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The Swedish Case Study Fire Safety Design for a Multitenant Business Occupancy

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Lund 1996

The Swedish Case Study Fire Safety Design for a Multitenant Business Occupancy

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Abstract: The report presents a sample design of a multi-storey building with respect to the fire safety. Three design strategies are examined, a standard solution according to the requirements, a fire safety engineering design without a sprinkler system and finally a fire safety engineering solution with a sprinkler system. Both occupant safety and structural safety have been considered in the design for the three cases. The use of fire safety engineering methods for the design shows that an optimised solution can be achieved with respect to both fire safety and economics. An executive summary is also attached to the report, which describes the major findings.

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PREFACE

On behalf of CIB/SFPE, in conjunction with an international conference on 24-26 September 1996 in Ottawa, Canada, a case study was carried out, based on Swedish conditions, on the subject of Fire Protection Engineering.

Fire protection was designed for a 4-storey office building with basement, for three cases:

- in accordance with detailed solutions and standard practice; - The Standard Method
- with the aid of calculation and design methods; - The Fire Engineering Design Method
- with the aid of calculation and design methods when sprinklers are installed.

The three cases have then been compared as regards fire engineering and finance.

The persons carrying out the survey are: Per-Anders Marberg (Project Leader) at Bengt Dahlgren AB, Robert Jönsson, Håkan Frantzich and Johan Lundin at the Department of Fire Safety Engineering, Lund University and Tomas Rantatalo at the National Board of Housing, Building and Planning.

Invaluable help has been contributed by:

-Boel Jonsson, Architect, National Board of Housing, Building and Planning, for doing the building drawings.

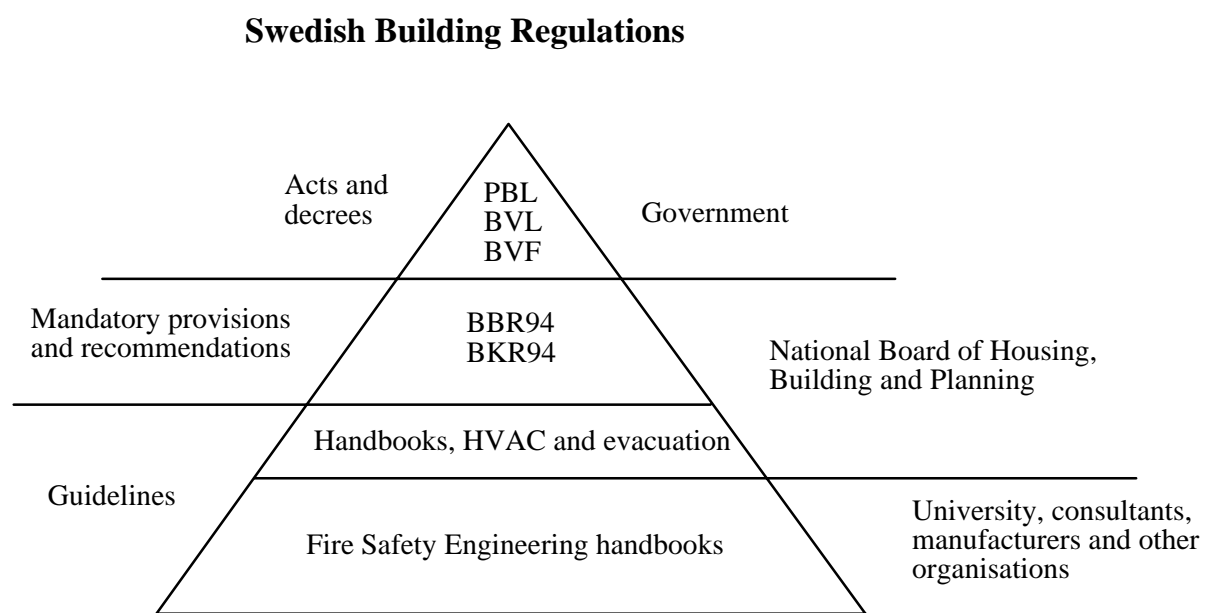
An executive summary of the report is attached.

The report is intended to provide examples of the various ways in which fire protection can be designed for a relatively simple building, in accordance with the Swedish performance based building code.

1. INTRODUCTION

Sweden has since 1994 had performance based building regulations. In some areas in fire safety this process started as early as 1967. The performance based regulations are in line with the decision made by the Parliament in 1985, to use more scientific based solutions in building fire safety design and not rely so much on "rule of thumb" and old experiences from building fires.

At the same time there has been a change in the Planning and Building Act where the building owner now has sole responsibility in proving that the building complies with the regulations. This means that the owner has to have the knowledge and experience within his project team. He can no longer leave the fire safety to be decided and/or checked by local authority, which previously used to be the fire service. The Swedish system is shown in the figure.



PBL - Planning and Building Act (1987:10)

BVL - Act (1994:847) on Technical Requirements for Construction Works etc

BVF - Decree (1994:1215) on Technical Requirements for Construction Works etc

BBR94 - Building Regulations (BFS 1993:57)

BKR94 - Construction Design Regulations (BFS 1993:58)

Figure 1. The Swedish building regulations.

One of the major improvements in the new building code, is the requirement of a fire safety documentation. The building owner shall, according to section 5:12 in BBR 94 [1] (see appendix 1), produce a detailed description about the fire safety design in the building and special care has to be taken if fire engineering methods are used in the design.

The main objective is that the building should be constructed so that the outbreak of fire could be prevented and the spread of fire and smoke in the building limited, and so that persons in the building could escape safely from the building or be rescued in some other way.

For the background information parts of a translated version of the building regulations [1,2] are presented in appendix 1.

The fire protection solutions for the sample building are not complete, and exemplifies only how some of the important fire prevention steps could be met. When believed that a cost effective solution could be achieved by other means than by following the detailed solutions given in guidelines, calculations have been used to find a satisfactory solution. The building is assumed to comply with the requirements formulated in the code if not otherwise stated. Other legislation's may also be applied to the construction, however these have not been considered.

In the calculations the computer program HazardI v 1.2 has been used. Only a limited number of data are presented from our calculations.

It is assumed that the action by the fire brigade would be expected within the normal attendance time (10 min), and that the building is located in a Swedish town. The threat of fire spread to neighbouring buildings is not considered. Safe evacuation of the occupants may be achieved by giving the early warning of an incident, clear instructions of what to do, maintaining safe escape routes and if the emergency would be a fire, by initial control of the fire size. Maintaining safe escape routes as well as the initial control of the fire size may primarily be done by fire compartmentation. The compartmentation for preventing fire spread should be done according to the minimum requirements and no extra attention has been paid to minimise the possible property damage.

In the building, an automatic fire detection system and escape alarm system are installed in some areas to give an early warning of a fire and clear instructions of what to do in case of fire.

Depending on their function, elements of structure are assigned to classes E (integrity) and I (insulation). The classification could be combined with the designation C (for doors with an automatic closing device), see appendix 1 section 5:221. The fire compartmentation is done in accordance with the code, in Class EI 60, and all doors to and in an escape route are assumed to be in class EI-C 30, if not otherwise stated. The symbols are according to the interpretative document Safety in Case of Fire from the European Community and used in the Swedish building code. The fire resistance classes which are used according to the code are based on fire load intensities lower than 200 MJ/m² (surrounding area). The classes could be applied without any special examination for dwellings, offices, schools, hotels, garages for cars, food selling shops, residents store rooms and comparable fire compartments. In this paper we have disregarded the fact that some parts of the building are constructed with timber.

The used classes could also be implemented for higher load intensities, if the building was protected by an automatic water sprinkler installation, or if conditions are such that a fire would be completely extinguished by the action of the fire brigade, not later than 60 min after the outbreak of fire.

Calculation of occupant loads are either done by code recommendations, engineering judgement or by the limitations set out by the escape possibilities.

The fire compartmentation is indicated on the drawings, which are included in appendix 2.

2. BUILDING DESCRIPTION

The building drawings are included in appendix 2.

The building is a square 4-storey office building with a basement, designed in the Swedish style. Materials choice is noted in chapter 3.1 and 7.1. An assembly room at the ground level for about 400 persons and a glass-covered outdoor yard (atrium) have been added to the original building specification.

Three fire engineering cases are reported in chapters 3-5, where the consequences of including the atrium are noted in a sub-chapter.

The basement includes the lower part of the assembly room, stores, a strong-room for the bank and various building services rooms. The ventilation equipment are located in the attic.

Floor 1 (ground floor) consists of a bank premises, assembly room with foyer, cafeteria with possible associated atrium, insurance company, office service, building maintenance etc.

Floors 2-4 contain pure office premises with modular office rooms. Two common conference rooms are included on each floor. It is intended that floors 2-4 should be able to offer flexible tenant accommodation, with 1-4 companies per floor. All workplaces have direct or indirect sun light, which is required by the regulation.

In the building, 2-4 staircases pass through each floor terminating in open air at ground level. The number are subjected to the fire safety design strategy.

It has been assumed that the Rescue Services will have started some activity within 10 minutes of they have been reached by an alarm. In addition, it is assumed that the distance to adjacent buildings would be at least 8 metres, so no special measures are required to prevent the spread of fire between buildings, in addition to that which is noted in chapters 3 and 7.

3. THE STANDARD METHOD - in accordance with detailed solutions in guidelines and standard practice

The required fire protection is reported below, designed in accordance with standards and recommendations in building guidelines and handbooks, without using calculations [3, 16]. This method meets the building function requirements on the basis of previous experience and practice.

3.1 Fire resistance classification

An office building of 3-4 storeys is classified Br1 (please refer to appendix 1 section 5:2). An office building is assessed to contain a fire loading of less than 200 MJ/m², and should therefore be fire resistant in at least 60 minutes in both structural and partitioning material. Structural elements and fire compartment separation partitions and floor structures are permitted to contain combustible material, for example wood.

The design of the structural elements is noted in chapter 7.

Fire compartment separation partitions consist of steel studs and 2 x 13 mm gypsum plaster sheets on each side (EI 60). Indoor windows and doors in fire compartment walls shall be made to class EI 60 (60 minutes), except for doors to staircases, which can be made in class EI 30 (30 minutes).

The surface layer must be made in the highest classification (Class I), in this case at least 9 mm gypsum plaster sheets. The same requirements apply to walls in staircases and assembly rooms (may be painted, not wallpapered). Other walls may be made to class II, which permits thin wallpaper, but not wood as the surface layer material. Most types of plastics, wood or textile floor coverings are generally permitted.

Facades and roofs shall be made of non-combustible material, apart from the facade surface of the ground floor, which may be combustible. The roof surface may be combustible, containing material which is difficult to ignite, on top of non-combustible material.

The components in HVAC-systems should, in principle, be made of non-combustible material.

Staircases are not permitted to contain furnishings. Assembly room furniture has material requirements referring to combustibility.

3.2 Escape routes

Evacuation shall be made via escape routes. Escape routes are either doors to the open air or other fire compartments in the building (staircases and corridors) which lead to the open air. Occupants are assumed to be able to get themselves to safety without the help of the Rescue Services. Four staircases have been arranged for floors 2-4 because of requirements in chapters 3.2.1 and 3.2.3.

3.2.1 Access to escape routes

All premises where people stay must have access to at least two escape routes. One single escape route is permitted if this is a special staircase with fire-proof lobbies, or if the room is located so it is possible to reach the outside air within 15 metres walking distance. One of the two escape routes may be accessible via another fire compartment if it can be guaranteed that the doors will be unlocked.

3.2.2 Exits

Doors which lead to or are in the escape routes must be easy to open in the direction of evacuation.

The required escape width is generally 0.9 metre (0.8 for door openings)

In premises for more than 150 persons, the required width is 1.2 metre, and the total width of emergency exits must be equal to 1.0 metre per 150 persons. (Applies to the assembly room and the cafe in the atrium case.

3.2.3 Walking distance

The maximum permitted walking distance to the nearest escape route is 45 metres for offices, where the coincident distance to another escape route must be multiplied by 1.5. This distance meant that two fire escape staircases were needed to supplement the two main staircases for floors 2-4.

In the assembly room, cafe and public areas of the bank and insurance office, the maximum distances are 30 metres and the multiplication factor is 2.0 for a coincident route.

3.2.4 Equipment

The equipment required for escape routes are exit signs, emergency lighting in meeting rooms, basement corridors and staircases, plus evacuation alarms in assembly rooms and conference rooms. The design is specified in chapter 3.4.

3.3 Fire compartment subdivision

The exact sub-division of fire compartments is noted in appendix 2.

In principle, staircases with lifts are separate fire compartments. The floors are separated from each other. An office floor is divided into two fire compartments, which Swedish rules do not require, but it is common practice to reduce the fire damage cost. Different tenants with similar activities as regards fire risk, may however share the same fire compartment.

Assembly rooms for more than 150 persons shall be separate fire compartments, as shall separate activities such as the cafe, garbage room, building services room and bank premises.

Without sprinklers, no fire compartment, apart from the staircases, may include more than two floor levels.

3.4 Installations

The requisite fire engineering installations are briefly noted here.

3.4.1 Smoke and heat ventilation

The four staircases have smoke and heat ventilation to facilitate extinguishing and rescue activation. Hatches or fans in the top of the staircases are opened/started manually from the entrance. Alternatively, the two fire escape staircases can be ventilated by opening windows on each floor.

The lifts have access to several fire compartments without a lobby in between, and therefore require a hatch or fan at the top of the shaft, which is opened/started automatically by a smoke detector.

The fire compartments in the stores in the basement are smoke and heat ventilated through vents to ground level, which are opened manually. The area of the hatches shall correspond to at least 0.5% of the floor area of the fire compartment. The smoke and heat ventilation in the basement shall be designed to facilitate extinguishing.

3.4.2 Extinguishing equipment

All premises have access to fire extinguishing equipment in the form of hand-held fire extinguishers, or internal fire hydrants. The extinguishing equipment are supposed to be used by persons in the building in case of fire.

3.4.3 Alarms

No alarm with direct communication with the Rescue Services is installed. On the other hand, an evacuation alarm is installed in the assembly room, which is activated manually by alarm buttons or smoke detectors in its escape routes.

Conference rooms on floors 2-4 shall be provided with alarm bells connected to smoke detectors in the adjacent corridors.

3.4.4 Exit signs and emergency lighting

Signs used to indicate an escape route or to inform about where the nearest escape route is located are present in the whole building. They are in compliance with the EU-regulation on safety at work. In the assembly room and in the basement, the signs are also equipped with emergency lighting. The emergency lighting also cover the floor in those areas. In other parts of the building the signs are back-lit or illuminated by the normal lighting depending on the situation.

3.5 HVAC-systems

An air supply and exhaust system with fans is installed in the attic. Open shafts and ducts go

through the floors. The shafts are made with 60 minutes fire resistance, by means of walls made of 3x13 mm gypsum plaster sheets. The fan room in the attic, common to almost the entire building, is a separate fire compartment and has 60 minutes fire resistance. The fans are shut off at night.

3.5.1 Protection against fire spread

In addition to the above measures, the ventilation ducts are insulated along lengths of about 1-2 metres on each side of a fire compartment wall. Alternatively, a fire damper is installed in the ducts where they pass the fire compartment boundaries.

The exhaust ventilation from the cafeteria is made separate from the rest of the ventilation, with insulation round the duct and its own fan, because of grease accretion in the ducts, which can cause fire to spread.

3.5.2 Protection against smoke spread

Several alternatives are generally approved. The safest and most expensive method is to have separate systems for every fire compartment. It is also possible to use smoke dampers in ducts between different fire compartments.

The method for preventing the spread of smoke to different fire compartments via the ventilation system, is that smoke detectors shut off fans and open smoke evacuation ducts to the roof. The smoke can easily be vented to the outside. A smaller amount of smoke is allowed to spread between fire compartments via the duct system, as long as personal safety inside the building can be guaranteed.

3.6 Atrium

When the outdoor yard is glassed over (please refer to the drawings in appendix 2), a number of necessary fire protection measures are added. The cafeteria with its light court becomes a separate fire compartment. The premises on the ground floor and floors 2-4 are separated from the atrium by means of walls and windows with 60 minute fire resistance. No smoke and fire ventilation is installed in the glass roof. The glass roof itself is made from hardened and laminated glass in steel frames with 60 minutes fire resistance (R60).

The cafeteria/light court premises are regarded as being able to hold at least 150 persons, so emergency lighting, 1.20 metre doors and a evacuation alarm are needed in the same way as in the assembly room.

4 FIRE ENGINEERING DESIGN METHOD - unsprinkled building

Swedish building regulations are performance based as stated in chapter 1. This means that it is up to the fire protection engineer to choose systems and methods freely, as long as the specified functions are complied with. The usual procedure is to start with a standard method as in chapter 3 and then do an analysis of what could be optimised with regard to fire safety and finance, using calculation methods and alternative solutions. The standard recommendations in chapter 3 are designated for the type of buildings that are "square " with less demanding activities such as residences or offices. It is therefore more common to use fire engineering methods in designing buildings with special architecture or activities such as exhibitions or conference buildings, shopping centres, laboratories etc.

For "normal" floor heights, activities and number of occupants, the fire engineering design methods seldom offer optimisation, the standard recommendation methods give a sufficiently good solution.

The current building is regarded as being relatively "normal", but a number of examples of solutions have been chosen, where calculations show that an alternative solution meets the function requirements in the building code. In other words, the fire engineering design method does not mean that the entire fire protection of the building should be "calculated", just selected portions.

4.1 Fire resistance classification - differences from standard method

Only a summary of the results of the calculations is reported here.

