Simulation of critical evacuation conditions for a fire scenario involving cables and comparison of two different cables

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Abstract
Previous studies on the evaluation of irritant species from burning cables in a modified prEN 50399 fire test produced FEC/FED values based on ISO TS 13571. However, the ISO standard mentions in its scope that these indices can only be used within e.g. modelling. For this reason Europacable (ECBL) initiated a preliminary case-study to asses the possibility of using modern fire safety engineering techniques. The scope of the project was the evaluation of the evacuation conditions for a realistic fire scenario involving two types of cable fires that produce different levels of heat, smoke and gases. Both CFD (Computational Fluid Dynamics) modelling by means of the software package FDS (Fire dynamics simulator) and evacuation modelling by means of the software package Simulex were performed. The results were used to calculate FED (fractional effective doses) and FEC (fractional effective concentration). The results showed that the developed methodology allows evaluation of critical evacuation conditions based on not only temperature and visibility, but also on gas composition. One of the selected cables created critical conditions for some of the occupants during evacuation for the chosen design fire when the production of irritant gases (HCl, acreolein, Formaldehydes) is considered.

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Preface

This report describes the research performed within a pre-study sponsored by Europacable. Europacable – is the abbreviation of "The European Confederation of National Associations of Manufacturers of Insulated Wire and Cable". Founded in 1991 Europacable is the European platform for cable manufacturers and the voice of the industry towards the European Commission in Brussels. The main missions are the promotion of the use of cables, the promotion of wire and cable technology which reflects state of the art safety and ecological aspects in all fields of application ranging from enamelled wires, general wiring cables for construction and industrial applications, energy cables, data and control cables to metallic and optical fibre telecommunication cables. Europacable represents approximately 90 % of the European industry and, through National Associations, more than 200 individual cable manufacturers. Europacable is a Co-operating Partner of Cenelec and Supporting Associate of IWCS. The authors would like hereby thank the sponsors of this project for the useful information provided.

Lund, 19 May 2010.

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Summary

Previous studies on the evaluation of irritant species from burning cables in a modified prEN 50399 fire test produced FEC/FED values based on ISO TS 13571. However, the ISO standard mentions in its scope that these indices can only be used within e.g. modelling. For this reason, Europacable (ECBL) initiated a preliminary case-study to asses the possibility of using modern fire safety engineering techniques to compare two types of cable fires based on fire performance data. The scope of the project was the evaluation of the evacuation conditions for a realistic fire scenario involving two types of cable fires that produce different levels of heat, smoke and gases. The evaluation is based on modern fire engineering principles that are used in performance based fire safety design. First, a typical building was chosen and the fire scenario was defined. Two cables were proposed by ECBL as input for the choice of the fire scenario. Then CFD simulations were performed using input data generated from prEN 50399 fire test plus effluents analysis (by FTIR). For the CFD simulation the freeware program FDS, which has been developed by NIST, was used. The program Simulex was used to simulate evacuation. The results from FDS and Simulex were combined to determine the FEC (fractional effective concentration) and FED (fractional effective doses) values for the building occupants during evacuation. Sensitivity analyses were performed for both the CFD and evacuation modelling to see how factors, e.g., the irritant gases and occupation of the building, influence the final outcome. The results show that the developed methodology allows evaluation of critical evacuation conditions based on not only temperature and visibility, but also on gas composition of the smoke. When comparing the two cables it can be seen that cable M creates critical conditions for some of the occupants during evacuation for the chosen design fire when the production of irritant gases (HCl, acreolein, Formaldehydes) is considered. In practice, this means that the fire safety engineer needs to find other solutions by either choosing other cables or other active systems (e.g. additional roof venting).

Contents

1. Introduction

A previous study on cables produced FEC/FED values from experiments performed in a modified prEN 50399[1] fire test. Data from these experiments[2,3] are used in this project. The ISO standard 13571[4] mentions in its scope that these indices produced can be only used within e.g. modelling. The standard mentions namely:

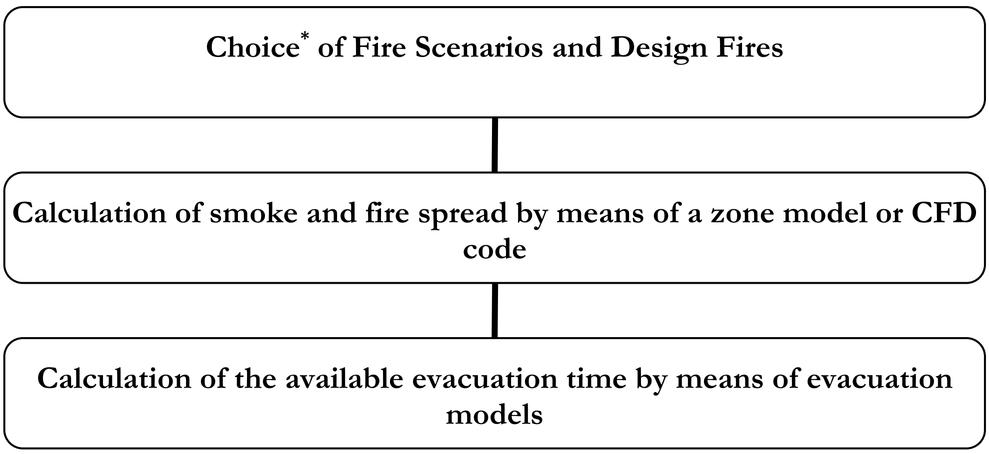
> *"It is intended to be used in conjunction with models for analysis of the initiation and development of fire, fire spread, smoke formation and movement, chemical species generation, transport and decay and people movement, as well as fire detection and suppression. This International Standard is to be used only within this context."*

This type of approach is something that was only studied very limited up to now. To explain how such an approach can be used we explain first the difference between a performance and prescriptive code, and then also explain how such an evaluation procedure can be done.

Building codes may be classified as prescriptive or performance-based. Prescriptive codes obtain their names from the fact that they prescribe specifically what to do in a given case. Performance-based codes express the desired objective or so called function to be accomplished and allow the designer to use any acceptable and well-established approach to achieve the required results or function[5]. Traditionally, general fire safety design has been highly reliant on prescriptive rules in building codes. This is particularly the situation for occupant safety in the case of fire. Detailed prescriptive building regulations have one major advantage since they are easy to use. The safety or risk is already implicitly included in the prescribed values and accepted by the regulator[6]. However there are some deficiencies associated with this type of regulations. They are, for example, rather inflexible if not applied to a standard type building or to new materials, which might not fit into the traditional test methods. These regulations, which for example, specify the maximum allowed travel distance to an emergency exit, also vary from country to country[7]. It can therefore be stated, that despite the relatively easy implementation of prescriptive regulations, they are inflexible and may lead to unnecessarily expensive buildings. As a consequence of these disadvantages, the so-called performance-based building regulations have been developed in several countries during the last three decades. At the end of eighties the first applications of fire engineering inside building design appeared and a framework for engineering practice and education was established[8].

Performance-based regulations design an objective, but do not say how it should be accomplished[6]. It is possibly a widespread misunderstanding that calculation procedures must be used to design fire safety measures that fulfils performance-based regulations. This is not true, as the method used to satisfy the regulation actually has nothing to do with the actual requirement. Performance-based regulations do not recommend any particular design method above another. Calculation methods have, however, become more frequent in the verification of the requirements stipulated e.g. for verification of safe evacuation.

Safe evacuation is also one of the key requirements for occupant safety. The procedure commonly used and explained here is quite common but it should be stipulated that it is not the only procedure that can be followed. As earlier stated fire performance based design is based on fulfilling a requirement by using a procedure selected by the designer. The designer is, however, in most cases forced to adopt a nationally or internationally accepted design procedure. The most common procedure, a deterministic or scenario based approach, is that specific fire scenarios are chosen from the risk assessment of the building. The risk assessment includes aspects such as type of building, type of occupancy, etc. The resulting fire scenarios contain information on the possible fire sources, the geometry, the ventilation conditions, the presence or absence of active systems, etc. A major item in each fire scenario is the choice of the so called design fire, which will be discussed below. With the known fire scenarios a calculation is then performed for each of them, which results in smoke and fire spread inside the building. Outcome of this smoke and fire spread calculation is then used in an evacuation model to calculate whether safe evacuation of the building can occur. This is obtained by comparing the available evacuation time from the model with the required evacuation time in the building code. A simple schematic is given in Figure 1. The input data used in the evacuation models are mostly the smoke flow, temperature and smoke opacity data (based on soot and or temperature). It is however also possible to use content of smoke to introduce irritant gas data in the evacuation model. An alternative to the deterministic approach a probabilistic procedure may be used. This has a lot in common with traditional Quantitative Risk Analysis (QRA) procedures adopted in for example the chemical process industry. The difference is now that risk has to be dealt with explicitly in terms of probability and consequences. This procedure is, however, not frequently used and will therefore not be further treated.



* How the choice is allowed to be made may be regulated in each country.

Figure 1. Schematic of deterministic FSE method for safe evacuation[19]

The choice of the design fire characteristics is important in this procedure since an error or misjudgement of it will propagate the error in the succeeding calculations predicting an inaccurate evacuation time. Design fires are often given as a heat release curve as a function of time. The way of obtaining design fire is e.g. given in ISO 13387[9], ISO 16733[10] or in a number of publications[11,12]. The design fire commonly includes three phases. The first one is a growing fire represented as a so-called "α-t square" curve where the α-value defines the fire growth rate, e.g., in kW/s^2. The first phase is then followed by a constant phase representing the fully developed fire and a decay period. Both the maximum values and the time the decay starts depend on a lot of factors such as available fire load, ventilation, availability and activation of active system etc. An example of a design fire is given in Figure 2.

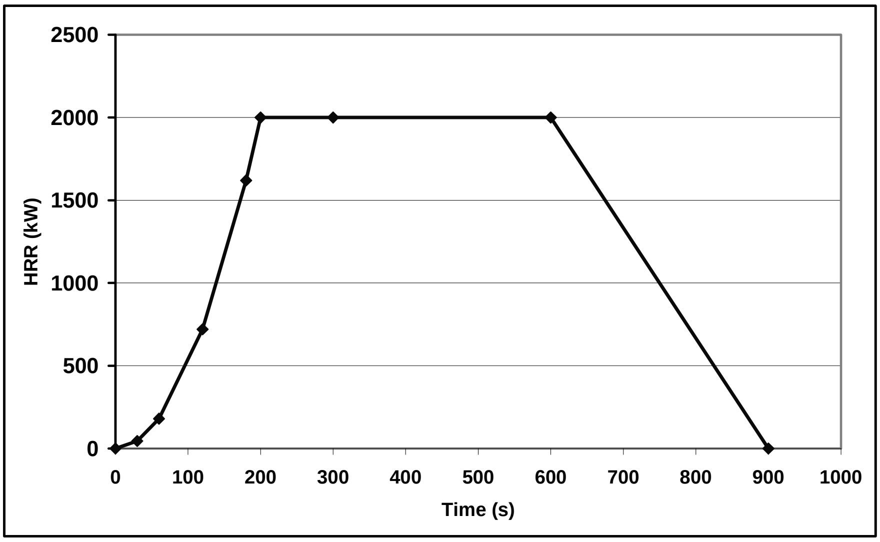


Figure 2. Example of a Design Fire

An important factor in the design fire is the fire characteristics of the building products and content. Building products are e.g. wall and ceiling linings, floor covering, insulation materials, cables etc. Building content are items of furniture, electrical equipments etc. The choice of the design fire can be either by using template numbers such as given in ISO 13387[9], ISO 16733[10] or in building codes. Another approach is to obtain the data via a combination of testing and modelling. The design fire can namely be obtained using for example one of the following options:

1. Real scale test of the fire scenario including items of building products and content.
2. Combination of HRR data of items of building content and building products obtained in full scale test data using so called open calorimeter techniques
3. Modelling by means of empirical models using small-scale test data such as given from the cone calorimeter test.
4. Modelling by means of flame spread models within advanced CFD codes.

As can be understood there are a lot of different possible routes. When data from scenario tests are available, such as prEN 50399[1], it is good to have this approach to start with.

