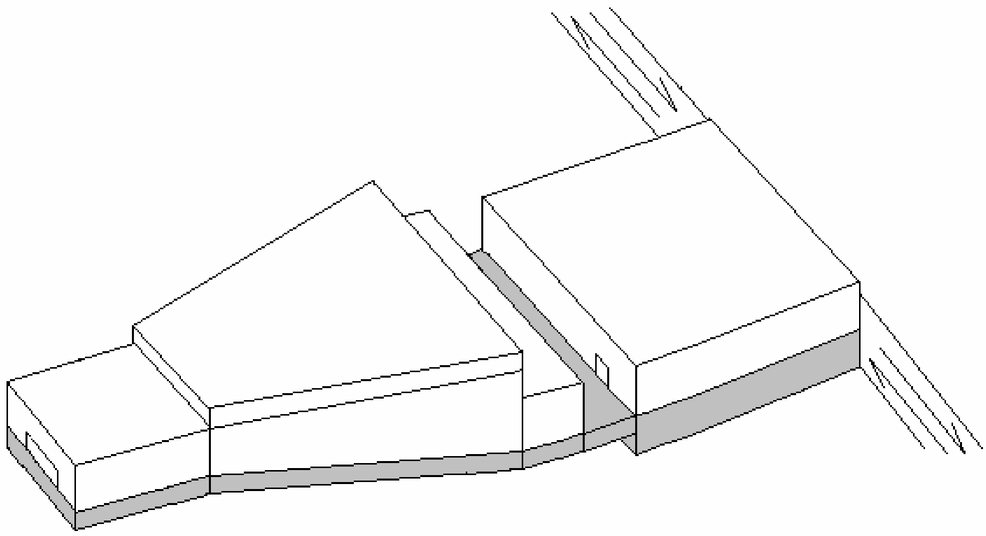
HØGSKOLEN STORD/HAUGESUND

Case study of a Transport Centre



Final Year Thesis Project

Stord/Haugesund University College - Dep. Haugesund - Engineering

Course: Firesafety Engineering

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Extract:

This report considers nearly every aspect of the safety at the transportation centre like: alarm organisation, detectors, smoke control etc.

The strategy was to carryout a performance based fire safety analysis. To undertake the performance based analysis it was chosen to use three computational programs to model the building and carryout the analysis.
Fire Dynamic Simulator (FDS) was used to model the design fires, Simulex to model evacuation of the building and ABAQUS to model the structural integrity of the building.

Calculations have been carryout to verify these simulations.

Foreword

This report is written as a mandatory and closing part in the three years Bachelor Degree Firesafety Engineering at Stord/Haugesund in Norway. The project shall have an workload that qualifies for 12 study points.

Audun Borg and Ronny Jakobsen were selected from Haugesund / Stord University – College (HSH) along with Richard McKeown, Benoit Guyonneau and Thomas Marshall from Edinburgh University to carry out a thesis project on Fire Safety Engineering: Case Study on Building Design Specifications.

The objective of our case study was to carry out a performance-based fire safety analysis and design for a transportation centre. The results of our project are to be presented at The Fifth International Conference on Performance-Based Codes and Fire Safety Design Methods in Luxemburg, October 2004.

We would like to thank the following parties for all their help, directions and advices:

- Leiv Anfin Drange: Teacher and Supervisor of this project at Stord/Haugesund University College
- Jan Torgil Josefsen: Teacher and Supervisor of this project at Stord/Haugesund University College
- Dr J Torero: Fire design of buildings Teacher in the University of Edinburgh and Supervisor of this project,
- Prof D. Drysdale: Fire design of buildings Teacher in the University of Edinburgh and Supervisor of this project,
- Allan Jowsey: PhD Student in the University of Edinburgh,

And especially to the guys we have worked together with:

- Thomas Marshall: 5th year MEng Student in the University of Edinburgh and in charge of the Structural behaviour analysis of the project,
- Richard McKeown: 5th year MEng Student in the University of Edinburgh and in charge of the Evacuation analysis of the project,
- Benoit Guyonneau: 5th year MEng Student in the University of Edinburgh and in charge of the FDS analysis of the project,

Haugesund May 7th 2004

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Ronny Jakobsen

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Audun Borg

Executive Summary

As part of our degree course we are required to undertake a final year thesis project. Audun Borg and Ronny Jakobsen were selected from /Stord University – College (HSH) along with Richard McKeown, Benoit Guyonneau and Thomas Marshall from Edinburgh University to carry out a thesis project on Fire Safety Engineering: Case Study on Building Design Specifications. The objective of our case study was to carry out a performance-based fire safety analysis and design for a transportation centre. The results of our project are to be presented at The Fifth International Conference on Performance-Based Codes and Fire Safety Design Methods in Luxemburg, October 2004.

We were provided with basic architectural plans showing the layout of the building and a short list of criteria which the building should adhere to. Any information that was required but not given, we could use our engineering judgement and make assumptions with regards to the specifications.

This report considers nearly every aspect of the fire safety at the transporting centre like: alarm organisation, detectors, smoke control etc.

Our strategy to tackling was to carryout a performance-based fire safety analysis. To undertake the performance-based analysis we chose to use three computational programs to model the building and carryout our analysis. It was used Fire Dynamic Simulator (FDS) to model the design fires, Simulex to model the evacuation of the building and ABAQUS to model the structural integrity of the building.
Calculations have been carryout to verify these simulations.

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1. INTRODUCTION

1.1 Introduction

The substance of this report is part of a final report that will be reproduced as a publication and later presented at the 5th International Conference on Performance Based Codes and Fire Safety Design Methods. This has been organised by the Society of Fire Protection Engineers (SFPE) and will be held in Luxemburg on October 6-8, 2004.

The final report has been made in cooperation with three students from civil and environmental engineering master degree course at the University of Edinburgh.

This report considers nearly every aspect of the fire safety at the transporting centre like: alarm organisation, detectors, smoke control etc.
The simulations made in developing the fire safety of the building is not considered in detail, but the results of the simulation have been used in this report.
The simulations that have been carried out are:

- ABAQUS, for the construction.
- Simulex, for the evacuation.
- FDS, for the fires.

Chapter 8 gives a summary of al three simulations.

1.2 Background Information

Major fires within buildings are a rare event, however when they do occur they have the potential to destroy life and property on a large scale
Over the years the protection process has been based around rules and regulations, such as those set out in the Norwegian and British Standards, which have been established and developed through past experiences, experimental practices and scientific theories. Generally these rules are centred on providing adequate passive measures, such as fire resistant doors, walls and compartments, and means of escape. The current rules could be improved substantially by enforcing the instalment of fire protection measures, such as sprinklers and other fire suppression measures, however this has the potential to become too expensive meaning buildings would be considered 'over-designed'.

1.3 The Protecting Process

The protection process against fires can be split up into three sections;

- Before the fire
- During the fire
- After the fire

As it is almost impossible to eliminate fire, is it of vitally importance to reduce the possible consequences long before they occur. Therefore it is crucial to identifying potential ignition sources within a building and any objects or materials that may generate high levels of smoke and toxic fumes or contribute to rapid fire spread.

By knowing these factors fire safety engineers can have a good understanding of the likelihood and intensity of potential fires and so generate models of how the building and its occupants will behave under these conditions. If the conditions are seen as too dangerous it is then a simple matter of readdressing the situation of ignition sources and combustible materials.

2. THE BUILDING

2.1 Description of Building

The following drawings show a sketch of the entire transportation centre and an architectural site plan and section drawing.

Figure 7 : Building sketch

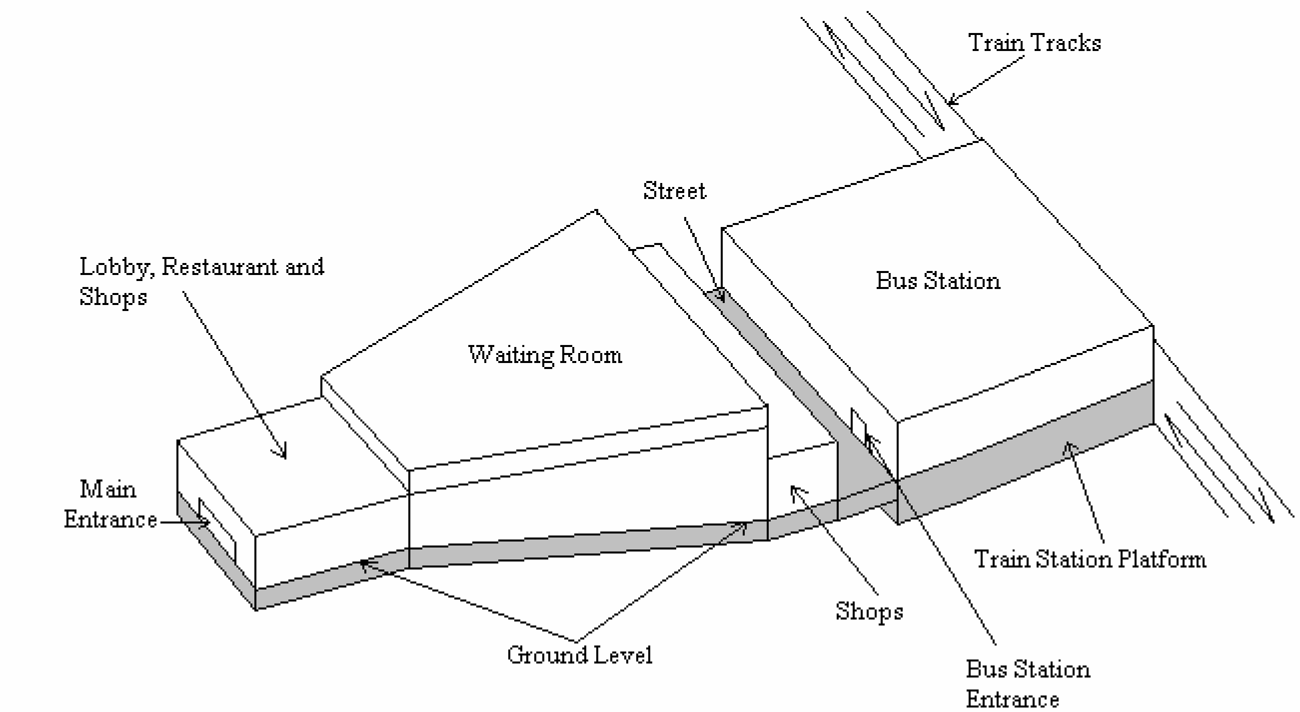
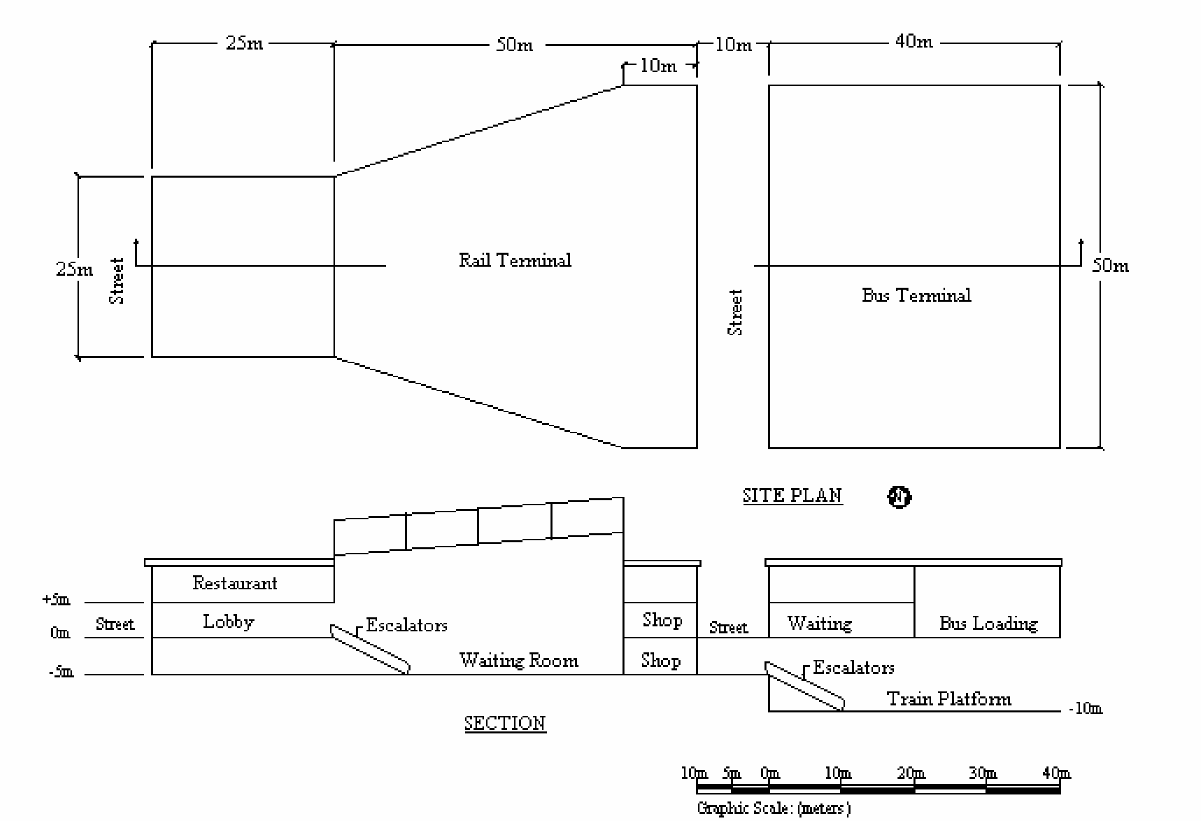