The actual calculations and their background material are described in chapters 6, 7 and 8.

Radiation calculations show that a simpler/cheaper type of glass can be used in fire compartment walls (the glass allows radiated heat to pass through but retains its separating ability for 60 minutes -E60). This can be used in glass partitions between staircases and in the foyer of the assembly room and the exhibition room.

Chapter 7 also contains a number of simplifications allowed by the calculations, mainly as regards steel columns and beams.

Other calculations which could be possible to do, but which have not been done in this report are:

- Reduced thickness of insulation material for the ventilation ducts.

- Smaller amounts of combustible material that could be permitted in and wooden panels in office rooms and corridors.

4.2 Evacuation

Instead of using standard door widths, walking distance etc., escape time can be compared with the time to the critical level in a fire, to demonstrate that there is sufficient occupant safety.

Two examples are reported below, and in detail in chapters 6 and 8.

4.2.1 Assembly room - maximum occupancy load

The objective of this calculation is to allow the number of occupants in the room to be increased relative to the number permitted by the calculation method in the standard recommendation, chapter 3. According to this recommendation, 360 (150 pers/m x 2.4 m) persons are permitted in the room.

The maximum desired occupancy loading, from the owners' point of view, is 490 persons (1.7 pers/m² x 288 m²). Can this increased number of persons be accepted while still meeting the safety goals?

The evacuation time for 490 persons was calculated to be less than 5 minutes, according to chapter 8. During a fire, the upper exit in the foyer will be blocked first, after about 1.5 - 2.0 minutes. The lower exit will not be blocked by smoke within evacuation time.

If 70% percent of the persons choose the lower exit, it will take more than 3 minutes for the remainder to exit via the upper exit.

If 490 persons are to be permitted to be in the premises, some action is needed to prolong the time to critical conditions.

Roof ventilation is installed in the upper section of the premises. The calculations show that 8-10 m² openings at roof level, which are opened by smoke detectors, give the necessary extension of time (critical time of more than 4 minutes). These could also be replaced by mechanical smoke ventilation with the equivalent capacity.

The most cost-effective alternative would appear to be to increase the door widths so that person flow through the exits is in relation to the number of persons and the smoke filling times. This is most probably easier to achieve than to install smoke and fire ventilation.

4.2.2 Office - walking distance, equipment

The objective of this calculation is to look for the possibility of eliminating one of the staircases in each fire compartment which would be required following the standard recommendation to the building code. According to this recommendation, the "allowed" walking distance (45 m) makes it necessary to have three mutually independent evacuation routes from each fire compartment. The difference in distance between the "allowed" distance and the actual most remote distance is very small, (10 m).

Calculations are aimed at demonstrating that an extra 10 metres to the nearest escape route can be compensated by an automatic evacuation alarm. The extra walking distance gives a walking time of 10 seconds, which should be put in relation to the "gain" offered by an automatic evacuation alarm.

The "gain", in the form of reduced detection time and reaction time would be considerably greater than the 10 seconds entailed by the extra walking distance. Please refer to chapter 8.3.

The time to critical conditions does not differ between the various solutions. For rooms close to the fire, the time to critical conditions is reached before the people have had time to escape, irrespective of the walking distance.

This "critical condition" is open to discussion, since it is in the initial stages of the fire, with very low temperatures and long visibility in the smoke layers, so people can still be expected to get to safety, although the smoke level falls below the specified 1.9 metres above floor level, please refer to guidelines in appendix 1 Sect. 5:361.

The automatic evacuation alarm in the office thus means that only two staircases would be enough, instead of four, please refer to drawings in appendix 2.

4.3 Atrium

The objective of this calculation is to design the smoke management system in the atrium for the design solution where smoke extraction is required. As required by the owner the smoke layer must not descend to the level where smoke will spread into the coffee-shop area. The goal is to design the roof vents in a cost effective way. This design is a pure protection of the property. The safety of the occupants will be considered using the standard recommended solution [3, 16]. The design area of the smoke vents will be optimised so that the cost for the smoke venting system and the glazing of the floors above the smoke interface level will be minimised.

By installing smoke vents which are automatically opened by smoke detectors, the smoke temperature falls and a smoke-free height is achieved which facilitates extinguishing. It is therefore assumed that it will not be possible for flashover to occur. The windows facing the atrium from stories 2-4 can then be made to a lower classification than EI 60. Opening the smoke vents will automatically notify the local Rescue Services.

Windows below the calculated smoke level do not need to be fire classified, whereas the windows in the smoke must be made to class E 30 (integrity resistance of 30 minutes without insulation requirements).

Windows straight above the cafe section on floor 2 shall be made to class EI 60 (Integrity and insulation requirements) because of the possible effects of flame if there is a fire in the cafe.

To stabilise the smoke level at 4 metres above floor level (floors 2-4 in the smoke layer), 15 m² of smoke ventilation area are required. To get the smoke level to 7 metres above floor level, (floors 3-4 in the smoke layer), 30 m² of smoke ventilation area is required. A 10 metre height requires 65 m² of smoke ventilation area

A cost analysis of the three solutions shows that 30 m² of smoke ventilation area and fire classified glass sections in floors 3 and 4 is the cheapest alternative, which is therefore selected. The solution costs half as much as EI 60-glass on all floors without smoke ventilation, which the standard recommendation in chapter 3.6 entailed.

For a 7,000 kW fire in the cafe, which was used for design, the smoke temperature would be 80• C (350 K). This size of fire gives the smoke enough buoyancy to allow non-mechanical smoke ventilation to function. At lower temperatures, the buoyancy of the smoke is less. On the other hand, it is not hazardous to either fire-separating glass partitions or evacuating people.

If the smoke and fire ventilation has a personal safety goal because of open galleries on the upper floors of the atrium, mechanical smoke ventilation by means of smoke and fire fans are required in Sweden.

5 FIRE ENGINEERING DESIGN METHOD - with sprinkler protection

Generally, in order for the fire engineering advantages of sprinklers to be gained, they have to be made in accordance with the rules of the Swedish Insurance Company Association (RUS†120) [5] or in accordance with NFPA 13 [6]. In office situations, these two bodies of regulations are relatively similar. Fast response sprinklers are normally used these days, (68°C and $\text{RTI} < 50\sqrt{ms}$).

Exceptions from the normally applicable requirements are frequently made when sprinklers are installed, without needing to prove by means of calculations that the fire protection levels are maintained. In borderline cases, the engineering assessments are supplemented by calculations.

5.1 Fire resistance classification - differences

Load bearing structures and partitions are reported in chapter 7.

The concept of smoke compartment is not included in Swedish codes, but are frequently used in conjunction with sprinkled low risk buildings. In these cases, the sprinkler is assumed to limit the fire, whereas protection against smoke spread is given by conventional means.

Fire compartment separating floor structures, partitions and doors can be made to class E60 instead of EI 60. If the building is regarded as being "light hazardous", the fire resistance can be reduced so that E 30 is sufficient, i.e. a smoke compartment.

The grounds for assessment include the reliability and extinguishing ability of the sprinkler installation, the opportunity given to people inside the building to get to safety themselves, and the fire damage consequences if the sprinkler function fails.

Using calculations (or for simpler cases - only engineering judgement), reduced requirements for surface layers can be allowed. Walls with wooden surfaces in office rooms, for example, and in corridors to a certain extent, are normally approved exceptions. No such calculation has been done in this report.

When there is a risk of fire spreading to adjacent buildings, the influence of sprinklers to the risk of fire spreading to adjacent buildings can be included.

5.2 HVAC system

Insulation of ducts near a fire compartment wall can be omitted if the fire compartment temperature does not rise above 200°C because of the sprinkler installation. This is common for normal soffit heights and light hazards, such as offices.

Fans, shutters and cable installations for these devices which are to function during a fire, would be subject to considerably lower temperature requirements than in an un-sprinkled building. The temperature requirement is normally reduced from 800°C to 300°C in a comparable fire situation.

5.3 Atrium

The requirement for smoke ventilation and the requirements for windows facing the atrium in the smoke layer, in a sprinkled building, are reported below. This should be compared with the un-sprinkled building in chapter 4.3.

The windows in the smoke layer shall be made to withstand 300• C for at least 30 minutes (class 300/30). Higher window classifications because of the risk of flames from the cafe if there is a fire do not need to be considered, since this is sprinkled. The high section of the atrium (> 10 metres) is not sprinkled, however.

The required smoke ventilation areas are about 5 m² inlet and exhaust air with a smoke layer 4 metres above floor level. 10 m² for 7 metres and 25 m² for 10 metres.

A cost analysis, where a comparison is made between the amount of smoke ventilation and fire classed windows shows that 7 metres is the optimum case here as well. The differences are relatively marginal, however.

6. CONDITIONS FOR THE FIRE ENGINEERING CALCULATIONS

6.1 Scenarios

The general conditions and assumptions for the different fire and evacuation scenarios will be presented in this section. The design consists of four fire scenario calculations where the occupant safety will be compared to a design fire. In each scenario a sensitivity study is performed to see how uncertainties in parameters will travel through the calculations and affect the result. This study will, however, not be a full probabilistic study but merely an indication of the importance of some of the parameters. The four scenarios to be considered are:

- fire in the assembly room on the ground and basement floor
- design of the smoke exhaust system from the atrium including evacuation from the coffee-shop
- fire on an office floor
- radiation through glass wall.

These scenarios will in the future be denoted assembly room, atrium, office and glass wall.

The reason for choosing these four scenarios is that the standard recommendations to the building code cannot be used to solve some of the designers intentions with the building. It is therefore necessary to seek other design solutions on these four locations. This will be done using fire safety engineering methods to show that the occupant safety objectives in the building code are achieved. The design parameters used, such as the design fire growth rate, will be chosen in a conservative way. The choice will, however, not be made too conservative but rather as a likely value with a tendency to the safe side. No values are chosen in an over-optimistic way, only with the purpose of solving a design proposal. Also, in no case is the code requirement on two mutually independent evacuation routes from a fire compartment neglected.

Therefore, no other safety factors will be used. The use of safety factors, not probabilistically determined, will not increase the level of safety. Those safety factors, that are possible to be used today, are also chosen by someone's judgement, as with the choice of our design values. The level of false security will probably be higher using safety factors than using reasonable values on the design parameters as the design method is more obvious in the latter case.

The overall design objective is to ensure that the occupants can evacuate safely without being subjected to what is defined as critical conditions.

6.2 Occupant safety design

In the evacuation design, the time needed to perform the evacuation is compared to the time to create untenable conditions or a standard recommendation is used. In the latter case a standard handbook [3] is used to design the building according to recommended distances to an exit. The solution to this design method is described in chapter 8 and appendix 3. In the case where the evacuation time is compared to the time to untenable conditions the limit state equation will be:

$$S-D-R-M \geq 0$$

The safety margin shall always be positive with an excess of time available. In this equation the following parameters are used:

- S = time to untenable conditions
- D = time to detect the fire
- R = time for response and behaviour
- M = movement time to safety

The calculations of the time to untenable conditions are done using the model CFAST from NIST [8] and the model used to calculate the detection times is the DETACT-T2 model [10]. As the calculated time to untenable conditions using the CFAST model is conservative a correction term of 1.35 is used on the predicted times [11].

6.2.1 Sprinklers

When sprinklers are installed, the RTI-value used is $50\sqrt{ms}$ and the detection temperature is 68 °C. Calculating response times for smoke detectors are performed in the same manner but with an RTI-value of $0.5\sqrt{ms}$ and an activation temperature of 30 °C.

6.2.2 Doors

Doors are normally open in the direction of walking. Emergency doors that are normally locked can be opened in an emergency situation without any key or other tool.

6.2.3 Escape alarm

In some parts of the building an escape alarm is installed. The areas covered by the escape alarm depends on which design methodology is used. The escape alarm can be started either manually with alarm buttons or automatically by the smoke detector fire alarm. The alarm usually signals in the fire compartment on fire and starts automatically if a fire occurs just outside or inside the present room. The escape alarm is a combination of flashing green light and a varying tone signal. Other fire compartments and floors will be notified by the escape alarm started manually by the management.

6.2.4 Critical conditions

Critical conditions are described in appendix 1, section 5:361 [1].

6.3 Scenario 1, Assembly room

6.3.1 Room

The room extends from the basement to the ground floor. The room height is varying as the floor slopes towards the stage. In the upper part of the room the height is 3.7 m and in the lower part 6.7 m. The ceiling is horizontal. Two doors are leading to safety, one in the lower part of the room and the other in the upper part of the room. The lower door is connected to the outside through a corridor in the basement. The upper door leads to the outside via the

foyer which is the normal entrance. Both doors are having a 1.2 m free width. The variation of fraction of the occupants using the two doors are investigated in the sensitivity study.

The floor area is 288 m² (16 x 18 m²). This area includes a stage area of 16 m².

6.3.2 Detection

The time to detect a fire in the room can be assumed to be rather low as the line of sight is unobstructed in the whole room. The detection time is assumed to be 15 seconds. There is, however, a smoke detector fire alarm in the room which detects the fire but it is used only to open the smoke vents.

6.3.3 Response and behaviour

After the fire is detected the occupants are supposed to interpret and act according to the fire stimuli. The appropriate behaviour is to evacuate and probably this will commence quite rapidly. The management will inform the occupants to evacuate as soon as possible. The reaction time will be assumed 30 seconds. An escape alarm is installed in this room but it must probably have to be started manually by the management to have any effect on the response and behaviour time. The alarm will also start if a fire occurs outside the assembly room i.e. in the escape routes from the room.

6.3.4 Movement

When calculating the movement time or the time to pass a doorway the following data is used. Occupant flow through a doorway is 1.0 pers/sec and the walking speed is 0.5 m/s [3]. These numbers are valid for conditions of high occupant density.

6.3.5 Design fire

The design fire consists of a spreading fire on the chairs in the audience section. The chairs are flame resistant and the fire spread and growth rate of the fire will be low. The material in the chairs are plywood and PUR-foam. Fire growth rate data is chosen from an experiment in reference [12] but modified a little. The design fire follows the relation indicated in figure 6.1.

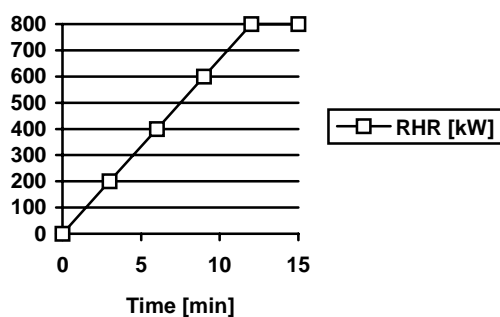


Figure 6.1. Design fire in assembly room

6.3.6 Active systems

In the room both sprinklers and a smoke detector fire alarm are installed. These systems do not affect the evacuation but will prevent the fire from spreading to other parts of the building, opens the smoke vents needed and alert the people in the rest of the building. A sprinkler head is covering an area of 12 m². In the sensitivity study the effect of different position of the activating sprinkler is studied.

6.3.7 Sensitivity analysis

Three parameters have been chosen for the sensitivity examination:

- choice of exits by the occupants
- position of activating sprinkler head
- fire growth rate and maximum rate of heat release

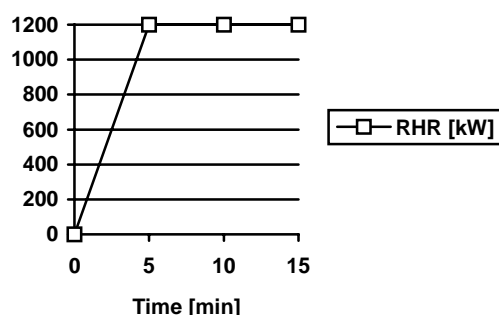
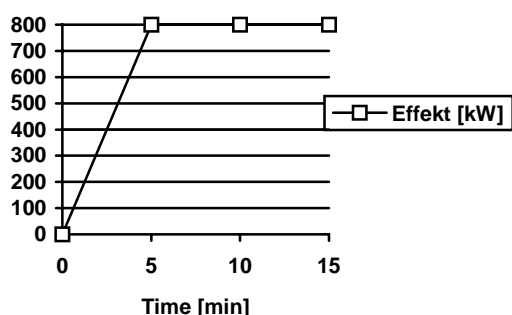
Three different exit choice conditions of the exits have been studied. The fraction of the occupants using a specific exit is presented in table 6.1.

Table 6.1. Sensitivity study of exit choice.

	Lower exit	Upper exit
Design situation	50 %	50 %
Sensitivity 1	70 %	30 %
Sensitivity 2	40 %	60 %

The response time for the activating sprinkler is calculated for two positions. The sprinkler can either be located at the upper exit or in the middle of the room. The room height at the upper exit is 3.7 m and in the middle of the room 5.2 m.

Three different fire characteristics have been studied. Apart from the design fire in figure 6.1, two other fires have been examined. These are having different fire growth rate or different peak burning rate, figures 6.2 and 6.3.



Figures 6.2 and 6.3. Sensitivity study of fire characteristics.

6.4 Scenario 2, Atrium

6.4.1 Room

The atria is 24 x 17 m² and has a height of 14 m. In the smoke layer the walls and the glazing areas will be constructed of non-combustible materials and in class E30 or 300/30, (see chapter 4.3 and 5.3). The smoke vents open on a signal from the smoke detector in the atria. The inflow of air will come from windows in the coffee-shop opening at the same time as the smoke vents in the ceiling of the atria.