1.1. Scope

The scope of the project is the evaluation of the evacuation conditions for a realistic fire scenario involving two types of cable fires that produce different levels of heat, smoke and gases. The evaluation is based on modern fire engineering principles that are used in performance based fire safety design and will investigate the feasibility of using these techniques.

1.2. Methods

First a typical building was chosen and the fire scenario was defined. Two cables, which represented cables commonly used in buildings, were proposed by Europacable as input for the choice of the fire scenario. Then CFD simulations were performed using input data generated from prEN 50399[1] fire test plus effluents analysis by FTIR[3,13]. For the CFD simulation the freeware program FDS[14,15] which has been developed by NIST, was used. The program Simulex[16] was used to simulate evacuation. The results from FDS and Simulex were combined to determine the FEC and FED values for the building occupants during evacuation. Sensitivity analyses were performed for both the CFD and evacuation modelling to see how factors, e.g., the irritant gases and occupation of the building, influence the final outcome.

1.3. Schematic of the procedure

Figure 3 below gives a schematic view of the procedure used in this research project. Each step will be explained in the next chapters.

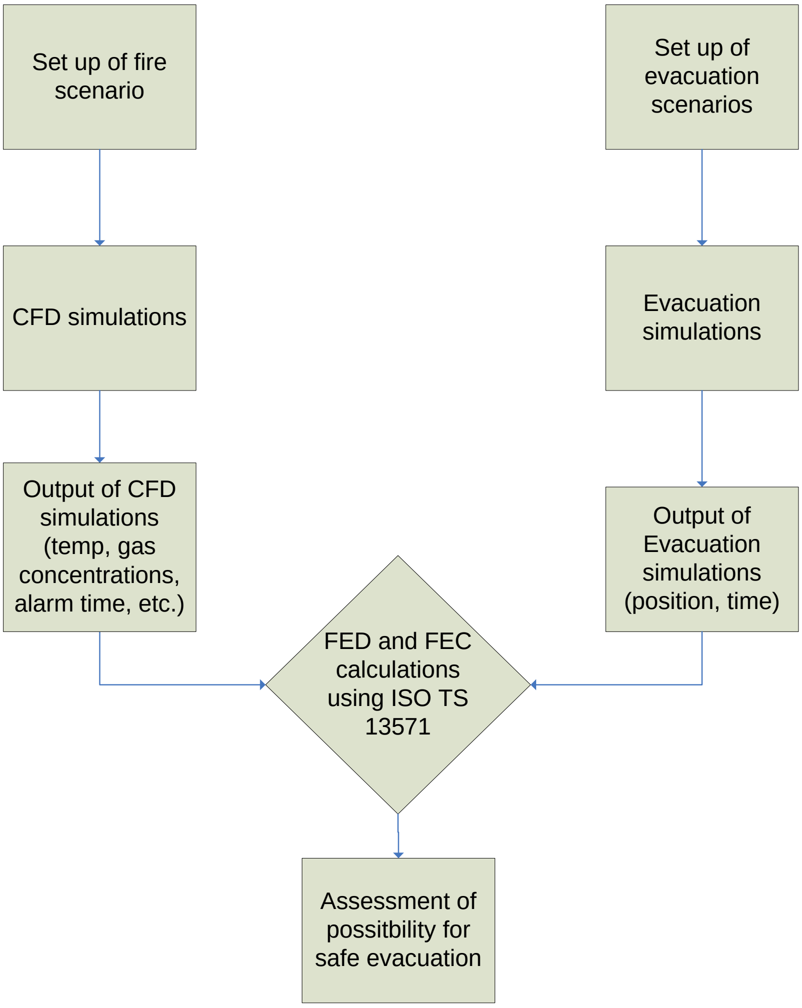


Figure 3. Schematic overview of the procedure

1.4. Limitations

This report is intended to be a pre-study to investigate the feasibility of using also the content of the smoke gases in addition to temperature and opacity for determining the critical conditions during evacuation. As such there are a number of limitations. These limitations can be summarised as follows:

- As realistic fire scenario only one type of building has been chosen.
- Comparison was made only between 2 cables obtaining Euroclass D in the recent established Euroclass system for cables.
- State of the art CFD modelling has been used in this project by means of the CFD code FDS but modelling the production of irritant gases is still limited in the code as well as a clear view on which input data has to be used. The spread of irritant gases inside the building was modelled by using a source term linked to the CO spread of the fire and should as such be considered as not changing depending on the detailed and complex reaction schemes which are often occurring during fires. Moreover there has been done a limited grid sensitivity analysis and no extensive validation of the spread of irritant gases e.g. HCl has been done with FDS. Input data to the CFD simulation was based on single test data from the intermediate cable fire test according to prEN 50399. This means that no real uncertainty of the input data is available which is especially sensitive for the content of gases and the soot yields. Irritant gas data and soot yields are namely very much depending on the ventilation conditions in intermediate scale tests and sensitivity analysis need to be done.
- State of the art evacuation modelling has been used in the project by means of the evacuation code Simulex. This model has certain limitations with respect to human behaviour as well as interaction between evacuation behaviour, e.g., travel speed, and content of smoke gases. The evacuation modelling has also been done without taking into account the presence of occupants with reduced moving capacities.
- For both CFD and evacuation modelling certain simplifications have been made to the geometry.

2. Selection of scenarios

This chapter describes the scenario used in the study to examine critical evacuation conditions for fire scenarios involving cables and comparison of different cables.

The major requirements for the scenario are:

- a public building with a multifunctional activity
- a realistic building for which a FSE (fire safety engineering) evaluation could be done
- the existence of fire risk related to cables
- availability of earlier simulation of fire or evacuation
- a population for which real exposure to gases can be expected
- a population for which a sensitivity analysis can be done with respect to number of people and position of people
- existence of real experiments either with respect to fire (connected to experimental fire tests) or evacuation (data from evacuation exercises)
- no complex situation for either fire or evacuation simulation

As it can be understood it might be difficult to find a specific case which incorporates all requirements but the proposal given comprises as many as practicable possible.

2.1. Description of building

The selected building is a three storey building at the Department of Economics at Lund University. It has reference EC3 and contains following functions:

- restaurant at ground floor containing an atrium up to the first floor
- large lecture rooms at ground and first floor
- smaller meeting rooms at the first floor
- a balcony within the atrium at the first floor that is connected to the ground floor with two separate stairs, see Figure 4
- a kitchen connected to the restaurant (electrical oven, stove, etc.)
- a fire detection system connected to the fire alarm

The total number of occupants in the building may range from approximately 200 and 500 depending on how it is used (lectures, shows, meetings, etc). Real evacuation experiments have been performed in the building, which means that there is data about exit choice and human behaviour in fire emergencies. Figure 4 to Figure 6 show some pictures of the building. There are also plan views form the ground floor and the first floor, see Figure 7 and Figure 8 gives a comparison of this building with the requirements given above. From the comparison between requirements and properties of the building in Table 1 we could conclude that the building was certainly appropriate to run the project. A major advantage of using this building was the availability of real scale evacuation exercises which assisted in the design of the evacuation scenarios.

Figure 4. View from first floor, staircase 1. On the right you see the emergency exit of the first floor that is a part of the atrium and where occupants can be exposed to fire gases when a fire starts on the ground floor.

Figure 5. View of the balcony exit on the first floor

Figure 6. View of the ground floor with the exit stair case

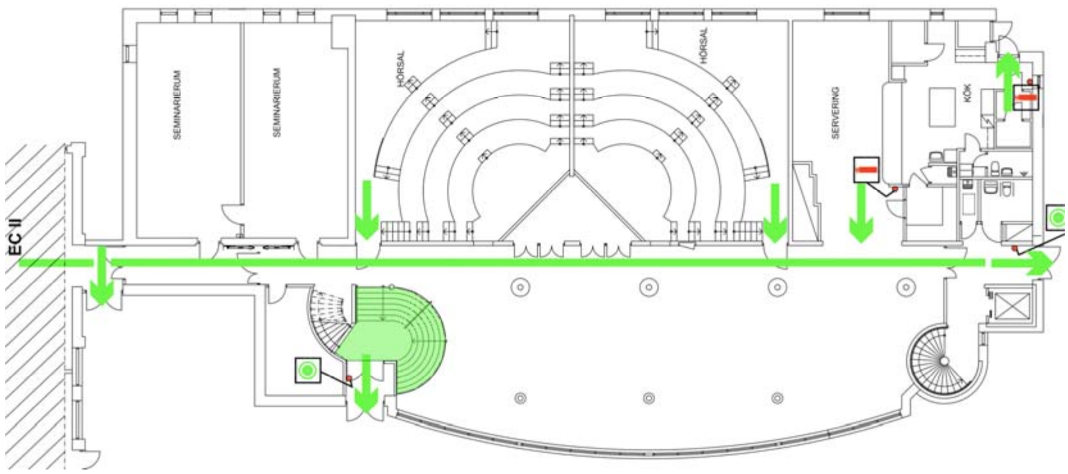


Figure 7. Plan view of the ground floor with exit routes

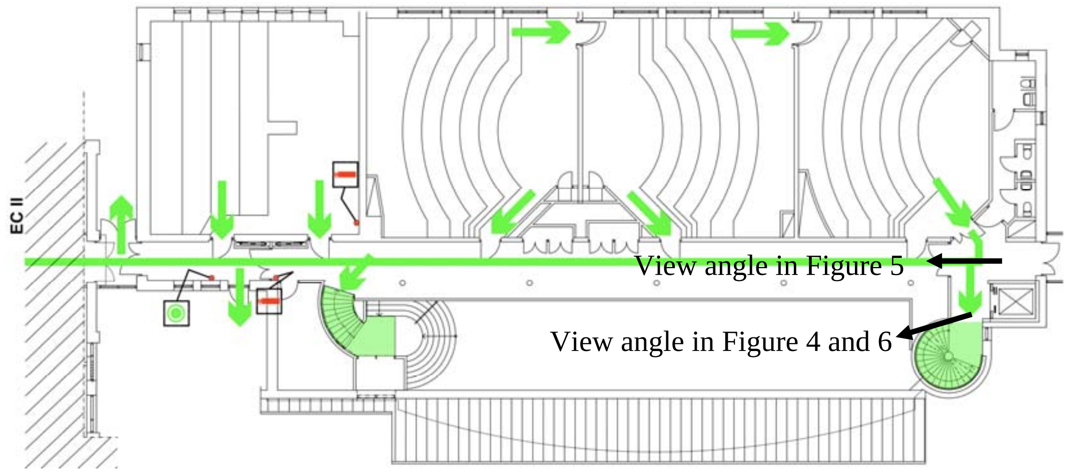


Figure 8. Plan view of the first level with exit routes (including view angles for Figures 4, 5 and 6)

Table 1. Overview of the requirements for the fire scenario and results of the comparison

Requirement	Result	Comment
a public building with a multifunctional activity	Yes	Both offices, restaurant and lecture/conference rooms are present as well as an atrium where people are present nearby ceiling level
as close as possible to a realistic building for which a FSE evaluation could be done	Yes	Building used at Lund university
existence of fire risk related to cables	Yes	Cables are present in the restaurant area as well as electrical cabinets
availability of earlier simulation of fire or evacuation	Partially	Evacuation simulation have been performed
have a population for which real exposure to gases can be expected	Yes	Both at the second level and at the gateway/platform at the first level nearby the atrium ceiling, exposure should be considered
have a population for which a sensitivity analysis can be done with respect to number of people and position of people	Yes	During different periods of the day/week/year the population can vary from xx to yy
Existence of real experiments either with respect to fire (connected to experimental fire tests) or evacuation (exercises with data from evacuation exercises)	Partially	Evacuation exercises have been done but of course no fire tests. The evacuation exercise can give us a reference for evacuation modelling without presence of smoke and heat and can give us useful information for submodels
No complex situation for either fire or evacuation simulation	Yes	The building is relatively easy to model in CFD of course by simplifying some of the geometry. For evacuation modelling there are no complex behaviours which could occur e.g. as in hospitals

2.2. Description of fire scenario

2.2.1. Position of the fire source

Before choosing the position, a sensitivity analysis was first done comparing three possible positions of the fire by means of 3 CFD simulations using a constant HRR of 500 kW. The three positions were (see also Figure 9 from left to right):