Figure 8: Site plan and section drawing



2.2 Design Criteria

2.2.1 General

The building should meet a wide range of requirements which can be divided into three major fields: the wishes of the future owner, the sustainability requirements in normal conditions of use, and finally the requirements in the event of fire.

2.2.2 Requirements of the client

The building should obviously respect the wishes of the future owner: the city where the transportation centre will be built.
Some basic plans of the building have been provided. See appendix1.
The transportation centre shall be built according to these plans. Particularly, the positions of the columns and facades can not be changed or moved. The use of the different parts of the building has been indicated by the client.
Here are the other requirements as specified in the subject of the thesis:

"The city has requested that the following be provided within the transportation centre:

- The dining terrace (+5m level) and the balcony where the shops are located on the 0m level shall be open to the waiting room below.
- With the exception of the shops, no visual obstructions shall be provided between the waiting room and the rail platform (i.e. no doors or walls shall be installed between the waiting room and the rail platform).
- The interior of the train terminal must convey a feeling of openness and be covered with long span construction with a maximum of glass to allow maximum natural lighting.
- The bus terminal shall provide for ease of access to buses and include both bus storage and repair facilities. Fuelling of buses shall take place outside of the facility.
- Other types of rooms as identified on the plans."

An other constraint induce by the use of the building is that the transportation centre will be located on the border of a country, so it shall welcome travellers who are coming from or going to other countries. That's why it includes passport control and customs inspection stations. A secure area shall be provided for passengers who have cleared passport control to await their train. And even more important a secure are for evacuation of arriving passages who have not cleared customs and passport control.

All these requirements are giving a general line to follow, but a wide part of the design remains free such as the locations and the width of the stairs, the choice of all the materials constituting the structure of the building and the uses of some parts of the transportation centre not is specified.

2.3 Design Assumptions

- Trains will remain outside the transportation centre (i.e. not come under the bus loading area). We will therefore only have to design for fire loading on the external east face, due to possible burning train.
- Only the trains shall be used for international travel and thus require passport control.
- Bus information obtained from St. Andrews Square Bus Station, Edinburgh. 12.2m long, 2.6m wide, 2.7m high, 14000Kg weight (un-laden, but including full fuel tank), Laden = 50 persons with average weight of 80Kg, each carrying 25Kg of luggage.
- Street has been assumed to be pedestrianised.
- It is assumed that there are appropriate foundations in place.
- The Bus Loading Area and Bus Service / Repair Areas have been structurally designed to accommodate as many buses as possible. This is for an extreme situation (i.e. a bus drivers strike, or large demand / delay of buses). The Service / Repair area has been designed for 10 busses. The Bus Loading area has been designed for 15 fully loaded buses.
- The assumed location of the transportation centre is in the London area and in an open space away from other buildings etc. This assumption will be used as the basis for wind and snow loading.
- It is assumed that it is not necessary to design for any notice boards / information signs etc that may normally be attached to walls or be suspended from the roof or roof trusses.
- The design of the structure is in steel.
- The building is designed to remain standing for the maximum size of design fire possible.
- The areas on the top floor, that is not labelled, will be treated as storage rooms.

3. FIRE SAFETY STRATEGY

3.1 General

The main aims of the safety design are as follows:

- Safeguard occupants from injury resulting from a fire
- Safeguard fire fighters while they attack fires and evacuate the building
- Avoid collapse of the structure due to fire
- In the event of a fire, minimize the interruption to businesses

The main fire safety strategy is to design the building so that it can remain standing and all it occupants can be evacuated safely, while ensuring that the building cost are kept at a minimum.
The key aspects of the fire safety strategy which this report considers are as follows:

- Evacuation
- Compartmentation
- Smoke control
- Detection and alarm
- Fire suppression
- Access for fire appliances and fire fighters
- Emergency lightning
- Emergency power
- Fire safety management

3.2 Fire Suppression

This requires the fire protection to be applied to the building only where it is absolutely necessary. Fire suppression is only provided in an area whit high fire load, the bus repair area.
Otherwise are the only active fire safety measures, mechanical smoke extraction and self closing doors.

3.3 Structural Protection

The transportation centre has been design such that no structural protection is required on any of the structural elements. Detailed modelling of the building has been carried out using Fire Dynamics Simulator (FDS) and a Finite Element Analysis computational program called ABAQUS. Results from the simulations with the corresponding fire loads will determent the dimensions of the buildings steel structure.
For details about the simulations look in section 8.

4. FIRE SCENARIOS

4.1 General

The requirements to the building in the event of fire are as specified in the fire safety strategy.
The purpose of the fire scenarios is to test if the building can stand a fire as it is suppose to. The choices of these scenarios are given by a search after worst case fire in each part of the building.
Each of these seven scenarios is corresponding to a location of a fire in the building.

- A bus burning in the bus loading area.
- A bus burning in the bus repair area
- A train carriage burning at the train platform.
- A fire in one of the shops.
- A baggage fire in the waiting areas.
- A fire in the restaurant.
- A fire in the kitchen.

4.2 Design Fires

	Location	**Fire Load (kW)**	**Area of Fire (m^2)**	**Area of Ventilation**
Train	Central	16000	33,6	Natural ventilation
Bus repair and loading area	Central	20000	28,8	Natural ventilation 32 m^2
Restaurant	Central	3000	3 m in diameter	Tree vents 5 m^3/s pr vent
Shop	Central	3750	3,5 m in diameter	Two vents 7 m^3/s pr vents
Baggage fire in main waiting area	Central	1000	1,6 m in diameter	Natural ventilation 44 m^2
Baggage fire in bus waiting area	Central	1000	1,6 m in diameter	Natural ventilation 8 m^2
Kitchen*	Against wall	Curve 0-400	0,4	Two vents 1,72 m^3/s pr vent

Table 1: Design Fire Summary *** This one is not calculated, but simulated in FDS**

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4.2.1 The Train Fire

The worst fire in a train carriage was found in a report from the company ARUP for the fire analysis of the St Pancras station: "St Pancras station – Fire Precautions and Evacuation" (100-RUP-RLEEA-00006-AF). They used "a conservative worst case 16MW train fire, which represents the peak heat output of a single carriage of an old type class 415 carriage at 4 minutes after flashover."
As they are indicating in the ARUP report, a fire in a modern train as Eurostar train should have a lower heat output. Indeed materials are chosen to limit the propagation of the fire.

4.2.2 The Bus Fire

From: 'Fire in Tunnels Proceedings', Swedish National Testing and Research Institute, 1994. Was the average peak of heat release rate about 29MW. A steady state fire for a bus is desired, and with conditions that gives a lower heat release than for a tunnel fire a 20MW fire was chosen.

4.2.3 Kitchen and Restaurant Fire

In a professional kitchen the materials used for the cabinets and shelves are chosen to avoid fire spread. Thus this is limiting the probable size of the fire to the burning of a single item on the stove.
A choice between two main types of fires has to be considered:

- A fire produced by some oil forgotten on a burner igniting spontaneously
- A fire produced by a plastic item forgotten on a burner.

These two fires are not indeed providing high heat release rates. The fire produced by a plastic item forgotten on a burner has been finally chosen because the heat release rate found was slightly higher, but the first fire is a realistic fire scenario as well.
The fire chosen had to be as realistic as possible, so the kitchen fire taken to recreate a real kitchen fire by the NIST in 2002 was finally preferred.

For the second part of this scenario: fire in the restaurants eating area. Has there been chosen a 3 MW steady state heat release fire. It has been chosen a large fire load for this area because it is desirable to have good flexibility in the restaurant when it comes to choosing furniture, decorations etc.

4.2.4 The Shop Fire.

The worst fire found for a shop fire was the one used by the company ARUP for the fire analysis of the St Pancras station – Fire Precautions and Evacuation" (100-RUP-RLEEA-00006-AF) a 3750kW steady state fire.

4.2.5 The baggage Fire

For a baggage fire a 1000 kW steady state fire was chosen for the waiting areas, it is the same as ARUP used for the fire analysis of the St Pancras station –" Fire Precautions and Evacuation" (100-RUP-RLEEA-00006-AF).

5. FIRE PROTECTING SYSTEMS

5.1 Structural Protection

The structural elements have been designed to stand and maintain bearing throughout the life of potential fires without use of any structural protection.

5.2 Compartmentation

Due to the function requirements and the nature of the geometry, has the building been divided into zones. The measure proposed to prevent fire spread between zones is a combination of sub-compartmentation within zones, active suppressions and smoke control.

The zones:
Zone 1A: Restaurant area with lobby.
Zone 1B: Kitchen.
Zone 2: Main entrance and lobby on street level, lower level and half of the waiting area.
Zone 3: Shops, storage rooms on top of shops and half of the waiting area.
Zone 4A: Bus terminal, waiting area.
Zone 4B: Bus terminal, loading area.
Zone 5: Bus repair and storage room.
Zone 6A: Train waiting area.
Zone 6B: Departure waiting area, after passport control.
Zone 6C: Arrival area, before custom control.
Zone 6D: Customs control room.
Zone 6E: Train platform.

Compartmentation to prevent fire spread between different zones of the building and within zones has been provided in accordance with Approved Document B.
It is several fire cells within some of the zones, the offices and shops in zone 2 and 3 are for example designed as fire cells.
Every wall in the building will be with fire resistance according to BS 5588-11/1997.