6.4.2 Calculation method

The method presented by Tanaka and Yamana [9] has been used to design the required smoke venting area. The mass flow rate in the fire plume is assumed to follow the relation by Heskestad for the case when the fire is located on the atrium floor:

$$m=0.071 Q^{1/3} z^{5/3}$$

which has been modified according to the draft BSI-guide [7]. When the fire is located in the coffee-shop, another plume equation will be utilised to also consider the extra air entrained when the smoke flows in the atrium room. The equation used to describe this situation is also chosen from the draft BSI-guide [7]:

$$m=0.23 Q^{1/3} w^{2/3} z$$

This equation gives the mass flow rate into the atrium from a line plume source.

6.4.3 Design fire

According to the calculation method a constant fire burning rate is required. This is usually a conservative assumption which is accepted. The design burning rate is 7000 kW which can be represented by the amount of furniture allowed in the atria. The design fire for the fire located in the coffee-shop will be 1000 kW if a sprinkler system is installed and 7000 kW without the sprinkler system. The choice of the design fires will create a restriction in the amount of furniture allowed in the atrium and in the coffee-shop. This restriction will be noted in the fire documentation. A sensitivity study of the dependence on the venting area due to different fire size is performed, see section 8.2.

6.4.4 Sensitivity analysis

Different fire burning rates have been used apart from the design fire, to evaluate the difference in smoke venting area. The other burning rates are

- 10.000 kW (atrium and coffee-shop)
- 3000 kW (atrium)
- 1000 kW (atrium).

All of them are also constant during the fire sequence

6.5 Scenario 3, Office

The fire is supposed to start in an office room close to one of the exits, which is considered to be a severe case. This results in a conservative design.

6.5.1 Rooms

The office floor has a standard layout with normal office rooms and corridors. All the office rooms have daylight access either direct to the outside or through the atrium. The room height on the floor is 2.7 m to the suspended ceiling both in the office room and in the corridors.

6.5.2 Detection

The floor is equipped with a smoke detecting fire alarm resulting in a short detection time for those occupants remote from the fire. Occupants close to the fire are likely to detect the fire earlier than the fire alarm when smoke enters the next room. Occupants in rooms remote from the fire might be alerted before the automatic fire detection by other evacuating occupants passing these rooms. This has been taken into consideration.

6.5.3 Response and behaviour

An escape alarm is installed and starts on a signal from the detection alarm. The escape alarm is a combination of flashing green light and a varying tone signal. The response and behaviour time is assumed to be short as the occupants are familiar with the premises, the evacuation procedure and escape alarm signal type. The occupants are subjected to regular evacuation drills.

6.5.4 Movement

No queuing is assumed as the occupancy load is low. The walking speed for the individuals will therefore determine the time to evacuate the floor. The walking speed used in the calculations is 1.3 m/s [3]. The evacuation direction is shown on the drawing in appendix 3.

6.5.5 Design fire

The fire used has the characteristics of a typical sprinkled office fire. The sprinkler system starts to extinguish the fire at activation and then will the burning rate descend linearly to extinction. The phase after activation of the sprinkler is chosen in a conservative way. Different fires will be studied in a sensitivity analysis. The design fire burning rate is shown in figure 6.4.

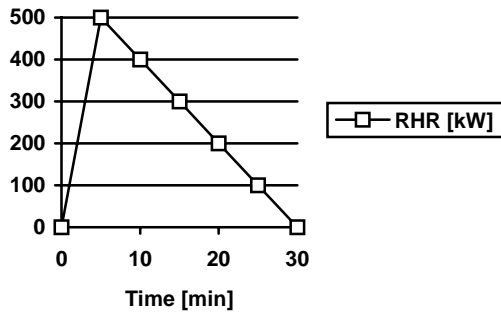


Figure 6.4. Design fire in the office.

As the temperature in the room of fire origin will be considerably high it can be assumed that the window to the atrium will break. In the calculations, however, it is assumed that the glass is of a protected type which can withstand a fire exposure for at least the time needed for the evacuation. Still, a small leakage area is assumed between the fire room and the atria. The size of the leakage area is 0.02 x 0.9 m and it is located at window height. The doors on the floor, except those leading to the escape route, are kept open during the sequence.

To cope with the lateral smoke spread problem in the CFAST model, long corridors are divided in shorter sections using imaginary soffits below the ceiling. The height of these soffits are 0.2 m.

6.5.6 Active systems

On each office floor three types of active fire protection systems are installed. These are a smoke detecting fire alarm, an escape alarm and a sprinkler system. The two first are designed to inform the occupants of the need for evacuation and are a part of the occupant fire safety. The sprinkler system is primarily for the property protection but reduces also the fire threat for the occupants during evacuation. Each office room is equipped with a sprinkler head and a smoke detector. Calculating the detection time for the sprinklers and the smoke detectors a fire growth rate of 0.029 kW/s^2 has been utilised. This number complies well with the growth rate of the office fire used as the design fire.

6.6 Scenario 4, Glass wall

The stairs in the evacuation routes from the upper floors are, on the ground floor, separated from the other fire compartments with a glass wall. This glass wall shall consist of glass with the rating of EI 60. This type of glass is rather expensive and a calculation will be performed to determine if a rating of only E60 can be accepted. The difference is that an E60-rated glass wall does not comply with the radiation criteria for a fire compartment wall. If evacuating on the unaffected side of the wall can be performed, without the occupants being exposed to critical conditions, this design may be chosen. A minimum distance between the occupants and the wall must therefore be calculated and compared to the actual floor plan.

6.6.1 Rooms

The calculation will be performed in the staircases on the ground floor with a fire in the exhibition room and the assembly room foyer for each staircase. Glass walls is separating the

stairs from the exhibition room and from the foyer. The glass walls have the rating of E60.

6.6.2 Design fire

A burning sofa will be the design fire. This fire has a peak burning rate of 2 500 kW which has to be considered to be a big fire. The value is conservatively chosen. The size of the sofa is 0.84 x 2.0 x 0.81 m and it is made up by PUR-foam padding and a wood frame. The mean flame temperature is chosen to 1173 K (900 °C) and the flame emissivity is chosen at the actual flame depth. The E 60-rated glass has proven, through a number of fire tests, to reduce the radiation by approximately 50 %. This value is used in the calculations.

6.6.3 Sensitivity analysis

As the design fire is chosen on the safe side no specific sensitivity analysis will be performed.

7. FIRE ENGINEERING DESIGN OF THE LOADBEARING STRUCTURE AND PARTITIONS

7.1 Introduction and summary

A structural engineer has designed the building in a simplified manner. The structural system will not be described in detail but, some of it will be shown on the attached drawings, appendix 2. This chapter will only show some examples of what you can do as a fire protection engineer, and does not describe all calculations and engineering judgements needed in the design process.

The calculations show that you certainly can save some insulation materials when using the real temperature - time process in the fire compartment as your design fire (natural fire sequence), instead of the standard ISO 834 fire curve. In the examples gypsum plaster sheets have been chosen as insulation material, and as shown the savings are not that great because the gypsum board only comes in certain sizes (9 and 13 mm). If some other insulation material would have been used, the savings would have been greater. Another fact added to this is that the steel columns have not been used to their fully extent because of the simplified design.

In all the calculations the design manual "Fire Engineering Design of Steel Structures", from 1976 [14]. has been used. A sample calculation is shown in chapter 7.4. In the case where sprinklers are installed the recommendations in Eurocode ENV 1991-2-2 [15] were used. There it is recommended that the fire load density is reduced to 60%. A better approach, depending of the design of the sprinkler system, is to use a temperature - time curve for a fire taking into account the effect of the sprinkler.

The partitions, steel stud wall insulated with gypsum plaster sheets, can resist real fire conditions. This is due to the fact that the acoustic insulation criteria demands for a "better" wall than would have been required if only the design has been according to the fire requirements of 60 minutes. This means that the partitions will resist a fully developed fire until the danger is over! This fact adds extra safety into the building. The partitions not being part of the fire cell enclosure will also have this fire resistance unless they have cable penetrations etc. with no fire resistance.

7.2 Building code requirements

"Loadbearing structures shall be designed and sized so that in the event of fire there is adequate structural safety with respect to material failure and instability in the form of local, overall and lateral torsional buckling and similar. Parts of the loadbearing structure including supports, joints, connections and similar shall be designed so that collapse does not occur - during a specified period of time in accordance with the fire resistance classes for elements of structures set out in subsection 5:82, under fire exposure conditions in accordance with the Swedish Standard SIS 024820 (ISO 834).", see appendix 1, [1].

"As an alternative, design of the loadbearing structure may also be based on a model of a natural fire sequence in accordance with subsection 5:83.", see appendix 1,[1] and further reference to appendix 1 [2].

The same type of approach applies for partitions.

The requirement for the loadbearing structure is 60 minutes, as seen in table a in appendix 1, chapter 5:8 from the building code [1], and 60 minutes for the partitions, chapter 5:6 [1].

7.3 Loadbearing structure and partitions.

The structural elements and partitions are described in appendix 2. The internal walls are made of steel studs, insulated on each side with two 13 mm gypsum plaster sheets.

The following cases have been studied:

Standard fire temperature curve according to ISO 834, 60 minutes. (S)

Natural fire, as described in reference [14], with a fire load density of 644 MJ/m² total floor area. For the resemblance hall/theatre the fire load is restricted to 320 MJ/m² (N). In the case of sprinklers 60% of these values were used.

Conference room - 9.5 m x 10.5 m (C), and an office 3.2 m x 4.5 m.(O). These rooms have been chosen to be the most representative in the building.

For the above combinations one beam centrally located, and one column in the entrance floor have been used for the calculations.

Results: Minimum required insulation thickness in mm.

Fire:	(S)	(N) without sprinkler	(N) with sprinkler
Beam (C)	12	9	5
Beam (O)	12	5	3
Column (C)	10	7	4
Column (O)	10	4	<2
Assembly room (only one beam)	8	6	<6

7.4 Sample calculation

Natural fire without sprinkler in conference room (combination N and C).

Nomenclature according to the design manual [14].

$q = 60$ kN/m, distributed load, $W = 3550 \cdot 10^{-6}$ m³

$L = 8,7$ m simply supported $A_i = 814$ mm

HE 500 A, beam $V_s = 9708$ mm²

Three sided fire exposure, $\sigma_s = 270$ MPa

$$h = \frac{1,8 \cdot 7,5 \cdot 1,8 + 2 \cdot 0,9 \cdot 2,0 \cdot 2,0 + 1,6 \cdot 2,0 \cdot 2,0}{(1,8 \cdot 7,5 + 2 \cdot 0,9 \cdot 2,0 + 1,6 \cdot 2,0)} = 1,87 \text{ m}$$

$$\frac{A \cdot \sqrt{h}}{A_{\text{tot}}} = \frac{(1,8 \cdot 7,5 + 2 \cdot 0,9 \cdot 2,0 + 1,6 \cdot 2,0) \cdot \sqrt{1,87}}{2 \cdot (9,5 \cdot 10,5 + 9,5 \cdot 3,2 + 10,5 \cdot 3,2)} = 0,085 \text{ m}^{1/2}$$

$$f = \frac{644 \cdot 105 \cdot 9,5}{2 \cdot (9,5 \cdot 105 + 9,5 \cdot 3,2 + 105 \cdot 3,2)} = 1962 \text{ MJ/m}^2$$

50% concrete and 50% gypsum in the surrounding surfaces \Rightarrow

$$k_f = \frac{0,5}{0,8} \cdot k_G + (0,5 - \frac{0,5}{0,8} \cdot 0,2) \cdot k_B \Rightarrow$$

$$k_f = \frac{0,5}{0,8} \cdot 1,22 + (0,5 - \frac{0,5}{0,8} \cdot 0,2) \cdot 0,85 = 1,08$$

$$\left(\frac{A\sqrt{h}}{A_{tot}} \right)_{fikt} = 1,08 \cdot 0,085 = 0,092 \text{ m}^{1/2}, \text{ opening factor}$$

$$f_{fikt} = 1,08 \cdot 196,2 = 212 \text{ MJ/m}^2$$

Fire load / total area of the enclosure

$$\text{case 2} \Rightarrow 60 \cdot 10^3 = (\beta + \Delta\beta) \cdot \frac{8 \cdot 270 \cdot 10^6 \cdot 3550 \cdot 10^6}{8,7^2}$$

$$\Rightarrow \beta + \Delta\beta = 0,59$$

$$\Rightarrow T_s = 515^\circ\text{C}$$

$$\left. \begin{aligned} \left(\frac{A\sqrt{h}}{A_{tot}} \right)_{fikt} = 0,08 \text{ m}^{1/2} &\Rightarrow \frac{A_i}{V_s} \cdot \frac{\lambda_i}{d_i} = 1750 \\ \left(\frac{A\sqrt{h}}{A_{tot}} \right)_{fikt} = 0,12 \text{ m}^{1/2} &\Rightarrow \frac{A_i}{V_s} \cdot \frac{\lambda_i}{d_i} = 2459 \end{aligned} \right\} \Rightarrow$$

$$\left(\frac{A\sqrt{h}}{A_{tot}} \right)_{fikt} = 0,092 \Rightarrow \frac{A_i}{V_s} \cdot \frac{\lambda_i}{d_i} = 1963$$

$$T_s = 515^\circ\text{C} \Rightarrow \lambda_i = 0,201 \text{ W/m}^\circ\text{C}$$

$$\Rightarrow d_i = \frac{0,201}{1963} \cdot \frac{0,814}{9708 \cdot 10^6} = \underline{9 \text{ mm}} \text{ (Gypsum)}$$

8. Calculations

The calculations presented below are made with the conditions and assumptions presented in chapter 6, 'Conditions for the fire engineering calculations'.

8.1 Assemblyroom

8.1.1 Evacuation

Occupant flow through doorway (1.20 m): 1 person/s [3]

Walking speed: 0.5 m/s [3]

The maximum walking distance in the assemblyroom is 18m which corresponds to a walking time inside the room of 36 seconds. The high occupant density will cause a queue at the doorways. The movement time will be assumed to be the time for all the occupants to pass the doorway.

Detection time 15 s

Reaction time 30 s

In the design situation the fraction of the occupants using a specific exit is assumed to be:

Design situation

Lower exit: 50 % = 245 occupants

Upper exit: 50 % = 245 occupants

The upper exit is the normal entrance.

In the sensitivity analysis the fraction of the occupants using a specific exit is assumed to be:

Sensitivity 1

Lower exit: 70 % = 343 occupants

Upper exit: 30 % = 148 occupants

Sensitivity 2

Lower exit: 40 % = 196 occupants

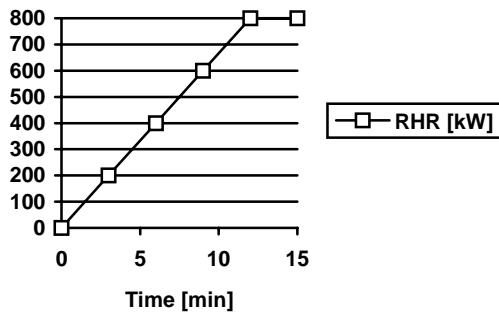
Upper exit: 60 % = 294 occupants

Movement time [s]	Lower exit	Upper exit
Design situation	245	245
Sensitivity 1	343	148
Sensitivity 2	196	294

8.1.2 Untenable conditions

The geometry of the assembly is 16m*18m*6.7m (L*W*H)

Input fire descriptions for the design fire:



4x4 chairs burning.

Seat and back: Plywood with PU padding

Frame: Metal

Reference: Y5.0/19 [12]

In the detection and activation calculations, the fire is assumed to be "slow"

Critical levels for untenable conditions:

Lower part of room: $1.6 + 0.1 \cdot 6.7 = 2.27$ m

Upper part of room: $4.6 + 0.1 \cdot 6.7 = 5.27$ m

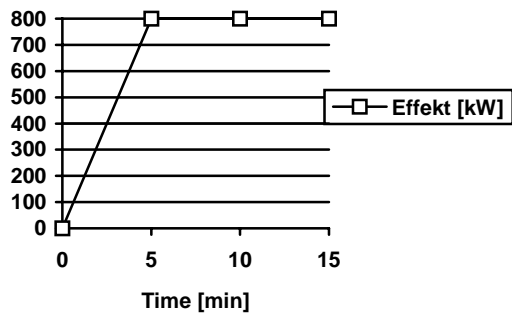
Entrance hall in connection with assembly room: $1.6 + 0.1 \cdot 3.7 = 1.97$ m

Time to untenable conditions are calculated with the model CFAST. Time to untenable conditions are also calculated using the CFAST correction factor.

	Lower exit [s]	Upper exit [s]	Entrance hall [s]
Design fire, no ventilation correction factor 1.35	not critical	93 126	271 366
Design fire, 5m ² roof ventilation correction factor 1.35	not critical	168 227	not critical
Design fire, 9m ² roof ventilation correction factor 1.35	not critical	190 256	not critical

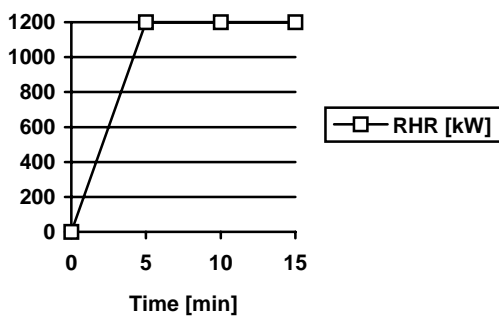
Sensitivity examination is made with two different fires, K1 and K2. The RHR graphs are presented below.

Fire K1



In the detection and activation calculations, the fire is assumed to be "medium", which corresponds to a fire growth factor of 0.012 kW/s^2 .