1. under the balcony and at the position were electrical cabinets are placed (left picture)
2. inside the kitchen area at the ground floor. This position would represent a fire e.g. in the electrical apparatuses within the kitchen. (middle picture)
3. just outside the kitchen area and at one of the exits. (right picture, area beneath the picture)

Since data from the vertical tests according to prEN 50399, performed earlier by ECBL will be used, it was decided to simulate a vertical tray fire. (position 3)

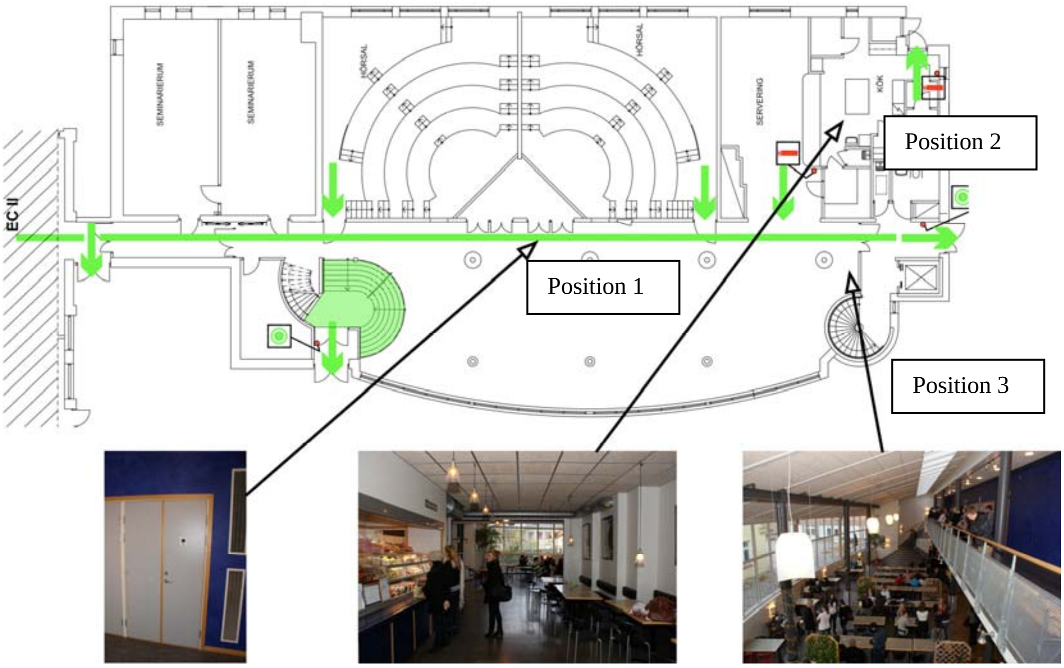


Figure 9. Position of the possible location of cable fires

From this sensitivity analysis it could be concluded that the worst conditions for evacuation were obtained for a fire scenario start with a cable fire in the restaurant area close to the kitchen (position 3) and creating a rising plume in the atria. The explanation is that this fire produce quickly smoke to the upper balcony where it is know that people will queue and will also have a clear plume nearby one of the emergency exits at the balcony which will lead to the fact that people will evacuate to the staircase at the other end of the balcony.

2.2.2. Type of fire source

Two cables from a previous Europacable study[2,3] were used, namely cables called I and M. The main difference between the two cables is the type and amount of species produced during combustion. Output data from tests in this Europacable study[2,3] were used in the simulation. With respect to the choice of cable it should be considered that the cables are the same Euroclass D but that they differ in HRR, smoke production and content of gases. Other combination or comparisons can be done at the second stage of the project. Table 2 to Table 4 give data on cable characteristics and content of smoke gases. Figure 10 and Figure 11 give an overview of the heat release rate curves from the prEN 50399 test. Both the figure and data in tables are a citation from the test results conducted in a previous study[2,3].

Table 2. Overview of cable characteristics [2,3]

Code	Type	Cross section	Diameter	colour	n° Specimens in prEN 50399	Distance between cables in prEN 50399
I	Non Halogenated	3G1,5mm²	10 mm	Green	15	10 mm
M	Halogenated	3G1,5mm²	9 mm	Black	17	9 mm

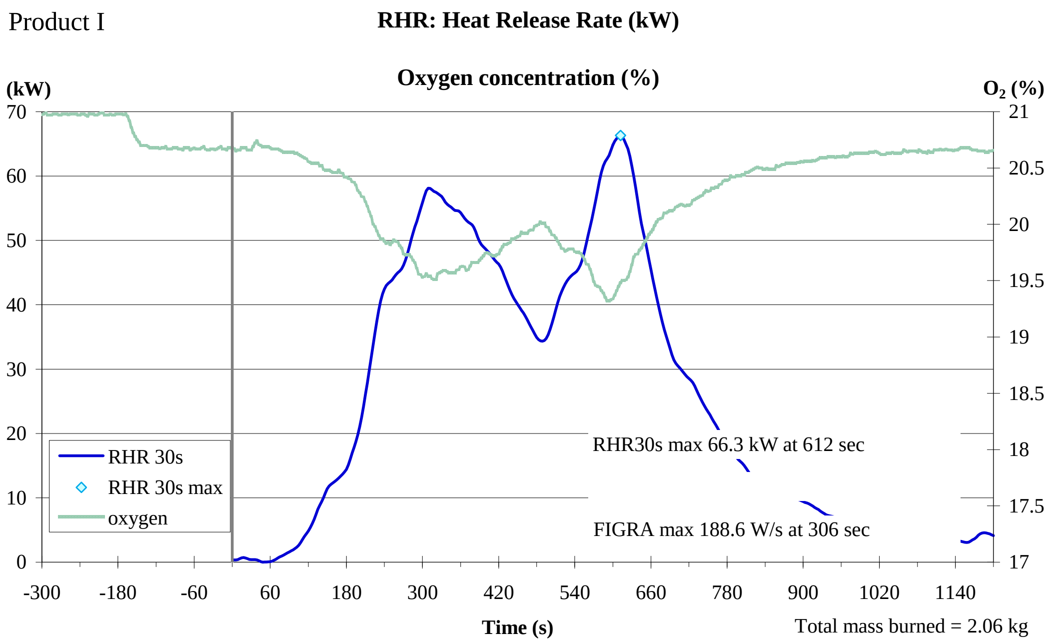


Figure 10. Heat release curves for cable I[2,3]

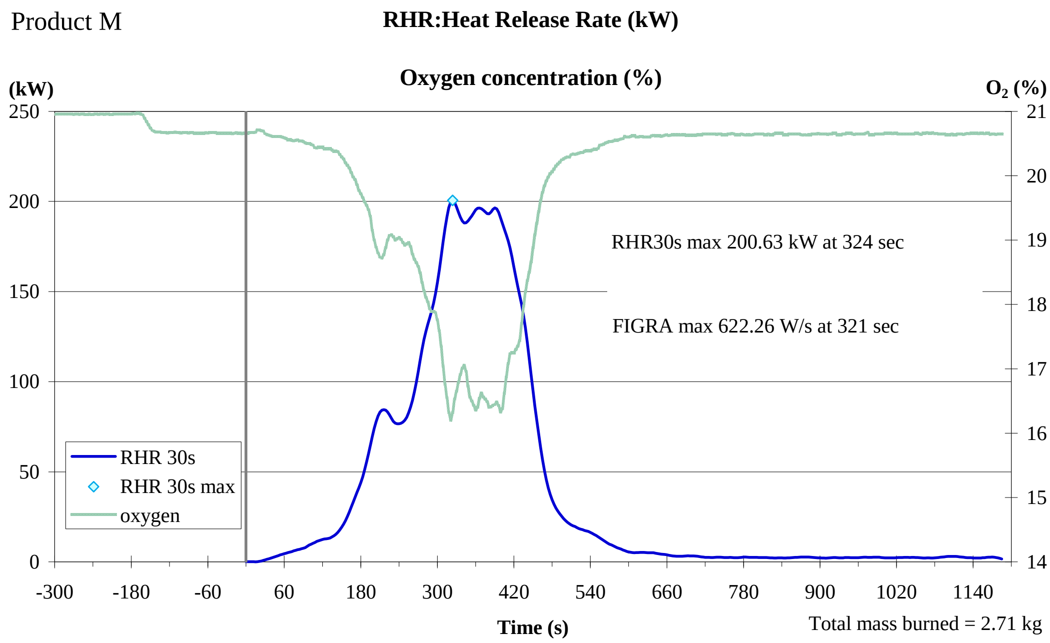


Figure 11. Heat release curves for cable M[2,3]

Table 3. Gas production data for cable I[2,3]

GAS			Peak of production		Total production (g) at			
		Detected	(g/s)	(s)	5 min	10 min	15 min	20 min
CO_2	Carbon Dioxide	Yes	3.990	330	239.39	882.38	1155.5	1282.9
CO	Carbon Monoxide	Yes	0.022	330	2.184	7.267	11.521	12.483
C_3H_4O	Acrolein	Not						
CH_2O	Formic Aldehyde	Not						
HCl	Hydrogen Chloride	Not						
COF_2	Carbonyl Fluoride	Not						
SO_2	Sulphur Dioxide	Not						
NO_x	Nitric Oxides	Not						
HCN	Hydrogen Cyanide	Not						
HBr	Hydrogen Bromide	Not						
HF	Hydrogen Fluoride	Not						

Table 4. Gas production data for cable M[2,3]

GAS			Peak of production		Total production (g) at			
		Detected	(g/s)	(s)	5 min	10 min	15 min	20 min
CO_2	Carbon Dioxide	Yes	7.274	300	795.99	1497.1	1497.1	1497.1
CO	Carbon Monoxide	Yes	0.774	300	103.6	149.9	151.3	152.4
C_3H_4O	Acrolein	Yes	0.046	300	3.296	5.807	6.516	6.516
CH_2O	Formic Aldehyde	Yes	0.110	315	4.482	9.504	9.504	9.504
HCl	Hydrogen Chloride	Yes	0.861	300	128.8	190.6	196.4	200.0
COF_2	Carbonyl Fluoride	Not						
SO_2	Sulphur Dioxide	Not						
NO_x	Nitric Oxides	Not						
HCN	Hydrogen Cyanide	Not						
HBr	Hydrogen Bromide	Not						
HF	Hydrogen Fluoride	Not						

2.2.3. Fire duration

From the evacuation exercises performed earlier in the building a fire duration of 20 minutes was chosen. The motivation is that this time is more than sufficient to investigate the whole evacuation period observed in the above mentioned experiments.

2.2.4. Occupants

The people present at the building represent a busy day at the university and are quite often present at different places especially at the lecture room with exit to the balcony at the first floor within the atrium. The values of a busy day were used as start value in order to increase and decrease in the sensitivity study. This can be achieved by increasing the people in main lecture rooms and restaurant. More details of the occupation are given in the chapter on evacuation modelling.

3. CFD simulations

3.1. Resources

The CFD simulations were performed at the Lunarc cluster using a multiprocessor version of FDS, dated 24th of December 2008 (5.2.5 Parallel, SVN Revision No. : 2945). Lunarc is a centre for scientific and technical computing for research at Lund University. The centre provides computational resources for academia in Sweden within all aspects of computational science. Lunarc has been in operation since 1986. The centre has different clusters. For this project the Milleotto cluster was used. This cluster is composed of 252 nodes with 4 processors per node. Each processor is an Intel Xeon 5160 with a clock frequency of 3.0 Ghz. The memory is 4 GB per node and the system was started up in March 2007. The original FDS source code was compiled with an Intel compiler (Intel 10) and an MPI library. Parallel calculations were used in order to reduce each simulation time to approximately one week.

3.2. Geometry and mesh

The geometry was represented as good as possible with as much as possible details. The major simplification made as the approximation of the ceiling in the atrium by means of a sawtooth approximation. This is necessary due to the fact that FDS can only have rectilinear meshes[15]. However FDS has an option to correct the flow at such surfaces so that it represents as much as possible a smooth area In total, 10 meshes were used in order to have an optimum values between size of cells at different places and total number of cells in the whole calculation domain. In the vicinity of the fire location the size and number of cells were according to the recommendations in the FDS user manual. For the size of cells in those areas were we would expect long exposure times for the occupants a size cell of 10 by 10 cm was used. This was value was taken as it can be compared to the amount of air a person will take in during a short breath. The sampling time was for this reason also taken as 10 s i.e. to get an averaging corresponding with a normal breathing rate. Figure 12 and Figure 14 show both the geometry used and the different meshes.

