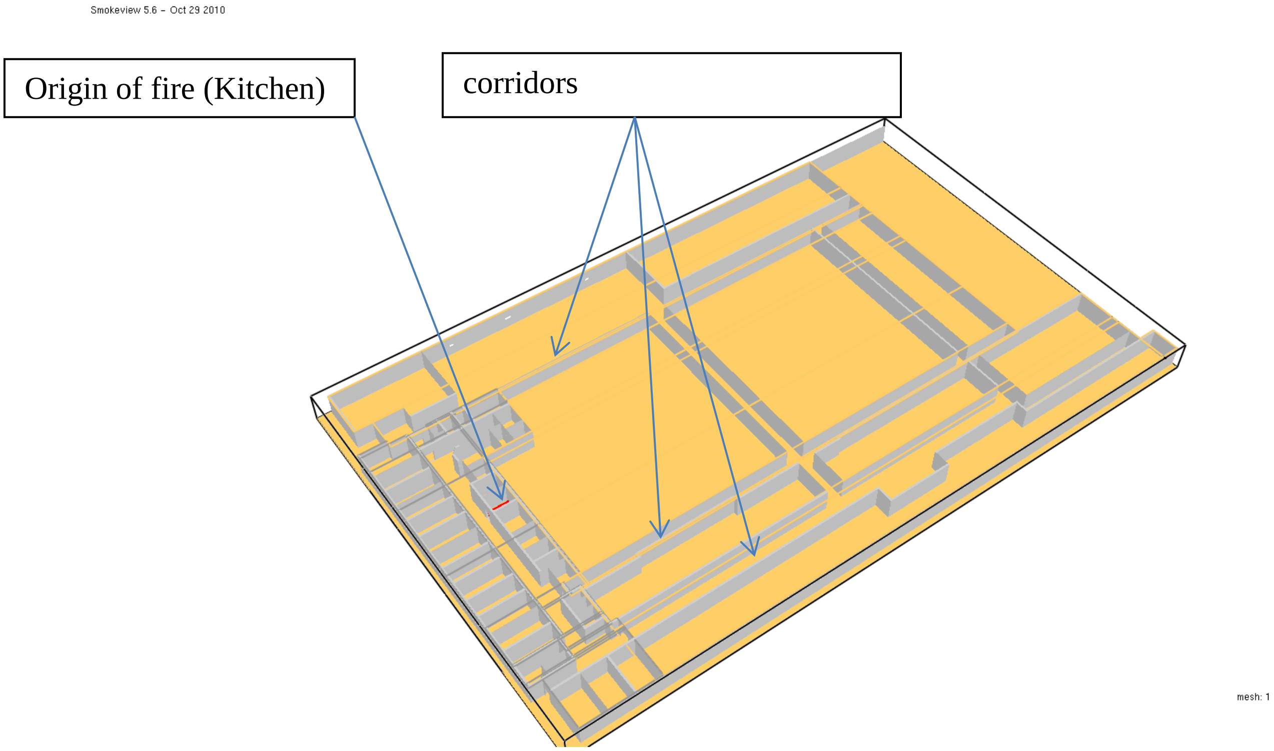

Figure 36 . 3 d figure of the FDS model.

The critical thresholds described above are used for comparison purposes. A more detailed analysis would consider in more detail critical visibility and temperature for hospital patients.

To account for a worst case scenario, it was assumed that the sprinklers were not working which are mandatory for hospital buildings in Iceland (Ministry of the Environment, 2006). In addition it was assumed that doors from the ward were open as well as doors in the corridors.

The main results are that critical conditions in visibility arise in the corridors of the ward of infectious diseases after about 5 minutes and begin to be critical in corridors outside the ward after about 10-11 minutes. Temperature was not a critical factor in the calculations with given assumptions outside of the burning ward but became critical at the burning ward after about 8 minutes. A more detailed look of the fire modeling properties is presented in Appendix 3.

In Section 6.4 the second floor evacuation properties are discussed.

6.4 Evacuation

To evaluate the evacuation time from the concerned ward and nearby treatment centers, the evacuation time (T_{evac}) is divided up to the following three main components as described by (Frantzich, 1997):

1. Detection time
2. Reaction time
3. Travel time

In order for the evacuation being successful it has to be over before the critical conditions arise, i.e. the time to critical conditions (M) > Evacuation time (T_{evac}). Below the evacuation time factors are described.

6.4.1 Detection time

Detection time is considered the time in which the fire is detected by people or staff at the hospital Treatment Center building.

The time of detection during the day is estimated of being 60 seconds if the fire alarm system works as intended and 90 seconds if it does not. During the night, the same detection time was used if the AFAS works as intended but 120 seconds if it does not.

6.4.2 Pre-movement time

The Reaction time is the time it takes people to figure out what is happening and react. The personnel at the ward are well trained and an emergency response plan will be active in the hospital building. The reaction time was therefore estimated to be 20 seconds.

6.4.3 Travel time

The Travel time is the time it takes to move patients and personnel to a safe location in the case of a fire. It is calculated with the following formula as described by (Frantzich, 1997) and (Olsson, 1999):

$t_{travel} = (t_{staffm} + t_{care} + t_{patm} + t_{queue}) x (No_{pat}/No_{staff})$

where:

t_{staffm} = The time it takes the personnel to reach the patient in the nursing room

t_{care} = The time it takes to prepare the patient for transportation

t_{patm} = The time it takes to move the patient to a safe location

t_{queue} = The time the personnel and patients queue at the exit.

No_{pat}/No_{staff} = The ratio between the number or patients and the number of staff.

In Appendix 4 the evacuation calculations and numerical values are presented.

6.5 Evacuation vs. Critical conditions

The two cases investigated here with regards to different probabilities in the arrival of CDFRS before critical conditions arise is seen figuratively in the following subsections.

6.5.1 Case 1- PMS responds to AFA alarm before the CDFRS

The average number of people being exposed to critical conditions has been calculated as 0,08 per year. The cumulative frequency of people exposed to critical conditions are shown in Figure 37 below.

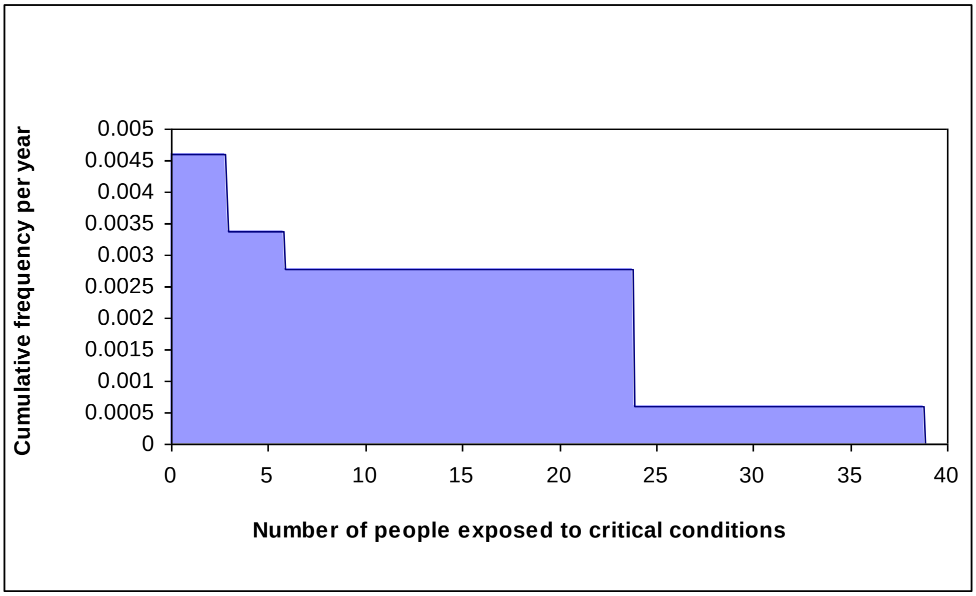

Figure 37 . Cumulative frequency of people exposed to critical conditions with regards to delayed response of the CDFRS.

6.5.2 Case 2 – No delay in the response of the CDFRS to alarms from AFA systems

The average number of people being exposed to critical conditions has been calculated as 0,05 per year. The cumulative frequency of people exposed to critical conditions are shown in Figure 38 below.

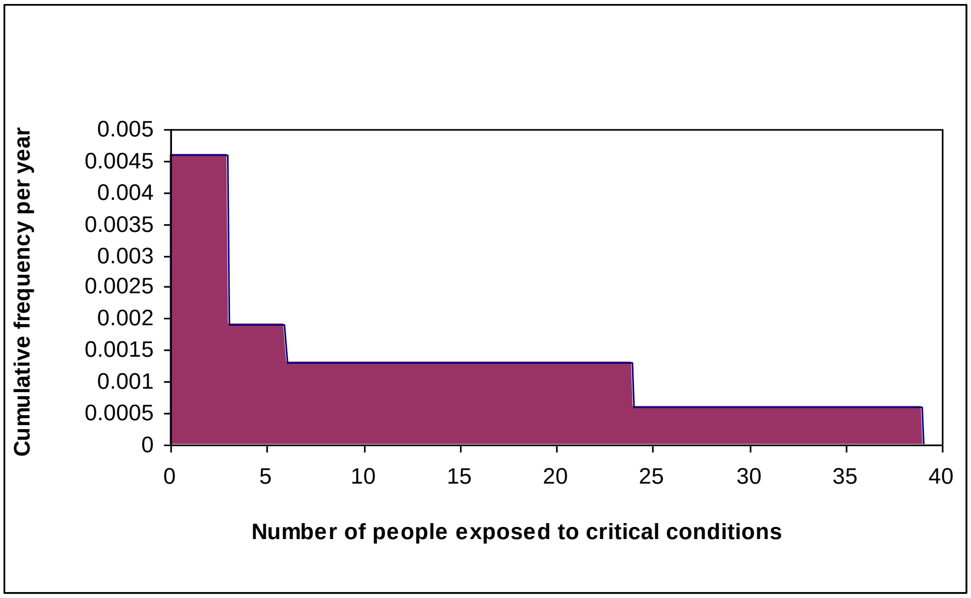

Figure 38 . Cumulative frequency of people exposed to critical conditions without a delay in CDFRS response.

6.5.3 Results and risk comparison

As Figures 37 and 38 indicate, the same number of people is expected to be exposed to critical conditions in the early stages of fire. The reason is that critical conditions arise after approximately 5 minutes in the corridors of the ward of infectious diseases, before the rescuing efforts of the CDFRS are in place. The difference in the number of people being exposed to critical conditions begins to show when considering areas outside of the burning ward. Figure 39 below shows a comparison between the two cases.

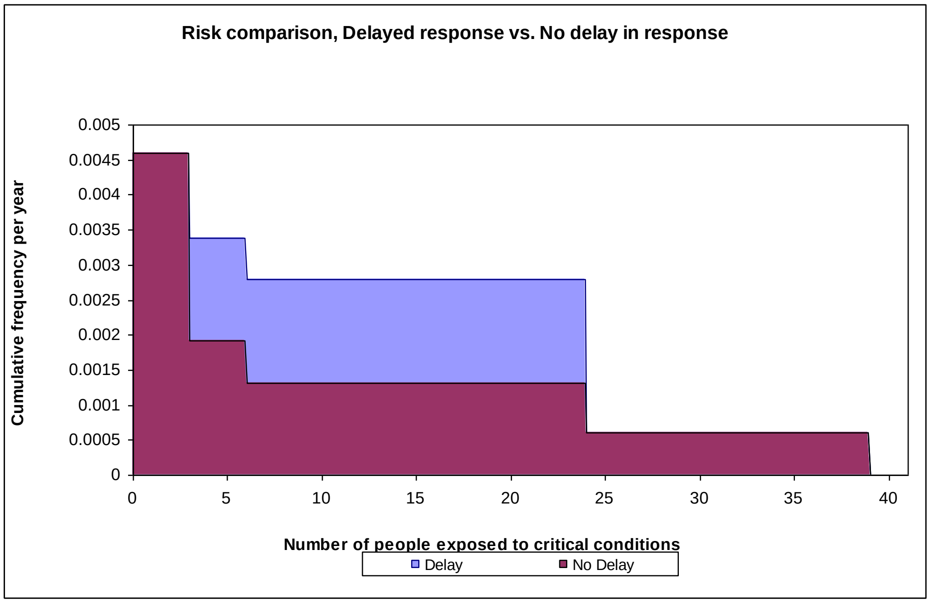

Figure 39 . Comparison of the cases, i.e. delayed response vs. no delay in response.