Fire K2



In the detection and activation calculations, the fire is assumed to be "medium"

	Lower exit [s]	Upper exit [s]	Entrance hall [s]
K1, no ventilation	not critical	77	238
correction factor 1.35		104	321
K1, 5m^2 roof ventilation	not critical	113	not critical
correction factor 1.35		153	
K2, no ventilation	not critical	70	236
correction factor 1.35		95	319
K2, 5m^2 roof ventilation	not critical	100	not critical
correction factor 1.35		135	

8.1.3 Sprinkler activation

RTI-value = 50

Detection temperature 68°C

Detector spacing = 4 m according to Swedish sprinkler design recommendations [5]

Since the room height varies, two different heights will be used. Case 1, with the fire in the middle of the room where the room height is 5.2 meters and case 2, at the upper exit where the room height is 3.7 m.

Activation simulations are made with the design fire and two other fires as a sensitivity analysis called K1 and K2.

Activation time [s]

	Design fire	K1	K2
At upper exit	443	257	257
In the middle of the room	543	306	306

The calculations show that the sprinkler will not activate until the evacuation is completed.

8.2 Atrium

The calculations have been made according to the model in the report Smoke Control in Large Scale Spaces by Tanaka and Yamana [9].

The atrium is 14 m high and has a floor measuring 24 m * 17 m. The roof vents are placed in the top of the atrium and the inlets of air are placed 2.5-3 m above the floor.

The calculations are made with four different steady state RHR and three different smoke layer heights.

RHR (Q): 500 kW
 1000 kW
 3000 kW
 7000 kW

Smoke layer heights: 4,7 and 10 m

In the calculations the following assumptions are made:

$Q = \text{convective heat release} = 0,7 * Q_{\text{tot}}$

Heat transfer coefficient, is assumed to be 0.035 kW/m²K considering the low smoke temperature. Calculations are attached from the spread sheet model Excel, appendix 3. Note that when the smoke layer height is 10m the inlet area (A_{in}) is changed from 10 m² to 20 m².

8.3 Office

8.3.1 Evacuation

Critical or untenable conditions are set to $1.6 + 0.1 \cdot H = 1.87$ m, according to the Swedish regulations [1].

It is assumed that people in room 2 (see appendix 2) moves away from the room of fire origin. They will have a longer distance to walk, but will not walk through smoke. It's assumed that all occupants in room 2 makes this choice.

The occupants in the offices that are connected to room 3 choose to walk to escape through the conference room.

The automatic detection time will be the same for the whole office building since the smoke detectors starts the alarm bell.

Manual detection will be different in the office. The detection is assumed to occur when smoke starts to flow into a room where people are staying.

The detection time is calculated with Detact-T2, using a fire growth rate $\alpha=0.03$ kW/s², which corresponds to the design fire in the office

During the evacuation it's assumed that there will be no queues in the doorways. The reason is that everyone is familiar with the building and will not be confused and that there is a low density of people.

The fire blocks one escape route to the stairs completely.

Since the detection time is effected by the burning rate, the evacuation calculations are presented together with the calculations of time to untenable conditions.

8.3.2 Untenable conditions

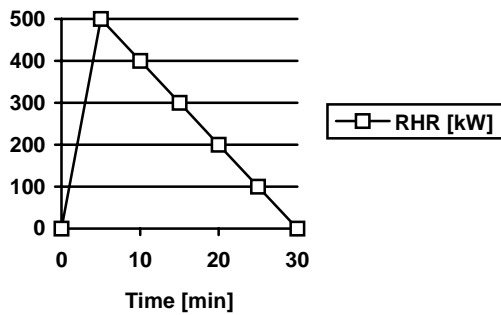
Critical levels for untenable conditions: $1.6 + 0.1 \cdot 2.7 = 1.87$ m and results of time to untenable conditions using the CFAST correction factor are also displayed.

	room 2		room 3		room 4		room 5	
	Alarm	No alarm	Alarm	No alarm	Alarm	No alarm	Alarm	No alarm
Detection time [s]	72	70	72	81	72	120	72	120
Reaction time [s]	30	30	60	120	60	120	60	120

	from room 2	from room 3	from room 4	from room 5
Longest walking distance [m]	62	82	52	20
Longest movement time [s]	81	107	68	26

	room 2	room 3	room 4	room 5
Untenable conditions [s]	72	120	210	236
Correction factor 1.35 [s]	97	176	309	321

Design fire



Reference [16]

In the detection and activation calculations, the fire is assumed to have $\alpha = 0.03 \text{ kW/s}^2$, which is between fast and medium fires.

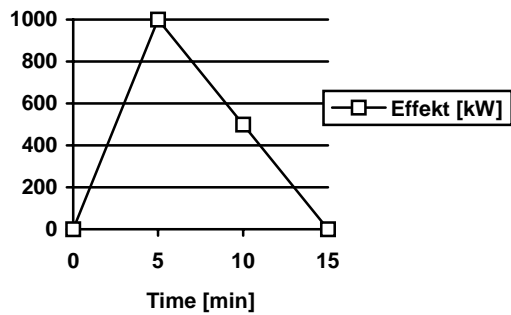
Sensitivity examination is made with two different fires, K3 and K4. The RHR graphs are presented below.

Fire K3

	room 2		room 3		room 4		room 5	
	Alarm	No alarm	Alarm	No alarm	Alarm	No alarm	Alarm	No alarm
Detection time [s]	60	58	60	101	60	170	60	170
Reaction time [s]	30	30	60	120	60	120	60	120

	from room 2	from room 3	from room 4	from room 5
Longest walking distance [m]	62	82	52	20
Longest movement time [s]	81	107	68	26

	room 2	room 3	room 4	room 5
Untenable conditions [s]	57	90	160	190
Correction factor 1.35 [s]	77	121	216	256

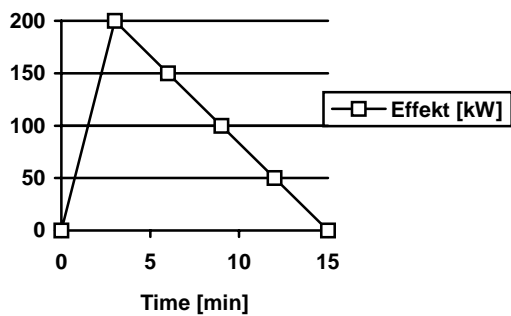


In the detection and activation calculations, the fire is assumed to be "fast"
Fire K4

	room 2		room 3		room 4		room 5	
	Alarm	No alarm	Alarm	No alarm	Alarm	No alarm	Alarm	No alarm
Detection time [s]	99	70	99	128	99	213	99	213
Reaction time [s]	30	30	60	120	60	120	60	120

	from room 2	from room 3	from room 4	from room 5
Longest walking distance [m]	62	82	52	20
Longest movement time [s]	81	107	68	26

	room 2	room 3	room 4	room 5
Untenable conditions [s]	78	136	255	267
Correction factor 1.35 [s]	105	184	344	360



In the detection and activation calculations, the fire is assumed to be "medium"

8.3.3 Sprinkler activation

$$RTI\text{-value} = 50 \sqrt{ms}$$

Detection temperature 68°C

Detector spacing = 4 m according to Swedish sprinkler design recommendations [6]

Room height = 2.7 m

Activation simulations are made with the design fire and two other fires as a sensitivity analysis called K3 and K4.

	Design fire	K3	K4
Activation time [s]	225	139	380

The evacuation is finished before the sprinkler activates.

8.4 Radiation calculation

8.4.1 Calculation of flame geometry

A "3-seat sofa" (0.84*2.0*0.81) with wood frame and PUR filling (worst case) generates a heat release of 2500 kW, [12].

$$\text{RHR} = Q = 2400 \text{ kW}$$

$$\text{Convective part} = Q_c = 0.7 \cdot Q = 1700 \text{ kW}$$

$$D = \sqrt{\frac{4 \cdot 0.84 \cdot 2.0}{\pi}} = 1.46 \text{ m}$$

$$h_{fl} = 0.23 Q_c^{2/5} - 1.02 D = 3.0 \text{ m}$$

The largest flame geometry will be

$$2.0 \cdot 3.0 \text{ m}^2 = 6.0 \text{ m}^2$$

The flame has a mean beam length of 0.8 m

8.4.2 Radiation through the glass wall

$$q_{1-2} = a \cdot \varepsilon \cdot \sigma \cdot (T_g^4 - T_a^4) \cdot \phi_{1-2}$$

$q_{1-2} = 10 \text{ kW/m}^2$ according to Swedish regulations [1]

$a = 50 \%$ for E - classified glass

$\varepsilon = 0.5$ when mean beam length of flame is 0.8m according to [16]

$$\sigma = 5.67 \cdot 10^{-8} \text{ W/m}^2 \text{K}^4$$

$T_g = 1173^\circ \text{K}$ for flames with high rate of soot, [16]

$T_a = 294^\circ \text{K}$

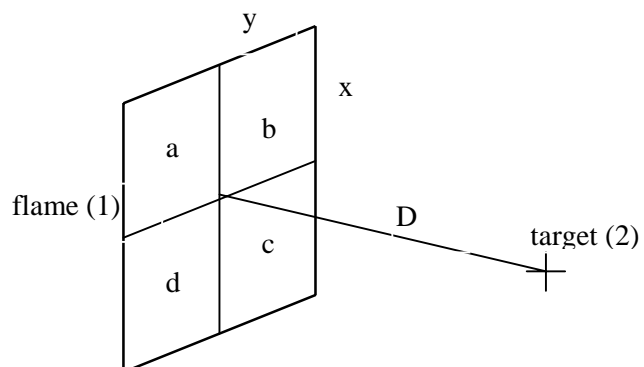
$$\phi_{1-2} = \frac{q_{1-2}}{a \cdot \varepsilon \cdot \sigma \cdot (T_g^4 - T_a^4)} = 0.374$$

$$\phi_{1-2} = \phi_{1a-2} + \phi_{1b-2} + \phi_{1c-2} + \phi_{1d-2}$$

$$\phi_{1a-2} = \frac{\phi_{1-2}}{4} = 0.0935$$

$$S = \frac{x}{y} = 0.67$$

$$\alpha = \frac{x \cdot y}{D^2} = \frac{1.5}{D^2}$$



From table in Fire Protection, relation between α , S and $\phi_{1\alpha-2}$ is taken.

$$S = 0.67, \phi_{1\alpha-2} = 0.0935 \Rightarrow \alpha = 0.5$$

$$D = \sqrt{\frac{1.5}{0.5}} = 1.7\text{m}$$

It must be at least a distance of 1.7 meters between the burning sofa and the evacuating people to avoid untenable conditions. It's assumed that the glass wall between the sofa and the escaping people is of class E.

9 INSPECTION AND MAINTENANCE ROUTINES

9.1 General

In general, it is specified in the Swedish building regulations that fire protection devices should have instructions for function checking, and the necessary maintenance. There are no specific requirements apart from those specified below, the manufacturer's recommendations are normally followed. There is no formal inspection body, so it is the responsibility of the building owner.

9.2 Alarm and sprinklers

The regulations for alarms and sprinklers (e.g. the NFPA rules) specify how, when and by whom inspection and maintenance of alarm and sprinkler installations are carried out.

9.3 HVAC-systems

Specially certified persons shall check the ventilation system regularly in Sweden. This inspection is intended for the benefit of health and the environment, but the fire protection of the installations is normally checked at the same time.

9.4 Personnel training

It is the responsibility of the employer, according to Swedish law, to ensure that their personnel are well acquainted with the fire and personnel protection in the workplace. There is no external inspection body to ensure compliance with this law.

10. FIRE CLASSIFICATIONS AND FINANCIAL COMPARISON - CONCLUSION

No full financial or fire engineering analysis which compares the three cases (chapters 3, 4 and 5) has been done.

Given the way that Swedish performance based codes are constructed, it is natural that case 1 (chapter 3) is not the most economical.

In each case, between the standard recommendations or calculations, the value is estimated when the calculation is carried out. It is seldom, however, that the planning costs entailed by the project planning process exceed the reduction in production cost which is given in exchange. For this reason, fire engineering design methods are becoming more common in Sweden.

The Atrium- and the Radiation-calculation are estimated to reduce the building costs for about SEK 700 000 (about £55 000 or \$100 000), because of cheaper windows in fire compartment walls. The calculation-time costs correspond to about 3% of the design-gain. The profit because the reduction of two stairways are more difficult to judge, but there is no doubt it is a considerable factor.

The sprinkler cost for the building in question is estimated to be about SEK 2.0 million (about £160 000 or \$285 000). Given the choices of materials which were made, it is estimated that the reductions in cost would not be able to "finance" a sprinkler installation if only the building construction costs are considered.

From the fire engineering point of view, it is not open to doubt that the sprinkler alternative would give lower fire damage costs. Only smoke damages are assumed, which are smaller compared to an unsprinkled building where it is possible that the fire compartment will be totally damaged in case of fire. Insurance companies in Sweden do not give any reductions in premiums, merely on the installation of a sprinkler system.

For this reason, the cost of the sprinkler installation must be reduced, or a sufficient number of individual tenants must demand it, because their operations must not be affected if a neighbouring company suffers a fire.

The examples in this report clearly demonstrates the benefits of having a performance based building code. The design can be done more cost effective using fire engineering methods and still having the same safety in case of fire in the building. This would not have been possible with a prescriptive regulation. Still, most of the design is according to standard solutions which, of course, also are permitted in the performance based building code.

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APPENDIX 1 - PARTS OF A TRANSLATED VERSION OF THE SWEDISH BUILDING REGULATIONS [1,2].

PARTS OF [1]:

5 SAFETY IN CASE OF FIRE

This section contains mandatory provisions and General recommendations pursuant to Chapter 3 Section 15 and Chapter 9 Section 1 of PBL and Section 4 of BVF. Further mandatory provisions and General recommendations regarding the loadbearing capacity of buildings in case of fire are given in the Design Regulations of the Board, BKR 94. (*BFS 1995:17*)

5:11 Alternative design (*BFS 1995:17*)

Fire protection may be designed in a way different from that specified in this section (*Section 5*) if it is shown by a special investigation that the total fire protection of the building will not be inferior to that which would obtain if all the requirements specified in the section had been complied with. (*BFS 1995:17*)

General recommendation: Such an alternative design may for instance be applied if the building is provided with fire protection installations *in addition* to those which follow from the requirements specified in this section. The special investigation shall be documented in the fire protection documentation in accordance with Subsection 5:12. (*BFS 1995:17*)

5:12 Documentation

Fire protection documentation shall be drawn up. This shall set out the conditions on which fire protection is to be based and the design of the fire protection. (*BFS 1995:17*)

General recommendation: The documentation should set out the fire resistance classes of the building and its components, compartmentation, escape strategy, the function of the air handling installation in the event of fire and if appropriate description of fire engineering installations, and control and maintenance schedule. (*BFS 1995:17*)

5:13 Design by calculation (*BFS 1995:17*)

If design of fire protection is based on calculations, calculations shall be based on a carefully selected design fire and shall be performed in accordance with a model which gives a satisfactory description of the problem at hand. The calculation model selected shall be stated. (*BFS 1995:17*)

General recommendation: The uncertainty in the selected input data may be illustrated by means of sensitivity analyses. (*BFS 1995:17*)

5:14 Control of design for escape

In buildings where there is a high risk of injury to persons, design for escape by calculation may be used only if the correctness of the calculation can be demonstrated by design control.

General recommendation: The term design control refers to control of design assumptions, construction documents and calculations. (*BFS 1995:17*)

5:2 Fire resistance classes and other conditions

General recommendation: Methods for the verification of fire resistance properties in different classes are given in advisory publication No 1993:2 of the Board, Guidelines for type approval, Fire protection.

5:21 Buildings

A building shall be constructed to Class Br1, Br2 or Br3. Classification shall take account of factors which affect the possibility of escape and the risk of injury to persons in the event that the building collapses. The possibility of escape shall be assessed in view of the height and volume of the building and the activity which shall be carried on in the building, and of the number of persons who are expected to be in the building at the same time and the likelihood that these persons can reach safety on their own.

A building where a fire entails a high risk of injury to persons shall be constructed to Class Br1. In such buildings the most stringent requirements are imposed on e.g. finishes and on loadbearing and separating structures. A building where a fire may entail a moderate risk of injury to persons shall be constructed to Class Br2. Other buildings may be constructed to Class Br3.

General recommendation: Buildings of *three or more storeys* should be constructed to Class Br1. The following buildings of *two storeys* should be constructed to Class Br1:

- Buildings containing sleeping accommodation for persons who cannot be expected to have good knowledge of the premises.
- Buildings intended for persons not very likely to reach safety on their own.
- Buildings with places of assembly situated on the second storey.

The following buildings of *two storeys* should be constructed to not less than Class Br2:

- Buildings intended for more than two flats and in which habitable rooms or workrooms are situated on the attic storey.
 - Buildings with places of assembly at ground level.
 - Buildings which have a building area greater than 200 m² and which are not divided into units not exceeding this size by compartment walls constructed to not less than Class REI-M60 (see Subsection 5:221).
- Buildings of *one storey*, with places of assembly at or below ground level, should be constructed to not less than Class Br2.

5:22 Elements of structure, materials, claddings and surface finishes

5:221 Class designations

Depending on their function, elements of structure are assigned in this statute to the following classes:

- R (loadbearing capacity),
- E (integrity), and
- I (insulation).

The designations R, RE, E, EI and REI are followed by digits specifying the time requirement, 15, 30, 45, 60, 90, 120, 180, 240 or 360 minutes.

The classification may be combined with the designation

- M (where special consideration must be given to mechanical action), or
- C (for doors with an automatic closing device).