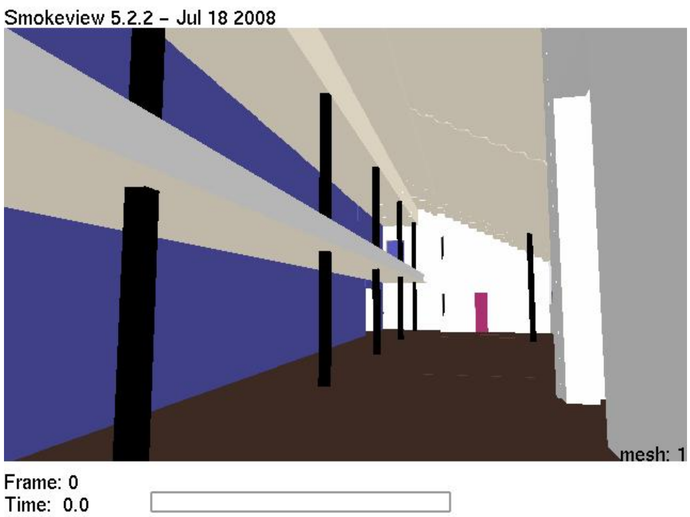


Figure 12. Overview of the geometry used

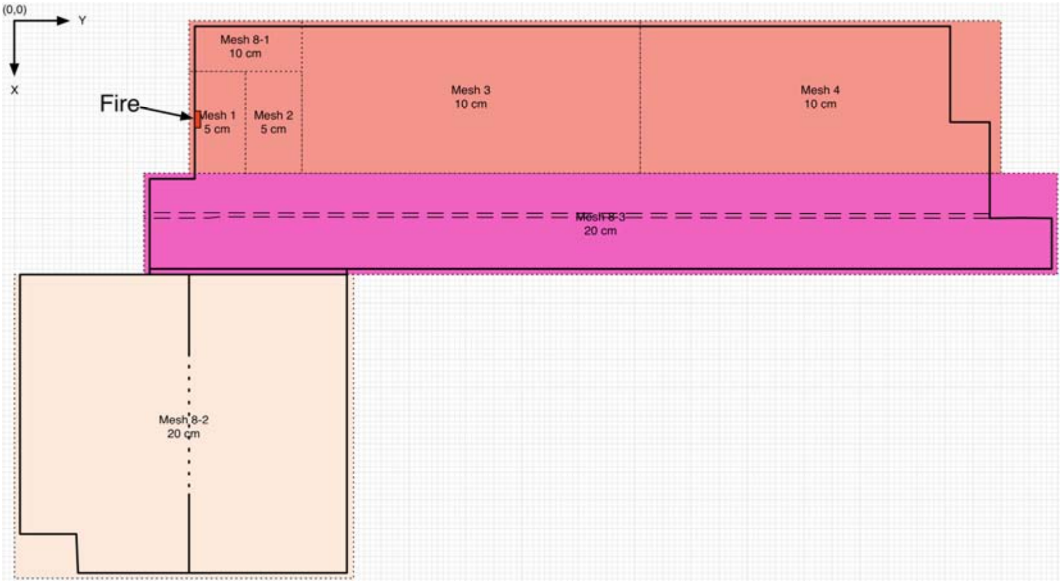


Figure 13. Overview of the different meshes on the ground floor

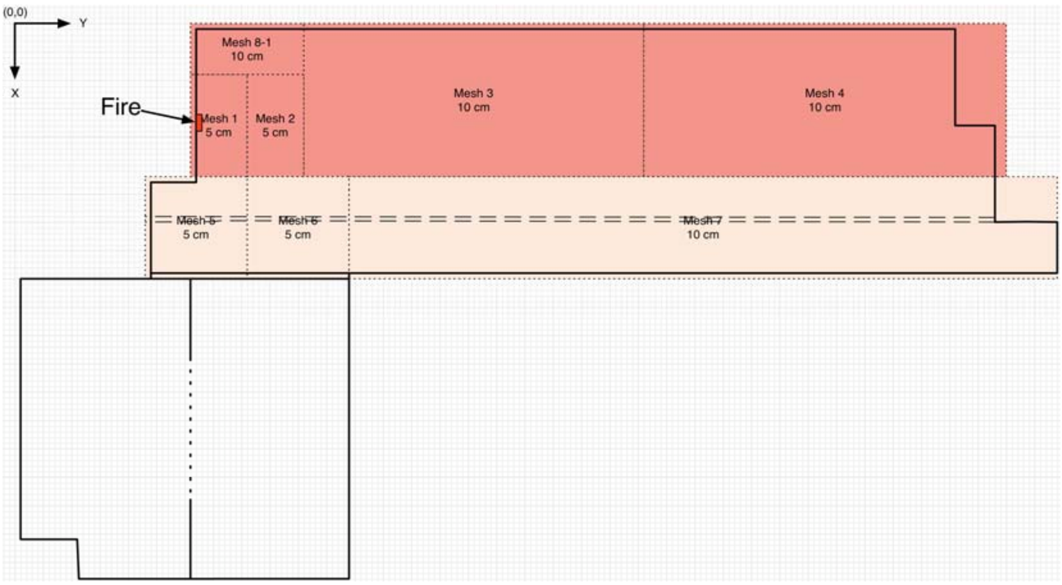


Figure 14. Overview of the different meshes on the first floor

3.3. Boundary conditions

Two open boundaries to the atmosphere were used for inlet of the air. These were located nearby the kitchen and nearby the emergency exit at the ground level (opposite to the location of the fire) and allow for air entering in the calculation domain. No other openings e.g. in the ceiling were made since the building has no smoke venting openings in the ceiling of the atrium. The conditions during the fire are so that it rather well ventilated during the 1200 s simulation time. This is motivated by the fact that the building has both a large volume and considerable mechanical ventilation and that the fire (see 3.4) is rather limited (maximum value of 500 kW).

Other boundaries were the walls of the building for which either a material corresponding with concrete or glass was used. Information of the boundary conditions for the fire is given in the next paragraph.

3.4. Description of the fire

First the actual design fire was chosen in correspondence with state of the art techniques, namely a αt^2-curve (see Figure 2). The maximum value of 500 kW was chosen based on the preliminary runs and based on cable M as a reference. The first motivation is that this value is sufficiently to produce smoke filling in the upper parts of the atrium. The second motivation is that for cable M it would correspond with a representative number of about 40 cables, which would be installed in a wide cable tray. This would then correspond to a HRR of approximately a cable tray with a double width of the one used in prEN 50399. One cable tray with 20 cables in prEN 50399 corresponds with a maximum HRR of approximately 250 kW, so two cable trays would correspond with 500 kW. A maximum value of 500 kW is also around the value of a flame propagation of 3 m in the prEN 50399 test.

As α in the αt^2-curve it was decided to use the actual HRR data from the cables. That means that both FIGRA and maximum HRR and time to maximum HRR were used to define the α values for cable M and I. The resulting design fire was for both cables "slow or lower than slow". I should be pointed out that the α value was different for both cables since their fire growth rate is different in the prEN 50399 tests and that the fire growth certainly should not be considered as a very severe or worst case condition. The α value for cable M was $6.0 \cdot 10^{-3}$ kW/s^2 while it was $6.2 \cdot 10^{-4}$ kW/s^2 for cable I.

For the fuel properties the values of effective heat of combustion resulting form the THR and mass loss from the experiments were used. As chemical composition a poleolifin based composition for C, H and N was used for cable I while for cable M a vinylchloride composition was chosen as it can be expected that this cable is PVC based. Even soot values and CO production values were calculated using the smoke and CO production values from the experiments. For the other components (HCl, acreolein, formalaldehyde) conversion factors were introduced to calculate the concentration by means of the CO values (which in FDS is spreading as a scalar value). The conversion coefficient was calculated using the yields from both CO and the other components in the prEN 50399 tests. The conversion factor for each component is equal to the yield of the specific component divided by the CO yield in the prEN 50399 tests.

The resulting design fire was introduced in FDS as a vertical vent boundary with a fixed area.

3.5. Output data

As output data in FDS following choices were made:

- Slice files as different location in the calculation domain to give an overall view of both temperatures and flow at certain cross section in the calculation domain
- Output data as slice files and plot3D files which could be used for input to the evacuation model and contain the data for the FED and FEC calculations
- Temperature devices and soot mass fraction devices at specific locations in order to determine the activation time for the smoke detectors. For the smoke detectors the smoke density criteria was used, namely a level corresponding to approximately 10 meters of visibility.

The data presented here is the data that is needed to discuss the final results and to draw the conclusions of the research project.

3.6. Results

The results of the CFD simulation are presented in the following figures. Figure 15 - Figure 17 show a 3D picture of the soot spread for both cable M and I at respectively 300, 600 and 900 s from the start of the fire.

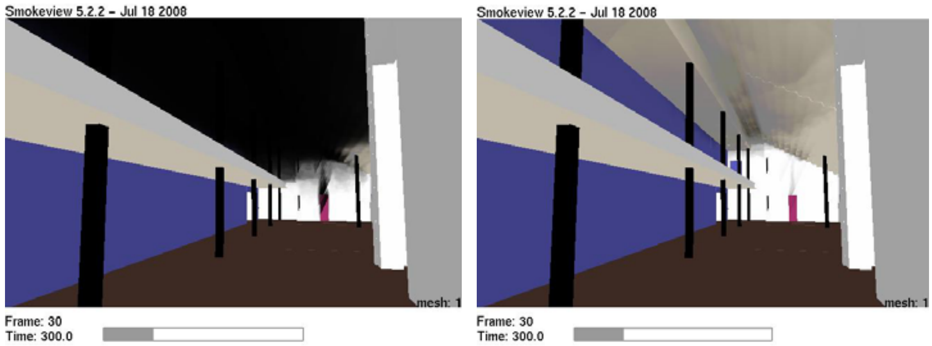


Figure 15. Comparison of soot concentration at 300s between cable M (left) and cable I (right)

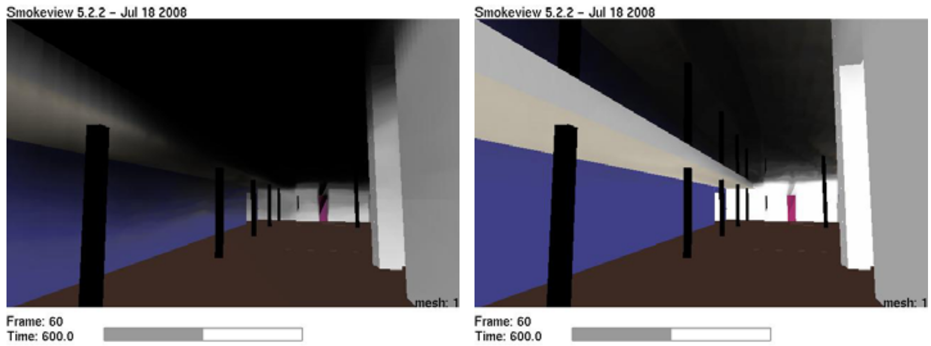


Figure 16. Comparison of soot concentration at 600s between cable M (left) and cable I (right)

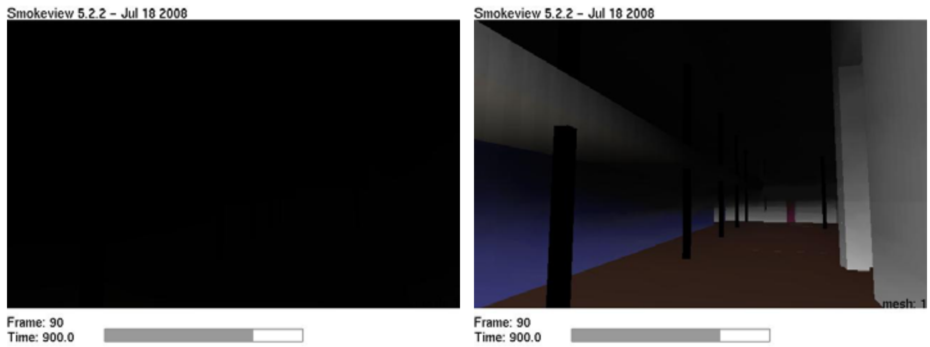


Figure 17. Comparison of soot concentration at 900s between cable M (left) and cable I (right)

An important part of the output of the CFD is the value for the time of activation of the fire alarm. For this study the smoke opacity was used as basis for detector activation and the threshold used was 10 m of visibility. This was calculated in the cell were the actual detectors in the building were located. This means that the start of the evacuation will be the time when the detector is activated in the CFD simulations plus a so called pre alarm time which was taken as 15 s. For cable M this results in an overall time of 80 s while for cable I this was 370s. Actual reaction time for the evacuation is taken into account in the evacuation simulations.