In Figure 39 the two cases have been merged to present the difference in frequency. To be able to see whether or not the risk is acceptable or not the lower limit of tolerable risk criteria for hospitals introduced by (Olsson, 1999) is compared with the results. The criteria consists of a curve where the lower limit for the risk tolerance is F $=10^{-1}$ for N = 1 and the elevation of the curve is -1. Figure 40 below shows the cumulative results for cases 1 and 2 along with the tolerable risk criteria.

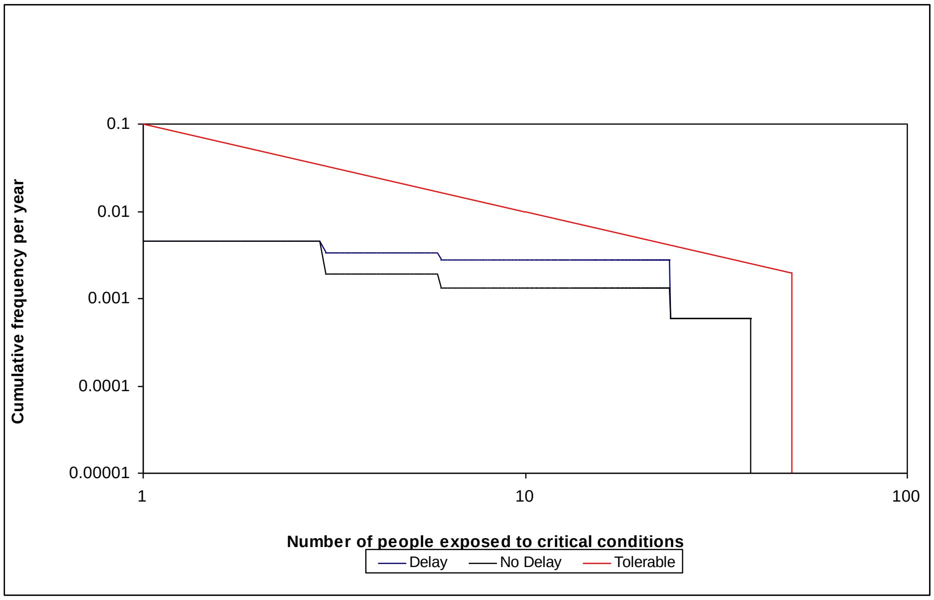

Figure 40 . Lower limit of the tolerable fire risk criteria for hospitals **(Olsson, 1999)** compared with cumulative frequencies of cases 1 and 2.

As seen in Figure 40, both cases lie under the lower limit curve in this analyses. Although this analysis is subjected to a number of limitations, it can provide an insight on how much delay can be allowed in the response to an alarm from AFAS. In this case a delay would be acceptable because of active fire protection measures as well as capable staff at location.

The result could be different for other types of housing or activity and therefore it is essential that there is a clear understanding between involved parties on what procedures should be followed. Here, the CDFRS would not benefit on responding to the AFA as the PMS response also keeps the number of people at risk of critical conditions below the unacceptable criteria.

6.5.4 Limitations

A number of limitations have been made to keep the focus on different effects of the unmitigated fire growth time. The response time factor is more likely to be of more importance in buildings where fewer people are housed as the model assumes that a security guard arrives on scene to investigate if there is a fire or not and then calls the Public Alarm Control Center 112 resulting in a significant delay in the response of the CDFRS.

It is unlikely as in hospitals and actual fire scenarios; the personnel, patients or others would have contacted the CDFRS before a PMS security guard would be at the scene.

The limitations regarding the fire scenario, event trees and evacuation are the same for both cases and affect each one equally. Another limitation to the Total reflex time of the CDFRS and PMS is that distances are not taken into account which would of course affect the model. However, the data and the above application provide a good indication on how to develop a system in responding to fire alarms from AFAS.

6.6 Summary

In this chapter we have presented a model which investigates a fire hazard at a single ward of a hospital being planned in downtown Reykjavík. Events leading to critical conditions following a fire have been discussed as well as calculations regarding fire and evacuation have been performed. Two different cases were investigated where the only difference is the probability of the CDFRS arriving before critical conditions arise at the second floor of the hospital building. The difference of the two cases was considered to be the monitoring of AFAS. In the first case, todays procedures were investigated whereas in the second case it was assumed that 112 would monitor the AFAS.

Although there was a considerable difference in number of people exposed to critical conditions between the cases, the risk is considered acceptable low in both cases. However as mentioned above, the results could be different for other kind of housing.

The model can be used on other types of buildings to see if a delayed response of the FRS is acceptable or not. In addition, as described in the following chapter, it can be used as a basis for developing clear working procedure for the public services and the private monitoring stations regarding AFAS.

In Chapter 7 a Building Classification Model (BCM) is introduced, which aims to give clear working procedures regarding the response to alarms from AFAS.

7 AFAS - Building Classification Model

The aim of this chapter is to build a basis for clear working procedures regarding alarms from AFAS for the PMS and the FRS based on the findings in previous Chapters. The work is thought as a risk mitigation measure for the general public and the FRS concerning AFA. A model is introduced which classifies buildings/activities with regards to the response procedures to AFA. The focus is, as in the above chapters on mandatory AFAS required by law as well as other housing/activities using AFAS.

The reason for the Building Classification Model (BCM) introduced here, is the fact that demands in Icelandic regulations governing the response to alarms from AFAS are lacking in today's regulatory environment. Also the fact, that in the past 2 years there have been 3 fatalities in fires in Iceland (Karlsson, 2010) where there was an alarm from AFAS. With a new building regulation being introduced in 2012 an opportunity arises to tackle these matters.

We want to make the response of the FRS as organized and systematic as possible without increasing risk of harm to people as well as minimize additional cost for the public services.

The data presented in Chapter 5 on UFGT, PMS and CDFRS callouts is utilized in the creation of this BCM.

7.1 General suggestion

The basis of this BCM is that the response of the FRS to alarms from AFAS is prioritized. The prioritization is built on classification of buildings/activity and a delayed response by the FRS. The classification consists of 4 classes, A, B, B+ and C.

In class A and B, are buildings where AFAS are required by law or approved fire safety design.

In class C are buildings where AFAS are optional.

In class A and B a delayed response to an AFA is sometimes or always permitted whereas it is always permitted in class C. Class B+ is for owners of systems in class B, willing to pay a fee for the same response of the FRS as Class A owners.

The basic assumption of this model is that regardless of class, there should be no delay in the response of the CDFRS when alarms are manually triggered. In addition, concerning all classes a 90 second delay is permitted to investigate the cause of alarm.

The suggested BCM with explanations is shown in Table 3 below.

Table 3: The classes of the BCM

Building Class	Explanations	System Required?	Delay permitted?
A	Very important that FRS response is swift. Delay not tolerable in the case of a fire	Yes	Sometimes
B+	Same as B	Yes	Sometimes
B	On site investigation tolerates a certain delay. A defined delay is acceptable in the case of a fire.	Yes	Always
C	Optional systems	No	Always

As of 2012 a new building regulation was introduced (Ministriy of Environment, 2012). The regulation categorizes buildings/processes into six main categories. Below in Table 4 an example of these categories is shown.

Table 4: Six building/occupancy categories of the new Icelandic building regulation. **(Ministriy of Environment, 2012)**

Category	Example of usage	Slept	Know escape routes	Can manage to safety by them selves
1	Structures where people work. Commercial buildings, industrial housing, warehouses, offices etc.	No	Yes	Yes
2	Structures where people can gather. Lecture halls, Churches, Cinemas etc.	No	No	Yes
3	Structures where people live. Condos, apartments, standalone guestrooms, summerhouses etc.	Yes	Yes	Yes
4	Structures offering sleeping accommodation. Hotels etc.	Yes	No	Yes
5	Hospitals, elderly and disabled apartments, preschools 1-4 grade etc.	Yes	No	No
6	Prisons, Closed wards in hospitals, Psychiatrics etc.	Yes	No	No

Below in Table 5 the categories are shown with respect to the requirement of AFAS.

Table 5: Categorization of buildings with regards to AFAS in the new building regulation. **(Ministriy of Environment, 2012)**

Category	AFAS required
1	Structures, 3 stories or higher. Structures > 1000 m^2 or when population exceeds 50 people in each category.
2	The first floor of structures where population exceeds 50 people but always if activities are in basement, second floor or higher.
3	No requirements
4	Structures where populations exceed more than 10 guests.
5	All buildings
6	All buildings

Here, this categorization in the new building regulation is combined with the introduced BCM of A, B, B+ and C. Below in Section 7.2, Class A is introduced.

7.2 Building Class A

Definition:
Buildings regarded so important that a delay in the response of FRS is not acceptable in the case of a fire but acceptable if it is not clear whether there is a fire or not.

Basic requirements:
Class A should apply to buildings where an AFAS with a direct link to a PMS is required by law and it is suggested that the following basic requirements are also met:

- Response plan, with a defined research capacity and a description of the fire brigades access.
- Evacuation plan.
- Active own control plan.

Classification:
Constructions in category 5 and 6 in the new building regulation should be in class A. Also, buildings where high concentrations of people is expected and buildings considered societal vulnerable because of infrastructure or cultural heritage should be in class A.

Examples of buildings/activities that are in category 5 and 6 in the building regulation and therefore class A:

- Structures hosting treatment facilities and hospitals
- Apartments and institutions for the elderly, physically or mentally disabled.
- Preschool divisions (1-4 grade)
- Structures hosting prisons
- Closed departments at hospitals, including psychiatric care and other places where people are shut off.

The above listed structures should without condition be classed as A with regards to the FRS response to AFA. The FRS should also have the capability of moving other structures into class A if it is considered necessary. Here, a systematic process of choosing those structures is introduced in Figure 41.

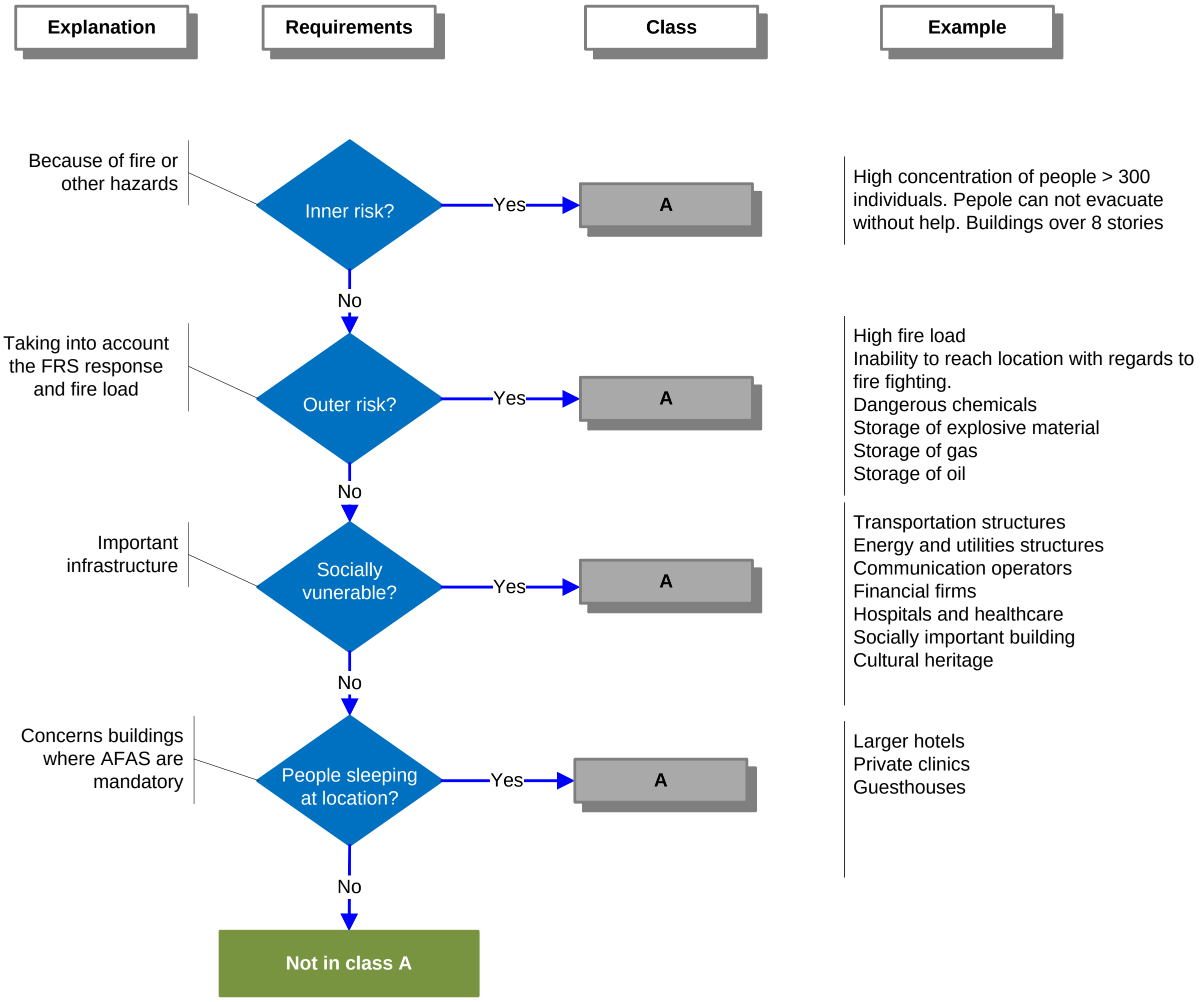

Figure 41. Suggested process of determining whether or not structures should be in class A.