The following class designations are used in addition:

- *Noncombustible* and *combustible* material and material of *low ignitability* (combustible material which complies with certain requirements).
- *Ignition retardant* cladding.
- *Pipe insulation* of Class P I, P II or P III.
- *Surface finish* of Class I, II or III (of which Class I complies with the most stringent requirements).
- *Floor covering* of Class G.
- *Roof covering* of Class T.

5:222 Separation to a certain fire resistance class

The term *separation to a certain fire resistance class* refers to separation by means of floors and walls - inclusive of openings for services and similar and junctions with adjoining elements of structure - which comply with the requirements regarding separation specified for the class concerned. Doors and windows in elements of structure with a separating function may in certain cases be constructed

5:3 Escape in the event of fire

5:31 General

Buildings shall be designed so that *satisfactory escape* can be effected in the event of fire. Special attention shall be paid to the risk that persons may be injured by the fall of elements of structure or due to falls and congestion, and to the risk that persons may be trapped in recesses or dead ends.

General recommendation: Satisfactory escape implies either complete evacuation of all persons who are present in a building or - as may arise in e.g. institutional buildings or very tall buildings - escape by persons who are in the part directly affected by the fire to a place of safety inside the building. In the latter case it must be possible for protection against heat and toxic gases to be provided during an entire fire sequence or at least during the time which in the most unfavourable instance is required for a fire under the conditions in question to be completely extinguished. Examples of methods for the design of escape routes are given in report No 1994:10, *Design for escape*, of the Board. (BFS 1995:17)

5:312 Windows as escape routes

In dwellings - but not in alternative forms of dwelling -, offices and comparable spaces in a building, one of the escape routes may consist of a window provided that escape can take place safely. In assessing the situation, consideration shall be given to whether or not the equipment of the rescue service can be used for escape.

General recommendation: Windows used for emergency escape should be openable without a key or other implement and should have a clear vertical opening not less than 0.5 m wide and not less than 0.6 m high. The sum of width and height should be not less than 1.5 m. The bottom of the window opening should be not more than 1.2 m above floor level. If the flat is larger than one room and kitchen or similar and is accessible only from a rescue road, it should have a balcony which can be reached from the rescue road.

5:313 Only one escape route

A door leading directly to a street or similar space may be the only escape route from small premises at ground level where only a small number of persons is likely to be present. A stairway, *Tr1*, may be the only escape route from dwellings - but not alternative forms of dwelling -, offices and comparable premises in a building irrespective of the number of storeys. The stairway may not be in communication with the basement. It is stipulated that the distance between the stairway and a place of occupation inside the dwelling or office is not so large that the storey cannot be evacuated before it is blocked in the event of fire. A stairway, *Tr2*, may under the same circumstances as those above be the only available escape route in a building of not more than eight storeys.

General recommendation: The distance to a stairway intended as an escape route should not normally be greater than 30 m.

5:314 Stairway, Tr1

The term *stairway Tr1* refers to a stairway which is constructed so that it prevents the spread of fire and fire gases to the stairway for not less than 60 minutes.

The stairway shall be in communication with other spaces through a *protected lobby* which is either open to the external air or is provided with arrangements which prevent the spread of fire gases to the stairway. The protected lobby may be fitted with doors to a lower fire

resistance class.

Neither the stairway nor the protected lobby shall be in communication with a storey that is situated below the storey which shall be used during escape as the means of exit to the external air.

A lift or an inlet opening to a refuse chute or similar shall not be placed inside the stairway.

General recommendation: Doors between the stairway and the protected lobby may be constructed to not less than Class E-C30. Doors between a dwelling or other premises and the protected lobby should be constructed to not less than Class EI-C60. If the protected lobby abuts onto a communication route, corridor or similar space in its own fire compartment, Class EI-C30 is sufficient.

5:315 Stairway, Tr2

The term *stairway Tr2* refers to a stairway which is constructed so that it limits the spread of fire and fire gases to the stairway for not less than 60 minutes. If the stairway serves a building with fewer than eight storeys, the doors to the stairway may be constructed to a lower class. The stairway shall be in communication with dwellings, working premises or other similar spaces where persons are present other than occasionally only through a space in its own fire compartment.

Spaces other than dwellings or working premises and other similar spaces where persons are present other than occasionally shall be in communication with the stairway only through a protected lobby. Such spaces shall however have access to at least one more escape route and access road for the rescue service unless this is evidently unnecessary.

Attic spaces with occupants' store rooms may be in direct communication with a stairway Tr2 through doors constructed to not less than Class EI-C60.

A lift or an inlet opening to a refuse chute or similar shall not be placed inside the stairway. (*BFS 1995:17*)

General recommendation: Doors to a stairway Tr2 should be constructed to not less than Class EI-C60. If the stairway serves a building with fewer than eight storeys, Class EI-C30 is sufficient. An attic space with small occupants' store rooms need not be provided with a second escape route or access road. (*BFS 1995:17*)

5:33 Travel distance

5:331 Travel distance to an escape route

The travel distance inside a fire compartment to the nearest escape route shall not be so great that the compartment cannot be evacuated before critical conditions arise.

5:332 Travel distance along an escape route

Along an escape route, the travel distance to the nearest stairway leading to another storey, or to an exit leading into the street or similar space, shall not be so great that escape cannot take place rapidly.

General recommendation: The greatest travel distance can be determined with regard to the activity which shall be carried on in the building. The travel distance should not normally be greater than 30 m if escape can be effected in two directions.

5:34 Access

5:341 The dimensions of escape routes

Escape routes shall be designed to be so spacious and to permit such ease of movement that they are capable of serving the number of persons for which they are intended.

General recommendation: The width of an escape route should be not less than 0.9 m. In escape routes from fire compartments intended for more than 150 persons, the width should be not less than 1.2 m.

5:36 Design conditions

5:361 Critical conditions in the event of escape

In design with respect to the safety of escape, the conditions in the building shall not become such that the limiting values for critical conditions are exceeded during the time needed for escape.

General recommendation: In evaluating critical conditions, consideration should be given to visibility, thermal radiation, temperature, noxious gases and the combination of temperature and noxious gases. The following limiting values can normally be applied:

- Visibility: level of fire gases not lower than $1.6+(0.1 \times H)$ m, where H is the height of the room.
- Thermal a short term radiation intensity of maximum 10 kW/m^2 , radiation: a maximum radiant energy of 60 kJ/m^2 in addition to the energy from a radiation of 1 kW/m^2 .
- Temperature: air temperature not higher than 80°C .

5:37 Special conditions

5:371 Places of assembly

Escape routes from places of assembly shall be designed for the number of persons who are permitted to be present in the premises.

Escape from places of assembly shall not take place through other places of assembly.

General recommendation: If the number of persons is not known, the following assumptions may be made:

- If the premises shall be used by seated persons and the seats are placed in rows, the escape routes should be designed for 1.7 persons/m^2 net area. The gangways in the premises which are intended for the seated audience should be counted as part of this area, but the stage or dais should not.
- If the premises shall be used for both standing and seated persons, the escape routes should be designed for 2.5 persons/m^2 net area.

The escape routes in a department store or similar installation for retail trade should be designed for 0.5 persons/m^2 net area for those spaces to which the public has access.

In places of assembly or in the anterooms of these there should be signs stating the maximum number of persons who are permitted to be in the premises at the same time.

Places of assembly should have not less than three escape routes if they are intended for more than 600 persons, and not less than four if they are intended for more than 1000 persons.

Escape routes from places of assembly may be in communication with one another through intermediate foyers or similar spaces which are separated from the escape routes by construction to not less than Class EI-C30.

5:3711 Escape alarm

Places of assembly shall be provided with an escape alarm which is activated automatically or from a staffed position when a fire is indicated.

General recommendation: The escape alarm should give those who are present in the place of assembly spoken information regarding appropriate action to be taken for escape.

5:3712 Emergency lighting etc.

Places of assembly shall be provided with general lighting and emergency lighting. Stairs in places of assembly shall be provided with emergency lighting. Emergency lighting shall be provided immediately before exits to the external air. It shall be possible for the lighting needed in places of assembly in the event of escape to be switched on from one position in the premises.

External escape routes from places of assembly shall be lit and provided with emergency lighting along their entire length.

5:5 Protection against the spread of fire inside a fire compartment

5:51 Requirements regarding materials, surface finishes and claddings

5:512 Surface finishes and claddings in escape routes

Surface finishes and claddings in escape routes shall be of materials which provide negligible contribution to the spread of fire.

In buildings of *Class Br1* or *Br2*, ceiling surfaces and internal wall surfaces in escape routes shall have surface finish of Class I. The surface finish shall be applied to Non-combustible material or to ignition retardant cladding.

In buildings of *Class Br3*, ceiling surfaces and internal wall surfaces shall have surface finish as follows:

- a) Escape routes in hotels, institutional buildings and places of assembly shall have surface finish of Class I on ceiling surfaces and not less than Class II on internal wall surfaces. The surface finish shall be applied to Non-combustible material or to ignition retardant cladding.
- b) Escape routes which are common to two or more dwellings or offices shall have surface finish of Class I on ceiling surfaces and not less than Class II on internal wall surfaces.
- c) Escape routes from premises for activity which presents a fire hazard shall have ceiling and wall surfaces with surface finish of Class I applied to non-combustible material or to ignition retardant cladding.

In buildings of *Class Br1* the floor covering in escape routes shall be constructed of a material with a moderate propensity to spread fire and evolve fire gases.

General recommendation: The floor covering should be made of non-combustible material or material which is assigned to Class G.

5:6 Protection against the spread of fire and fire gases between fire compartments

5:61 Division into fire compartments

Buildings shall be divided into fire compartments separated by elements of structure which impede the spread of fire and fire gases. Each fire compartment shall comprise a room - or associated groups of rooms - in which the activity has no immediate connection with other activities in the building. A fire compartment shall not - with the exception of dwellings, stairways, lift wells and open garages - comprise spaces on more than two storeys unless the spaces are protected by an automatic water sprinkler installation or other arrangements, and it is shown by special investigation that the requirements in this section (*Section 5*) are complied with.

Each fire compartment shall be separated from other spaces in the building by elements of structure (including service penetrations, necessary supports, connections and similar) constructed to not less than the fire resistance class commensurate with the requirements in Sections 5:6-5:8.

General recommendation: Dwellings or offices, stairways, garages, boiler rooms, refuse storage rooms, hospital wards, guest rooms in hotels, escape routes and large staff rooms are examples of self contained fire compartments. In industrial buildings it is appropriate to place in their own fire compartments spaces for activities where it is known by experience that fire may have serious consequences or is of great significance for the activity as a whole. This applies, for instance, to central heating plants, power supply installations and different types of warehouses.

5:62 The fire resistance class of elements of structure separating fire compartments

5:621 Fire resistance class

5:6211 Buildings of *Class Br1*

Elements of structure shall be constructed to not less than the fire resistance class set out in

Table (a) below. The fire resistance class in Column 1 ($f \leq 200$) may be applied for dwellings and offices, schools, hotels, garages for cars, shops for the sale of food, residents' store rooms and comparable fire compartments. The class may also be applied for fire load intensities higher than 200 MJ/m² for buildings protected by an automatic water sprinkler installation or if conditions are such that a fire is completely extinguished by the action of the rescue service not later than 60 minutes after the outbreak of fire.

Walls and ceilings in a part of an attic which is converted into living or office accommodation, with not more than one storey above the attic floor, may be constructed to Class EI 30 adjacent to an attic space which is not utilised.

Table a. Prescribed fire resistance class with respect to the separation function in a building of Class Br1.

Element of structure	Fire resistance class for a fire load intensity f (MJ/m ²)		
	$f \leq 200$	$f \leq 400$	$f > 400$
Element of structure separating fire compartments in general, and a floor above a basement	EI†60	EI†120	EI†240

5:6212 Buildings of Class Br2 and Br3

The elements of structure shall be constructed to not less than the fire resistance class set out in Table (b) below.

Table b. Prescribed fire resistance class with respect to the separation function in a building of Class Br2 or Br3.

Element of structure	Fire resistance class
1. Element of structure separating fire compartments in general	EI 30
2. Element of structure separating flats in a block of flats	EI 60

5:6213 Fire resistance alternatives

Fire resistance class EI may be replaced by class E if the distance to the travel route for escape and to combustible material is sufficient to ensure that safety of escape is not reduced or the risk of fire spread is not increased.

5:6214 Doors, shutters and access panels

Doors, shutters and access panels in elements of structure separating compartments shall normally be constructed to the same fire resistance class as that which applies for the element of structure in question in accordance with the tables in Subsections 5:6211 and 5:6212.

If it can be shown that the fire and fire gas separating function is not impaired appreciably or that the risk of fire spread is evidently slight, the doors and similar may however be

constructed to a lower fire resistance class, but not lower than one half of the class which otherwise applies and in no instance lower than Class E30. Doors and similar may be constructed to not lower than Class E if the safety of escape is nevertheless maintained and there is little risk of the spread of fire.

For buildings in Class Br1, doors and similar between escape routes and dwellings or offices, schools, hotels, residents' store rooms and comparable fire compartments may be constructed to not less than Class EI 30. (BFS 1995:17)

General recommendation: Examples of applications where the fire and fire gas separating function is not appreciably impaired or the risk of fire spread is slight are doors, shutters and access panels installed between fire compartments of low fire load intensity, < 50 MJ/m², or buildings protected by an automatic water sprinkler installation.

The safety of escape may be considered to be secured and the risk of the spread of fire gases may be considered slight if doors and similar are so sited that the distance between the doors and similar and escaping persons is such that the level of radiation does not exceed 3 kW/m² and that, within a sufficiently large protection zone in front of or behind the door or similar, there is no combustible material. (BFS 1995:17)

Doors and similar of non-combustible material which satisfy the requirements regarding insulation of Group 2 (previously Class A) and integrity (imperforateness) in accordance with the general recommendations *Guidelines for type approval, Safety in case of fire* (BFS 1993:2) of the Board or corresponding previous regulations, may however be used as alternatives to doors and similar of Class EI for the following applications:

- a) Between a stairway and
 - a basement or attic,
 - a lobby or protected lobby, and
 - shop, storage, warehouse or industrial premises.
- b) Between a lift well which constitutes a fire compartment of its own and a lobby or corridor.
- c) Between a pipe duct and an institutional building.
- d) In a fire wall.
- e) As a door to a flat.

Doors and similar into, or inside, escape routes shall be self closing. Doors and similar into dwellings or offices, small spaces which are normally kept locked, lift machine rooms, fan rooms and similar premises, or into premises situated above storeys where persons are present other than occasionally, need not however be self closing.

Self closing doors and similar may be fitted with a door stop provided that this automatically closes when fire gases are detected near it. (BFS 1995:17)

5:676 Lifts

A lift well inside a self contained fire compartment shall be designed so that fire or fire gases are not spread, from or via the lift well, to other fire compartments which are not exposed to fire.

A lift well shall be placed in a self contained fire compartment unless the lift well is situated -entirely outside the building,

-inside or adjacent to a stairway and has doors to this or to a space in open communication with the stairway, or

-in a building whose design or construction in other respects does not provide an obstacle to the spread of fire such that increased fire safety can be achieved by placing the lift well in a self contained fire compartment.

General recommendation: The spread of fire or fire gases to other fire compartments from or via the lift well can be prevented by fire gas ventilation, by a lobby between the lift and adjacent fire compartments, or by doors imperforate to fire or fire gases.

The spaces for lift machinery and diverter pulleys may be placed in the same fire compartment as the lift well, provided that the spread of fire and fire gases from the lift machinery does not cause the limiting values for critical conditions to be exceeded in the car.

General recommendation: Electric cables for the machinery for a lift permitted to carry passengers, which in the event of power failure does not automatically proceed to the nearest landing, should be protected from the direct action of fire.

5:8 Loadbearing capacity in the event of fire

5:81 General

Loadbearing structures shall be designed and sized so that in the event of fire there is adequate structural safety with respect to material failure and instability in the form of local, overall and lateral torsional buckling and similar. Parts of the loadbearing structure including supports, joints, connections and similar shall be designed so that collapse does not occur - during a specified period of time in accordance with the fire resistance classes for elements of structure set out in Subsection 5:82, under fire exposure conditions in accordance with Swedish Standard SIS 02 48 20 (2).

As an alternative, design of the loadbearing structure may also be based on a model of a natural fire sequence in accordance with Subsection 5:83.

After a special investigation, the consequences of collapse may in certain cases be accepted. A departure may then be made from the fire resistance classes set out in Tables (a) and (b) in Subsection 5:821. In such cases care shall be taken to ensure that the safety of escape is not jeopardised and the risks for the personnel of the rescue service and environmental effects do not increase. Elements of structure for which collapse is accepted shall be so situated that they can be readily identified and observed.

General recommendation: Examples of elements of structure referred to in paragraph three are eaves, balconies and ceilings which do not have a separating function. (*BFS 1995:17*)

In some cases a lower part of a building may be constructed to a lower fire resistance class, provided that the loadbearing capacity and stability of the taller part are independent of those of the lower part.

If an element of structure is required to be constructed to a higher fire resistance class with respect to its separating function, the element of structure shall be constructed to this higher class with respect to its loadbearing function also. Floors which shall be constructed to a certain fire resistance class with respect to their separating function shall have a loadbearing structure to not less than the same class. Walls which provide separation to a certain fire resistance class may be stabilised by floor constructions in accordance with Subsection 5:82.