Figure 9: Plan & Section Drawings Showing Zoning Areas of Building

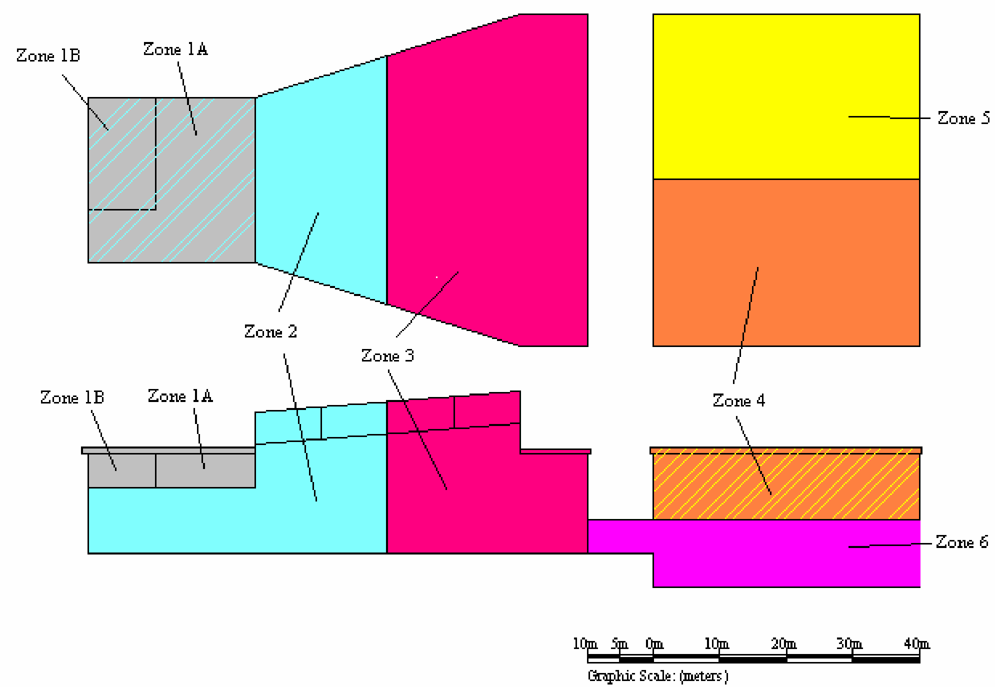
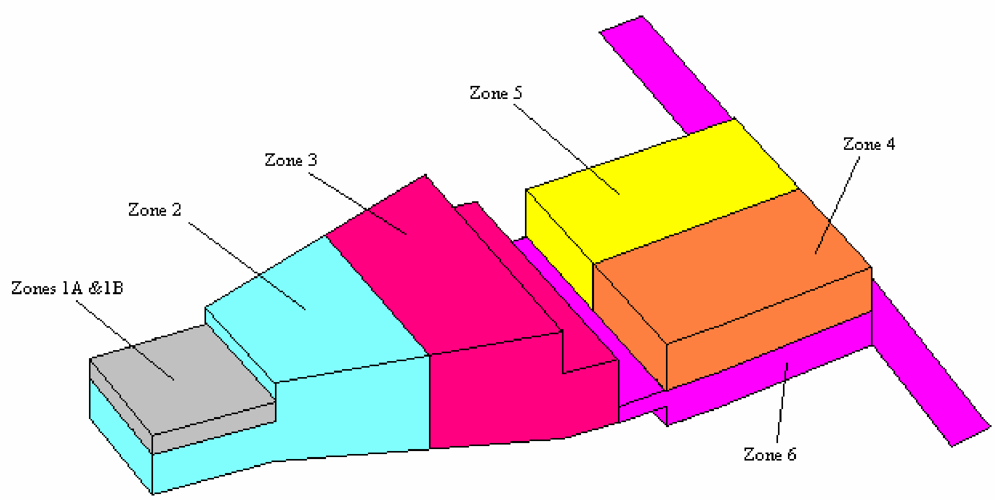


Figure 10: 3D Drawing Showing Zoning Areas of Building



5.2.1 Fire spread from floor to floor

Every floor in this building is made of 20 cm concrete, and designed to withstand a fire without spreading the fire to other floors.

5.2.2 Zone 1A - Restaurant area with lobby

This zone will be equipped with mechanical smoke control systems. The calculations show that it is necessary with only one extraction point in this area. But because of the shape will there be provided three. One extraction point in the lobby and two in the restaurant area. Every wall in this area will be with one hour fire resistance.
If a fire starts in this zone all the doors in this area will automatically self close. Doors that self close will people be able to open, but when they are gone through the door will close again.

5.2.3 Zone 1B – Kitchen

It has a mechanical smoke ventilation system for transportation of smoke made from cooking and one for the event of fire. This system will be automatically put on in the event of an alarm goes of in this zone. The system can be controlled from the fire alarm panels. The walls shall have one hour fire resistance. The cooking station will be installed with a wet chemical system.

If a fire starts in this zone all the doors in this area and in the restaurant will automatically self close.

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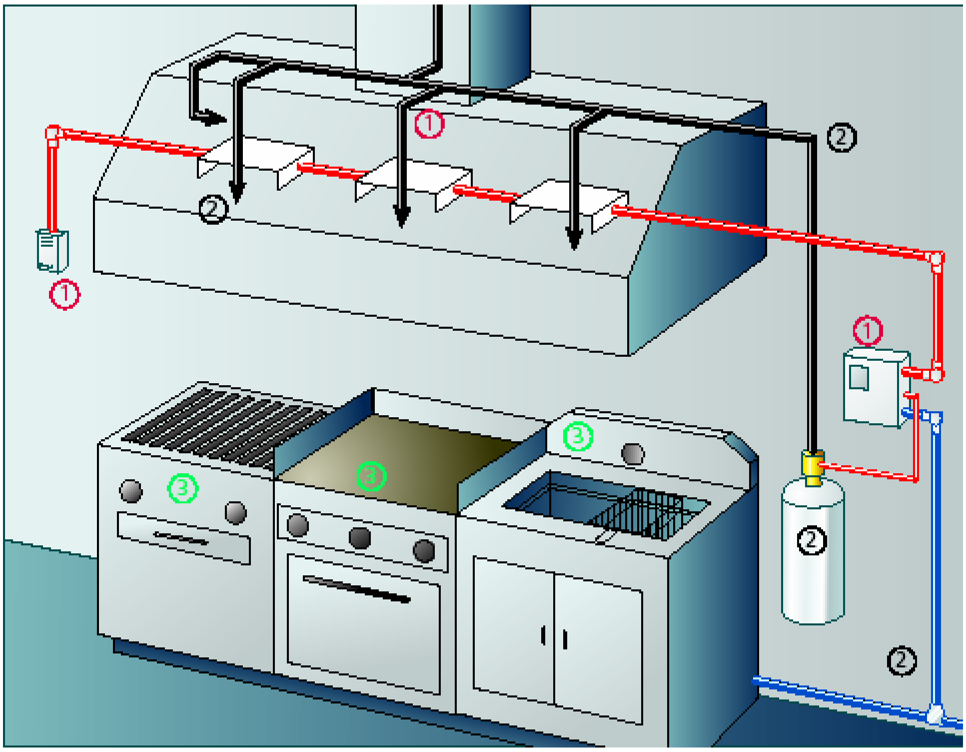
Figure 11: Wet Chemical system (KIDDE system)



How it works:

1: The fire is detected by heat detectors that activates the control box (or the manual station is activated) and the container valve is opened.

2: Wet chemical is stored under pressure in the container and is led through the piping and out through the nozzles. All electrical installations is turned automatically of.

3: The wet chemical strangulates the fire fast and forms a protection layer that extinguishes the fire and disables the fire to flare up again.

5.2.4 Zone 2 - Main entrance and lobby on street level, lower level and half of the waiting area.

This zone has a lot of different units, such as shops, offices, storage and a control room. A fire in this area will be contained, until the Fire Brigade arrives, with walls that have a fire resistance of one hour. The shops in this area will have a mechanical smoke ventilation system.

In the waiting area a smoke curtain will drop down from the ceiling when the alarm goes to stage "Big alarm". If a fire starts in this zone all the doors in this area and in zone 1A and 3 will automatically self close, except from the main entrance and the exits in the west that supports air in.

5.2.5 Zone 3 - Shops, storage rooms (+5m) and half of the waiting area.

The shops and the storage rooms will have walls with fire resistance of one hour.
A mechanical smoke ventilation system is placed in the shops.
If a fire starts in this zone all the doors in this area and in zone 1A and 2 will automatically self close, except from the main entrance and the exits in the west that supports air in.

5.2.6 Zone 4A – Bus Terminal, waiting area

This area will have natural smoke ventilation and the fire resistance on the walls shall be at least one hour. The wall that separates the bus terminal area with the bus repair and storage room shall be made of 20 cm concrete.
If a fire starts in this zone all the doors in this area will automatically self close, except from the main entrance and the exits in the west corner that supports air in.

5.2.7 Zone 4B – Bus loading area

Natural smoke ventilation is located in this area. As seen in section 5.2.6 the wall against the repair area shall be of 20 cm concrete.

5.2.8 Zone 5 - Bus repair and storage room

Natural smoke ventilation and a system with water screens (see 6.3.1) between the buses are located in this area. As seen in section 5.2.6 the wall against the bus waiting area shall be of 20 cm concrete, the west wall shall also be of 20 cm concrete.

5.2.9 Zone 6 A, B and C – Train waiting area.

A mechanical smoke ventilation system is located at this area, and the walls shall have a fire resistance of one hour.

5.3 Smoke Control

The smoke control strategy for the building will be a combination of natural ventilation and automatic mechanical extraction.
The principle adopted is that smoke will be prevented from compromising escape and make as little damage to the building that it will entail closing of the building.

In the event of a fire in zone 2 and 3 will the smoke be let out into the waiting area and out of the hatches in the ceiling. All areas with air-conditioned or where a smoke control system is provided, can be used by the Fire Brigade to assist their operations. Hatches used for natural ventilation, can also be used as part of the ventilation of the building in normal use.

5.3.1 Zones 1a and 1b - Restaurant and Kitchen

Mechanical smoke extraction will be provided. The fan in the restaurant must extract totally 15 m^s/s, and it shall be located on the roof. The restaurant will be provided with two extraction points and one in the restaurants lobby (i.e. $5m^3/s$).
There will bee provided two extraction points in the kitchen, the fan needs to extract minimum 1, 73 m^3/s from each extraction point.

5.3.2 Zone 2 – Main entrance and lobby on street level, floor below lobby and half of the waiting area.

If a fire starts in one of this areas the smoke will be let out throw the hatches in the ceiling in the waiting area.
A smoke curtain will drop down in centre of the waiting area to prevent the smoke from flowing to the other zones.
This curtain will drop down 9m; this will be 13m above the floor. This is to prevent the smoke from spreading to the hole waiting area. It will be placed in centre of the room.

The natural ventilation will provide a clear layer at 14m above the floor in the waiting area. It has been calculated how much smoke a baggage fire will make, and then how much ventilation is needed in the ceiling.
The total ventilation area on one side of the curtain must be: $44m^2$. The hatch will be operated with hydraulics that is connected to the alarm system.

The shops in this area will be supported with a mechanical ventilation system that will extract 14 m^3/s smoke per shop. There will be two extraction points placed in each shop point will extract 7 m^3/s.

5.3.3 Zone 3 - Shops, storage rooms on top of shops and half of the waiting area.

It is the same for this zone as for the zone above. The smoke will be let out of the hatches in the ceiling in the waiting area and through fans with the same size as above for the shops. It will also be 44 m^2 with hatches for ventilation on this side of the curtain.

5.3.4 Zone 4 A and B – Bus Terminal

Natural ventilation through smoke hatches, that is distributed all over the ceiling.
It shall be put in hatches that have an area of 8 m^2 at the bus waiting area and 32 m^2 at the loading area.
Every hatch will be operated with hydraulics that is connected to the alarm system.

5.3.5 Zone 5 – Bus repair and storage area

Natural ventilation through smoke hatches in the ceiling.
It shall be put in hatches that have an area of 32 m^2.
Every hatch will be operated with hydraulics that is connected to the alarm system.

5.3.6 Zone 6 A, B and C – Passport control, and waiting area to the trains.

Mechanical smoke extraction will be provided in this area. There will be provided two extraction points in each area in this zones (zone 6: A, B and C), except from zone 6D where it is only necessarily with one extraction point. The fan needs a minimum extraction capacity of 22 m^3/s smoke, and located on the best suitable place.