Delay and response:

Within class A, as mentioned above there are some times when a delayed response of the FRS is allowed and sometimes not. Below in Figure 42 a process is introduced which takes into account the investigation of Chapter 5. The process should apply for all structures categorized as 5 or 6 in the building regulation and other structures that the FRS see fit to put in class A.

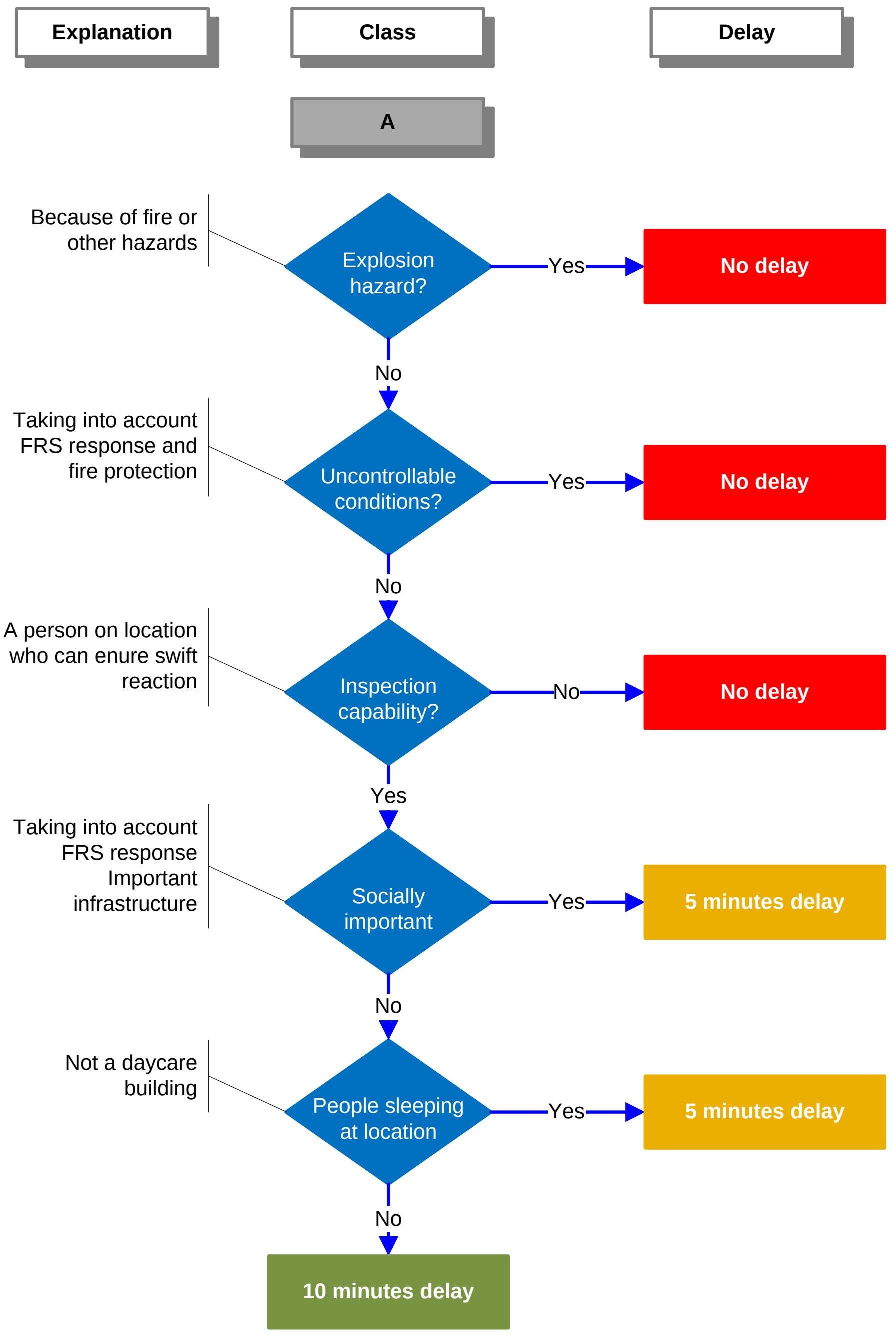

Figure 42: Suggested process of determining maximum time of delay in FRS response to AFA for class A.

As seen in the above flowchart the delay factor is limited. Delay is only allowed if there is a person on site that can be reached by phone or other means. The PMS then has 5-10 minutes to investigate the cause of alarm before contacting the 112. The time limits are strict as the buildings and activities in class A are thought to be important with a societal point of view as well as in some cases people are closed in as described above. The 10 minute delay is chosen because of interviews with involved parties at the CDFRS and the investigation performed in Chapter 5 where it was found that the average Inspection time of the PMS was around 12 minutes. By setting the maximum delay to 10 minutes, the PMS can prioritize their working procedures regarding class A buildings and activities. For the PMS to do so, a process is introduced here on how PMS should handle alarms from class A systems. The process is shown in Figure 43 by a means of a flowchart.

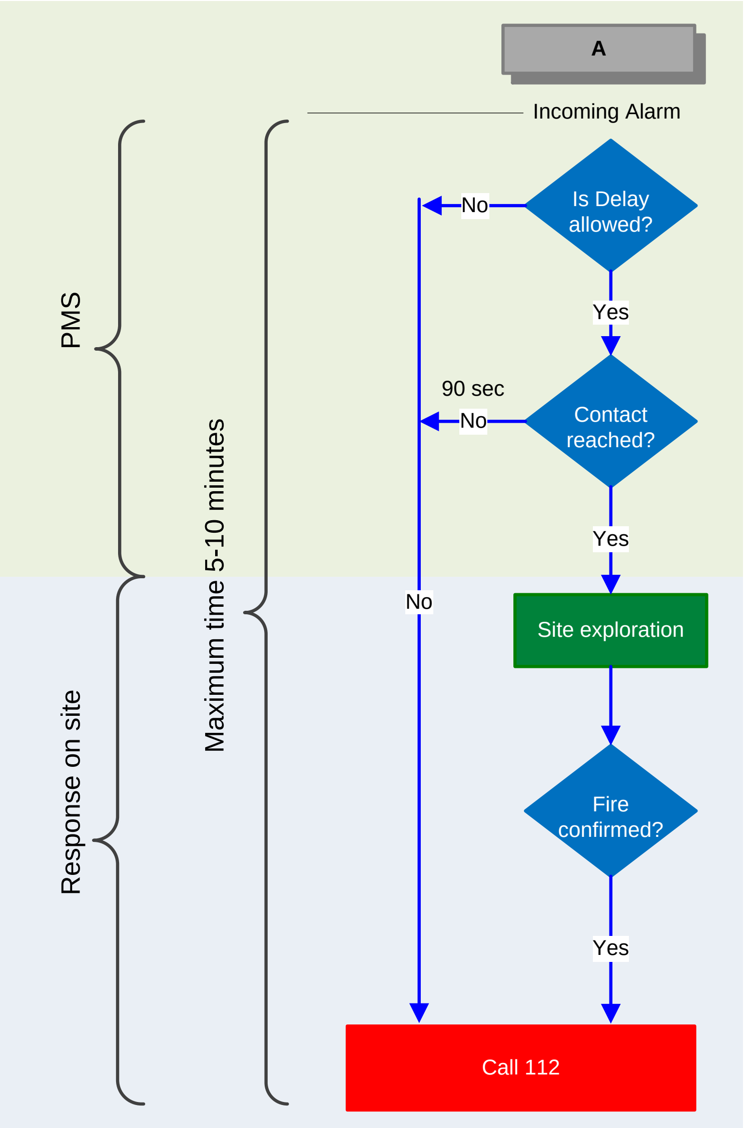

Figure 43: Suggested procedures for PMS in responding to alarms from AFAS – Class A

As shown in Figure 43 there are 90 seconds given to reach a contact at the alarm location. The reason for this timing is the fact that most of the alarms that the PMS receive are dealt with through the phone as shown in Chapter 5 where only 20 % needed a PMS security guard on alarm location to investigate the cause of alarm and the fact that a vast majority is not a genuine fire alarm where the FRS is needed. Class B is the topic of discussion in Section 7.3.

7.3 Building Class B

Definition:
Class B: All buildings/activities where there is a requirement by law to be protected by an AFAS with a direct link to the PMS except those buildings/activities already in Class A.

It is assumed that the building categories 1, 2, 3 and 4 in the building regulation fall into class B, that is, offices > 300 m^2, industrial buildings and buildings where people are assumed to gather, such as theaters and lecture halls.

Delay and response:
The delay chosen for class B is 15 minutes. The data shown in Chapter 5 indicates that 70 % of the PMS inspection time regarding mandatory AFAS is less than 15 minutes.

A verification of an alarm should be confirmed by a contact on scene, owner or owner's representative and a PMS security guard is sent on alarm location. A process has been created here, aimed at the PMS on how to handle alarms from AFAS in class B housing, shown in Figure 44.

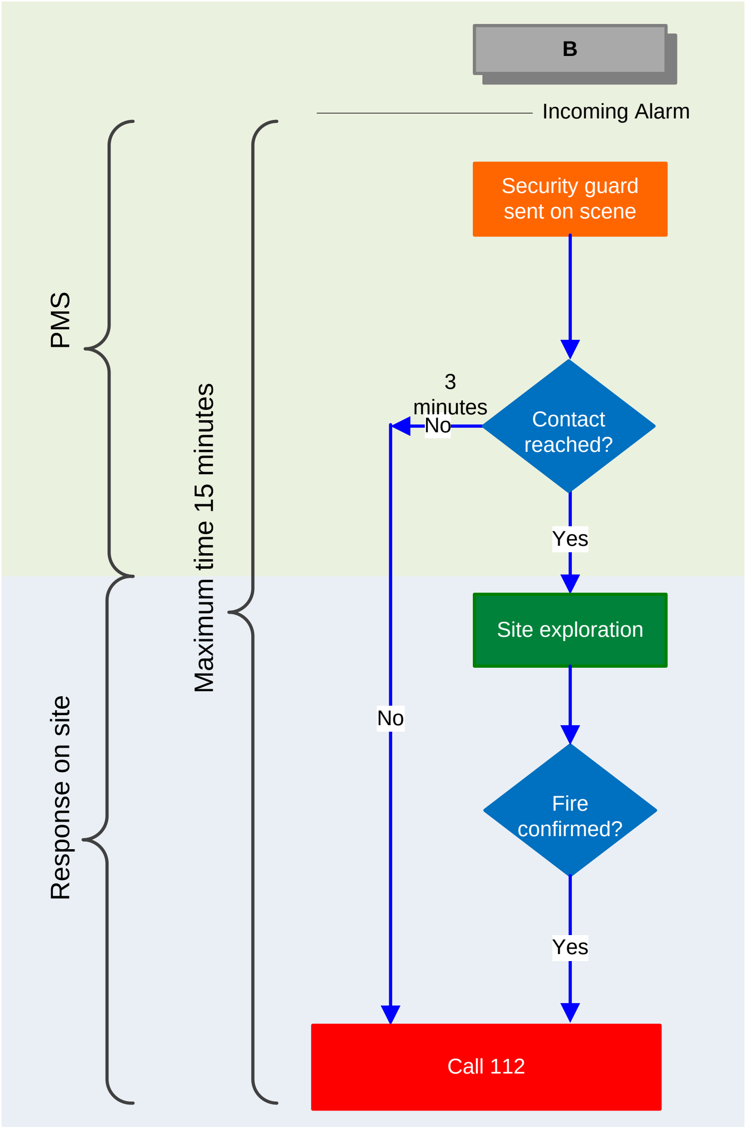

Figure 44: Suggested procedures for PMS in responding to alarms from AFAS– Class B

The reason for the three minute timeline to get in contact with people at alarm location is because a security guard is sent on scene as soon as alarm arises as well as the PMS control center should be trying to reach a contact at alarm location. As mentioned earlier, it is assumed that the owners of AFAS in class B can contact the FRS and make a request of being set in class B+ for a certain fee. Class B+ would then have identical procedures as class A.