5:82 Design by classification

5:821 Classes of performance

Elements of structure shall with respect to loadbearing capacity be constructed to the fire resistance class prescribed in Tables (a) and (b) below. Column 1 ($f \leq 200$) in Table (a) may thus, without special investigation, be applied for e.g. dwellings and offices, schools, hotels, garages for cars, shops for the sale of food, occupants' store rooms and comparable fire compartments. Column 1 may also be applied for fire load intensities higher than 200 MJ/m^2 if the building is equipped with an automatic water sprinkler installation or if the conditions exist for a fire to be completely extinguished by the action of the rescue service not later than 60 minutes after the outbreak of fire. If the element of structure contains combustible material, this need not be taken into consideration other than to a reasonable extent in calculating the fire load intensity. (*BFS 1995:17*)

Table a. Prescribed fire resistance classes with respect to loadbearing capacity for a building of Class Br1.

Element of structure	Fire resistance class for fire load intensity f (MJ/m ²)		
	$f \leq 200$	$f \leq 400$	$f > 400$
1. Vertical loadbearing structure and horizontal structure which provides stability for the structural frame			
a) in a building of not more than two storeys	R†60	R†120	R†240
b) in a building of 3-4 storeys			
ñ floors	R†60	R†120	R†240
ñ other loadbearing structure	R†60	R†120	R†240
c) in a building of 5 - 8 storeys ¹			
ñ floors	R†60	R 120	R†240
ñ floors	R†90	R 180	R†240
ñ other loadbearing structure	R†90	R 180	R†240
ñ other loadbearing structure	R†90	R 180	R†240
d) in a building of more than eight storeys ¹			
e) below topmost basement storey			
2. Horizontal structure which does not provide stability	R†60	R 120	R†240
3. Flights and landings in stairways	R†30	R† 30	R† 30

Table b. Prescribed fire resistance classes with respect to load-bearing capacity for a building of Class Br2 or Br3.

Element of structure	Fire resistance class for building of class	
	Br2	Br3
1. Vertical loadbearing structure and horizontal structure which provides stability for the structural frame		
a) residential building	R†30	R†15
b) building other than residential building	R†30	ñ
c) below topmost basement storey ¹	R†90	R†90
2. Horizontal structure which does not provide stability		
a) residential building	R†30	R†15
b) ground floor in dwellings where there is a contiguous crawling space below the floor	R 30	R 30
c) building other than residential building		
3. Flights and landings in stairway below the topmost basement storey	R†30	R†30

¹ For fire load intensities higher than 200 MJ/m², Table (a) shall be applied.

5:822 Design by testing and/or calculation (*BFS 1995:17*)

The characteristic loadbearing capacity of a loadbearing element of structure may be determined by

- testing* in accordance with Swedish Standard SIS 02 48 20 (2),
- calculation* in accordance with the same fire sequence, or
- a combination of testing and calculation* as above.

General recommendation: Further mandatory provisions and general recommendations regarding testing and calculation are given in the Board's Design Regulations, BFS 1993:58, BKR 94.

5:83 Design based on a model of a natural fire sequence

Design may be based on a model of a natural fire sequence.

General recommendation: Further mandatory provisions and general recommendations regarding such design are given in the Board's Design Regulations, BFS 1993:58, BKR 94.

PARTS OF [2]:

10 RESISTANCE IN CASE OF FIRE

Further mandatory provisions and general recommendations regarding the resistance of buildings in case of fire are to be found in Section 5:8 of Boverket's Building Regulations, BBR 94.

10:1 REQUIREMENTS

Parts of the loadbearing structure, inclusive of supports, joints, connections and similar, shall be constructed in such a way that collapse does not occur either

- within a certain period of time according to the requirements applicable to the fire resistance classes specified for elements of structure in Subsection 5:82 of BBR 94, or
- during a complete fire process, or
- during part of a complete fire process, if it can be shown by a special investigation that the safety of escape is not affected adversely and that the risks for the personnel of the rescue service and the effects on the environment are not increased.

General recommendation: In the same way as in conjunction with ordinary combinations of action, the requirements regarding safety against failure in case of fire should be differentiated in view of the consequences of failure. The factors which influence the choice of safety class in an ordinary combination of actions, namely the type and use of the building, the type of the loadbearing structure or element of structure and the character of the envisaged failure, are also relevant in the event of fire. In a fire, the consequences of failure are to a high degree dependent on whether there are still people inside the building when failure occurs. This implies that the longer the period of time after the outbreak of fire during which there is a certain probability that people are present in the building or in its immediate vicinity, the more stringent should be the requirements regarding structural safety.

In *design by classification* in accordance with Subsection 5:82 of BBR 94, these conditions are taken into consideration by the fire resistance class prescribed for the application in question; this class is dependent on the use of the building, the height of the building, the magnitude of the fire load density, and the significance of the element of structure for the overall resistance of the building structure.

In *design based on a model of a parametric fire exposure* in accordance with Section 5:83 of BBR 94, the above conditions are taken into consideration by differentiating the design fire load density and the duration of the fire with regard to the application in question. In this way, the influence of the factors which affect the selection of safety class for the design resistance of the building structure in the event of fire is taken into consideration indirectly.

During a fire, considerable temperature movements may occur in the loadbearing structure of the building. For frames and other statically indeterminate structures, these movements may give rise to appreciable increments to, and redistributions of, section forces and section moments, and cause cracking and other damage in e.g. columns, beams, floor constructions and walls. These effects occur not only in the elements of structure directly affected by fire but also in the building carcass outside the fire compartment in question. It is essential that these effects should be taken into consideration in design, and that the building carcass should be detailed appropriately with regard to these effects.

10:11 Factor of safety with respect to failure and instability in case of fire

The partial factor γ_n may be put equal to 1.0 irrespective of the safety class of the structure.

The design load effect S_d shall be determined for the most unfavourable load combination, using the partial factor q_f for load in accordance with Table (b) in Subsection 2:321.

The design resistance R_d according to the method of partial factors shall be determined in view of the following conditions:

- Consideration shall be given to the reduction in strength at elevated temperatures and to the reductions in effective cross section due to combustion and the action of fire. In calculations,

the strength and deformation properties, thermal conductivity and specific heat capacity of each material must be sufficiently well known within the temperature region concerned.

-Consideration shall be given to the changes in the properties of fasteners, connectors and similar under the action of fire.

-The value of the partial factor γ_m for materials in accordance with Subsection 2:322 may be assumed to be equal to 1.0 unless other values are specified in Sections 4 - 9.

10:2 Design by calculation and testing (*BFS 1995:18*)

10:21 Determination of resistance by classification

The characteristic resistance of a loadbearing element of structure may be determined by *testing* in accordance with Swedish Standard SIS 02 48 20 (Nordic Standard NT FIRE 005, ISO 834). The element of structure is assumed to be acted upon by an external static load during the entire test period, corresponding to the intended period of fire resistance.

This load shall be adjusted so that the stresses at critical sections are the same as those which occur due to the design loads in the event of fire in accordance with Subsection 2:321.

Temperature development at critical sections shall if possible be recorded during the test.

The resistance of the structure for a certain period of fire resistance shall be determined on the basis of associated values of applied action and time.

The characteristic resistance of a structure may be *calculated* on the basis of the conditions set out in Section 10:11 and the fire exposure in accordance with SIS 02 48 20 (NT FIRE 005, ISO 834). The assumptions regarding dimensions, spans, support conditions, design in other respects and mechanical moduli shall be made in accordance with the principles which are approved in design without regard to fire in accordance with Section 2.

The characteristic resistance of a loadbearing structure in the event of fire may be determined by *combined testing and calculation*. The tests may be made on unloaded test objects if loading cannot be assumed to affect the behaviour of the test object. Temperature development at critical sections shall if possible be recorded during the test. On the basis of the recorded temperature curves and e.g. the measured depth of fire penetration in timber structures, the resistance can then be calculated if the relevant material data are known and verified.

10:22 Determination of resistance by design based on a model of a parametric fire exposure

Determination of the resistance of the structure on the basis of a model of a parametric fire exposure can in certain cases be made by testing. A combination of testing and calculation may also be applied. In all cases, the mandatory provisions of Section 10:21 shall apply as appropriate.

10:221 Fire load density

The design value of the fire load density shall be the value which is included in 80% of the observed values in a representative statistical material. However, in designing elements of structure which, according to Column 1 of Table (a) in Subsection 5:821 of BBR 94, shall be constructed to Class R 90, this value of the fire load density shall be increased by 50%.

Elements of structure which shall be constructed to Class R 60 or higher shall be designed for a complete fire process (inclusive of cooling), while for lower fire resistance classes design shall be based on the time indicated by the numerical value of the class designation (but exclusive of cooling).

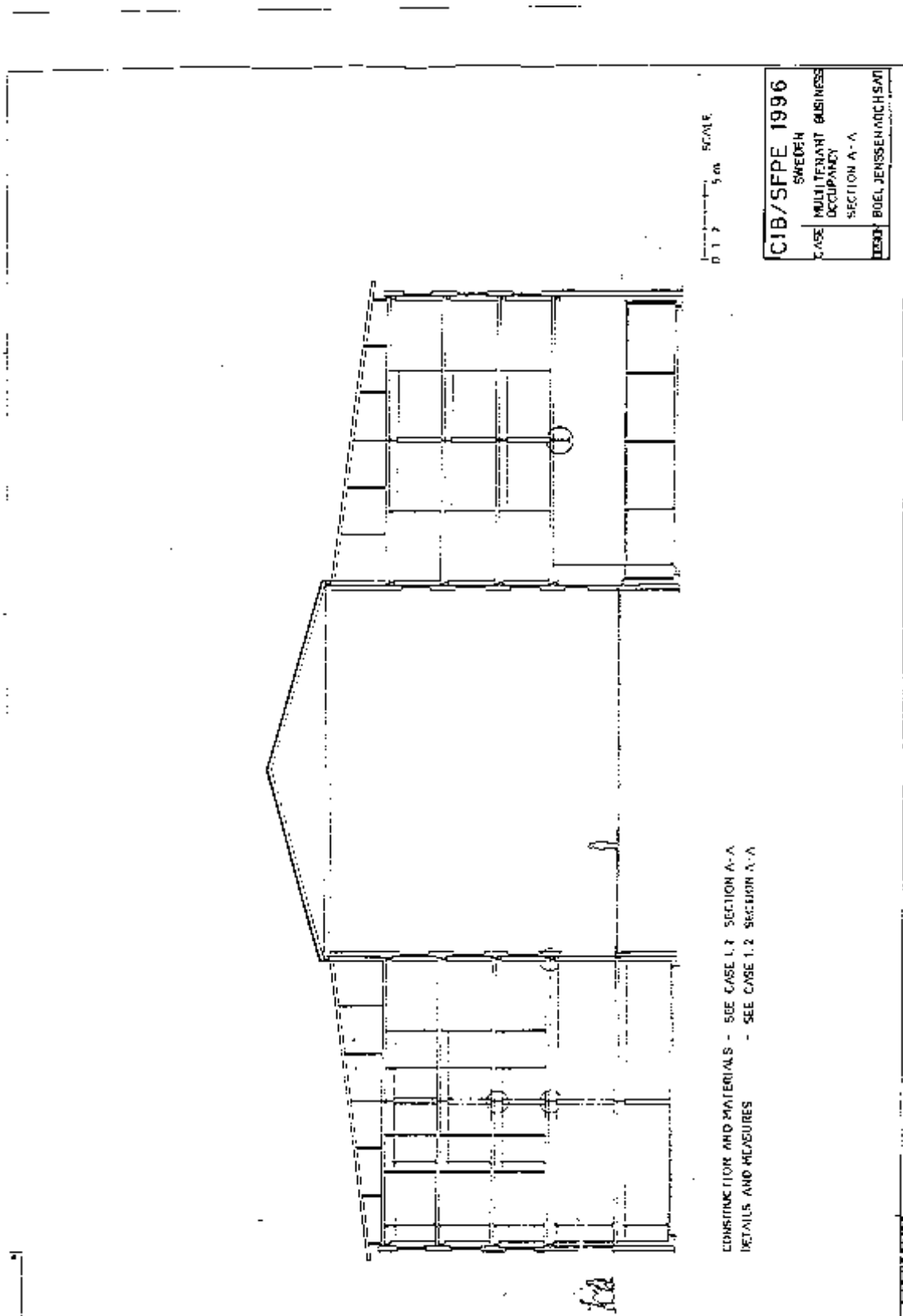
General recommendation: Examples of characteristic values are given in the report *Fire engineering design of concrete structures*, published by the Swedish Council for Building Research, 1992.

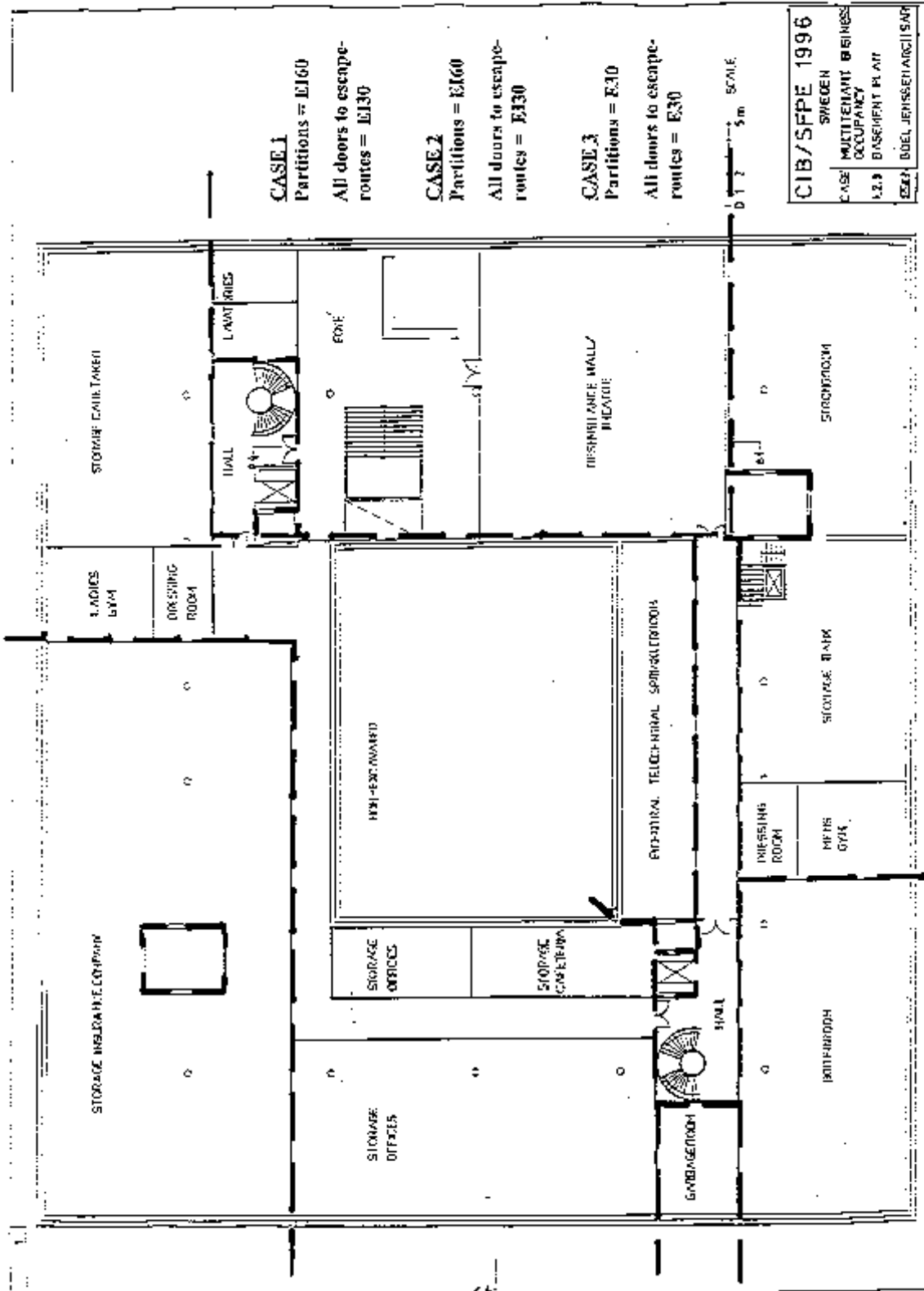
10:222 Fire compartment temperature

The gas temperature T_f in a fire compartment is to be calculated from heat and mass balance equations (model of a parametric fire exposure). Consideration may be given to an automatic water sprinkler installation and fire gas ventilation.

Where flashover is not likely to occur and the fire will be limited in extent, the gas temperature T_f may be assumed to depend on the area and heat output of the fire, and not on the magnitude of the fire load density.