Figure 18 to Figure 20 show slice files of the temperature for both cable M and I at respectively 300, 600 and 900 s from the start of the fire.

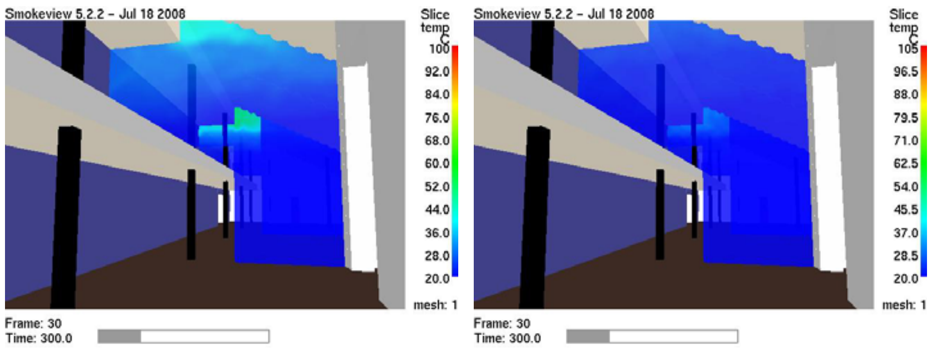


Figure 18. Comparison of temperatures at 300s between cable M (left) and cable I (right)

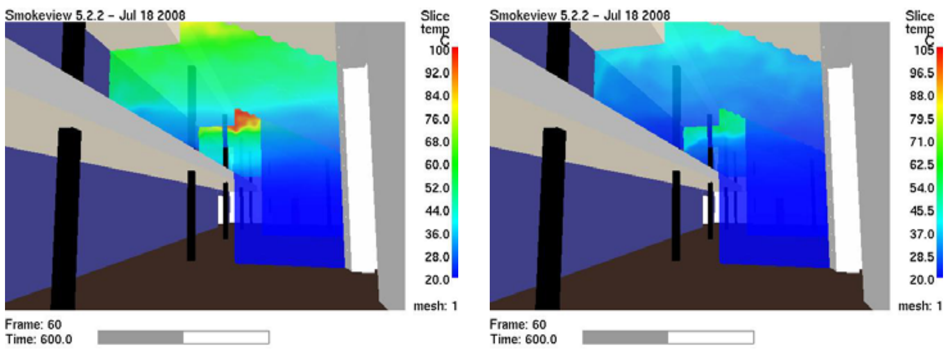


Figure 19. Comparison of temperatures at 600s between cable M (left) and cable I (right)

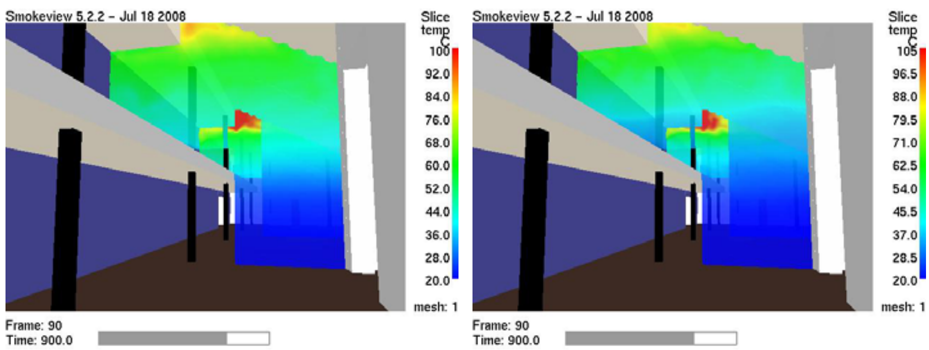


Figure 20. Comparison of temperatures at 900s between cable M (left) and cable I (right)

4. Evacuation simulations

Simulations of evacuation were performed with the egress model Simulex[16]. Six simulations with different input data, e.g., number of people and exit choice, were performed in order to investigate the importance of the underlying assumptions. Based on the simulation results a representative case was chosen for the FED and FEC calculations, which are reported in chapter 5. The following sections describe the evacuation simulations that were performed in the study.

4.1. The evacuation process

The evacuation process for each person can be represented as phases that take a certain time, see Figure 21. In the figure it can be seen that the escape time, i.e., the time from the start of the fire until the person has evacuated, can be divided into smaller parts. Before the evacuation can be commenced the fire has to be detected and the alarm has to be activated. According to section 3.6 the detection and alarm time was 370 s for cable I and 80 s for cable M. When the fire alarm has been activated the participants have to recognize the alarm and respond, e.g., prepare to evacuate. The time to do these activities is called the pre-movement time. Finally, the person travels to a safe place or an exit, i.e., the travel time. In the evacuation simulations in Simulex the pre-movement time distribution was specified in the program, which then simulated the movement of people in the building. The results in this chapter are presented as the total evacuation time, i.e., the time from activation of the fire alarm until the building is empty, and the time to empty the balcony, i.e., the time from activation of the fire alarm until the balcony is empty. This means that the detection and alarm time has to be added to get the total escape time. Also, in the FED and FEC calculations in chapter 5 it was considered that people heard the fire alarms at different times for cables I and M.

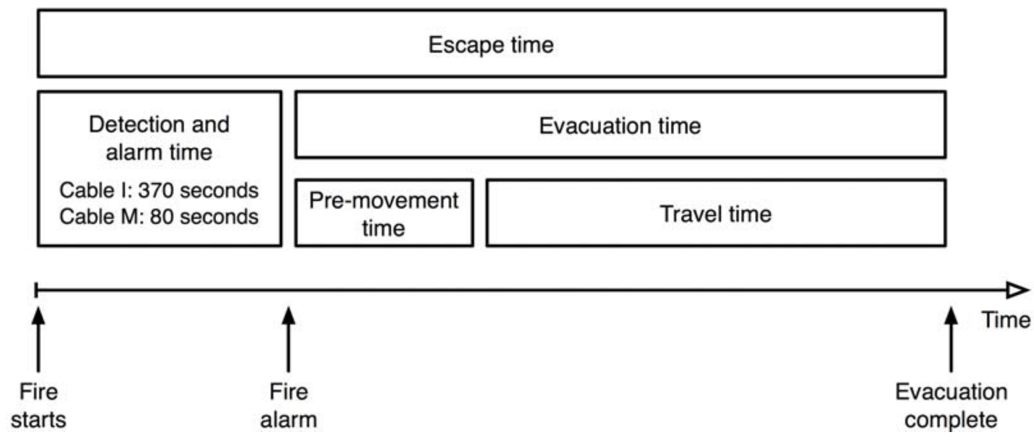


Figure 21. The evacuation process

4.2. Choice input data

The input data for the simulations in SIMULEX were, to a great extent, based on an unannounced evacuation experiment that was performed in building EC3 at the School of Economics on 9 April 2008 at 9.45. In the experiment the participants were not informed about the evacuation, which meant that the conditions were realistic and very similar to a real emergency. The fire alarm in building EC3 was a voice alarm that was activated manually at 9.45, i.e., approximately 15 minutes before the classes ended. The entire evacuation was documented with video cameras and by observers. This meant that the pre-movement time, choice of exit and movement on stairs could be properly documented. This data was also used as input in the simulations in Simulex.

Based on the experiments it was decided to use a pre-movement of 10±10 seconds. This means that a value between 0 and 20 seconds was chosen for each person in the simulations according to a uniform distribution. The pre-movement time distribution corresponds to a relatively homogeneous response to the alarm. This has also been shown to be the case in evacuations in similar settings, e.g., cinema theatres, when a voice alarm is used[17].

The default population type was chosen in all the simulations, since limited information about the people's unimpeded walking speed and the body size was collected in the evacuation experiment in building EC3. The default population type in Simulex is called *office staff* and consists of a mixture grown men and women.

CAD drawings of building EC3 were slightly modified and imported into SIMULEX to create the different floors. The modification of the drawings consisted of deleting of building parts that were not necessary or had to be removed to enable simulation in the program. The drawings were also modified slightly to enable the creation of stairs between the two floors. Figure 22 shows the geometry that was used in one of the evacuation scenarios, i.e., the ground floor and first floor of the building. The figure also shows the three exits, called *main exit*, *secondary exit* and *exit to EC2*, and the two stairs between the floors, called *main stair* and *secondary stair*.

The experiment in building EC3 showed that most people on the first floor chose to evacuate using the balcony and the stair form the balcony to the ground floor, i.e., main stair. These people then evacuated through the everyday exit of the building, called main exit, that was the most commonly used exit. Some participants used the alternative exit at the other side of the building, called secondary exit, and very few walked to the exit that leads to an adjacent building, called exit to EC2. In the simulations it was assumed that people do not want to go past the fire or plume, which meant that most people used either the main exit or the exit to EC2. Figure 23 and Figure 24 show schematic views of people's choice of exit in the scenarios. A more detailed description of the people's route choice in the different scenarios can be found in the subsequent section, see section 4.3. Figure 23 and Figure 24 also show the room names that will be used in subsequent text and tables.

In initial simulations attempts the width of the stairs from the balcony to the ground floor, i.e., main stair, was varied between 1.6 or 1.0 meters. The width 1.6 meters corresponds to the actual width of the stairs. However, because the stairs were spiral stairs it was suspected that people will not use the entire width. The result from the initial simulations with the different stair widths was compared with films from the experiment to determine what width was most appropriate to use. A reduced width of 1.0 meter was found to be most appropriate, since the flow on the stair in the simulations agreed with the flow that was observed in the experiments. A width of the main stair was therefore set to 1.0 meter in all scenarios.