The walls in this area are made of glass, but do not go all the way up to the ceiling.

5.4 Surface Spread of Flames

All internal surfaces will be Class 0 (Approved Document B): material non-combustible or presenting a limited combustibility.

It is not possible to control furniture and fittings through Building Regulations.

5.5 Detection and Alarm

This transportation centre will be provided with an analogue addressable fire detection system in accordance with BS5839 Part 1/2002.
Type L1X, linked to a voice and visual alarm system which will be used to raise and control a phased evacuation.
The recommendations of BS5839 Part 1 on the general design, control, equipment and zoning of multiple occupancy should be followed.

5.5.1 Detection

The fire detection system will be used to initiate fire investigation procedures and automatic operation of plant associated with smoke control, public evacuation and other life and property systems.

Depending on the method of detecting will the station be provided with: smoke, heat, flame and aspirating detectors.

Because of high level of staffing and management procedures associated with the platforms and size of the space and the nature of potential fire sources will there not be automatic detectors on the train's platform.

Smoke detectors will be provided throughout the centre, with the exception of the platforms and some places with heat detectors.

Heat detections will be provided where the ambient air quality or steam would render a smoke detector unsuitable such as the kitchen and vehicle loading areas.

A combination of heat and flame detectors will be provided in areas that are likely to contain material that will contribute to a rapid fire spread, such as the loading bay and storage rooms.
An aspirating system is installed in the control room to make sure an early detection of smoke before outbreak of flaming combustion.

Manuel help points, break glass units and CCTV surveillance system will be provided throughout the transportation centre giving additional fire safety.

Automatic fire detection is necessary to satisfy legislation under this circumstance:
Where fire protection systems, such as door closing facilities or smoke control systems, are to be operated.

The whole Transporting Centre will be provided with a category L1 and P system.

Category L systems are automatic fire detection systems intended for the protection of life.
Category L1 is a system installed throughout all areas of the building.

The objective of the system is to offer the earliest possible warning of fire, so as to achieve the longest available time for escape.
Even in buildings with comprehensive fire detection, the provision of manual call points will still normally be of great value; people in the vicinity of a fire will normally be aware of the fire, and able to raise the alarm by use of a manual call point, before it is detected automatically.
Therefore it will be put out some manual call points inside the building.

Category P systems are automatic fire detection systems intended for the protection of property.
Category P1 is a system installed throughout all areas of the building.
The objective of the system is to offer the earliest possible warning of fire so as to minimize the time between ignition and the arrival of fire-fighters.

5.5.2 Manual Break Glass Units

In each areas there will be placed out manual break glass units, so people can give an manual alarm if they discoverer a fire before the fire alarm has been activated.
These units will be linked to and compatible with the central fire control panel.

5.5.3 Alarms

Alarms will be given by means of a voice and visual alarm system to public areas. Every monitor in the public areas shall give a visual alarm for the people with impaired hearing. This message will be pre-recorded and start automatically if the fire alarm system goes in alarm. The different alarms will give different messages.

There have been some good results from tests with directive public address announcement; this has shown that the result is much shorter pre-movement and evacuation times. The messages will be pre-recorded and automatic with manual override facilities. Links with the voice alarm system will be provided at the emergency services rendezvous points using a fireman's microphone and the management suite for other conditions when coded staff alarms are made. The voice alarm system will also be used for multilingual public announcements.

Fire sounders will be provided in staff areas where they are familiarity with the premises.

The alarm system will use a delayed evacuation initiated, based upon a "double knock" system. Upon receipt of an alarm from a single smoke detector or an alarm from a single manual call point, an alarm will be given to allow staff a pre-determined time to investigate the incident prior to the automatic evacuation process being initiated.

The second stage of the alarm will be initiated by either the allowed time elapsing without action, another smoke detector goes of, manual call point being received or a manual break glass unit is triggered.
At this stage the evacuation procedure will be activated and the fire brigade will be called to attend the transportation centre.

The platform that has no smoke detectors, the second stage alarm will be initiated either by the allowed time elapsing without action, manual call point being received, a manual break glass unit is triggered or by the guards.

The fire alarm panel will be located in the control room and one fireman's panel at every entrance.

Type of alarm	Signal	Activating	Action
Pre caution (not alarm level)	Light up and buzzes in fire alarm central	Some dust or similar in detectors.	Fix it and reset The alarm goes not to the next stage.
Quiet alarm (1. stage) Time delay for next stage: 2 min	Light up and buzzes in fire alarm central. Call guards via phone/pager.	Detection of smoke or similar in a detector.	Check cause, reset or activate big alarm.
Big alarm (2. stage) Evacuation No time delay	Triggers all alarm organs in the building (bells, voice and visual systems) Signal goes to Fire Brigade and all guards in the building.	Two or more smoke detectors go in alarm. Manual break glass unit trigged. Not reset quiet alarm	Start evacuation and putting out the fire if it's possible.

Table 2: Type of alarm

5.5.4 Vertical Transportation

The elevator will return to street level and bee locked with the door inn open position.
The escalators will be turned of when the alarm goes in the different zones. It is important that they do not stop right away but stops slowly so no one falls and get injured.
They can bee started again by employers to make the evacuation from the train waiting area more efficient.

5.5.5 Cabling

Every cable connected to the alarm system, voice and visual alarm system will be wired using cabals complying with BS 6387 that has been categorised as CWZ.

5.6 Fire Suppression

Active fire suppression will be provided inn rooms and areas in the building where it is necessary for the safety for occupants, and in areas whit great economical value.

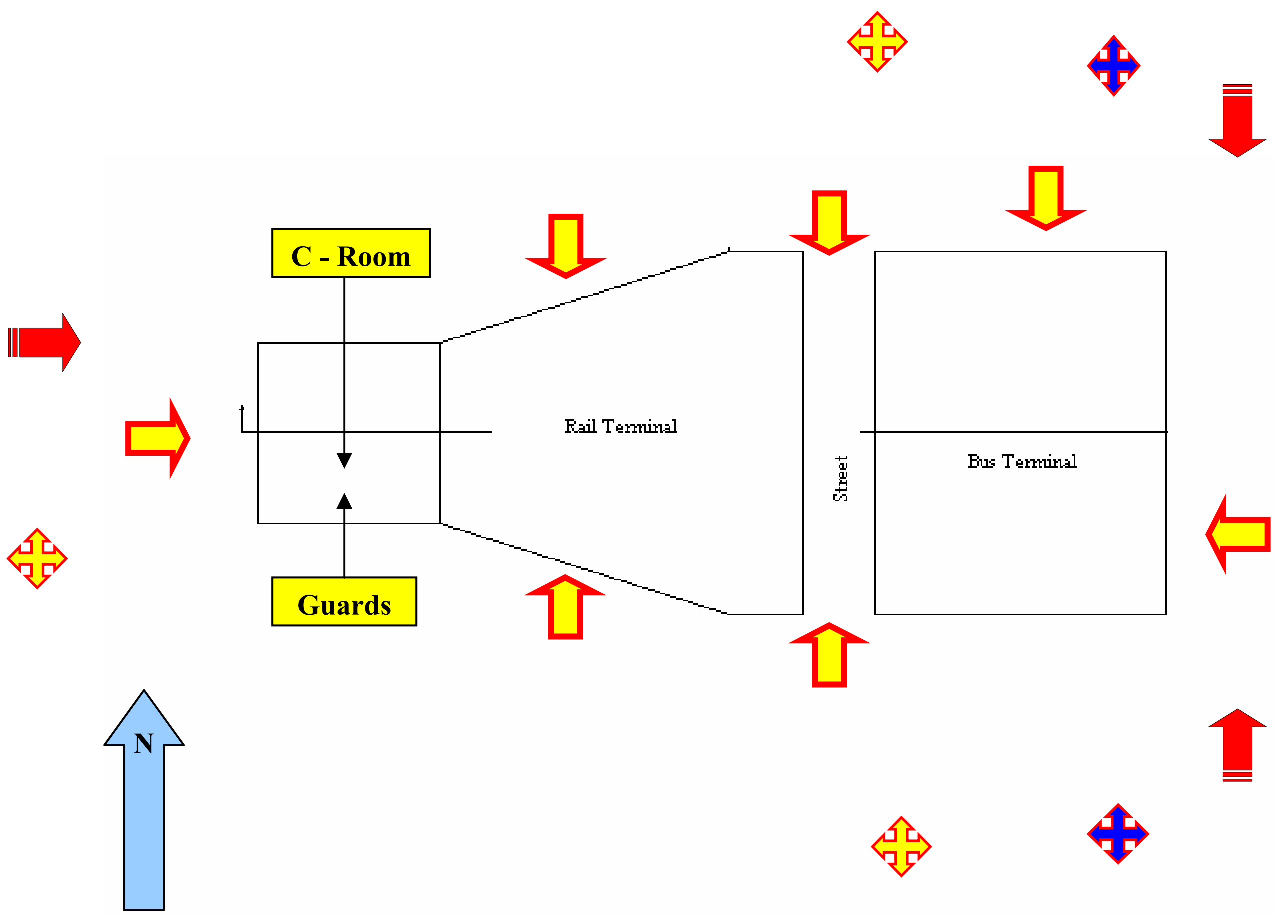
The bus storage and repair area, zone 5, and the control room are specially considered in chapter 6. For details and illustrations look in appendix 1.

5.7 Access for fire appliance

Fire brigade can enter the building at all the marked entrances in the figure under, the north and south entrance on the rail terminal is for fire brigade entrance only. At these locations large doors are to be provided and kept clear for fire fighters.
There shall also be a building plan and fire zone diagrams clearly provided.
The main entrance for the fire brigade should be through the main entrance because of the control room, look in chapter 5.8 Fire safety management.

Symbols according to: NS-ISO 6790, 1. 1993

Guards	24 hour guards.	**C - Room**	Building control room with fire panels.
	Attack way for Fire brigade.		Restricted evacuation area International passengers.
	Access to building		Evacuation area for all other occupants.



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5.8 Fire Safety Management

Fire safety is to be managed from the control room and is to be manned 24 hours a day. This room will work as a Crisis Management Room in an event of a fire or other crisis. The control room is to be located in the room marked as 'Office' next to the main entrance to the building on the street level ±0 m. This room will contain the CCTV surveillance screens of the entire building, fire panels, ventilation control and a central alarm system.

Should an incident occur to the control room that disabled the fire panels, a visual display of the state of the fire system is available on the fire mans panels. These panels are located at every entrance, also in the fireman's entrances on the sides of the terminal building.

Control of the fire safety systems is possible by using a lap-top computer which can by plugged into the system either at the fireman's panels.

Other aspects of the fire safety management are not considered in this report. The fully development should be done in line with the operational requirements of the users.

6 Special Areas

6.1 General

The bus storage and repair area is considered to bee an area that will require special fire protecting systems because of the high fire load.
One of the scenarios is bus fire in the repair area. There can be up to ten buses stored there plus various spare parts.
It is therefore important not to allow a fire in one bus spread uncontrolled to other busses.

To achieve that is it important to reduce the heat radiation from one bus to the next as much as possible. And ventilate the hot smoke to reduce the radiation back from the hot smoke layer.

The other special area in the building is the control room located in street level near main entrance to the building on the street level ±0 m.
It is of vitally importance for the transporting centre to keep the electrical equipment in this room operational.

6.2 Heat radiation bus area

In order to calculate the heat radiation, was it necessary to make some assumptions:

- The window, on the side of the bus, goes all the way from the front to the rear.
- The fire is located on the edge of the windows.
- Heat radiation from the fire plum outside the windows is not considered.
- The flame temperature is 1300 K (1027 °C) and the emissivity is sat to 1.0.