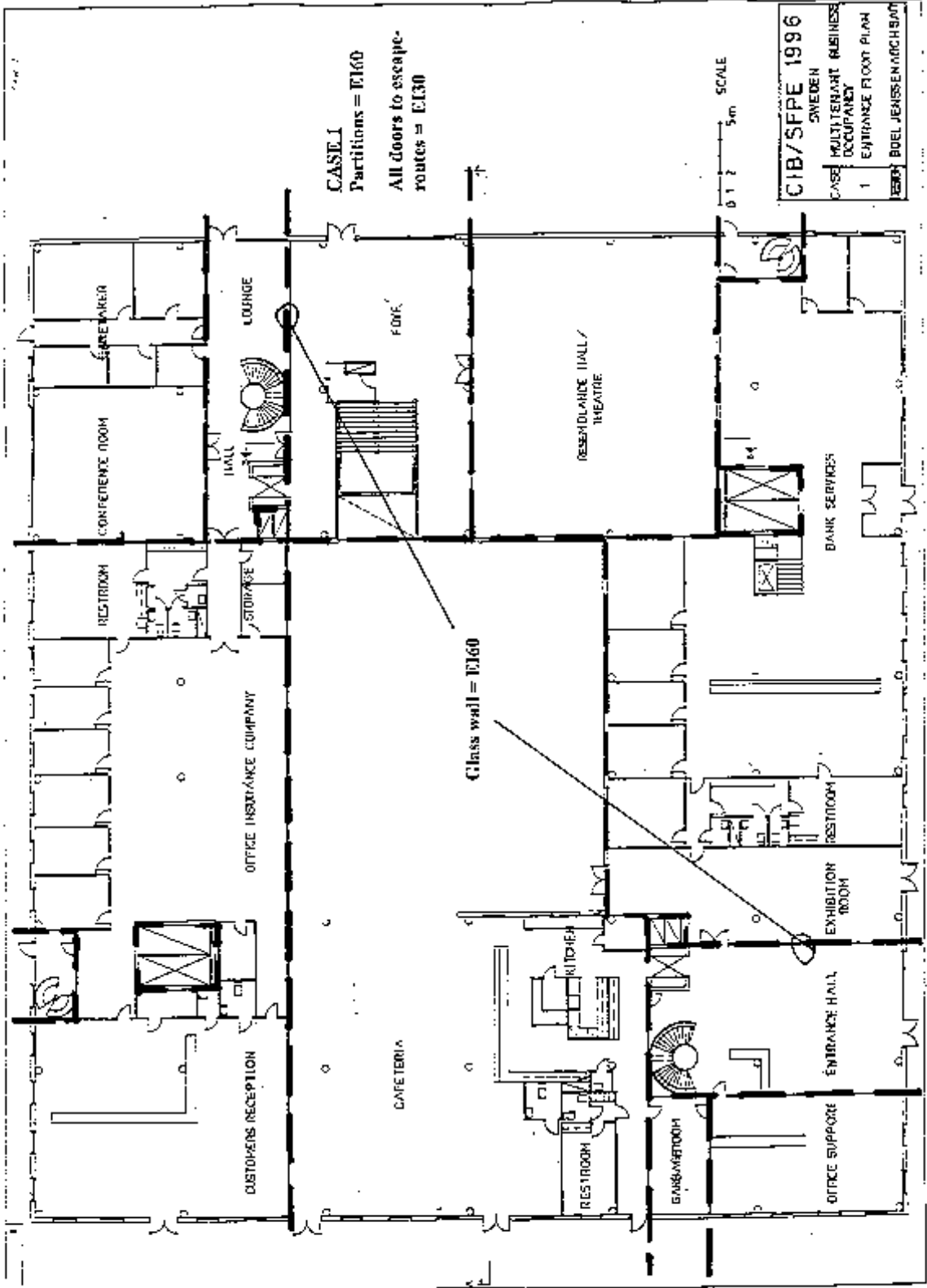
Appendix 2
Drawings of the building





CIB/SFPE 1996

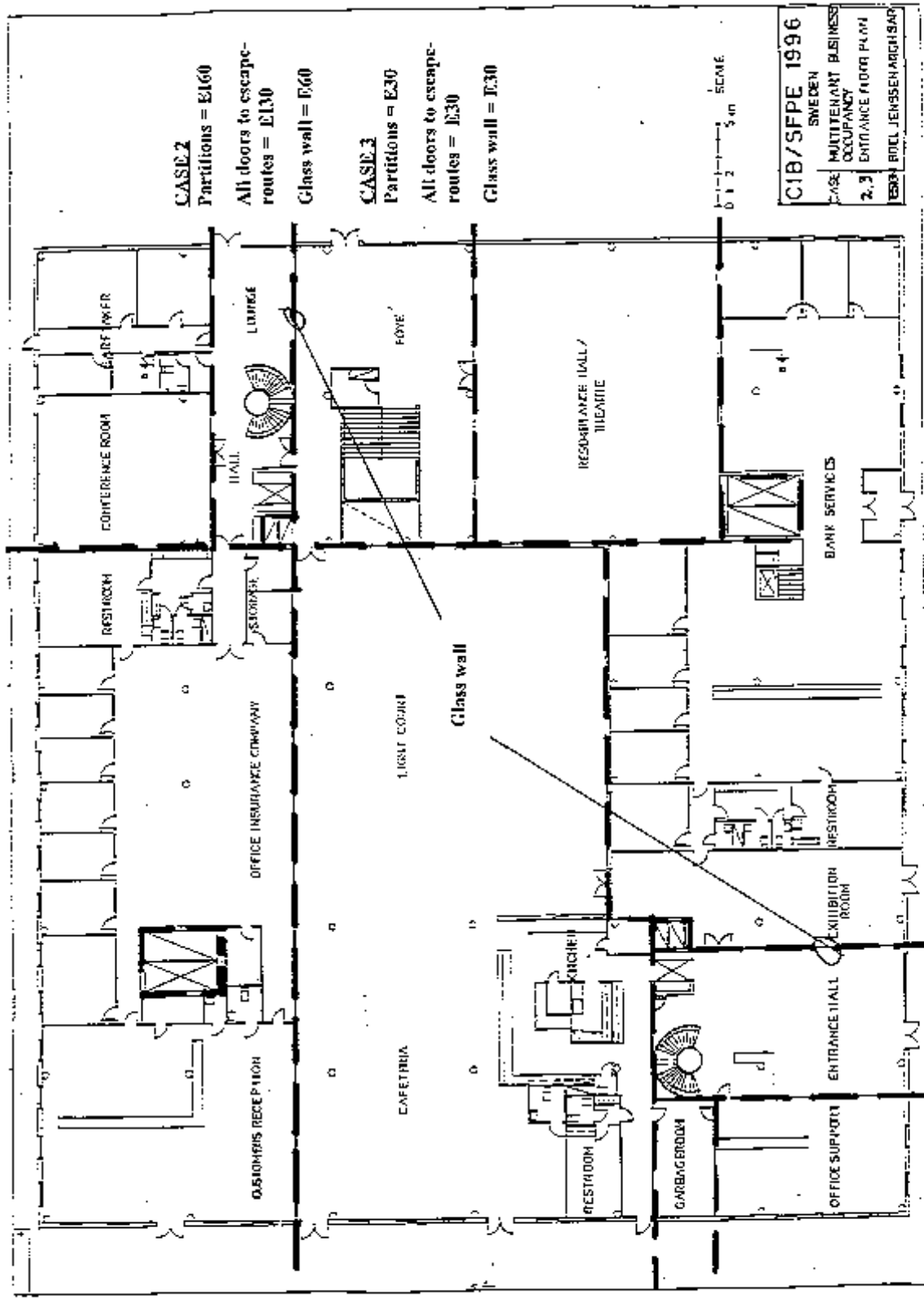
CASE	SWEDEN	MULTITENANT	BUSINESS
1.2.3	OCCUPANCY	BASEMENT PLAT	
0047	BOEL JENSEN/ARC/ISAP		



CASE 1
 Partitions = EI160
 All doors to escape-
 routes = EI130

SCALE
 0 1 2 3m

CIB/SFPE 1996	
CASE	SWEDEN
OCCUPANCY	MULTITENANT BUSINESS
1	ENTRANCE FLOOR PLAN
REVISION	BOEL JENSEN/ARCHIBO

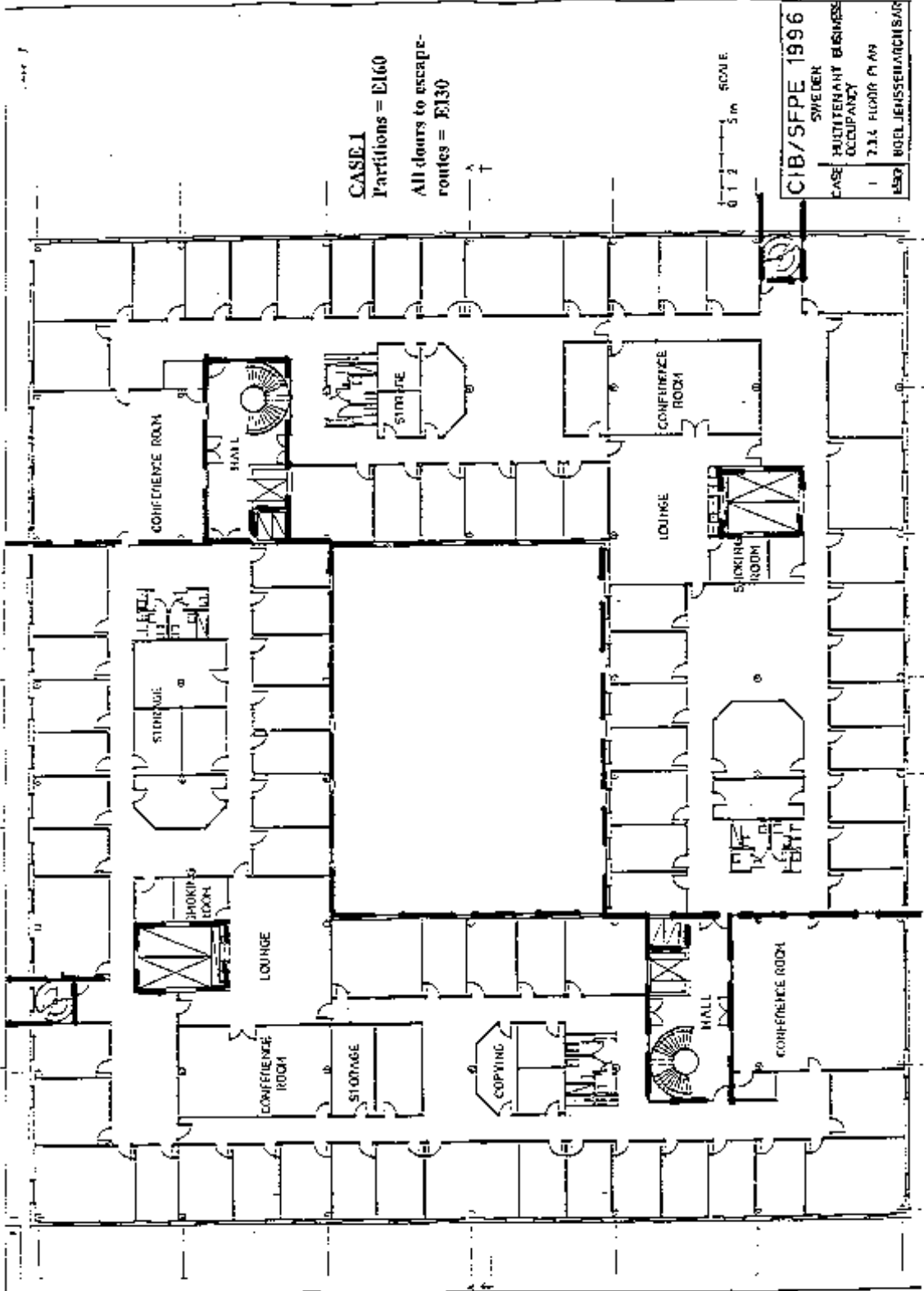


CASE 2
Partitions = E160
All doors to escape routes = E130
Glass wall = E60

CASE 3
Partitions = E30
All doors to escape routes = E30
Glass wall = E30

0 1 2 3 m SCALE

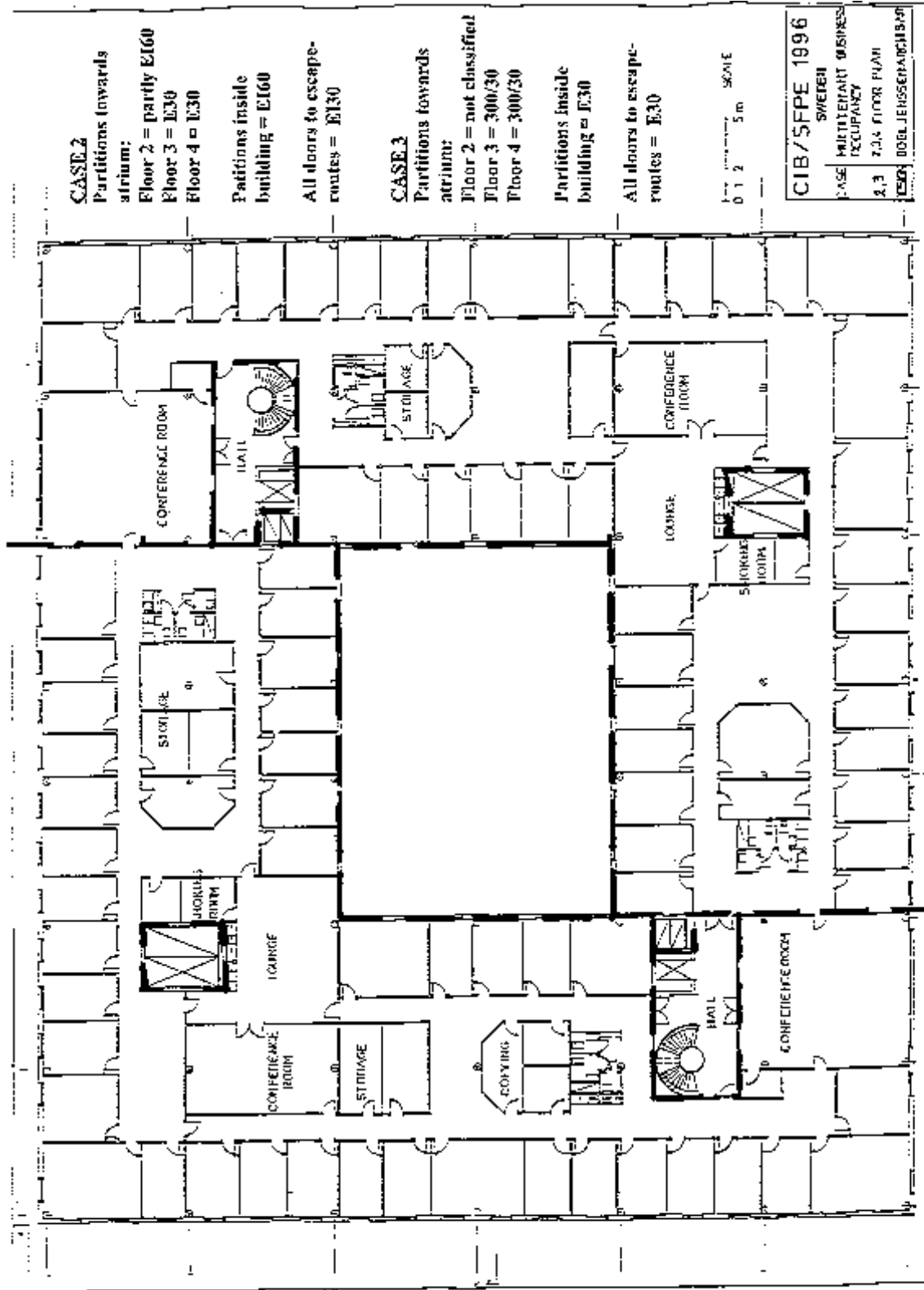
CIB/SFPE 1996
SWEDEN
CASE MULTITENANT BUSINESS OCCUPANCY
2.2 ENTRANCE FLOOR PLAN
TESDA BODL JENSENHAGEN/SAP



CASE 1
 Partitions = EI60
 All doors to escape-
 routes = EI30

0 1 2 3 4 5 m SCALE

CIB/SFPE 1996	
SWEDEN	
CASE	MULTITENANT BUSINESS
OCCUPANCY	1
FLOOR PLAN	2.1.1
HOTEL JENSEN MARCHSAR	



Calculations - input data for smoke ventilation area in atrium

Calculations of roof-vent area in the atrium												
Plyme equation = "Flow from an opening" BSI guide												
Q [kW]	C _p [kW]	z [m]	h [kW/m ² K]	w [m]	A _{ov} [m ²]	m [kg]	T _s [K]	ρ _s [kg/m ³]	A _{in} [m ²]	P _{in} [Pa]	P _{out} [Pa]	A _{ov} [m ²]
7000	4900	4	0.036	5	820	45,69	358,87	0,984	15	7,89	21,22	12,74
10000	7000	4	0.035	5	820	51,48	380,33	0,928	15	10,01	26,67	13,22
Q [kW]	Q _b [kW]	z [m]	h [kW/m ² K]	w [m]	A _{ov} [m ²]	m [kg]	T _s [K]	ρ _s [kg/m ³]	A _{in} [m ²]	P _{in} [Pa]	P _{out} [Pa]	A _{ov} [m ²]
7000	4900	7	0.035	5	574	79,96	341,98	1,032	30	6,04	11,52	33,96
10000	7000	7	0.035	5	574	90,06	356,55	0,990	30	7,66	14,42	35,17
Q [kW]	Q _b [kW]	z [m]	h [kW/m ² K]	w [m]	A _{ov} [m ²]	m [kg]	T _s [K]	ρ _s [kg/m ³]	A _{in} [m ²]	P _{in} [Pa]	P _{out} [Pa]	A _{ov} [m ²]
7000	4900	10	0.035	5	328	114,23	331,98	1,063	65	2,63	5,36	67,64
10000	7000	10	0.035	5	328	128,65	342,95	1,029	65	3,33	6,70	69,80
T _{emission} [K]	z = height of opening + plume height above opening (design value)											
ρ _s [kg/m ³]	h = Heat transfer coefficient (assumption)											
C _p [kJ/Kkg]	w = width of opening (assumption)											
α	m = 0.23 Q _b ^{1/2} w ^{2/3} z											