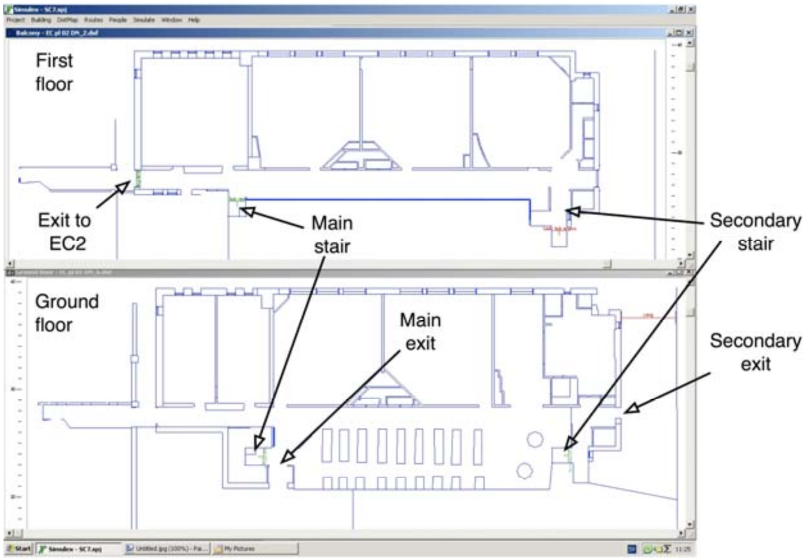


Figure 22. The geometry that was used in the evacuation scenarios (screen shot from SIMULEX)

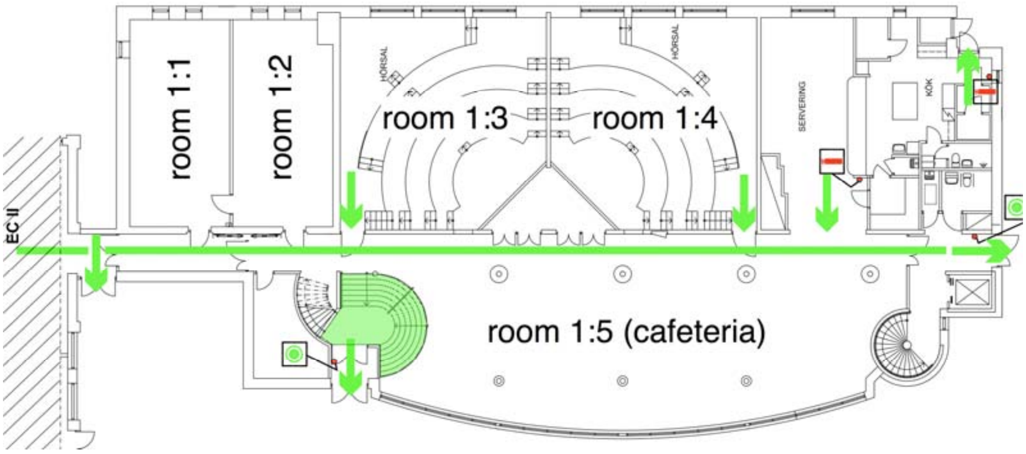


Figure 23. A schematic view of people's choice of exit on the ground floor

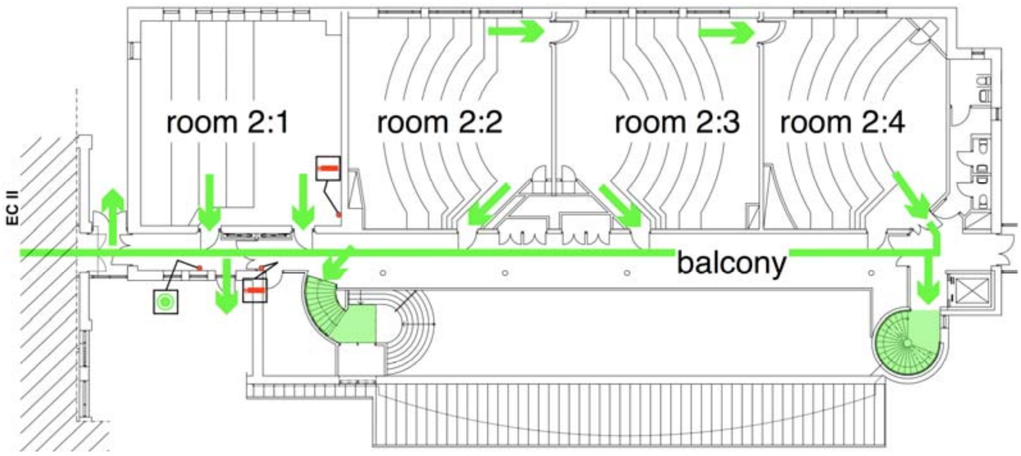


Figure 24. A schematic view of people's choice of exit on the first floor

4.3. Choice of scenarios

The six evacuation scenarios that were simulated in SIMULEX are briefly described in the subsequent sections, see section 4.3.1 to 4.3.6. Those aspects that differentiate the scenarios are people's choice of exit and the number of people in each room.

4.3.1. Scenario 1

In scenario 1 it was assumed that all the lecture theatres, i.e., rooms, were filled to maximum capacity. Furthermore, almost everyone was assumed to evacuate through the main exit. Also, everyone on the first floor, except those in room 2:4, used the main stair. Table 5 summarizes the basic assumptions of scenario 1, i.e., number of people, location of people and exit choice.

Table 5. The basic assumptions of scenario 1

Floor	Room	Number of people	Chosen exit
Ground	1:1	18	Main exit
Ground	1:2	18	Main exit
Ground	1:3	60	Main exit
Ground	1:4	60	Main exit
Ground	1:5	0	Main exit
First	2:1	35	Main exit
First	2:2	85	Main exit
First	2:3	85	Main exit
First	2:4	85	Secondary exit

4.3.2. Scenario 2

Scenario 2 represents a case when some people become impatient when they stand in line at the main stair and therefore begin to use the exit to EC2. The conditions for this scenario are similar to that of scenario 1, but it is assumed that 25 % of people on in rooms 2:1, 2:2 and 2:3 use the exit to EC2. It seems natural that more people in room 2:1 will use the exit to EC3 and it is therefore assumed that everyone in this room use the exit. Table 6 summarizes the basic assumptions of scenario 2, i.e., number of people, location of people and exit choice.

Table 6. The basic assumptions of scenario 2

Floor	Room	Number of people	Chosen exit
Ground	1:1	18	Main exit
Ground	1:2	18	Main exit
Ground	1:3	60	Main exit
Ground	1:4	60	Main exit
Ground	1:5	0	Main exit
First	2:1	35	Exit to EC2
First	2:2	75	Main exit
First	2:2	10	Exit to EC2
First	2:3	79	Main exit
First	2:3	6	Exit to EC2
First	2:4	85	Secondary exit

4.3.3. Scenario 3

Scenario 3 represents a case when many people become impatient when they stand in line at the main stair and therefore begin to use the exit to EC2. The conditions for this scenario are similar to that of scenario 1 and 2, but it is assumed that 50 % of people on in rooms 2:1, 2:2 and 2:3 use the exit to EC2. As for scenario 2, it is also assumed that everyone in room 2:1 use the exit to EC2. Table 7 summarizes the basic assumptions of scenario 3, i.e., number of people, location of people and exit choice.

Table 7. The basic assumptions of scenario 3

Floor	Room	Number of people	Chosen exit
Ground	1:1	18	Main exit
Ground	1:2	18	Main exit
Ground	1:3	60	Main exit
Ground	1:4	60	Main exit
Ground	1:5	0	Main exit
First	2:1	35	Exit to EC2
First	2:2	40	Main exit
First	2:2	45	Exit to EC2
First	2:3	63	Main exit
First	2:3	22	Exit to EC2
First	2:4	85	Secondary exit

4.3.4. Scenario 4

Normally the lecture theatres are full of people during daytime. However, it is also interesting to examine if there is any significant difference in evacuation times if the number of people is lower. In scenario 5 the number of people is reduced in all the rooms. The reduction is in the order of 30 to 40% in each of the rooms. Apart from the reduction of the number of people the scenario is identical to scenario 1. Table 8 summarizes the basic assumptions of scenario 4, i.e., number of people, location of people and exit choice.

Table 8. The basic assumptions of scenario 4

Floor	Room	Number of people	Chosen exit
Ground	1:1	11	Main exit
Ground	1:2	11	Main exit
Ground	1:3	40	Main exit
Ground	1:4	40	Main exit
Ground	1:5	0	Main exit
First	2:1	23	Main exit
First	2:2	55	Main exit
First	2:3	55	Main exit
First	2:4	55	Secondary exit

4.3.5. Scenario 5

Scenario 5 is based on the same assumptions about exit choice as scenario 2, but includes a reduction of the number of people in all the rooms. The reduction is in the order of 30 to 40%. Table 9 summarizes the basic assumptions of scenario 5, i.e., number of people, location of people and exit choice.

Table 9. The basic assumptions of scenario 5

Floor	Room	Number of people	Chosen exit
Ground	1:1	11	Main exit
Ground	1:2	11	Main exit
Ground	1:3	40	Main exit
Ground	1:4	40	Main exit
Ground	1:5	0	Main exit
First	2:1	23	Exit to EC2
First	2:2	50	Main exit
First	2:2	5	Exit to EC2
First	2:3	50	Main exit
First	2:3	5	Exit to EC2
First	2:4	55	Secondary exit

4.3.6. Scenario 6

Scenario 6 is based on the same assumptions about exit choice as scenario 3, but includes a reduction of the number of people in all the rooms. The reduction is in the order of 30 to 40%. Table 10 summarizes the basic assumptions of scenario 6, i.e., number of people, location of people and exit choice.

Table 10. The basic assumptions of scenario 6

Floor	Room	Number of people	Chosen exit
Ground	1:1	11	Main exit
Ground	1:2	11	Main exit
Ground	1:3	40	Main exit
Ground	1:4	40	Main exit
Ground	1:5	0	Main exit
First	2:1	23	Exit to EC2
First	2:2	30	Main exit
First	2:2	25	Exit to EC2
First	2:3	37	Main exit
First	2:3	18	Exit to EC2
First	2:4	55	Secondary exit

4.4. Results of Simulex

The results of the simulations show that the total evacuation time, i.e., the time from the activation of the fire alarm until the building is empty, is between 2 and 4.5 minutes depending on the scenario, see Table 11. Naturally, the total evacuation time is shorter when fewer people are included in the simulations and when they use more of the exits.

An important aspect that is linked to calculations of FED and FEC is when people leave the balcony. In the CFD calculations it was found that the location close to the main stairs at the balcony, i.e., at the queue to the main stair, seemed to be one of the worst places in the building. At this location the smoke seemed to build up quite early and create potentially dangerous conditions, i.e., low visibility and high levels of irritant species. It is therefore important to report the time until everyone has left the balcony, i.e., the time from the activation of the fire alarm until the balcony is empty. It can be seen in Table 11 that everyone has left the balcony approximately between 1 and 4 minutes after activation of the fire alarm in the scenarios. As previously pointed out, the time is shorter if fewer people are included in the simulations and if more exits are used.

Table 11. The total evacuation time and the time to empty the balcony for the different scenarios

Scenario	Evacuation time (mm:ss)	Time to empty the balcony (mm:ss)
1	4:26	4:04
2	3:40	3:17
3	2:44	2:21
4	3:10	2:49
5	2:34	2:12
6	1:50	1:29

In the simulations it was observed that a queue formed quickly in front of the main stair on the balcony. This queue remained until shortly before the entire building was evacuated, since people from the ground level could exit the building more easily than those who came down the main stairs, i.e., from the first floor. This result is supported by observations from the evacuation experiment.

4.5. Conclusions

The results of the evacuation simulations show that the assumptions that underlie the different scenarios can significantly influence the evacuation times and the time to empty the balcony. It is therefore important to use a scenario that represents a worst probable case in order to get reasonable estimates of FED and FEC. Based on the results it seems reasonable that scenario 2 is the most representative case, since people on the first floor choose to use both the main exit and the exit to EC2. In the experiment almost everyone who used the balcony chose to use the main exit, but if people are exposed to smoke for some time it can be expected that some may re-assess their original choice of exit. However, it seems unrealistic that a very large proportion will change their choice of exit, e.g., scenario 3. Scenario 2 therefore appears to represent the worst credible case and is hence chosen for the calculation of FED and FEC in chapter 5.

The results also suggest that the area in front of the main stair on the balcony is the worst location in the building with regards to evacuation safety. At this location a queue formed quickly and was not resolved until shortly before the last person had evacuated. This means that many people will stand at the balcony for a considerable time. It is therefore deemed appropriate to perform the FEC and FED calculations for people that evacuate to either the main exit or exit to EC3 using the balcony.

5. Calculation of FED and FEC

In the final step of the project FED and FEC calculations were performed in the program Matlab based on the simulation results from FDS and evacuation scenario 2 in Simulex. The calculations were performed for all persons on the balcony, since this location seemed to be the worst with regards to both evacuation and fire conditions, e.g., highest temperature and species concentration. Conditions in other parts of the building, e.g., at the ground floor, were considerably less severe and were hence ignored. The following sections describe the calculation procedure and the results of the calculations.

5.1. Calculation procedure

In the first step of the calculation procedure data was retrieved from FDS and Simulex. For FDS the program FDS2ASCII was used to transform slice files from the simulations to text files for cables I and M. One text file was created for each ten second interval, i.e., for the time 0 s, 10 s, 20 s, etc, after ignition. Apart from the coordinates of the different cells (x,y,z) the files also contained the temperature, density, carbon monoxide mass fraction and soot mass fraction for each cell. The output file from Simulex simulation was used to create two text files, namely one for cable I and one for cable M, that contained information about the location of each person on the balcony as a function of time in ten second intervals, i.e., at 0 s, 10 s, 20 s, etc. When the file was created it was taken into consideration that the detection time was different for the two cables, i.e., 370 s for cable I and 80 s for cable M.