7.4 Building Class C

Definition:
Buildings/activities where there is no requirement of an AFAS. Homes, small businesses- and institutions. FRS is not sent on scene unless there has been a confirmation of a fire.

Delay and response:
Class C is housing with optional AFAS and delay should be dependent on PMS Inspection time. The process of the PMS of handling fire alarms from a class C system can be set up as the following flowchart in Figure 45 describes:

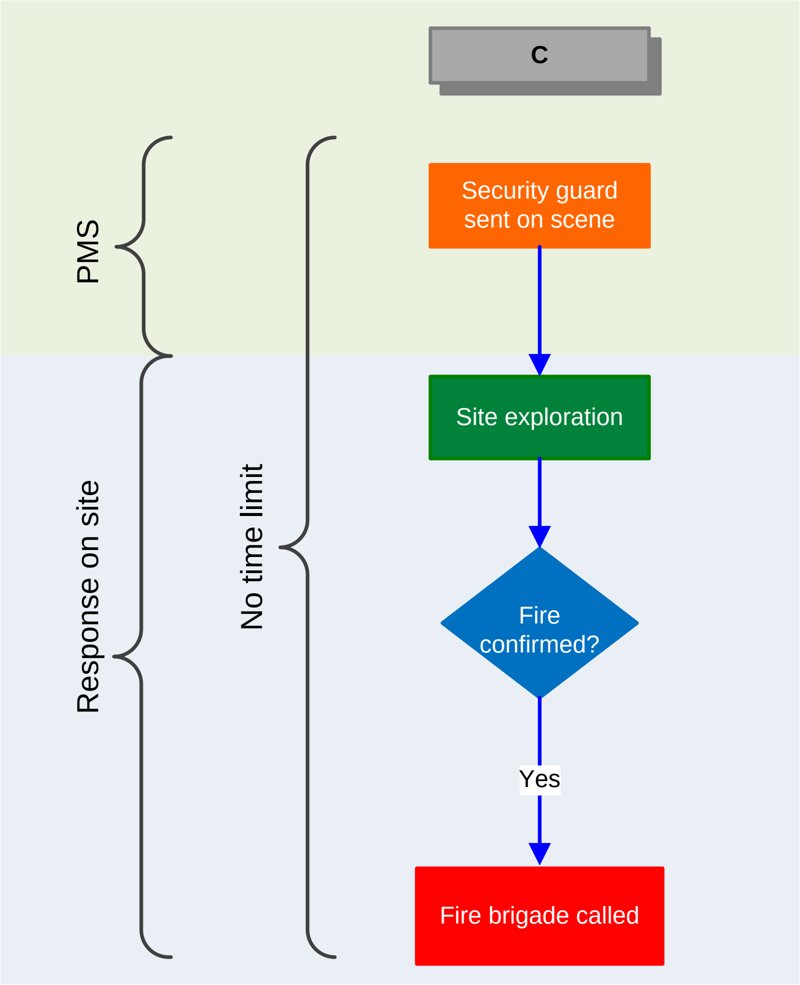

Figure 45: Suggested procedures for PMS in responding to alarms from AFA systems – Class C

7.5 Private Monitoring Stations requirements

It is necessary to coordinate the information contained in the AFAS at different PMS as it seems that these firms are not equally equipped regarding the information capacity of the systems. That assumption is made as other PMS were contacted to get data on AFA but were unable to give the information needed for this study.

Automatic Fire Alarm Systems are very different in capability. The basic system only gives a single alarm whereas the more advanced systems pinpoint the sensor alarming and have the capability of recording historic data. As mentioned before it is very important that there is no delay in contacting the FRS when an alarm is raised manually by hazard buttons and therefore important that the PMS have the capability of seeing if the alarm is automatic or manually triggered. Also, ability to know whether or not one or multiple sensors are raising the alarm is a useful tool in evaluating the reliability of an alarm.

7.5.1 PMS data submission to appropriate authorities

It is important to coordinate the procedures regarding the AFA process and the data regarding it. Also it is vital that the equipment is properly installed in order to reduce the constant number of alarms which in fact are false alarms.

Details of systems and information about alarms to appropriate authorities are important and necessary in order to change current work and response procedures regarding AFA. It is necessary for the authorities to be able to request the following information at any time from the PMS that service the AFAS:

- How many systems in class A, B, and C are in service by the concerning PMS
- The number of alarms per day from AFAS
- How the systems are installed
- What data does the system display and what can be retrieved?
- Does the exact location of the alarm appear at the PMS control center?.
- The time of alarm along with response and callout times of security guards
- The time the PMS alarms the 112 (Public Alarm Control Center)

7.5.2 Treatment of false alarms

In order to prevent a large number of unnecessary false alarms it is suggested that the PMS document all the false alarms they receive in a report and send to the FRS.

The report should include amongst other things the location of the false alarm (address), the date of the false alarm, the sensors and whether or not the FRS were contacted or sent on scene because of the false alarm. In addition the reason for the false alarm should be listed as well as the measures taken to prevent it from happening again.

7.6 Implementation

With the introduction of the new building regulation the ability to connect buildings in category 5 and 6 directly to class A arises as well as other buildings under defined classification.

It is suggested that other systems which do not fall into class A will in the beginning remain unchanged to get information on the magnitude of buildings and activities in class A. However it is also suggested the FRS have the ability to move buildings to A class if there is any uncertainty on where it should be. The above process introduced in Figure 40 provides the tools for doing that. It is also important that the procedures are processed with the PMS and time given for improvement.

7.7 Delay management

It is suggested that the Chiefs of the FRS have exclusive authority to allow any delays outside of Building Class A, subjected to the requirements of the Iceland Construction Authority (ICA).

7.7.1 Building Class A

The procedure should involve an agreement between the owner/guardian of AFAS in class A. The agreement should include the following:

- 90 seconds of observation time to check the reasons for an alarm, if duty person/guard is absent, immediate response
- An inspector sent to investigate false alarm
- A requirement for quick repair if the system is not installed based on circumstances
- Charge of false alarms, when the FRS has left their home station
- Demand of a response plan that specifically takes into account the reception and information to the FRS

It is also suggested that if the frequency of false alarms are more than 3 per year the ability of moving buildings between classes is available as repeated false alarms are involved. If the reason for the false alarm is because of poorly installed systems there should be a possibility to make the concerning PMS responsible for unnecessary callouts of the FRS.

7.7.2 Building Class B

Owners of the systems should make an agreement with the PMS regarding monitoring of the system. The possibility of conducting fire technical evaluations on buildings that overcome a certain amount of false alarm per year should be considered along with the possibility of demanding a response plan on how to react to alarms from AFAS.

If owners of systems want a quicker response the possibility of an agreement of upgrading to class B+ should be possible if the requirements for class A are met.

The possibility of charging for unnecessary callouts because of repeated unnecessary alarms should be considered.

7.7.3 Building Class C

Owners of the systems should make an agreement with the PMS regarding monitoring of the system. The possibility of charging for unnecessary callouts because of repeated unnecessary alarms should be considered.

7.8 Summary

In this chapter we have introduced a building classification model which aim is to create clear working procedures regarding the response of alarms from AFAS. The goal is to make the model simple and effective for both the FRS and PMS.

Four building classes have been created, A, B, B+ and C. The focus has primarily been on class A which are buildings required by law to be protected by means of AFAS. The classification is simple and can easily be integrated with the building categorization in the new building regulation in Iceland.

In the model, time delay limitations have been introduced which should increase accountability and eliminate uncertainty on when the PMS should call the FRS in the case of alarms from AFAS.

The implementation should be done in steps and changes should be relatively easy within the PMS as, although delay restrictions are made for Class A systems, the restrictions are much less for the other classes where most of the AFAS are on today's market.

8 Conclusion

As was stated in Chapter 1 the aim of this work was to identify risks that might be at hand with current working procedures in Iceland regarding the response to alarms from Automatic Fire Alarm Systems (AFAS). A survey showed that the most significant difference in the handling of the response between Iceland and neighboring countries is that in Iceland, the monitoring of AFAS is carried out by private monitoring stations or firms. In the neighboring countries the monitoring is handled by the Fire and Rescue Service (FRS), leading to a very high percentage of false callouts when compared to false callouts in Iceland. The procedure in Iceland works like a filter on incoming alarms from AFAS and should not affect the FRS unless there is an actual fire to be fought. Valuable time is gained by the FRS in Iceland on other assignments as they deal with all kinds of emergencies other than fires in buildings.

The Icelandic procedure however lengthens the unmitigated fire growth time in the case of a real fire scenario. In this work we have shown that unmitigated fire growth time increases by using these procedures as the total response of the public services, 112 and the Capital District Fire and Rescue Services (CDFRS) on average increases considerable which for a vulnerable building/occupancy is unacceptable. In this work it was also found that legislation regarding the Private Monitoring Stations (PMS) reactions and response to fire alarms is lacking and flawed. This increases fire risk as the PMS cannot be held accountable if delays become substantial, possibly causing harm to people as the public services may arrive too late to help.

In order to reduce these risk factors a Building Classification Model has been introduced in this work Using risk analysis methods and data from a number of databases, the analysis was used to develop guidance procedures on how to handle alarms from different types of housing. The proposed guidelines do not exert any formal or legally binding demands on the public services or the private monitoring stations, but the legal responsibility of prompt callout to a fire still rests on the Fire and Rescue Services.

In the Building Classification Model it is class A which is of greatest importance since this class corporates all buildings in category 5 and 6 in the new building regulations (e.g. hospitals). The Iceland Construction Authority (ICA) and the FRS can incorporate other buildings into the same class if they see fit, for example storages of flammable explosives or other dangerous goods. The FRS can use the model to see whether or not a certain building or activities should fall into class A by using the flowcharts presented in this work as guidelines.

The work presented here has shown that it is quite necessary to construct much more rigorous procedures regarding the AFAS since the current legislation on the issue is very vague. A model has been introduced in this with guidelines set up for the FRS and PMS, proposing a set of procedures for this purpose. The procedure does not put undue cost or expensive demands on the FRS or the PMS but still retains the benefits of the low rate of the FRS false alarms callouts. It is the hope of the author that this work will in some way contribute to a sensible solution to matters concerning response to AFAS.

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Appendix 1: Questionnaire

Questionnaire sent by the Iceland Capital District Fire and Rescue Services. Questions as seen in Chapter 4, Section 4.2:

7. Are there any delays allowed in the regulations and procedures between an alarm from a mandatory fire alarm system and the callout of the fire brigade?
8. If delays are allowed, what rules apply on the handling of the alarm? Which criteria need to be in place in order for the delay to be allowed and which demands on procedures do the private monitoring stations need to fulfill (if private monitoring stations deal with the alarm).
9. Are buildings and companies classified with reference to permissible delays in callouts and is there a difference in the handling of alarms with respect the time of day?
10. Is there a monetary charge for a fire brigade callout due to a false alarm?
11. If there is a charge for false alarms, what is the amount charged? And is the charge permitted by the laws and regulations?
12. Who is charged? The owner of the system or the user of the system.

Answers

Answers to the questions have been broken down to make them more accessible in the table below.