Some of these assumptions are conservative, like the flame temperature at 1300K and that the side of the bus is one window. On the other hand is it not considered to assume that the fire plume is located on the edge of the windows. Some of the flames will come out of the windows and be even closer to the next bus, creating even more heat radiation.
The sum of these assumptions makes a conservative estimate.

The calculations (appendix 5) show that with a distance of 1 meter between the busses is the heat radiation over 70 kW/m^2, from one bus to the next. But with a distance of 2 meters is the radiation down to 40 kW/m^2.

6.3 Fire Protection

6.3.1 Bus area

Because of the high heat radiation a burning bus provide, is there a risk that the next bus will self ignite. It is therefore necessary to install fire protection systems in this area to inhibit the fire to spread from one bus to the next.

This area will therefore be provided with water screens and smoke control. Water screen creates a "wall" of water from the floor and approximately 6 meters up, and spreads total 24 metres. The water drops will reflect and absorb much of the heat radiation. Some of the drops will hit the busses or the fire plum and give a some cooling effect; this is not considered in the calculations.
Water screens take away about 65 % of the heat radiation, and will be placed between every bus. It shall be installed and integrated down in the floor.
Busses that are stored over night will be placed with 1, 2 meters distance between them on marked parking places. It is very important that the buses are placed on these marked places. Heat radiations between the busses when the water screen is operational are reduced to approximately 22 kW/m^2.
In an event of fire in this area will in worst case only one bus burn completely up.
For water screen results, look in appendix 4.

6.3.2 Control room

There will not bee installed more fire suppression in the control room, but the room will bee provided with an aspiration smoke detector. This is a more sophisticated detector than the traditional smoke detectors; this provides a faster response to smoke in the room. The control room will be manned 24 hours a day, so they will be able to start fire extinguishing as early in the fire development as possible.
The room will bee provided with a CO_2 fire extinguisher.

6.4 Smoke ventilation

A fire in the bus storage and repair area will produce large volume of smoke. The smoke will be ventilated by natural ventilation through hatches on the roof.
The smoke hatch area is set to be 32 m^2, it is calculated to be 7 meters from floor to smoke layer, and the calculations are in appendix 3.

7 EVACUATION

Shown in Appendix 1.

The evacuation of the building is made so it may not always be necessarily to evacuate those parts of the transportation centre which remain unaffected by a fire in another area of the building. This is described further in the next sections. People shall be lead out to designated areas when their being evacuated.

The philosophy of the alarm and detection system will be integrated into the zoning so that upon evacuation of a zone or group of zones, the other zones will be put on alert.

Simulex program have been used to simulate evacuation times.

All over the transportation centre the management will direct people out and to designated areas and making sure that people do not go to areas where the alarm has gone of.

7.1 Platform Evacuation

In the event of a train fire at platform level or a fire in zone 6, people in zone 1, 2 and 3 will be put on alert but not necessarily evacuated. People in zone 4 and 5 will be evacuated. The voice and visual alarm system will be used to give message to evacuate this area and warn people in rest of the building not to go to this area.

It is important that people that has not gone through customs is separated from other people. They will be directed to a restricted area so they can go through customs and passport control later.

7.1.1 Zone 6A and 6B shown in drawing nr 4.

People in this area will evacuate to the west and up the stairs to street level, or through zone 6B and out to the platforms and there by up to the street.

7.1.2 Zone 6C and D shown in drawing nr 4.

People in this zones shall evacuate out to the platform and there by to street level or up the stair on south wall in zone 6C and out to the street. They shall go to a restricted area.

7.1.3 Zone 6E, shown in drawing nr 4.

For International platforms, escape is possible to both north and south. This stairs led to a restricted area outside of the building.

For national platforms, escape will be up stairs to the north and south. These lead out to the street.

7.2 Terminal Evacuation

In the event of a fire in this zone, people in zone 1, 2 and 3 will be evacuated. People in zone 4, 5 and 6 will be put on alert but not necessarily evacuated. The voice and visual alarm system will be used to give message to evacuate this area and warn people at rest of the building not to go to this area.

7.2.1 Zone 1A and 1B, shown in drawing nr 6.

From the kitchen there are two doors that lead out to the restaurant. There it is possible to escape down two different stairs, one is located in the lobby in the north and one is located at the southeast corner of the restaurant. These lead to street level inside the transportation centre. From her people can go either to the main entrance in the west or through the waiting area and out the doors in the east.

7.2.2 Zone 2, shown in drawing nr 2 and 3.

People can both escape out the main entrance at the west or up the stairs at the shops and out through the doors in the east.

7.2.3 Zone 3, shown in drawing nr 3.

People can both escape out the main entrance at the west or up the stairs at the shops and out through the doors in the east.

7.3 Bus Station Evacuation

In the event of a fire in this zone, people in this zone and in zone 5 and 6 will be evacuated. People in zone 1, 2 and 3 will be put on alert but not necessarily evacuated. The voice and visual alarm system will be used to give message to evacuate this area and warn people at rest of the station not to go to this area.

7.3.1 Zone 4 – Bus Terminal, shown in drawing nr 5.

Evacuation from this area can be done through doors in the east or west, both leads to out to the street.

7.3.2 Zone 5 – Bus repair and storage area, shown in drawing nr 5.

Escape can be done through the gates at the north.

7.4 Disabled and Special Needs Evacuation

Disabled people shall meat at marked areas at the station for evacuation. The management will then help them out. These areas are located at the escalators at zone 2; at the stairs in the restaurant, nearby the stairs at the shops in zone 3 and at the escalators in the passport control room.

7.5 Emergency Lightning and Signing

An emergency lightning system will be installed throughout the station to cover both occupied and unoccupied areas (as shown in Appendix 1). The installation will be designed in accordance with BS5266 Part 1, and contain the following mode of operations:

- All designated escape routes will be category M/2 (with 1 hour battery duration due to having dual supply).
- The control room will be category NM/3.
- Other areas and plant rooms will be category NM/1.

Exit signs will be maintained on all times and have the same battery duration as the areas they serve.
Retail areas will provide their own emergency lightning installations which comply with Retail Fit-Out Guide.

All public and operationally critically areas shall have addition to emergency lightning, a percentage of normal lightning installation supplied from a standby source to allow operation of the station under a loss of main conditions.

Each emergency luminaire, which is also part general lightning installation, will be fitted wit a change over relay that will monitor loss of normal supply. All emergency fittings will be equipped with LED indication of battery backup.

Emergency signage will be provided throughout the station as part of an integrated signage package and commonly accepted pictograms will be used wherever applicable, in locations to be agreed with HMRI and Fire Authorities.

7.6 Emergency Power

This station will be provided with a secure electrical network comprising dual independent incoming HV supplies.
Fans used for mechanical smoke extract will be supplied via fire rated cables.
Emergency generators will not be provided.

Every smoke control fans will have duty/standby motor configurations fed from independent sources and be wired in CWZ grade cables.

8 SIMULATION PROGRAMS

The simulation calculations in chapter 8 are a summary of the reports from the students at the University of Edinburgh. 8.1 Abaqus simulation is made by Thomas Marshall, 8.2 the FDS simulation is made by Benoit Guyonneau and 8.3 the Simulex simulation is made by Richard McKeown.

8.1 ABACUS

8.1.1 Background

ABAQUS is a computational program, which models structures using finite element analysis to determine how they will perform under certain design conditions. Finite element analysis is the breaking down of a rigid structure into finite elements, which are deformable. Rigid bodies, on the other hand, move through space without changing shape. ABAQUS uses the multiple rigid bodies within a finite element program to create a deformable structure that can be analysed.

The ABAQUS program has been used to model and analyse, the behaviour of a structural elements in the transportation centre, using two-dimensional cross-sections through the building. It's then possible examine how the structure will perform under both static and thermal loading conditions.

It will be showed that the actual temperature conditions that will be created by the design fires that have been modelled in FDS are less severe than the standard fire temperature conditions that are specified in BS 8110.

8.1.2 Results and Analysis

The ABAQUS results show that the maximum displacements caused by applying the standard temperature time curve to the structural elements in the vicinity of the design fires are significant, but not sufficient to cause the building to collapse.

The deflections experienced when running the ABAQUS models with the design fire temperature time curves are also significantly smaller than those experienced under the standard fire conditions. Figures 6-9 below show the displacements caused to the sections by the temperature time curve produced by FDS. All of the displacements are scaled up by a factor of 100.

Figure 12: Kitchen: FDS Fire

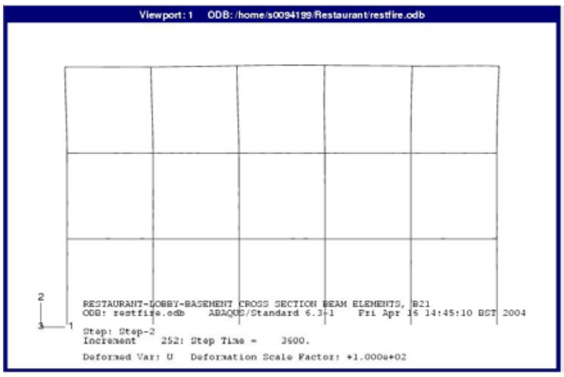


Figure 13: Shop: FDS Fire

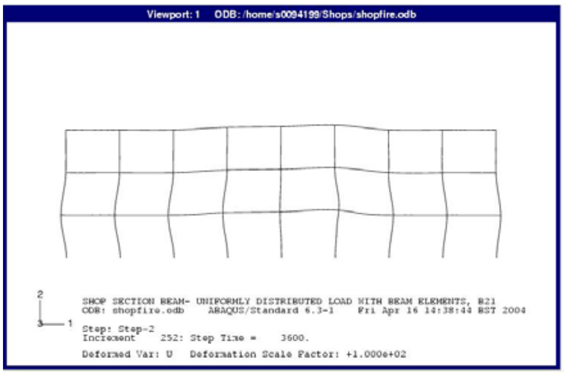


Figure 14: Train: FDS Fire

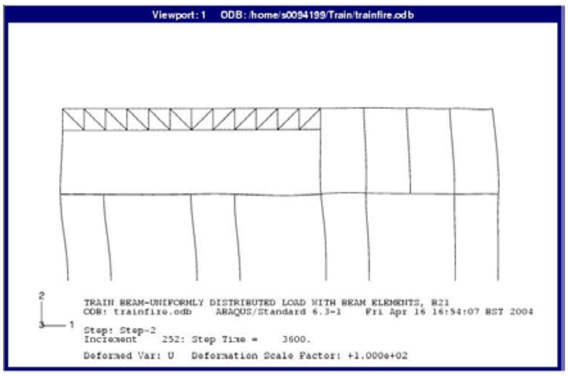
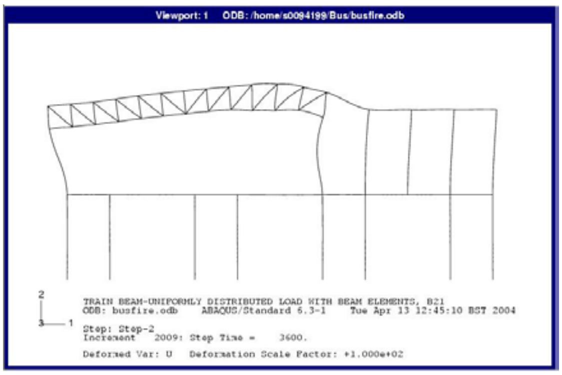


Figure 15: Bus: FDS Fire



8.1.3 Conclusion

Consequently, the results show that if a performance-based analysis of a building is carried out then money can be saved on fire protection and the building will also be safer as all the possible hazards will have been identified and designed for.