In the final step of the calculation procedure the created text files were combined to calculate the FED and FEC values for persons on the balcony based on the equations in ISO TS 13571. This was done by first opening the text files with information about the location of persons. For each time step, i.e., ten second interval, the location of each person was then used to get the appropriate value of temperature, density, carbon monoxide mass fraction and soot mass fraction. All the values were taken at a height of 1.6 meters above the floor, which roughly corresponds to the nose and mouth of a person who is standing up. The carbon monoxide mass fraction was used to calculate the mass fraction of other species, i.e., HCl, acreolein and formalaldehyde. After transformation to volume fraction the values were then used to calculate FED and FEC values according to the equations in ISO TS 13571. The soot concentrations were also calculated based on the soot mass fraction. All the calculations were performed in Matlab and the results were saved as text files.

5.2. Results

The results of the FED and FEC calculations for the two cables are shown in subsequent sections. FEC values for the combined effect of HCl, acreolein and formalaldehyde are only reported for cable M, since no irritants were generated for cable I in the FDS simulations.

5.2.1. FED

The temperatures at the balcony were relatively low, about 30 to 35 ºC for both cables. This meant that the FEC value for heat was negligible in both cases and is hence not shown in this report. However, the FED values for carbon monoxide was significantly higher and is shown in Figure 25 and Figure 26 for the two cables. In the figure a line corresponds to the accumulated dose (FED value) for each person in the simulation. It can be seen in Figure 25 and Figure 26 that the highest FED value is approximately 0.002 for cable I and 0.008 for cable M. This should be compared to the suggested value of 0.3 that is stated in most general occupancies.

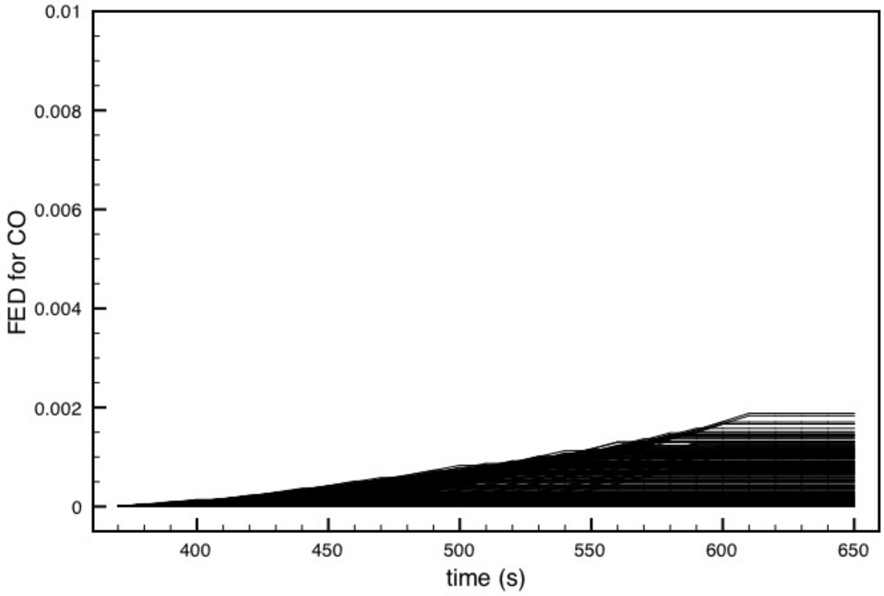


Figure 25. FED values for each person in the simulations for cable I

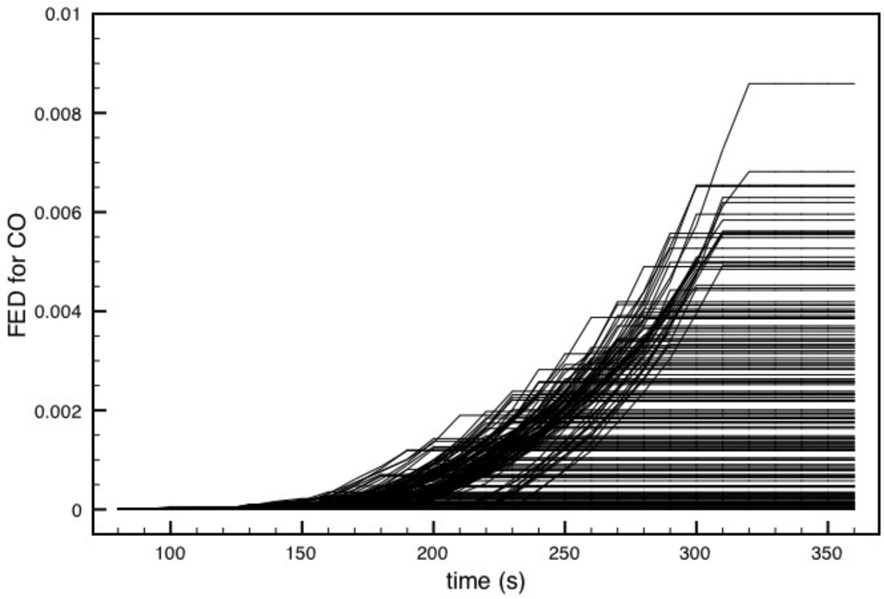


Figure 26. FED values for each person in the simulations for cable M

5.2.2. FEC

FEC values for irritant gases were only performed for cable M as pointed out earlier. Figure 27 and Figure 26 show the FEC values for each person in the simulations. It can be seen in the figure that some of the persons were exposed to a value above 0.3, i.e., an unacceptable level, in the simulations.

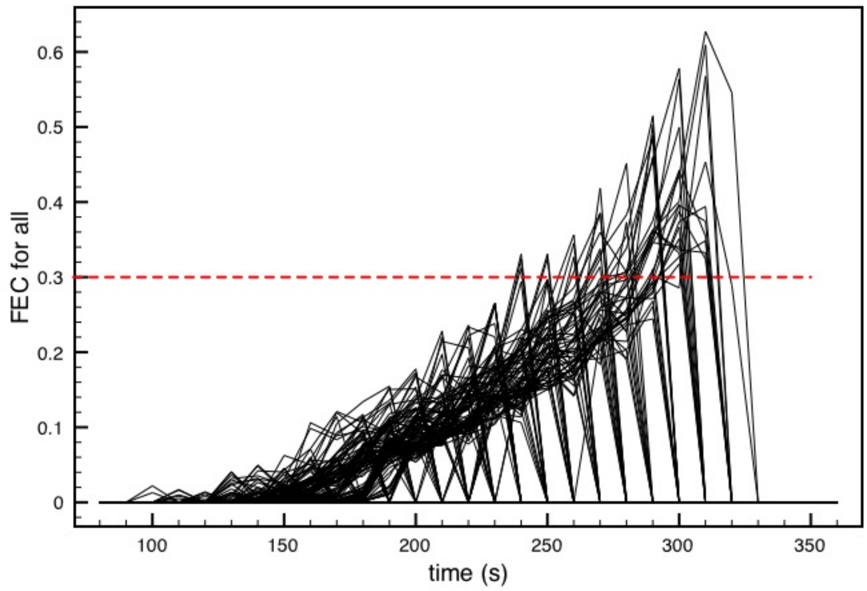


Figure 27. FEC values for each person in the simulations for cable M

The soot concentration did nor exceed the recommended critical value of 0.8 g/m^3 for any of the cables. However, some person experienced visibility below approximately 10 meters for cable I and M, and below 5 meters for cable M. Figure 28 and Figure 29 show the soot concentration that each person experienced in the simulation. The soot concentration at a visibility of 10 meters (lower dashed line) and 5 meters (upper dashed line) is also shown in the figures. These two values of visibility correspond to limits that are often used in performance based fire safety design of buildings[18]. Table 12 gives the number of occupants and their total FEC for the scenario.

Table 12. Number of occupants and the total FEC values for the same scenario

Max FEC	Number of occupants	Percentage of total number of occupants (%)
0	269	60
0-0,1	57	13
0,1-0,2	39	9
0,2-0,3	40	9
>0,3	41	9

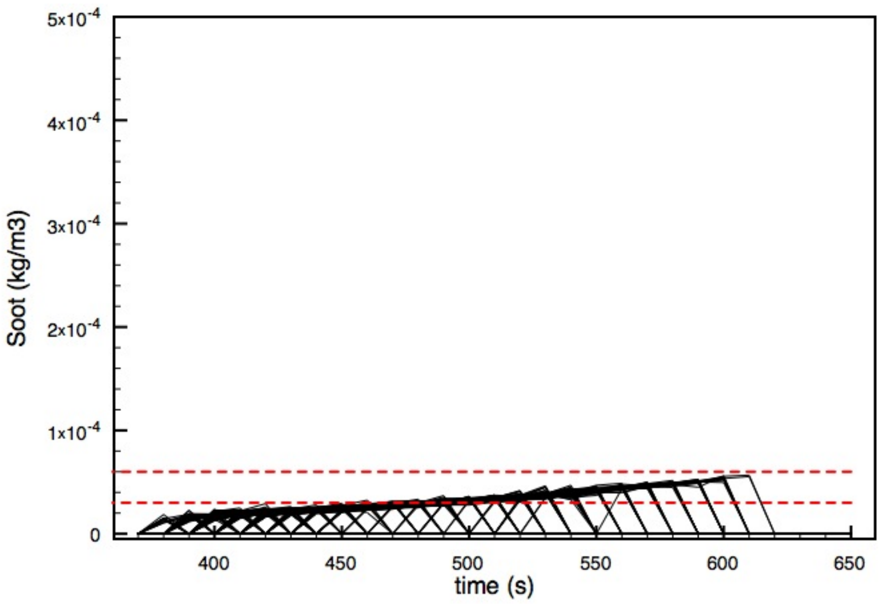


Figure 28. Soot concentration (kg/m³) for each person in the simulations for cable I

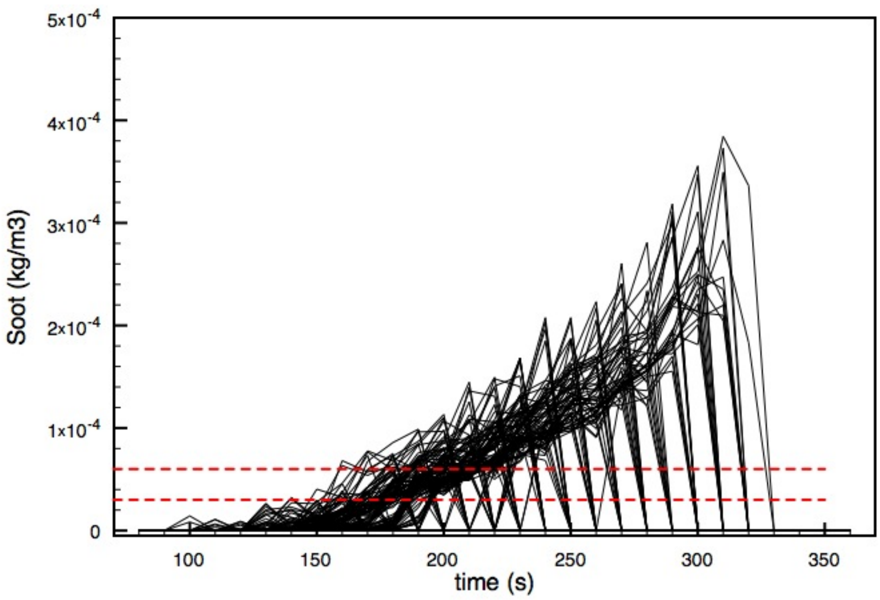


Figure 29. Soot concentration (kg/m³) for each person in the simulations for cable M

5.3. Conclusions

The calculations of FED and FEC show that there is difference between cables, but also that the values are, in many, cases quite low and below the accepted values. Only cable M resulted in a FEC value for irritant gases that was above the often recommended limit 0.3. However, the results suggest that the method developed in the present project can potentially be used to compare different cables.

6. Discussion

6.1. CFD simulations

When studying the results of the CFD calculations it can be observed by comparing cable M and I in Figure 15 to Figure 17 that there is difference between the smoke spread for both cables. Cable M is creating faster a filling up of the atrium then cable I. It should be noted that the pictures in these figures show the soot produced in the fire based on the settings of the postprocessor Smokeview. This means that the view seen in the picture might not be completely the same as what will be perceived by the occupants in the building.