Question	Copenhagen	Stockholm	Gothenburg	Oslo
Are delays permitted?	Yes, hotels, shopping malls, product stocks etc.	Yes, e.g. homes for the elderly	Yes	Yes, delays used widely but direct line to watch precinct seldom required, the requirement is the system itself
What rules apply in the handling of AFA alarms?	Max delay 5 min and precincts need to be contacted within 2 min. Delay not allowed if manual alarm	Usually the precinct has to be contacted within 1-2 min and max	Contact the precinct within 1 min. By doing that a max 10 min adds to the verification time. Max time is 10 minutes but the times vary with regards to structure layouts, activities and technical solutions. Delay is not permitted if there is a manual alarm.	No rules. Only mutual agreement between involved parties. Usually there is no delay although delay is allowed in many places if there is security staff on site who can investigate the validity of the AFA
What are the requirements of allowing delays in response to AFA?	Trained supervisor of the system and trained personnel on site.	There has to be an active response plan group trained in fire protection amongst employees who know how to handle delays. The system supervisor needs to fulfill education requirements. Companies need to prove that the above is fulfilled and the system is working correctly.	Active response plan amongst trained personnel members who can deal with AFA. The members have various duties and must have been educated and trained within the companies on how to react to AFA.	
Are there any requirements on monitoring stations regarding delays?	The Fire brigade monitors the AFAS	The Fire brigade monitors the AFAS	The Fire brigade probably monitors the AFAS.	The Fire brigade monitors the AFAS.
Are buildings /activities categorized with regards to delayed response to AFA?		No. There is no general classification. Although, delays are allowed in nursing cares for the elderly but not in hospital emergency wards.	Trained members amongst the personnel are different with regards to building/activities but these members need to be in place if the building is getting delayed Fire brigade response to AFA.	
Is there any difference in response to AFA by time of day?	Yes, for example if hotels only have one security guard on site during nights, there is no delay allowed.		The callout strength of the Fire brigade varies with buildings, activities and on site risks. “hotbild”	For example, in schools where there is a contract of direct monitoring, no delays are allowed after school hours but during school hours the Fire brigade tries to contact the supervisor at the school .
Is there a monetary charge for responding to a false alarm?	Yes. Assessment on site whether or not a charge will be made. Smoking, cooking and unknown cause of alarm call for a charge. Also, unnecessary manual triggering of sprinklers are charged.	Yes	Yes. There is a predetermined fee and the Fire brigade determines if there is a cause of charging that fee.	False alarms, because of working personnel, steam, maintenance etc. are charged.
How much is charged?	3.500 DKR. About 84.000 ÍSK	10.000 SKR. About 181 ÍSK.	7.800 SKR plus added value. There is a charge for resetting the system. There is a special discount system in place which is subjected to the willingness of companies to stop repeated false alarms.	2.800 NKR. About 68.000 ÍSK
Is the charge permitted by law?	Yes	Yes, by the municipality laws. Companies in the ownership of the municipalities may charge for their service. The rate is decided by the municipality.		No, only in contracts between involved parties.
Who is charged? The owner or the user?	The owner is always charged.	The person that signs the contract, usually the owner. The Owner can then re-charge the user.	Always the one who signs the contract.	The contract owner. The owner or the business.

Appendix 2: Event tree analysis and evacuation calculations

This appendix contains the event trees used in the analysis in Chapter 6. In the event trees it is assumed that the fire has already started. To get the actual fire risk in the ward of infectious diseases, the likelihood of a fire starting calculated in Section 6.2, 0,14 should be multiplied to each sub-scenario of the trees.

Event tree 1: Fire at the ward of infectious diseases.

The first tree contains events at the burning ward. It was used to see how many people would be affected by critical conditions at the ward itself, excluding other parts of the second floor. The reason was that critical conditions arise sooner at the burning ward than in other parts of the second floor considered. Critical conditions arise in the ward after about 5 minutes with regards to visibility.

Event tree 2: Fire at the ward of infectious diseases. Adjacent corridors included. A delay in the arrival of the CDFRS before critical conditions arises.

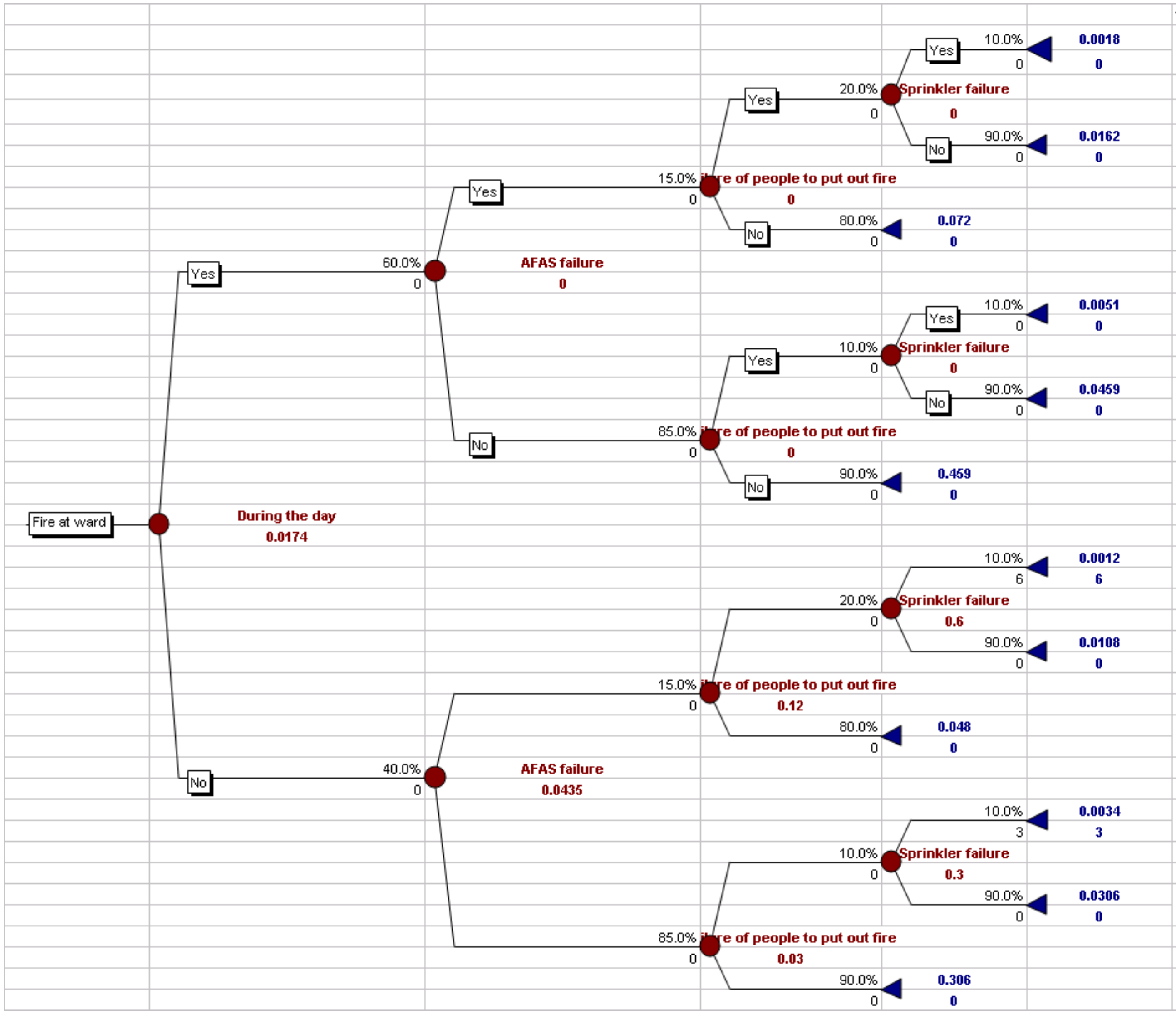
The second tree contains the same events as Event tree 1 but now the adjacent corridors are taken into account as well as staff and patients on the second floor. Critical conditions arise after about 11 minutes with regards to visibility. In this event tree, the delayed arrival of the CDFRS is assumed.

Event tree 3: Fire at the ward of infectious diseases. Adjacent corridors included. No delay in the arrival of the CDFRS before critical conditions arises.

The third tree is identical to the second tree with one exception, No delay in the arrival of the CDFRS assumed.

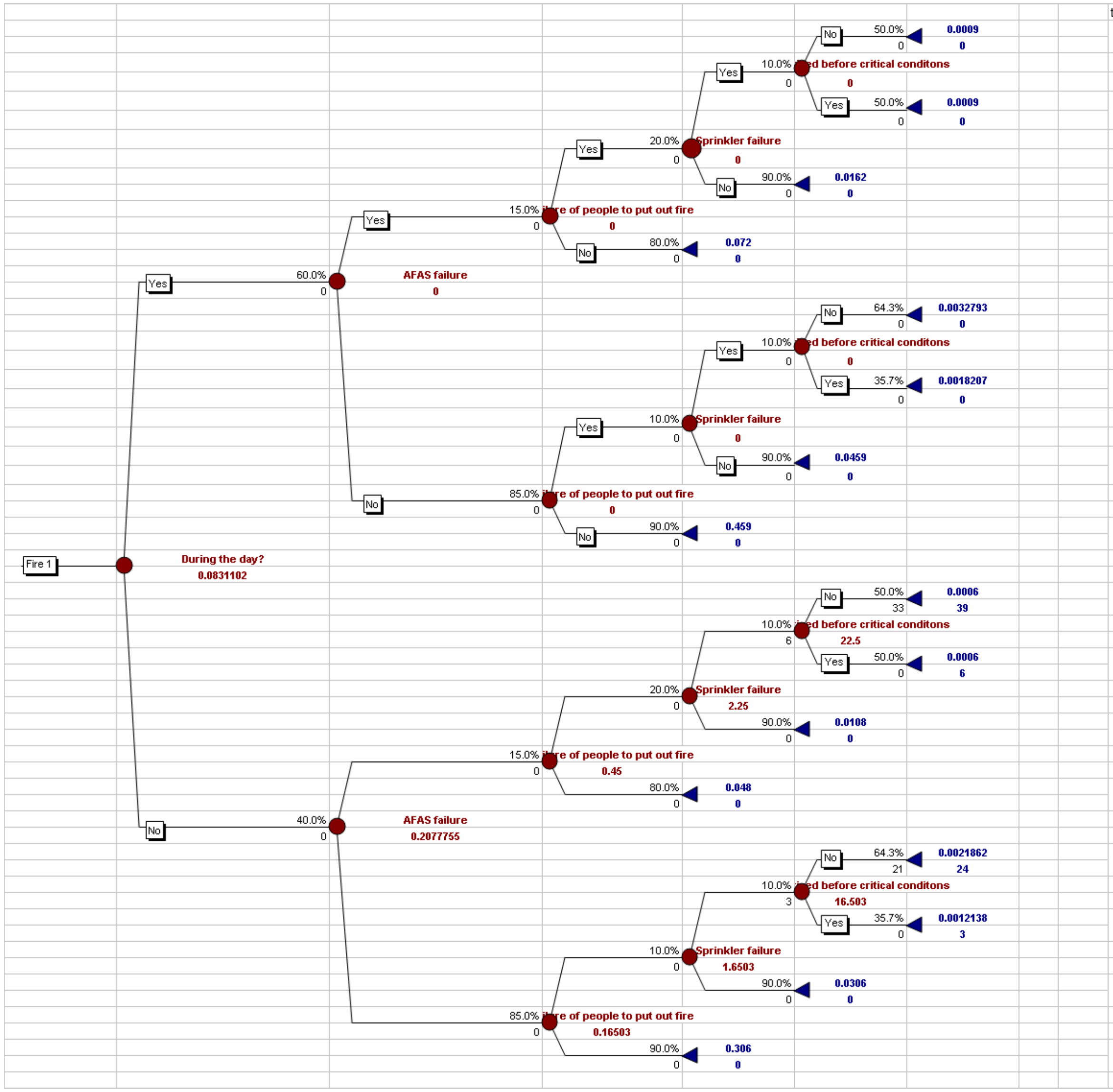
Below a schematic figures of all the trees are shown.