8.2 Fire Dynamics Simulator (FDS)

To forecast the fire behaviour a computer program dedicated to the transfers of heat and the production of gases involved in combustion reactions: Fire Dynamics Simulator (FDS), has been used.
Fire Dynamics Simulator is a CFD model (Computational Fluid Dynamics). A CFD model requires that the compartment considered be divided into small three-dimensional rectangular volumes or computational cells.
FDS is used to model and analyse 3 dimensionally the consequences of a fire in terms of temperature distribution, heat transport and behaviour of the smoke released. The visualization of the results of an FDS calculation is done with the program Smokeview. The results can after be used as a base for other analysis to determinate for example the behaviour of the structure and also the time necessary for people to evacuate the building.
Fire Dynamics Simulator has been developed by the National Institute of Standards and Technology (NIST). FDS and Smokeview are freewares and can be downloaded on the website of NIST: http://www.bfrl.nist.gov/. This project is based upon FDS 3.1 and Smokeview 4.0.

8.2.1 Model Uncertainty

FDS can provide valuable insight into how a fire may develop. However the model is only a simulation.
But provided that there are a lot of uncertainties on the fire sizes, fire sites and on the possible other fuel loads, it can be assumed that conservative choices for these inputs will compensate these uncertainties.
Nevertheless basic verifications will be conducted to check if the results seem correct.

8.2.2 Performance criteria

The building must fulfil the requirements of fire and life safety. To know if this is the case, it's necessarily to know if one of the two critical conditions was reached:

- Structure gets too hot to sustain the loading
- Too much heat or lethal products in the building or compartment to allow safe evacuation.

The knowledge of these two conditions was also required: critical values of the temperature and of the heat or lethal products release in each scenario.
If one of these two critical conditions is reached, an increase of the structural dimensions and perhaps the use of fire protections are required and other series of tests have to be conducted.
Thus the performance criteria selected to assess the fire safety goals is in this project the assurance that the critical values of the temperature and of the heat or lethal products release in each scenario won't be reached.

8.2.4 Results

To determine the conditions in the rooms, so it can be accessed whether or not people in the rooms will be able to evacuate safely, slices have been taken to measure the following: evolution of temperature, visibility, concentration of carbon monoxide and concentration of carbon dioxide.

When considering the safety of the occupants the conditions below a level of 2.5m are most interesting. This is because the vast majority of people will be beneath this level. When examining the temperature conditions in the rooms, it is most concerned with the maximum temperature of air that can be breathed. "Occupants can not breathe 'wet' air at more than 100°C and 'dry' air at more than 220°C". When examining the visibility conditions in the rooms a value of about 2 metres should be sufficient to allow for occupants in an "involved tenant space" to find their way out of that space and in more vast areas a visibility of 10m people should be sufficient.

Table 3 shows how different concentrations of Carbon Monoxide physiologically affect humans and table 4 shows how different concentrations of Carbon Dioxide physiologically affect humans.

	Parts of CP per million parts of air
Threshold limit value	50
Concentration which can be inhaled for 1 hour without appreciable effect	400 to 500
Concentration causing unpleasant symptoms after 1 hour of exposure	1000 to 2000
Dangerous concentration for exposure of 1 hour	1500 to 2000
Concentrations that are fatal in exposure of less than 1 hour	4000 and above

Table 3: Physiological Response to Various Concentrations of CO

	Parts per million parts of air
The threshold limit for CO2, that is the concentration that can be tolerated by workers day after day without adverse effect	5,000
Stimulation is pronounced, and 30-minute exposure produces signs of intoxication	50,000
Unconsciousness results in a few minutes	70,000
Loss of consciousness is predicted to occur within 2 minutes	100,000

Table 4: Physiological Response to Various Concentrations of CO2

8.2.4 Conclusion

The knowledge of the fire behaviour is the basic point of the project. Understanding the possible fire scenarios gives all the data necessary to forecast the structural behaviour of the building, the concentrations of lethal products and the distribution of heat within the building, consequently giving us all the information necessary to undertake an evacuation analysis.

The results of the FDS analysis show that for the design fire scenarios that it has been adopted temperatures and the concentrations of lethal products in the air are at levels that allow safe evacuation of the building.

FDS can provide valuable insight into how a fire may develop. However, the model is only a simulation and there a lot of uncertainties on the fire sizes, fire sites and on the possibility other fuel loads being present. Nevertheless, it can be assumed that the conservative estimates that have been adopted for these inputs will compensate for these uncertainties. Even so basic verifications will be conducted to check if the results seem correct.

8.3 Simulex

During the early stages of the project, four main fire scenarios were identified as the most important to concentrate on for this study.
It was also considered very important to test a scenario where the whole transportation centre had to be evacuated, for example in the situation of a bomb scare or something similar.

As a result, five main evacuation scenarios were identified to be tested using the Simulex programme.

8.3.1 Assumptions from simulex booklet

- No people have started the simulation within the stairway
- People are initially starting the simulation in a static position
- There is no time delay for people to react to the alarms and decide to evacuate
- The scenarios have been modelled for a 'rush hour' situation
- Max populations considered

8.3.2 Aims and Objectives

The Simulex program is used to show that the building can be safely evacuated, for any of the alternative fire scenarios that have been mentioned earlier, before untenable conditions and reached within the building.

8.3.4 Background

Simulex is a software package which models the evacuation of large populations from multi-storey buildings. The software accurately models the movement of each individual person in a total building simulation.

Simulex allows the user to set up a populated building very quickly, by importing CAD drawings. The building space is analysed by the program, and accurate travel distances and exit routes are calculated throughout the entire building automatically, within a few minutes.

The software is based on real-life data which enables it to model human movement, simulating behaviour which includes side-stepping and overtaking patterns, speed fluctuations and queuing behaviour. Each person's position, orientation, walking speed and route-assessment is modelled every 0.1 seconds.

The user can watch a simulated evacuation on-screen as it happens, and areas such as crowded stairways and congested doorways can be seen immediately through different animated 'windows'. Each simulation can be recorded onto hard disk for repeat viewing and analysis.

The Institute for Environment and Sustainability (IES) believes that the information provided by Simulex surpasses planning control in most countries. Modelling building evacuations with Simulex adheres to the modern concept of 'performance-related' design, where simple engineering rules are replaced by the integration of advanced engineering solutions.

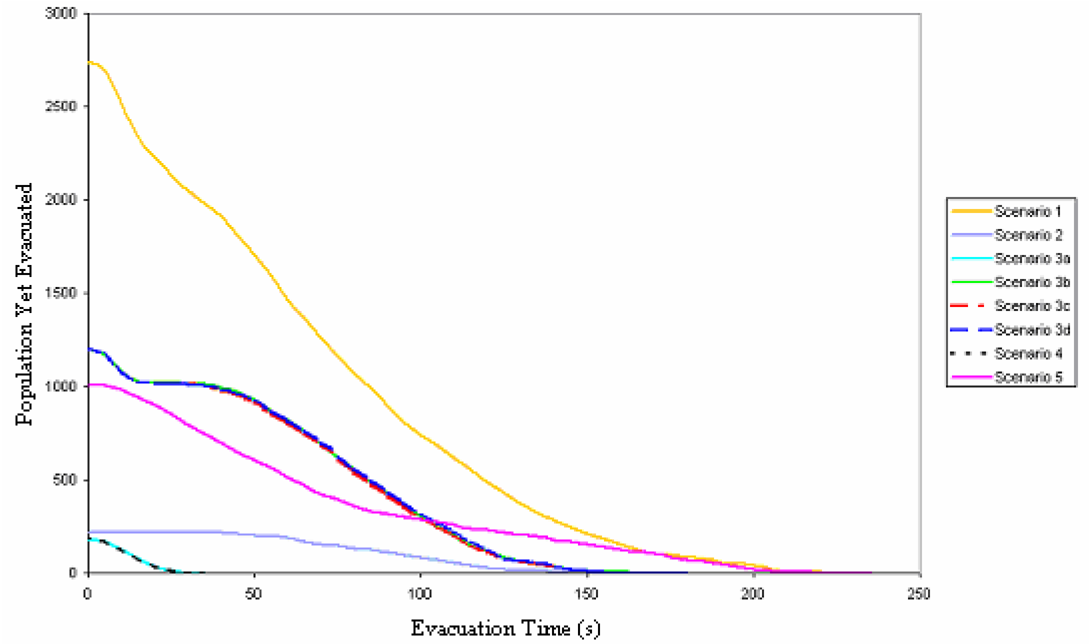
8.3.5 The Model

Figure 16: Simulex program

8.3.6 Results

Figure 11 and Table 5 show the time taken for people to evacuate the building for the different fire scenarios. Scenario 1 represents the situation where there has been a bomb scare and everyone has to evacuate the building immediately. This is considered to be the worst case scenario as there is the maximum number of people to be evacuated. As figure 15 shows, initially there are approximately 2750 people in the building and it takes them approximately 230 seconds to completely evacuate the building.

Figure 17: Graph showing Evacuation Times for the Different Scenarios



Fire Scenario Code	Fire Origin
1	No Fire- Bomb Scare Scenario
2	Kitchen Area of Restaurant
3a	Any of the Shops on Street Level (0m)
3b	Southern Shop on -5m Level
3c	Central Shop on -5m Level
3d	Northern Shop on -5m Level
4	Bus Situated in Bus Terminal
5	Train Carriage Situated to East of Building

Table 5: Fire Scenario Code

Scenario	Population to be Evacuated	Evacuation Time
1	2736	3 minutes 44.6seconds
2	221	2 minutes 43.4 seconds
3a	186	2 minutes 31.6 seconds
3b	1204	2 minutes 45.7 seconds
3c	1204	2 minutes 55.1 seconds
3d	1204	2 minutes 55.1 seconds
4	1204	31.5 seconds
5	1204	3 minutes 51.0 seconds

Table 6: Evacuation Times

8.3.7 Conclusion

The Simulex results show that there are sufficient escape routes in place so that all the people in the building can be evacuated safely in the event of any of the design fire scenarios or possible bomb scare.

From the result of FDS and the evacuation times calculated by Simulex have been able to show that everyone in the building is able to evacuate safely before untenable conditions are reached.

Simulex can provide useful insight into evacuation times and how people may react in the event of an emergency. However, the model is only a simulation and it is created using a number of simplifications and assumptions, which should be taken into account when applying the results to real life situations. For example, although there are different types of people entered into the model, there is no break down of the individual characteristics of people within those types. There model also does not take into account people mental state and the possibility that some people may panic and others may simply ignore the alarms completely. Nevertheless, it's assumed that the conservative estimates that have been adopted for these inputs will compensate for the simplifications.

8.4 Conclusions from simulations

Finally the building has been designed and tested for four different fire scenarios. With no special protection, the model results show that the fires are unlikely to present a risk of failure for the structure or for its occupants.
Indeed, with values of temperatures and hazardous fire products staying below all the critical levels, the safety of these parts of the building is guarantied against such fires without any use of fire protection or fire suppression.
The results show that the building does not collapse when subjected to the standard temperature time curve. They also show that the actual design fires, as modelled by FDS, produce significantly lower temperatures on the structural elements than the standard temperature time curve. Consequently, the displacements and stresses calculated by ABAQUS are significantly higher when the sections are exposed to the standard temperature time curve.

9 Achieving the Objectives

Through the use of performance based design it has been shown that the Transportation centre meets the objectives.

- All of the buildings occupants are able to evacuate safely in the event of a fire. It has been shown through the use of FDS and Simulex that all of the building occupants will be able to evacuate safely before untenable conditions are reached.

- Fire fighters will be able to safely evacuate the building or attack the fire. Special access has been provided for fire fighters, where there is information provided on the layout of the building. It has been shown though the use of ABAQUS, the building will not collapse in the event of a fire, so the fire fighters will be able to carry out there job safely.

- The structure will not collapse due to fire. It has been shown through the use of FDS and ABAQUS that the building will not collapse due to the worst-case scenario design fires.

- In the event of a fire there will be minimal business interruption. Through the use of compartmentation and zoning and with smoke extraction, the business interruption has been minimized.

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Appendix 1: Auto Cad Drawings.

These drawings contain evacuation routes and fire safety symbols.