The difference between the two cables are on is one hand due to the different HRR curves but also the different soot production in the intermediate scale test according to prEN 50399. The different level of heat release rate will result in a faster filling up of the atrium because of the faster fire growth. The difference in soot production means that cable M will produce much more dense smoke causing lower visibility for the same amount of heat generated by the fire.

When looking and comparing Figure 18 to Figure 20 it can be see that the temperature is increasing also quicker for cable M compared to cable I. This is mainly due to the faster growth curve for cable M. At a later stage of the fire (900s) the temperature field is rather similar for both cables. This is not strange since at this point of the fire both cables have reached the maximum value of heat release of 500 kW.

An important output of the CFD simulation is the detector activation which is in this case calculated as the time where the soot represents a value corresponding with 10 m of visibility. This means that the start of the evacuation is different for both cables but this is considered as normal practice in fire safety engineering. What can be done in the future is to investigate more in details the validation of using this threshold with respect to real fire data and to perform a sensitivity analysis.

The use of a computer cluster for calculations has been of high value for this project. Since the output of the data had to be used for evacuation modelling we could not increase the size of the cells too much and risk that we would have a large difference in cell size at different positions in the domain. The final calculation with the finest grid contained around 5 million cells and the overall calculation time was within one week. On a normal PC this would have taken several weeks. For these calculations there is always the risk that the computation crashed and that no restart is possible since the restart capabilities of FDS are not so good and stable enough to rely on.

For this study it was also not observed that the use of 10 different meshes caused abnormal flow or temperature fields for this scenario. Disadvantage with the parallel version of FDS is still the fact that each processor takes care of one mesh and that the linearity depends on the possibility of having more meshes which is from a practical point not always possible. Mesh boundaries should namely not be in areas with high activity or high gradients e.g. in the middle of a fire plume. This limits the linearity of the calculation time considerably.

6.2. Evacuation simulations

The evacuation simulations are based on a number of assumptions that can influence the results. Most of the assumptions were based on the evacuation experiment in building EC3, which means that the input is based on empirical data. It is therefore believed that the simulations adequately represent a realistic evacuation with regards to such aspects as the pre-movement time, exit choice and flow on stairs. However, the simulations were also based on assumptions about the total number of people, which might be more uncertain. The scenario that was chosen for the FED and FEC calculations, namely evacuation scenario 2, is believed to represent a worst credible case, since all the rooms except cafeteria were filled to maximum capacity and most people on the first floor used the main exit via the main stair. Scenario 2 is therefore believed to be the most representative and realistic case, and should therefore be used in future evaluations.

The program Simulex is associated with a number of modelling aspects that can also potentially influence the results. For example, it is not possible to include the influence of irritant products and smoke on the behaviour of people. This means that people can not be removed or fall to the ground, i.e., become obstacles, if their FED and FEC values exceed the threshold. Instead data has to be taken from the program and compared to data from CFD calculations. If it is observed that the conditions become so severe that the may influence the behaviour of people the used has to go back and modify the Simulex simulations. This is a tedious process that could potentially be removed if there were a direct link between the CFD and evacuation simulations, e.g., an integrated software program.

6.3. FED and FEC calculations

The FED and FEC calculations were performed at the balcony by combining results from FDS and Simulex. This was done because both the CFD and evacuation simulations revealed that the conditions were worst at the balcony, more specifically at the location in front of the main stair where a queue quickly formed. It is estimated that the contribution to the FED and FEC values in other parts of the building are negligible due to low temperatures, gas concentrations and soot concentration. In addition, the previously mention limitation in Simulex meant that people could not be removed from the evacuation simulations when their FEC values exceeded the threshold. However, these limitations are estimated to be of minor importance because the approach aims to compare different cables. The limitations therefore effect the calculations for both cables in approximately the same way and it is hence expected the approach will yield comparative results with adequate validity and reliability. As was shown by the results in chapter 5, it was possible to compare cables M and I.

7. Conclusions

The main conclusion of the study are summarised below.

1. From this feasibility case study it can be concluded that a combined CFD and evacuation simulation methodology for determining FEC and FED values was developed successfully, see **Figure 30**. This methodology allows critical evacuation conditions to be determined based on not only temperature and visibility, but also on gas composition of the smoke. The approach works in accordance with ISO TS 13571 and uses data from intermediate scale tests. The methodology can also be applied to other combinations of buildings and cable fires.

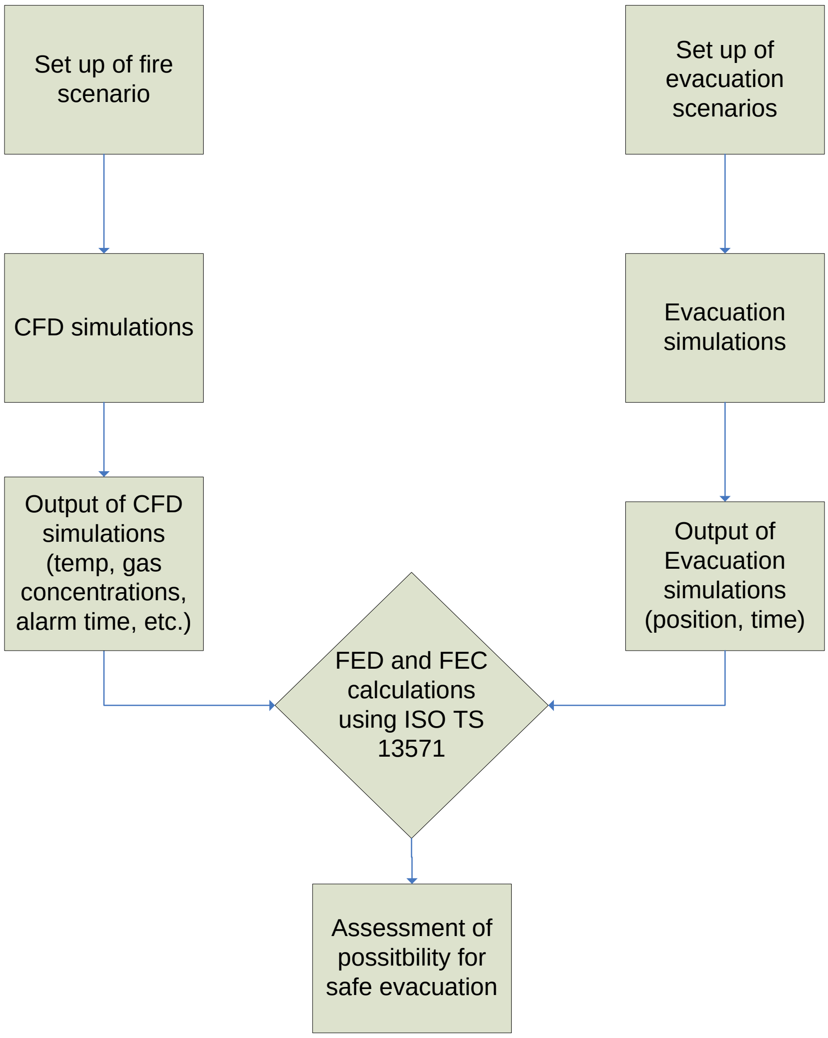


Figure 30. Scheme of the methodology.

2. When comparing the two cables it can be seen that cable M creates critical conditions for some of the occupants during evacuation for the chosen design fire when the production of irritant gases (HCl, acreolein, Formaldehydes) and smoke (reducing visibility below 10m or 5m) are considered. In practice this means that fire safety engineering principles can be used.

8. Further research

This study investigated the feasibility of using combined CFD and evacuation modelling for the determination of critical conditions based on ISO TS 13571 and taking into account not only temperature and visibility but also the content of the smoke gases. The research project showed clearly the applicability of the method and the opportunities of using a fire performance based approach but in order to have a broad application area some further research can be identified.

- The methodology developed has been rather novel from the point of view of combining FDS, Simulex and Matlab for the final evaluation of the critical conditions. Some refinements and further validation therefore needs to be performed.
- The study compared 2 cables belonging to one Euroclass. It would be important to look to more cables with a variety of fire properties with respect to fire growth, smoke production and content of smoke (e.g. containing other gases than the one in this study).
- The focus of this case study was on one specific building where a specific fire scenario could be determined. The chosen building represents a building with a specific occupants and building characteristic. Especially the atrium scenario is one of the typical fire safety engineering scenarios but other scenarios such as room corridor, retail premises etc can create other fire conditions. Also the use of smoke vents and/or sprinkler can change the choice of design fire and hence the outcome of both CFD and evacuation modelling.
- The occupants are now considered not being influenced by the smoke gases with respect to speed and reaction. This can be further developed but actual models are not yet well validated.
- For the CFD modelling the spread of specific gases in the smoke has been modelled by considering them as a scalar connected to the CO production. This method needs some additional validation as well as the grid sensitivity when using this technique.
- In the design fire of this project only a cable fire has been considered. It would be of interest to investigate a design fire of not only cables but also other building materials and building content. With this respect it is important to investigate what the results are if a combination of a cable with building contents would be chosen. In this case the design fire could have a higher maximum and the mixture of gases can be higher
- The input for the CFD modelling has been based on one single test at intermediate scale. The results for the production of gases in the intermediate scale test is very much depending on the ventilation conditions and might not always represent all fire models with respect to production of gases. A further sensitivity analysis is desired both with respect to the input data from the prEN 50399 test but also with respect to data coming for other fire tests and under other ventilation condition i.e. other equivalence ratios.
- Underventilated fires were not considered in this study and are the scenarios were high amounts of unburned products are produced. The

capability of existing CFD models to simulate this type of fires is still limited and might need more consideration.

- As start for the evacuation alarm activation by means of a smoke detector simulation has been used. The threshold value was 10 m visibility. It is important to investigate the sensitivity of the alarm activation with respect to evacuation and creation of the critical conditions as well as the threshold value and the validation of the detector activation against real fire data. The detector is namely placed nearby the ceiling and is within the boundary layer of the smoke and the validation of such detectors is rather limited up to now.
- Results from the procedure were presented in this study but it was impossible to perform a broad sensitivity study which allows the user to determine the uncertainty of the outcome. ISO TS 13571 fore example reports that one should take into account an uncertainty of at least 50% for the values chosen in the FED and FEC calculations.

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Acronyms

CAD: Computer Aided Design

Cenelec: European Standard Organisation

CFD: Computational Fluid Dynamics

ECBL: Europacable - The European Confederation of National Associations of Manufacturers of Insulated Wire and Cable

Euroclass: European Classification system for e.g. wall and ceiling linings, floor coverings and cables to be used for CE marking of products

FDS: Fire Dynamics Simulator software programme

FDS2ASCII: Software programme to produce output data from the FDS software

FEC: Fractional Effective Concentration

FED: Fractional Effective Dose

FSE: Fire Safety Engineering

CH2O: Formic Aldehyde

CO: Carbon Monoxide

CO2: Carbon Dioxide

COF2: Carbonyl Fluoride

C3H4O: Acrolein

FIGRA: Fire growth rate index

FTIR: Fourier Transform Infrared

GB: Gigabyte

Ghz: Gigahertz

HBr: Hydrogen Bromide

HCl: Hydrogen Chloride

HCN: Hydrogen Cyanide

HF: Hydrogen Fluoride

HRR: Heat Release Rate

Intel: Type of processor

Intel Xeon: Type of processor

IWCS: International Wire and Cable Symposium, Inc

Lunarc: Center for scientific and technical computing for research at Lund University

Matlab: Mathematical computation program

Milleotto: Name of one of the clusters at LUNARC

MPI: Message passing interface

NOx: Nitric Oxides

ISO: International Standardisation Organisation

Plot3D: output format for data produced from FDS software

prEN: pre European Standard

QRA: Qualitative Risk Analysis

SIMULEX: Software programme for simulation of evacuation

SVN: Apache Subversion (formerly called Subversion, command name svn) is a revision control system initiated in 2000 by CollabNet Inc. Developers use Subversion to maintain current and historical versions of files such as source code, web pages, and documentation

SO2: Sulphur Dioxide

TS: Technical Specification

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