Event tree 1



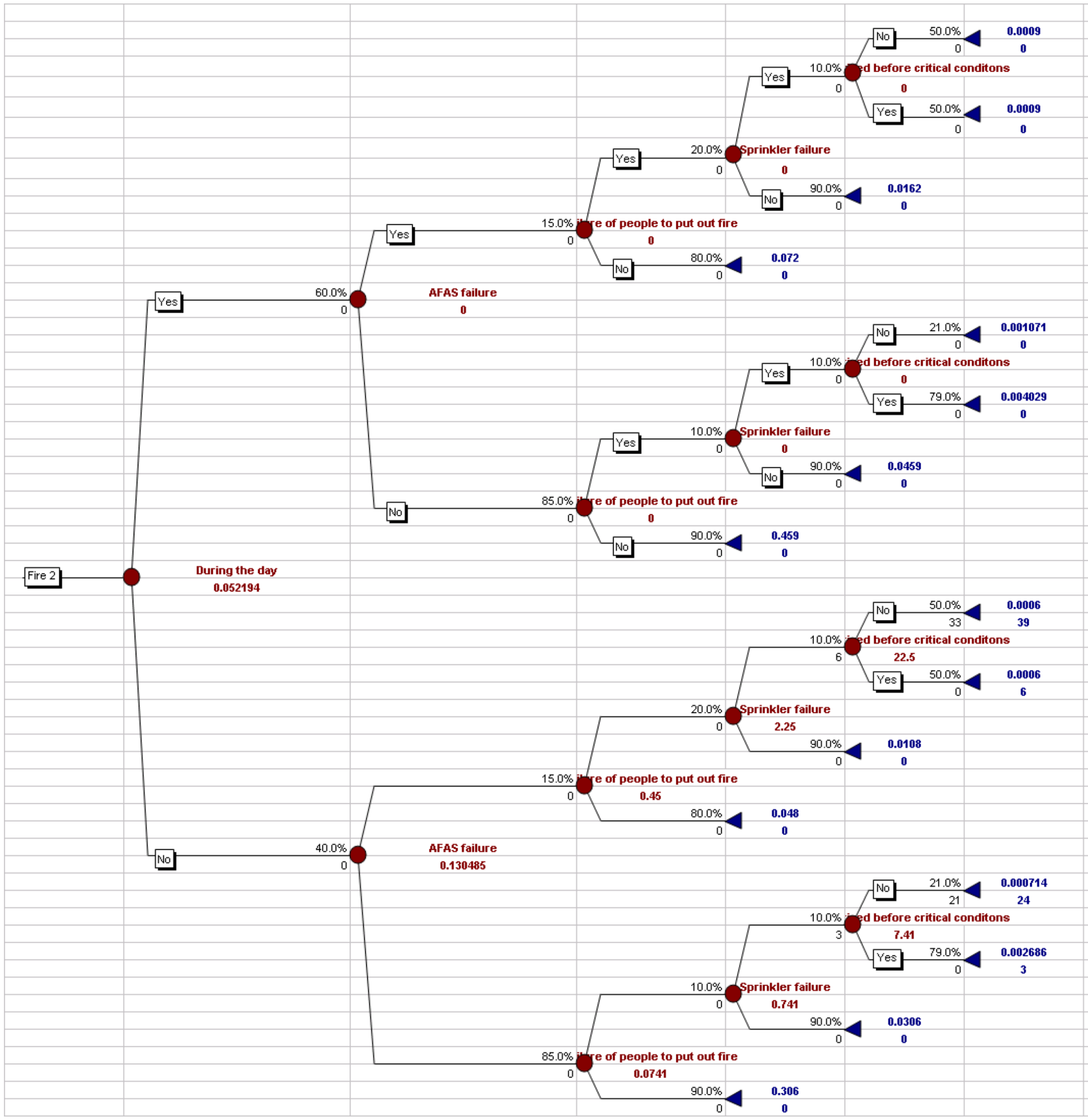
tcritical	tdetect	t react	t travel	t EVAC	m
300	90	20	140	250	50
NA	90	20	0	110	
NA	90	20	0	110	
300	60	20	140	220	80
NA	60	20	0	80	
NA	60	20	0	80	
300	120	20	280	420	-120
NA	120	20	0	140	
NA	120	20	0	140	
300	60	20	280	360	-60
NA	60	20	0	80	
NA	60	20	0	80	

Event tree 2



tcritical	tdetect	t react	t travel	t EVAC	m
600	90	20	300	410	190
NA	90	20	300	410	
NA	90	20	300	410	
NA	90	20	300	410	
600	60	20	300	380	220
NA	60	20	300	380	
NA	60	20	300	380	
NA	60	20	300	380	
600	120	20	600	740	-140
NA	120	20	600	740	
NA	120	20	600	740	
NA	120	20	600	740	
600	60	20	600	680	-80
NA	60	20	600	680	
NA	60	20	600	680	
NA	60	20	600	680	

Event tree 3



tcritical	tdetect	t react	t travel	t EVAC	m
600	90	20	300	410	190
NA	90	20	300	410	
NA	90	20	300	410	
NA	90	20	300	410	
600	60	20	300	380	220
NA	60	20	300	380	
NA	60	20	300	380	
NA	60	20	300	380	
600	120	20	600	740	-140
NA	120	20	600	740	
NA	120	20	600	740	
NA	120	20	600	740	
600	60	20	600	680	-80
NA	60	20	600	680	
NA	60	20	600	680	
NA	60	20	600	680	

Appendix 3: Critical Conditions - FDS simulation

This appendix contains a fire analysis of the second floor of the Hospital Treatment Center Building. A fire has been simulated in a three dimensional model of the building and the results have been compared to thresholds of critical condition to evaluate the risk to people from fires in the structure.

The object

The simulated structure is the second floor of the Treatment Center building which is a part of Reykjavík University Hospital.

In Figure 1 the principal layout of the structure is presented.

Figure 1. Drawing of the simulated structure. Simulated part marked with a blue line. Red line accoutns for the ward where the fire starts.

As seen in Figure 1, a large portion of the second floor was simulated, around 6000 m^2. The main focus was on the corridors as those are used for evacuation purposes if there should be an actual fire at the floor.

Method

The results from the CFD simulations are compared to critical conditions that might arise during a fire. During the early lapse of the fire, personal safety is the parameter that is of most interest. Thus, a couple of thresholds have been established, when the conditions are deemed to be non-acceptable for evacuation, meaning that evacuation of people should be finished before that point is reached.

However, if a person is still inside a room when a threshold is exceeded, it does not h mean that there will be injuries or fatalities, but rather that there is an elevated risk to the person in the room. The thresholds are exceeded when [1]:

- People are subject to temperatures higher than 80 °C.
- The visibility is less than 10 meters.

Simulation parameters

The simulations were conducted with the Fire Dynamics Simulator (FDS) 5.2.6 software from the National Institute of Standards and Technology (NIST) [2]. FDS is an American CFD software that specifically have been developed for fire simulations and is today one of the most used software for fire simulations.

General parameters

Most of the second floor of the Treatment Center building was set up and modeled in FDS, as shown in Figure 2.

The volume was divided into six different grids to make it possible to run the simulations on multiple processors and thus reduce the time it takes to run the simulation.

The grids had different dimensions but the sides of the cells in all the grids were quite small or 40 cm. The total number of cells used in the simulations was 1.030.125.

In the model it was assumed that 4 windows and one door were open to ensure oxygen levels. The placement of windows and the door are shown in Figure 2. The total size of openings was about 3,5 m^2.

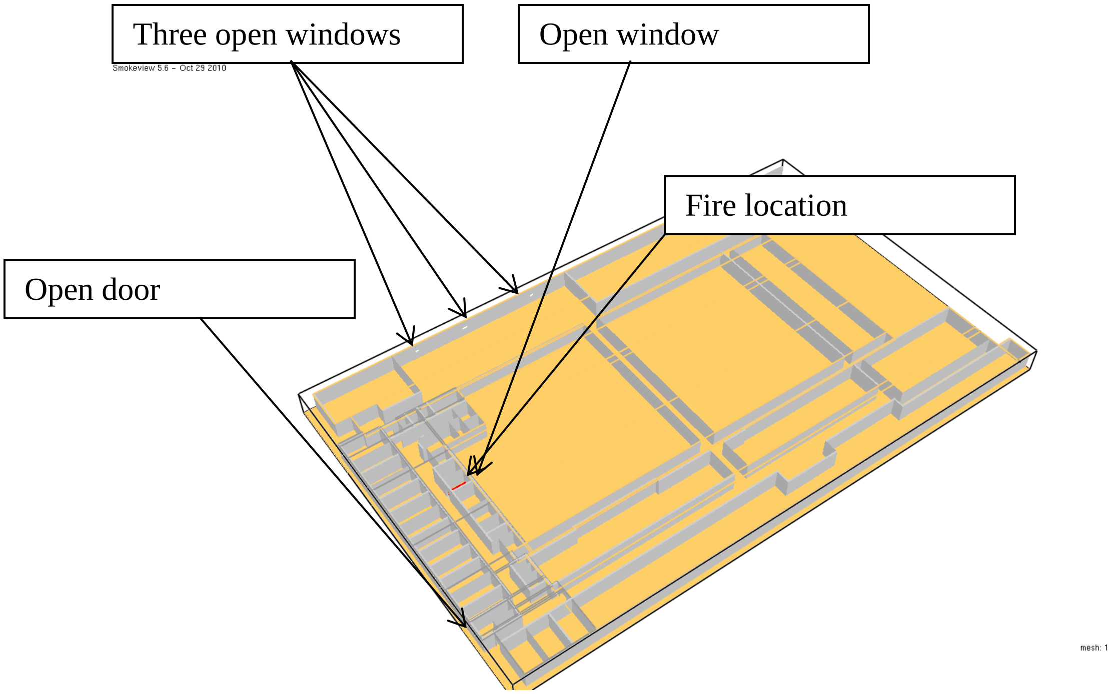


Figure 2. The simulated structure (preferably with arrows pointing out the main features of the model)

Fire parameters

The simulated fire was a fast $\alpha t^2 (\alpha=0,047)$ with a Heat Release Rate (HRR) of 350 kW/m^2 and the fire area was 14 m^2 located in the kitchen area. The maximum heat release rate was thus around 5 MW and was reached after approximately 5 minutes as seen in Figure 3. As a conservative approach the fire was simulated for 1200 seconds and assumed that it would keep the maximum heat release rat for that time.

It was assumed that the fire would have a soot yield of 0,03 and a carbon monoxide yield of 0,06.

It was assumed that doors from the burning ward were open to the adjacent corridors as well as doors in the corridors themselves.

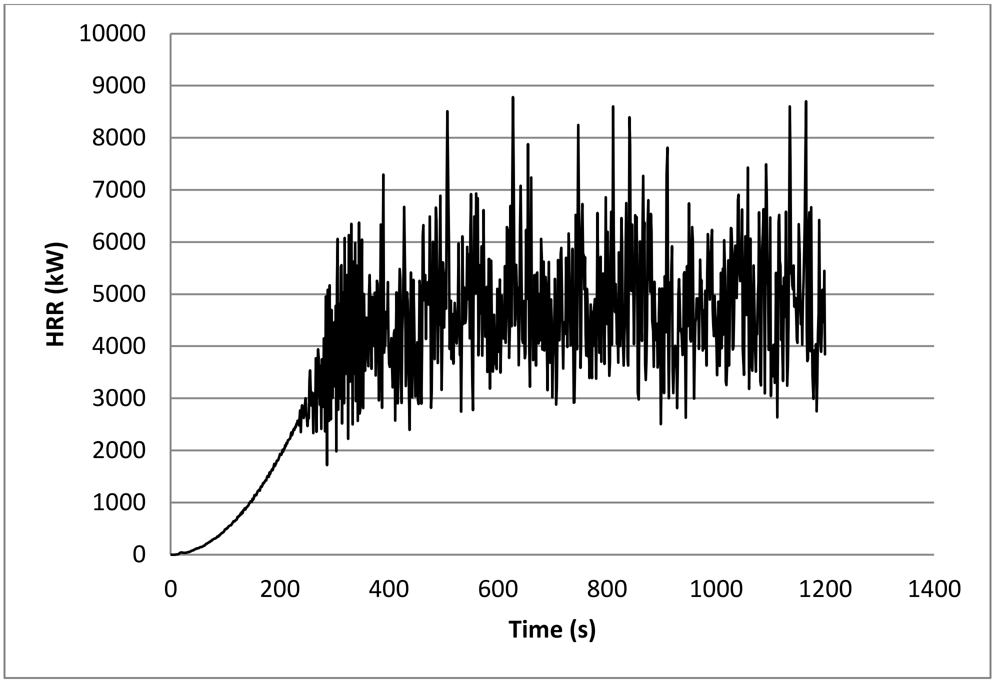


Figure 3. Heat release rate with regards to time. A fast 5MW fire in the kitchen.

Results

A Fast 5 MW fire in the kitchen of the ward of infectious diseases and recovering patients.

As can be seen in Appendix A, the visibility is getting critical after 5 minutes in the ward of infectious diseases at 2 m height above floor level (Figure 5). The visibility at adjacent corridors begins to be critical after 10-11 minutes as seen in Figure 9.

The temperature reaches critical limits after about 7-8 minutes in the concerned ward as seen in Figure 11. The temperature was not a critical factor in the adjacent corridors as seen in figures 10-13.

References

[1] Brandskyddslaget & Brandteknik vid LTH: Brandskyddshandboken, Report 3134, Brandteknik, Lunds tekniska högskola, Lund, 2005.

[2] McGrattan, K., Klein, B., Hostikka, S. & Floyd, J: Fire Dynamics Simulator (Version 5) User’s guide, NIST Special Publication 1019-5, National Institute of Standards and Technology, 2007.