Nr. 1: Site Plan
Nr. 2: Main Terminal, street level
Nr. 3: Main Terminal, lower level
Nr. 4: Platform level
Nr. 5: Bus Terminal
Nr. 6: Main Terminal, upper level

Appendix 2: Mechanical Smoke Extraction

The calculations are taken from CIBSE Technical Memoranda TM19: 1995: Relationships for Smoke Control Calculations

Variables used are defined as follows:

M = Mass flow of entrained air (kg/s)

Q = Rate of heat release (kW) = 1,5 Q_P

Q_P = Convective portion of heat release rate (kW)

Z = Height above base of fire to bottom of smoke layer (m)

Z_1 = Limiting height of intermittent flames (m)

T_m = Average temperature of plume (K)

T_0 = Ambient air temperature 293 K

T_S = Average temperature of smoke layer (K)

C_p = Specific heat capacity of air 1,02 kJ/kgK

ρ_0 = Density of ambient air (kg/m^3) 1,22 kg/m^3

g = Acceleration due to gravity 9,81 m/s^2

h = Height of ceiling above base of fire (m)

V_S = Volume of smoke (m^3)

β = Extract factor: 2 where extract near wall
2,8 otherwise

Scenario:
Fire in Restaurant area.

Assumptions:

3,5 m Z, clear layer height above floor level.

5 m, ceiling height above floor

3000 kW, steady state heat output Q

2000 kW, steady state convective heat output Q_P

3 m, diameter fire (d_S)

Calculations:

Mass flow rate:

$M = 0{,}071 * Q_P^{1/3} * Z^{5/3}$

$M = 7{,}21$ kg/s

Temperature in smoke layer at Z = 3,5m

$T_S = Q_P/(M * c_P) + T_0$

$T_S = 564{,}67$ K 291,67 °C

Flame height:

$Z_1 = 0{,}035 * Q_P^{2/3}/[d_S + 0{,}074 * Q_P 2/5]^{2/3}$

Z_1 2,02 m

The top of the flames is lower than the bottom of the smoke layer, Z = 3,5

Volume of smoke extract required:

$V = M/\rho_0 + Qp/(\rho_0 * T_0 * cp)$

V 11,40 m^3/s

To avoid plugholing is it necessary to have several extraction points to limit the amount of smoke being extracted from a single point.

Assuming dimension of 1m, and the critical dimension is the distance from the intake to the base of the smoke layer.

The critical mass extract rate through a single extract point is :

$M = \beta[g(h\text{-}Z)^5*(T_S\text{-}T_0)*T_0]^{0,5}/T_S$

M 12,07 kg/s

Number of extraction points:

2 extraction points would be sufficient in the restaurant
1 in the lobby

5 m^3/s each has been provided per extraction point.

Scenario:
Fire in Shop

Assumptions:

3,5 m, diameter fire (ds)

3,5 m Z, clear layer height above floor level.

5 m, ceiling height above floor

3750 kW, steady state heat release

2500 kW, steady state convective heat output Q_P

Calculations:

Mass flow rate:

$M = 0{,}071 * Q_P^{1/3} * Z^{5/3}$

$M = 7{,}77$ kg/s

Temperature in smoke layer at Z = 3,5m

$T_S = Q_P/(M*c_P)+T_0$

$T_S = 608{,}24$K 335,24 °C

Flame height:

$Z_1 = 0{,}035*Q_P^{2/3}/[d_S+0{,}074*Q_P^{2/5}]^{2/3}$

Z_1 1,96 m

The top of the flames is lower than the bottom of the smoke layer, Z = 3,5

Volume of smoke extract required:

$V = M/\rho_0+Qp/(\rho_0*T_0*C_P)$

$V = 13{,}22$ m^3/s

To avoid plugholing is it necessary to have several extraction points to limit the amount of smoke being extracted from a single point.

Assuming dimension of 1m, and the critical dimension is the distance from the intake to the base of the smoke layer.

The critical mass extract rate through a single extract point is:

$M = \beta[g(h\text{-}Z)^5*(T_S\text{-}T_0)*T_0]^{0,5}/T_S$

M = 12,07 kg/s

2 extraction points would be sufficient per shop

Two extraction points witch extract 7 m^3/s each will be provided per shop.

Scenario:
Baggage fire in train waiting area.

Assumptions:

1,6 m, d_S diameter fire

8 m, Z, clear layer height above floor level.

10 m, ceiling height above floor

1500 kW, steady state heat release

1000 kW, steady state convective heat output Q_P

Calculations:

Mass flow rate:

$M = 0{,}071 * Q_P^{1/3} * Z^{5/3}$

$M = 22{,}72$ kg/s

Temperature in smoke layer at Z = 8m

$T_S = Q_P/(M * c_p) + T_0$

$T_S = 336{,}15$ K   63,15 °C

Flame height:

$Z_1 = 0{,}035 * Qp^{2/3}/[d_S + 0{,}074 * Qp^{5/2}]^{2/3}$

$Z_1 = 1{,}62$ m

Volume of smoke extract required:

$V = M/\rho_0 + Qp/(\rho_0 * T_0 * c_p)$

$V = 21{,}36$ m^3/s

To avoid plugholing is it necessary to have several extraction points to limit the amount of smoke being extracted from a single point.

Assuming dimension of 1m, and the critical dimension is the distance from the intake to the base of the smoke layer.

The critical mass extract rate through a single extract point is:

$M = \beta[g(h-Z)5*(TS-T0)*T0]0,5/TS$

M 16,59 kg/s

Number of extraction points:

2 extraction points would be sufficient

There will be several extraction points in the waiting area, |minimum two per zone in the area.

Appendix 3: Natural Smoke ventilation

Scenario:
Bus burning in repair area, or bus loading area.

The calculations is from: Byggdetaljer 520.327 Eidmund Skåret 1995
Based on :
Meland, Øystein, Jensen, Geir og Skåret Eidmund: Smoke control. Oslo 1989
Heskestad, Gunar: Engineering Relations for Fire Plumes. Fire Safety Journal nr. 7, 1984

Assumptions:

Ground Area: A: 1000 m^2

Convective factor for the fire: C_F: 0,6

Height to ceiling: Z_H: 10 m

Height from floor to smoke layer: Z_{SJ}: 7 m

From fire to smoke layer: Z = 5,65 m

Thickness smoke layer: Z_{SL} = 3 m

Loss of heat to surroundings: C_S = 0,85

Thermal capacity: c_p = 1,02 kJ/kgK

Smoke hatches extraction efficiently: C_V = 0,6

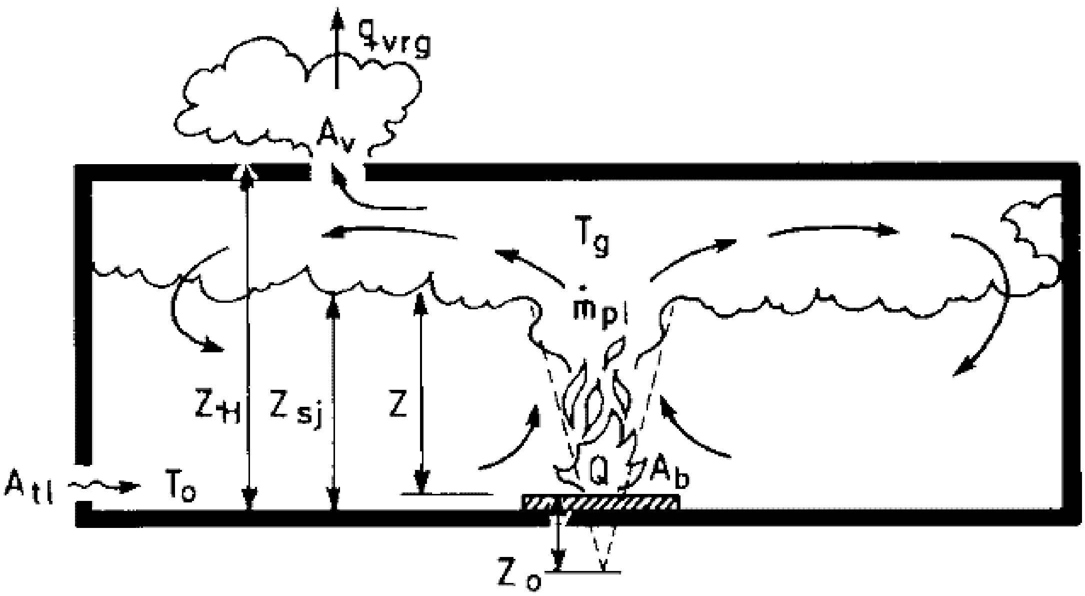
P_f: Perimeter of the fire. r = 3,1784 m, P_f = 19,9704762 m

T_0 = 293 K

N = 1 Fire in middle of room
N = 2 Fire near wall
N = 3 Fire in corner

Time to fire brigade arrives: 10 min

Rate if heat release: Q = 20000 kW



Calculations:

Virtual origin:
$Z_0 = -1,02*D+0,083*Q^{2/5}$
$Z_0 = -2,12$ m

Critical height:
$Z_1 = Z0+0,166(C_F*Q)^{2/5}$
$Z_1 = 4,98$ m
$Z/Z_1 = 1,13 >1$

Mass flow of entrained air:
$m_{PL} = 1/N*0,071*(C_F*Q)^{1/3}*(Z-Z_0)^{5/3}*(1+0,026*(C_F*Q)^{2/3}*(Z-Z^0)^{-5/3})$

$m_{PL} = 71,74$ kg/s

Density of ambient air
$\rho_0 = 1,22$ kg/m^3

Necessary extraction capacity:

$q_{EC} = (C_S*Q)/(\rho_0*T_0) + (m_{PL}/\rho_0)$

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q_{EC} = 106,36 m^3/s

Temperature rise in smoke layers:

$\Delta T_{PL} = (C_S*Q)/(C_P*m_{PL})$

ΔT_{PL} = 232,31 K

Temperature in smoke layer:

$Tg = T_0 + \Delta T_{PL}$

Tg = 525,31 K

Decrees of pressure coefficient:

$\xi v = 1/C_V^2$

ξv = 2,77777778

Decrees of pressure coefficient for the air in to the building:

ξ_{AI} = 2,4

Smoke hatch area

$A_V = q_{EC}*(\xi v*(1+(\xi_{AI}*T_0)/(\xi v*Tg)))^{1/2}/(2*9,81*(Z_H-Z_{SJ})*\Delta T_{PL}/T_0)^{1/2}$

Av = 31,58 m^2

Area smoke hatches: 32 m2
Will be provided in both areas

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Scenario:
Fire in Main Waiting area:

The calculations are taked from CIBSE Thechnical Memoranda TM19: 1995:Relationships for Smoke Control Calculations

Assumptions:

The following design criteria have been used in the calculations:

1000 kW, Qp convective heat output (baggage fire)
14 m, Z_{SJ} clear layer height
21 m, Z height to ceiling
* Smoke extracted trough hatches in the ceiling
* Axisymmetric smoke plume

The mass flow rate of smoke into layer is given by:

$M = 0{,}071*Qp1/3*Z_{SJ}^{5/3}$

M = 57,73 kg/s

The temperature of the smoke is given by:

$Ts = (Qp/M*Cp) + T_0$

Thermal capacity:
Cp = 1,02 kJ/kgK

Temperatur of the ambient air:
T0 293 K

Ts: 309,97 K 36,97 °C

Flame height:

$Z_1 = (0{,}035*Qp^{2/3})/(ds+0{,}074*Qp^{2/5})^{2/3}$

Fuel diameter:
ds = 1,6 m

Z_1= 1,77 m

Necessary extraction capacity:

$q_{EC}=(M/\rho_0)+(Qp/(\rho_0*T_0*Cp))$

Density of ambient air:
$\rho_0 = 1{,}22\ kg/m^3$

$q_{EC} = 50{,}06\ m^3/s$

Temperature rise in smoke layers:

$\Delta T_{PL} = (Cs*Q)/(Cp*M)$

Loss of heat to surroundings:
$Cs = 0{,}85$

$\Delta T_{PL} = 14{,}43\ K$

Temperature in smoke layer:

$Tg = T_0 + \Delta T_{PL}$

$Tg = 307{,}43\ K$

Decrees of pressure coefficient:

$\xi v = 1/Cv^2$

Smoke hatches extraction efficiently:
$Cv = 0{,}6$

$\xi v = 2{,}77777778$

Decrees of pressure coefficient for the air in to the building:

$\xi_{AI} = 2{,}4$

Smoke hatch area

$Av = q_{EC}*(\xi v*(1+(\xi_{AI}*T_0)/(\xi v*Tg)))^{1/2}/(2*9{,}81*(Z_H-Z_{SJ})*\Delta T_{PL}/T_0)^{1/2}$

$Av = 43{,}32\ m^2$

Area smoke hatches: 43,32 m^2

Air in to this area:

*Main entrance: 8*3 24 m2*
*West entrance: 3,3*3*2 19,8 m2*

Sum 43,8 m2

Scenario:
Fire in Bus Waiting area:

Assumptions:

The following design criteria have been used in the calculations:

1000 kW, Qp convective heat output (baggage fire)
6 m, Zsj clear layer height
10 m, Z height to ceiling
* Smoke extracted trough hatches in the ceiling
* Axisymmetric smoke plume

The mass flow rate of smoke into layer, is given by:

$M = 0{,}071*Qp^{1/3}*Z^{5/3}$

M = 14,06 kg/s

The temperature of the smoke is given by:

$Ts = (Qp/M*cp)+T_0$

Thermal capacity:
Cp = 1,02 kJ/kgK

Temperatur of the ambient air:
$T_0 = 293$ K

Ts: 362,69 K 89,69 °C

Flame height:

$Z_1 = (\ 0{,}035*Qp^{2/3})/(ds+0{,}074*Qp^{2/5})^{2/3}$

Fuel diameter:
ds =1,6 m

$Z_1 = 1{,}77$ m

Necessary extraction capacity:

$q_{EC}=(M/\rho_0)+(Qp/(\rho_0*T_0*Cp))$

Density of ambient air:
$\rho_0 = 1{,}22\ kg/m^3$

q_{EC} = 14,27 m^3/s

Temperature rise in smoke layers:

$\Delta T_{PL} = (Cs*Q)/(Cp*M)$

Loss of heat to surroundings:
Cs = 0,85

ΔT_{PL} = 59,24 K

Temperature in smoke layer:

$Tg = T_0 + \Delta T_{PL}$

Tg = 352,24 K

Decrees of pressure coefficient:

$\xi v = 1/Cv^2$

Smoke hatches extraction efficiently:
Cv = 0,6

ξv = 2,77777778

Decrees of pressure coefficient for the air in to the building:

ξ_{AI} = 2,4

Smoke hatch area

$Av = q_{EC}*(\xi v*(1+(\xi_{AI}*T_0)/(\xi v*Tg)))^{1/2}/(2*9{,}81*(Z_H-Z_{SJ})*\Delta T_{PL}/T_0)^{1/2}$

Av = 7,82 m^2

Area smoke hatches: 8 m^2

Air into this area is sufficient

Main entrance:

*4*3 12 m2*

Appendix 4: Water screen

These results is taken from the report made by Øyvind E. Reiersen and John Ivar Stange, students at there final year for Bachelor in Fire Engineering at Stord/Haugesund University College in Norway. It is possible to get this report if you contact the University.

Type	Plasement against the fire	Loss of heat radiation in %							
			1 m	3 m	5 m	Average loss for each height			Average loss for overall heights
	Center								
Modifyed		**Attempt 8**	87	87	81	70,5	72,5	68,5	70,5 %
		Attempt10	54	58	56				
	On the side								
		Attempt 4	63	66	67	67,0	70,5	68,0	68,5 %
Modifyed		**Attempt 5**	71	75	69				

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Appendix 5. Heat Radiation.

The calculations are taken from:
Enclosure Fire Dynamics, Bjørn Karlsson and James G. Quuintiere, 1999

$q = \Phi \varepsilon \sigma T^4$
q = Radiation [w/m2]
Φ = Configuration factor
ε = Emissivity 1
σ = Stefan-Boltzmann constant 5, 67E-08 W/m^2K^4
T^4 = Flame temp. [1300 K]

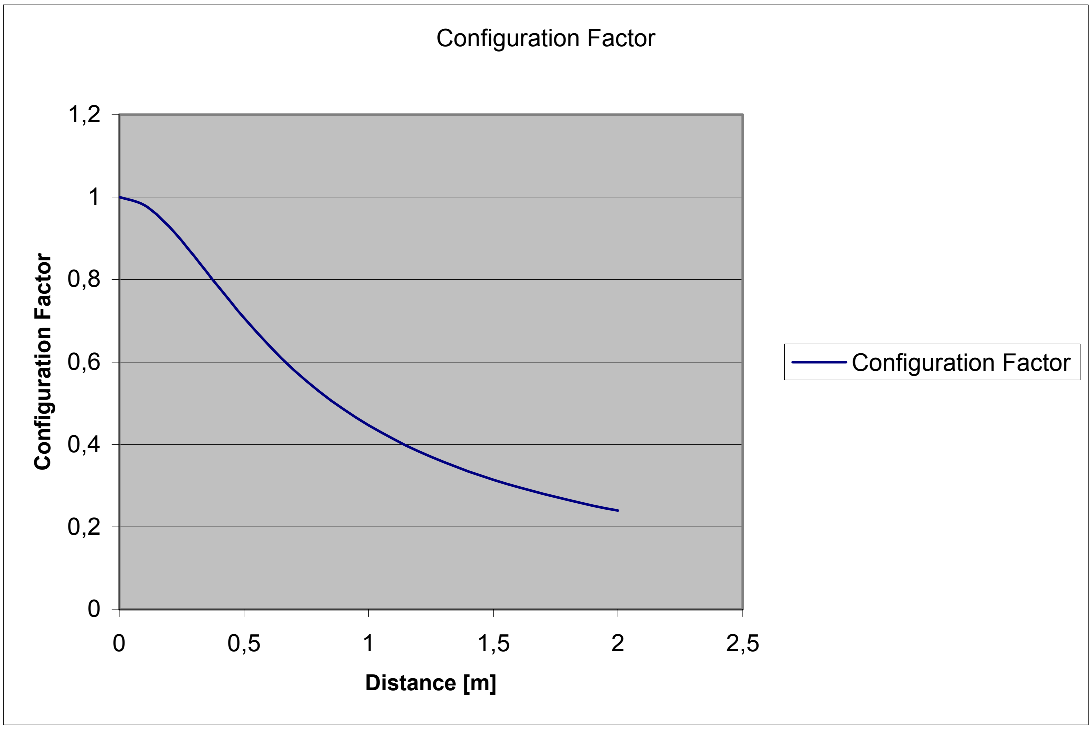
Table 7,1 gives this equation for configuration factor

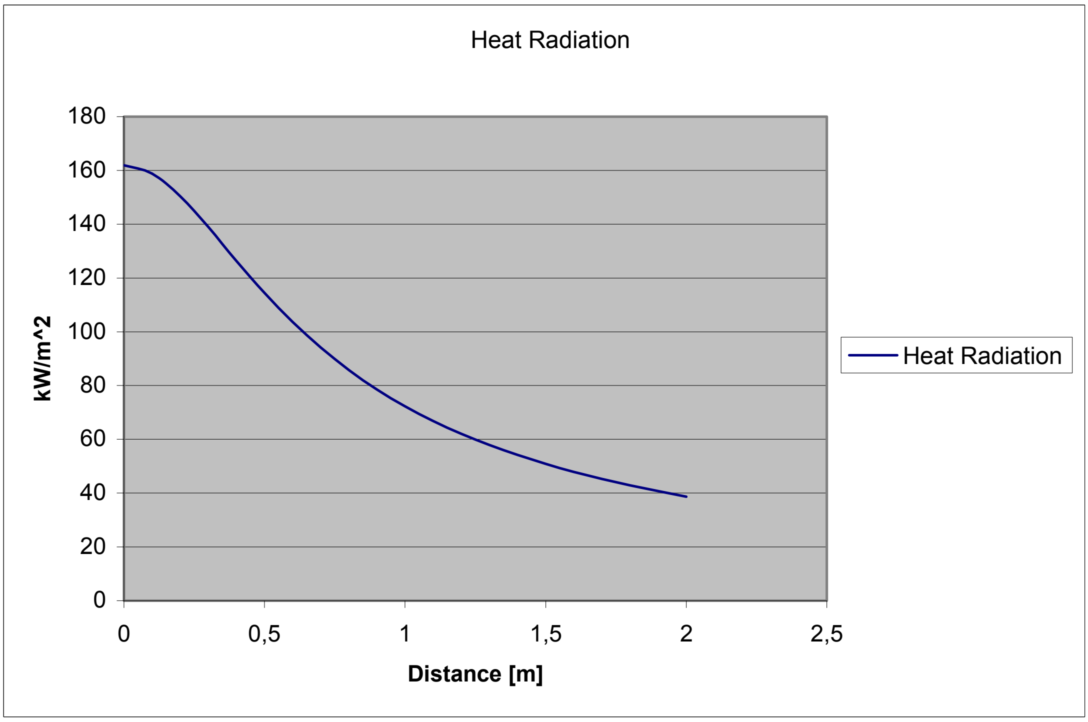
$F_{d\ 1\text{-}2} = 1/2*\pi$ [a/rot(a^2+$c^{2)*}$tan^{-1}*(b/rot(a^2+c^2) + b/rot(b^2+c^2)* tan^{-1}*(a/rot(b^2+c^2)]

Ftot = 4*Fd 1-2

a = 0,5 m
b = 6,1 m
c = distance m

Distance				Configuration factor	Heat Rad.
c [m]				F_{tot}	q [kW/m^2
0		1,48901195	0,08178438	1	161,94087
0,1		1,45851543	0,08176246	0,98057135	158,794578
0,2		1,37669251	0,08169675	0,92843944	150,352291
0,3		1,26522782	0,08158748	0,85740925	138,8496
0,4		1,14491772	0,081435	0,78072039	126,430539
0,5		1,02911773	0,08123978	0,70687554	114,47204
0,6		0,92407564	0,08100244	0,63985258	103,618284
0,7		0,83157658	0,08072374	0,58078842	94,0533818
0,8		0,75119746	0,08040453	0,52941427	85,7338071
0,9		0,68164421	0,0800458	0,48490692	78,5262486
1		0,62141404	0,07964863	0,44631036	72,2758873
1,1		0,56908042	0,07921422	0,41271719	66,8357802
1,2		0,52339339	0,07874384	0,38333246	62,0771928
1,3		0,48329734	0,07823885	0,35748504	57,891438
1,4		0,44791603	0,07770069	0,334618	54,1883293
1,5		0,41652727	0,07713085	0,31427252	50,8935646
1,6		0,38853664	0,07653088	0,29607118	47,9460242
1,7		0,36345411	0,07590238	0,27970302	45,2953509
1,8		0,3408742	0,07524696	0,26491096	42,8999118
1,9		0,32045992	0,0745663	0,2514815	40,7251329
2		0,3019297	0,07386204	0,23923645	38,7421592


Configuration Factor
1,2
1
0,8
0,6
0,4
0,2
0
Configuration Factor
0
0,5
1
1,5
2
2,5
Distance [m]
Configuration Factor


Heat Radiation
180
160
140
120
100
80
60
40
20
0
kW/m^2
0
0,5
1
1,5
2
2,5
Distance [m]
Heat Radiation