Appendix A. Visibility and Temperature. Fast 5 MW fire in the kitchen

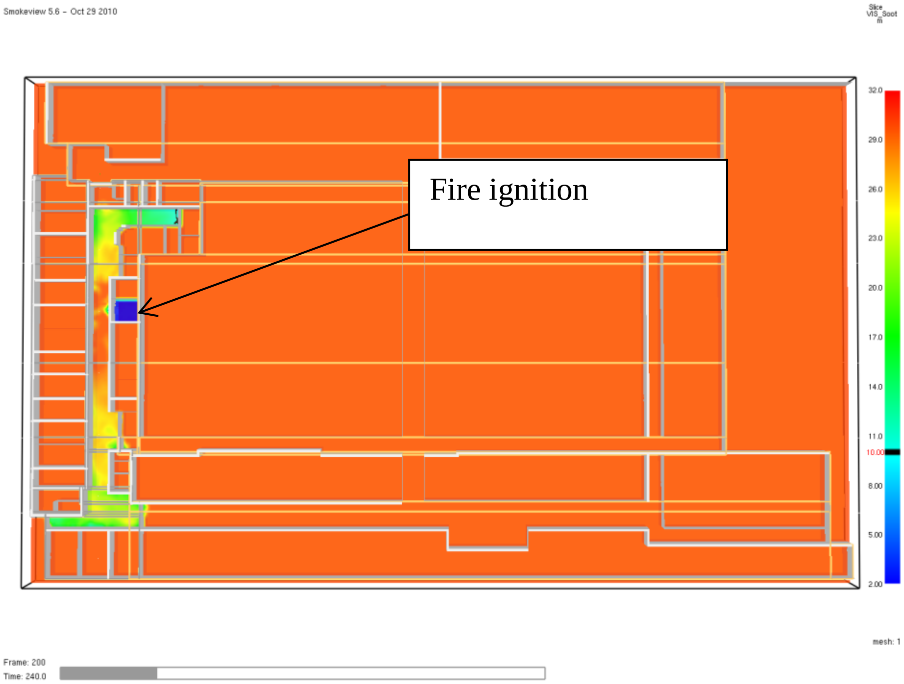


Figure 4. The visibility 2 meters above floor level after 4 minutes. The colorbar on the right side represents visibility in meters. Black color represents critical visibility, 10 m and blue represents visibility less than 10 m.

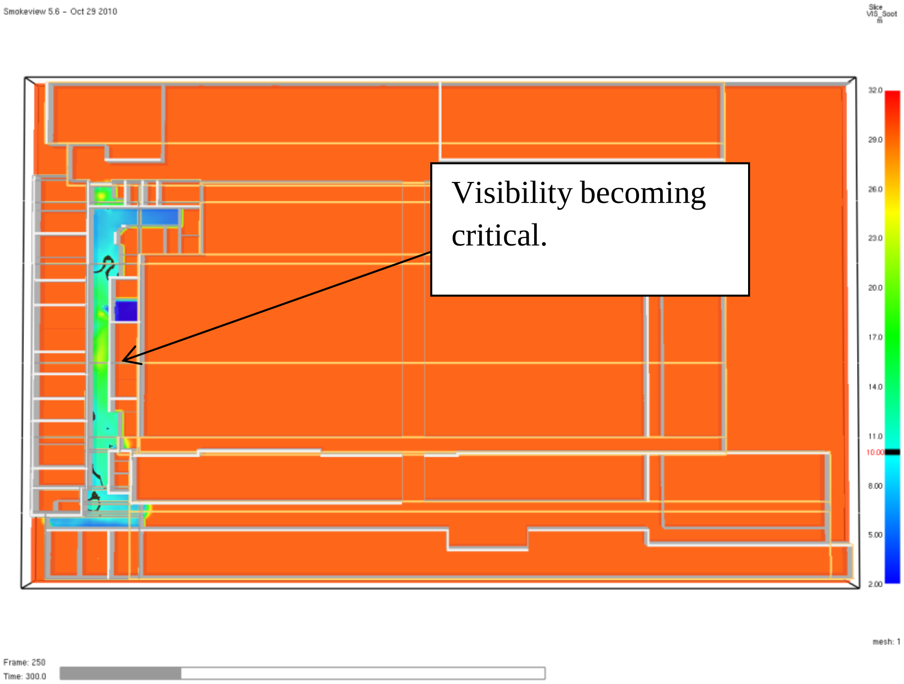
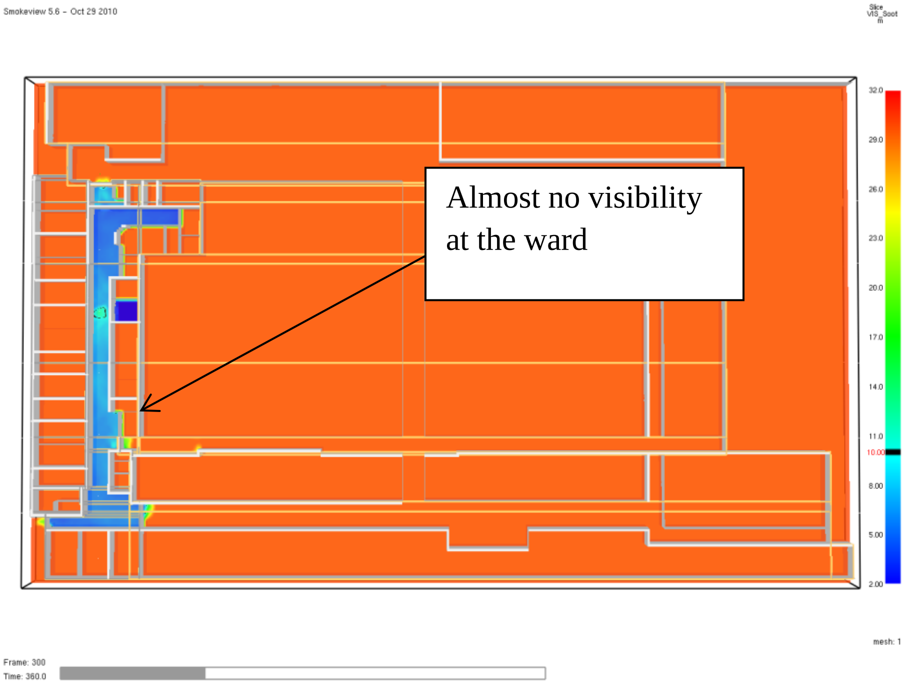


Figure 5. The visibility 2 meters above floor level after 5 minutes. The colorbar on the right side represents visibility in meters. Black color represents critical visibility, 10 m and blue represents visibility less than 10 m.



Almost no visibility at the ward

Figure 6. The visibility 2 meters above floor level after 6 minutes. The colorbar on the right side represents visibility in meters. Black color represents critical visibility, 10 m and blue represents visibility less than 10 m.

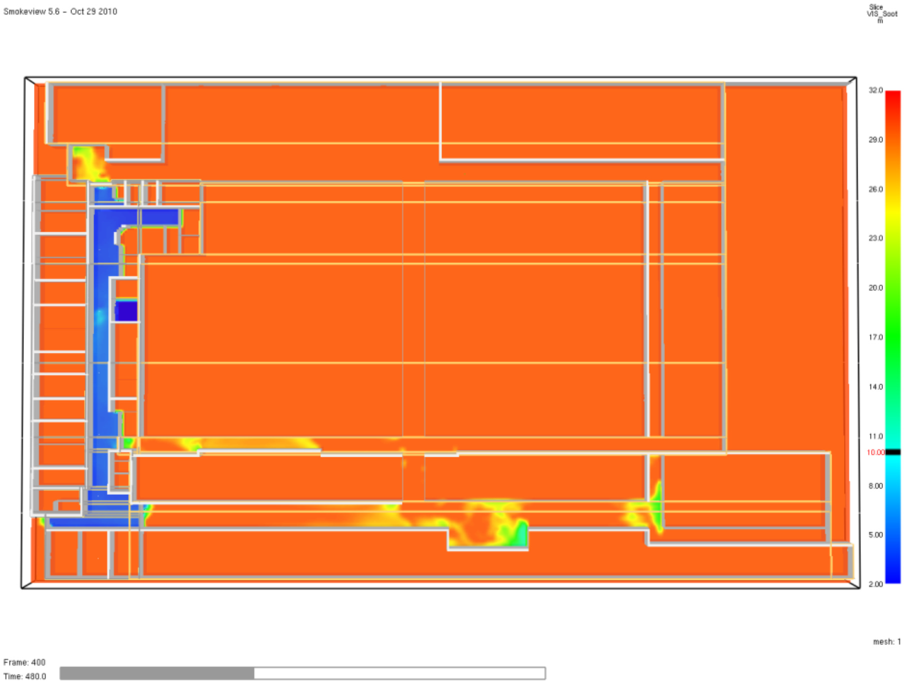


Figure 7. The visibility 2 meters above floor level after 8 minutes. The colorbar on the right side represents visibility in meters. Black color represents critical visibility, 10 m and blue represents visibility less than 10 m.

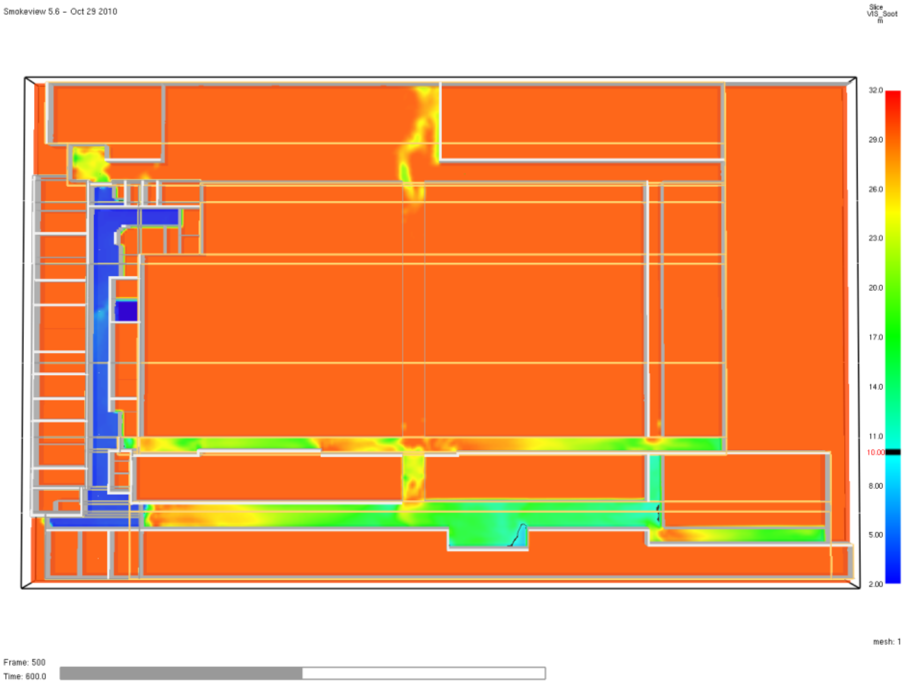


Figure 8. The visibility 2 meters above floor level after 10 minutes. The colorbar on the right side represents visibility in meters. Black color represents critical visibility, 10 m and blue represents visibility less than 10 m.

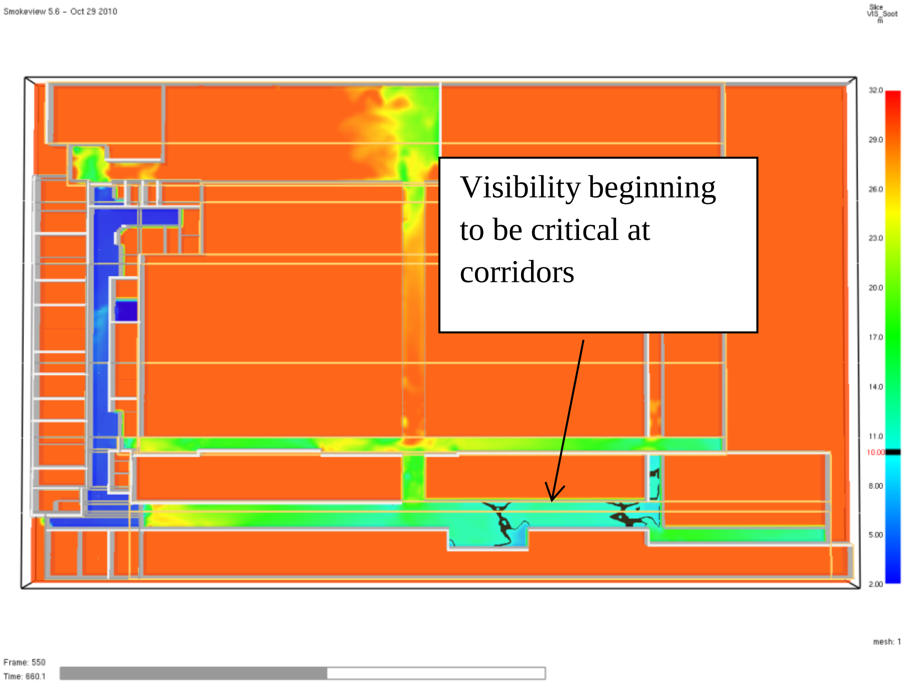

Visibility beginning to be critical at corridors

Figure 9. The visibility 2 meters above floor level after 11 minutes. The colorbar on the right side represents visibility in meters. Black color represents critical visibility, 10 m and blue represents visibility less than 10 m.

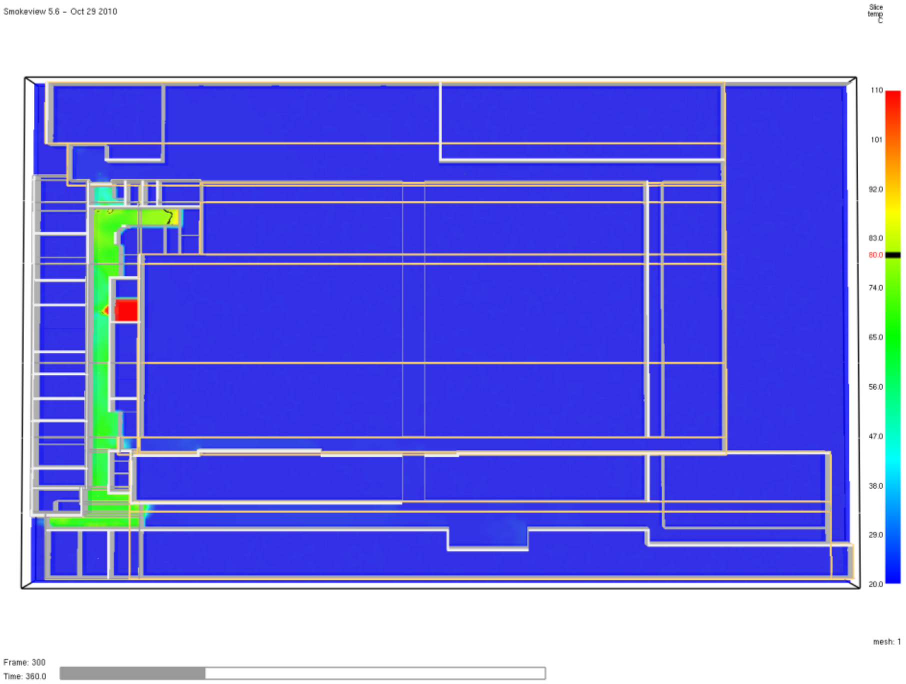
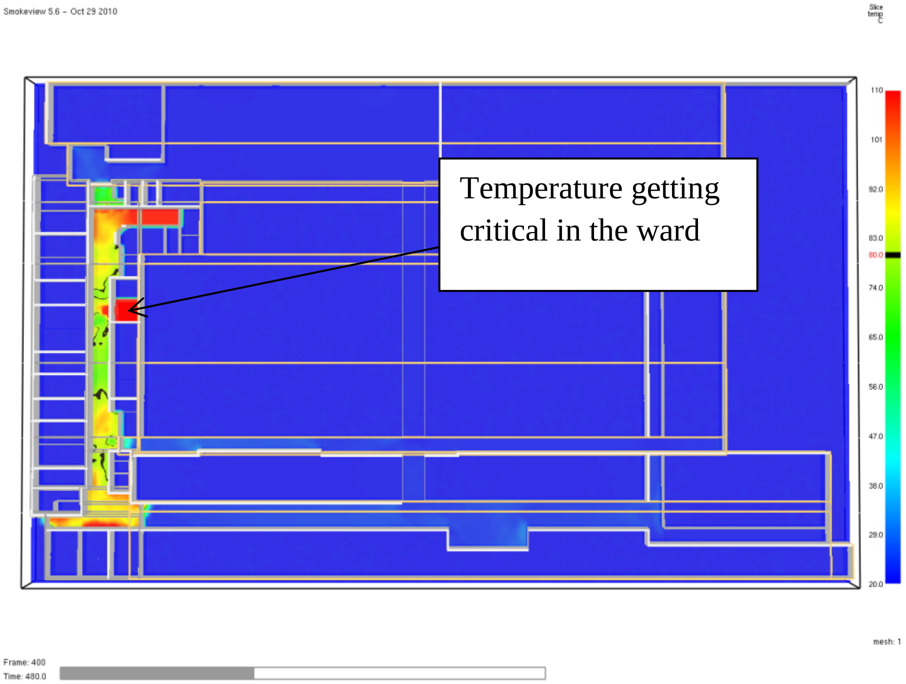


Figure 10. The temperature 2 meters above floor level after 6 minutes. The colorbar on the right side represents temperature in °C. Black color represents critical temperature, 80 °C and yellow-red represents temperature higher than 80 °C.



Temperature getting critical in the ward

Figure 11. The temperature 2 meters above floor level after 8 minutes. The colorbar on the right side represents temperature in °C. Black color represents critical temperature, 80 °C and yellow-red represents temperature higher than 80 °C.

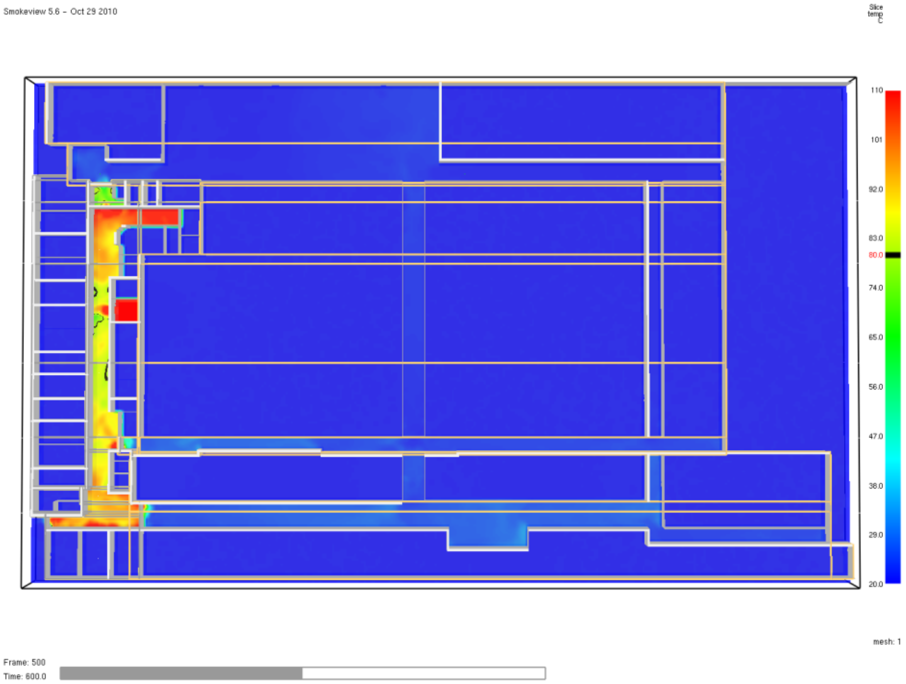


Figure 12. The temperature 2 meters above floor level after 10 minutes. The colorbar on the right side represents temperature in °C. Black color represents critical temperature, 80 °C and yellow-red represents temperature higher than 80 °C.

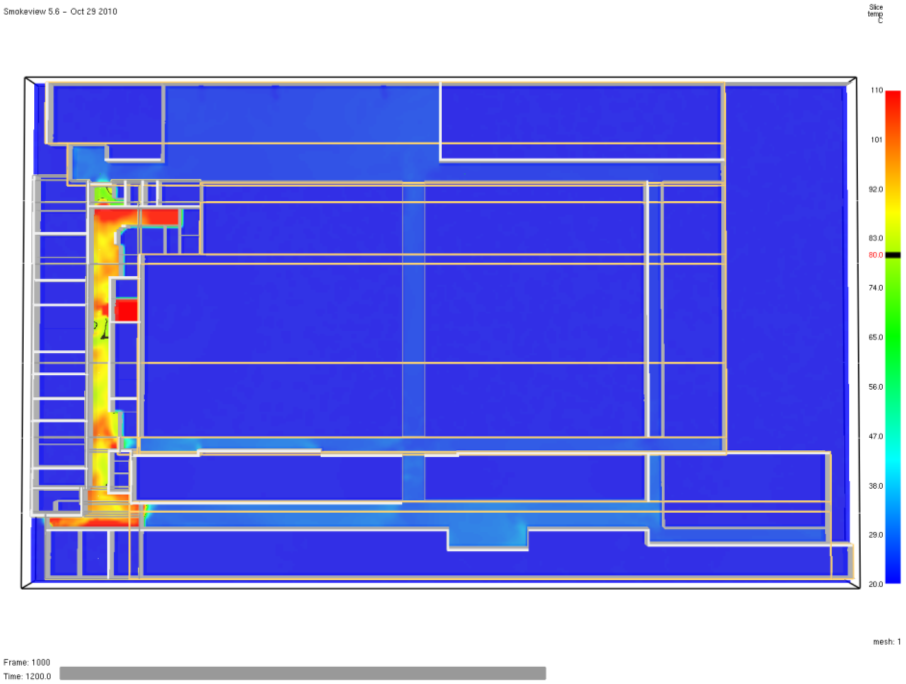


Figure 13. The temperature 2 meters above floor level after 20 minutes. The colorbar on the right side represents temperature in °C. Black color represents critical temperature, 80 °C and yellow-red represents temperature higher than 80 °C.

Appendix 4: Evacuation calculations

In this appendix, the evacuation calculations are discussed. As pointed out in Section 6.4, the evacuation time has been divided up to:

4. Detection time
5. Reaction time
6. Travel time

The evacuation time can then be described by the following equation:

$T_{Evac} = T_{Detect} + T_{React} + T_{Travel}$

It is assumed that detection time is 60, 90 or 120 seconds, depending on AFAS functionality and time of day. Reaction time has been estimated 20 seconds and the equation in Subsection 6.4.3 has been used as basis for the travel time:

$t_{travel} = (t_{staffm} + t_{care} + t_{patm} + t_{queue}) x (No_{pat}/No_{staff})$

where:

t_{staffm} = The time it takes the personnel to reach the patient in the nursing room

t_{care} = The time it takes to prepare the patient for transportation

t_{patm} = The time it takes to move the patient to a safe location

t_{queue} = The time the personnel and patients queue at the exit.

For the evacuation being successful, it has to be over before critical conditions described in Appendix 3 arise in the ward of infectious diseases and adjacent corridors. As the time to critical conditions is not the same at the burning ward and the corridors the evacuation calculations have been divided up to two analyses, first considering only the burning ward and second, other areas on the second floor of the Treatment Center building. First we look at the ward of infectious diseases.

Evacuation – Burning ward

The exact number of patients and staff is not known exactly and therefore some assumptions have been made. The basis for the evacuation calculations are shown below:

Number of patients:	14
Number of staff, day/night:	10/5
t_{staffm}:	30
t_{care}:	30
t_{patm}:	40
t_{queue}:	No queuing as it is assumed that all escape routes are available.
No_{pat}/No_{staff} ,day/night:	1,4/2,8 (2/3)

The travel time is then calculated as 140 seconds during the day and 280 seconds during the night.

The Evacuation time varies with the functionality of the AFAS, as well as time of day. Ranging from 220-420 seconds as seen in the Event trees in Appendix 2.

Evacuation – Outside the burning ward.

The exact number of patients and staff is not known exactly and therefore some assumptions have been made. The basis for the evacuation calculations are shown below:

Number of patients:	150
Number of staff, day/night:	57/28
t_{staffm}:	30
t_{care}:	30
t_{patm}:	40
t_{queue}:	No queuing as it is assumed that all escape routes are available.
No_{pat}/No_{staff} ,day/night:	3/6

The travel time is then calculated as 300 seconds during the day and 600 seconds during the night.

The Evacuation time varies with the functionality of the AFAS, as well as time of day. Ranging from 410-740 seconds as seen in the Event trees in Appendix 2.