Calculations of roof-vent area in the atrium

Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		Plume equation = Hoskstad		
Q_p [kW]	Q_p [kW]	z [m]	h [kW/m ² K]	A_w [m ²]	m [kg]	T_s [K]	ρ_s [kg/m ³]	A_{in} [m ²]	P_{in} [Pa]	P_{st} [Pa]	A_{in} [m ²]	P_{in} [Pa]	P_{st} [Pa]	A_{in} [m ²]	P_{in} [Pa]	P_{st} [Pa]	A_{in} [m ²]	P_{in} [Pa]	P_{st} [Pa]	
500	500	350	4	0,035	820	5,04	303,37	1,164	10	0,22	3,57	10	0,22	3,57	10	0,22	3,57	10	0,22	3,57
1000	1000	700	4	0,035	820	9,35	312,07	1,128	10	0,34	7,07	10	0,34	7,07	10	0,34	7,07	10	0,34	7,07
3000	3000	2100	4	0,035	820	9,16	348,46	1,013	10	0,71	18,34	10	0,71	18,34	10	0,71	18,34	10	0,71	18,34
7000	7000	4900	4	0,035	820	12,16	412,94	0,855	10	1,36	33,86	10	1,36	33,86	10	1,36	33,86	10	1,36	33,86
10000	10000	7000	4	0,035	820	13,69	458,13	0,771	10	1,69	42,13	10	1,69	42,13	10	1,69	42,13	10	1,69	42,13
11000	11000	7700	4	0,035	820	14,13	472,77	0,747	10	1,70	44,47	10	1,70	44,47	10	1,70	44,47	10	1,70	44,47
500	500	350	7	0,035	574	12,82	303,64	1,163	10	1,40	2,57	10	1,40	2,57	10	1,40	2,57	10	1,40	2,57
1000	1000	700	7	0,035	574	16,15	312,32	1,130	10	2,22	4,70	10	2,22	4,70	10	2,22	4,70	10	2,22	4,70
3000	3000	2100	7	0,035	574	23,29	341,41	1,034	10	4,61	11,40	10	4,61	11,40	10	4,61	11,40	10	4,61	11,40
7000	7000	4900	7	0,035	574	30,89	389,12	0,907	10	8,11	20,11	10	8,11	20,11	10	8,11	20,11	10	8,11	20,11
10000	10000	7000	7	0,035	574	34,79	420,55	0,839	10	10,29	24,76	10	10,29	24,76	10	10,29	24,76	10	10,29	24,76
500	500	350	10	0,035	328	23,22	303,09	1,165	20	1,15	1,39	20	1,15	1,39	20	1,15	1,39	20	1,15	1,39
1000	1000	700	10	0,035	328	29,26	310,18	1,138	20	1,82	2,43	20	1,82	2,43	20	1,82	2,43	20	1,82	2,43
3000	3000	2100	10	0,035	328	42,20	332,12	1,063	20	3,79	5,38	20	3,79	5,38	20	3,79	5,38	20	3,79	5,38
7000	7000	4900	10	0,035	328	55,07	365,64	0,965	20	6,86	9,20	20	6,86	9,20	20	6,86	9,20	20	6,86	9,20
10000	10000	7000	10	0,035	328	63,04	386,93	0,912	20	8,45	11,29	20	8,45	11,29	20	8,45	11,29	20	8,45	11,29
$T_{amb,vent}$ [K]		293																		
ρ_s [kg/m ³]		1,2																		
C_p [kJ/(K·kg)]		1																		
α		0,7																		

z = smoke layer height (design value)

h = Heat transfer coefficient (assumption)

$$m = 0,071 Q_p^{1/4} z^{1/4}$$

Calculation of the financial comparison in chapter 10**General assumptions:**

- 1 \$ = 7 SEK
- 1 £ = 12,5 SEK

Atrium and windows costs:

- Smoke vents in atrium (both inlet- and outlet- area): 2 000 SEK/m²
- Windows in class EI 60: 7 300 SEK/m²
- Windows in class E 60: 4 300 SEK/m²
- Windows in class E 30: 3 300 SEK/m²
- Windows in class 300/30: 700 SEK/m²
- Windows with no class: 300 SEK/m²

There is 28 windows · 2 m² in each floor (6 of them are placed above the coffee shop in second floor).

Sprinklercosts:

- Sprinkler installation costs 160 SEK/m² floor area.
- Sprinkled area of floors 1-4: 4 x 3000 m²

Cost analysis:

- Sprinkler installation in floors 1-4:
 $160 \times 3000 \text{ m}^2 \times 4 = 1\,930\,000 \text{ SEK}$ **2 000 000 SEK**
- **Atrium without smoke and fire ventilation (chapter 3.6):**
 $28 \times 2 \text{ m}^2 \times 3 \text{ floors} \times 7\,300 \text{ SEK} = 1\,226\,000 \text{ SEK}$ **1 250 000 SEK**
- **Unsprinkled building with smoke ventilation (chapter 4.3):**
 Windows above coffeshop (EI 60): $6 \times 2 \text{ m}^2 \times 7300 \text{ SEK} =$ 88.000 SEK
 Alt. a. 2 x 15 m² smoke ventilation area, floor 2-4 class E 30:
 $2 \times 15 \text{ m}^2 \times 2000 \text{ SEK} +$
 $(28 \times 2 \text{ m}^2 \times 3 \text{ floors}$
 $- 6 \times 2 \text{ m}^2) \times 3300 \text{ SEK} =$ 575.000 SEK

Alt. b. 2 x 30 m' smoke ventilation area, floor 3-4 class E 30:
 2 x 30 x 2000 SEK +
 28 x 2 m' x 2 floors
 x 3 300 SEK + (28-6) x 2 m' x 300 SEK: 503 000 SEK

Alt. c. 2 x 65 m' (impossible inlet area), floor 4 class E 30:
 2 x 65 x 2000 + 28 x 2 x 3300 + (28 x 2-6) x 2 x 300: 475.000 SEK

Alternative b will be chosen:

88 000 + 503 000 = **600 000 SEK**

- **Sprinkled building with smoke ventilation area (chapter 5.3):**

Alt. a. 2 x 5 m' smoke ventilation area, floor 2-4 class 300/30:
 2 x 5 m' x 2 000 SEK + 28 x 2 m' x 3 floors x 700 SEK = 138 000 SEK

Alt. b. 2 x 10 m' smoke ventilation area, floor 3-4 class 300/30:
 2 x 10 x 2000 + 28 x 2 x 2 x 700 + 28 x 2 x 300 SEK = 135 000 SEK

Alt. c. 20 + 30 m' smoke ventilation area, floor 4 class 300/30:
 50 x 2000 + 28 x 2 x 700 + 28 x 2 x 2 x 300 SEK = 173 000 SEK

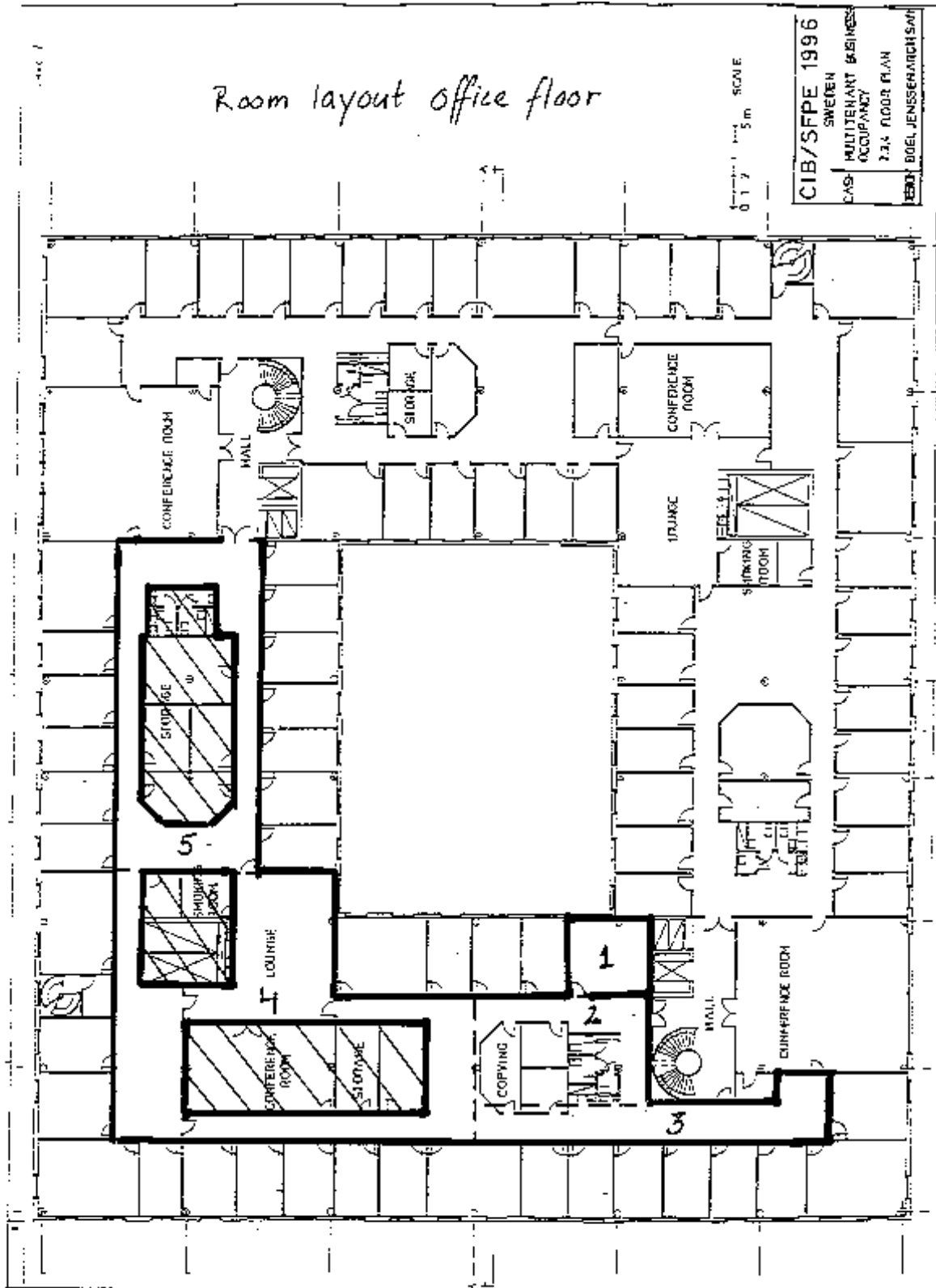
Alternative b will be chosen : **2 135 000 SEK**

Radiation through glass wall:

The glass-wall (about 40 m' glass-area) between staircases and foyer in entrance floor will be about **50 000 SEK** cheaper with E 60 instead of EI 60.

Appendix 5

Room layout in CFAST input data (office floor)



THE SWEDISH CASE STUDY - EXECUTIVE SUMMARY

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1. INTRODUCTION

Sweden has since 1994 had performance based building regulations [1,2]. One of the major improvements in the new building code, is the requirement of a fire safety documentation. The building owner shall produce a detailed description about the fire safety design in the building and special care has to be taken if fire engineering methods are used in the design.

At the same time there has been a change in the Planning and Building Act where the building owner now has sole responsibility in proving that the building complies with the regulations. This means that the owner has to have the knowledge and experience within his project team.

On behalf of CIB/SFPE, in conjunction with the international conference on 24-26 September 1996 in Ottawa, Canada, a case study have been carried out, based on Swedish conditions, on the subject of performance based fire protection for buildings.

Fire protection was designed for a 4-storey office building, for three cases:

- in accordance with detailed solutions in guidelines and standard practice. (The standard method).
- with the aid of calculation methods. (Fire engineering design method).
- with the aid of calculation methods when sprinklers are installed.

An assembly room at ground level for about 400 people plus a glassed-over outdoor yard (atrium) have been added to the original building specification. The occupant loads and the fire compartmentation are indicated on the drawing in page 10-12.

The solutions are not complete, and exemplifies only how some of the important fire prevention steps could be met. When believed that a cost effective solution could be achieved by other means than by following the detailed solutions given in guidelines, calculations have been used to find a satisfactory solution.

It is assumed that the action by the fire brigade would be expected within the normal attendance time (10 min), and that the building is located in a Swedish town. The threat of fire spread to neighbouring buildings is not considered.

In the calculations the computer program CFAST and DETACT-T2 has been used [3,4]. Only a limited number of data are presented from our calculations.

The main objective is that the building should be constructed so that the outbreak of fire could be prevented, the spread of fire and smoke in the building limited and the persons in the building could escape safely or be rescued in some other way.

Safe evacuation of the occupants may be achieved by giving the early warning of an incident, clear instructions of what to do, maintaining safe escape routes and if the emergency would be a fire, by initial control of the fire size. Maintaining safe escape routes as well as the initial control of the fire size may be primarily done by fire compartmentation. The compartmentation for preventing fire spread should be done according to the minimum requirements and no extra attention has been paid to minimise the possible property damage.

Calculation of occupant loads are either done by code recommendations, engineering judgement or by the limitations set out by the escape possibilities

2. STANDARD METHOD

The fire protection reported below in this section, is designed according to standards and recommendations in building codes [5], without using calculation models.

Fire resistance classification

Depending on their function, elements of structure are assigned to classes E (integrity) and I (insulation). The fire compartmentation is done in accordance with the code in Class EI 60 and all doors to and in an escape route are assumed to be in class EI-C 30, if not otherwise stated. The symbols are according to the interpretative document Safety in Case of Fire from the European Community.

Structural elements and fire compartment separation partitions and floor structures are permitted to contain combustible material.

Surface layer must be made in the highest classification, class I. Walls must be made without wood in the surface layer material (class II).

Evacuation in event of fire

All premises must have access to at least two mutually independent escape routes. One of the two escape route may be accessible via another fire compartment or another tenant.

In premises for more than 150 persons (places of assembly), the requisite door width is 1.2 metres and the total width of escape routes must amount to 1.0 metre per 150 persons.

The maximum permitted walking distance to the nearest escape route is 45 metres for offices and 30 metres for assembly room, coffee shop and public areas in banks.

Division into fire compartments

Stairways and lifts are separate fire compartments. Each storey is kept separate. Office floors are divided into two fire compartments. Different tenants with similar activities as regards fire risk may however share the same fire compartment, if it is their wish.

Installations

In the building, an automatic fire detection system and an evacuation alarm system are installed to give an early warning of a fire and clear instructions of what to do in case of fire. This is the result of some of our conclusions and sometimes also regarded by the code. The alarm system would be needed to keep the occupants informed that an unusual event has occurred.

The four stairways are provided with fire gas ventilation to facilitate extinguishing and rescue action. A vent or fan at the top of each stairway opens/starts manually from the entrance. The lifts have a fire vent or fan at the top of the lift shaft if there is no lobby between the lift and adjacent compartments. The fire compartments in the stores in the basement are fire ventilated through vents to ground level, which are opened manually from outside.

All premises have access to fire extinguishing equipment in the form of hand-held fire extinguishers, or internal fire hydrants.

Exit signs used to indicate an evacuation route or to inform about where the nearest escape route is located is present in the whole building. In the assembly room and in the basement, the signs are also equipped with emergency lighting.

HVAC-Systems

The ventilation ducts are insulated with mineral wool or equivalent, by the fire compartment wall lead-ins, along lengths of about 1-2 metres on each side. Alternatively, a *fire* damper can be installed in the ducts where they pass the fire compartment boundaries.

Smoke detectors in the ducts shut off the fans and open the smoke evacuation shafts leading to the roof, which allows the smoke an easier way out than through adjacent fire compartments. As an alternative, *smoke* dampers can be used in the ducts between different fire compartments.

Atrium

When the outdoor garden is glazed over, a number of fire protection measures are added. The cafeteria, with its atrium, forms a separate fire compartment. The premises on the ground floor and on the 1:st - 3:rd floors are separated from the atrium by walls and windows with 60 minutes fire resistance (EI 60). No roof ventilation has to be installed in the glass roof.

3. FIRE ENGINEERING DESIGN METHOD - UNSPRINKLED BUILDING

The usual method is by using a standard method in accordance with chapter 2, and then do an analysis of what could be optimised with regard to fire resistance and cost, using calculation methods and alternative solutions [5]. A number of examples of solutions have been chosen, where calculations have shown that an alternative solution meets the performance based requirements in the building regulations. In other words, the calculation method does not mean that the entire fire protection of the building should be "calculated", just selected portions.

The four scenarios to be considered are

- radiation through glass wall.
- fire in the assembly room on the ground and basement floor
- fire on an office floor
- design of the smoke exhaust system from the atrium including evacuation from the coffee-shop

Fire resistance classification

Radiation calculations show that a simpler/cheaper type of glass can be used in fire compartment walls i.e. E 60. This glass allows radiated heat to pass through but retains its separating ability for 60 minutes. This can be used in glass partitions adjacent to stairways and in fire classed doors.

Assembly room - maximum occupancy load

The objective of this calculation is to allow the number of occupants in the room to be increased relative to the number permitted by the standard method described in section 2. According to that method, 360 persons are permitted.

The maximum desired occupancy loading, from the owners' point of view, is 490 persons (1.7 pers/m² x 288 m²). Can 490 persons be accepted instead of 360 persons, while still meeting the safety goals?

The evacuation time is compared to the time to untenable conditions the limit state equation will be:

$$S-D-R-M > 0$$

The safety margin shall always be positive with an excess of time available. In this equation the following variables are used

S = time to untenable conditions

D = time to detect the fire

R = time for response and behaviour

M = movement time to safety

The duration of the evacuation time is the sum of the three variables D, R and M. The evacuation time for 490 persons was calculated to be less than 3-5 minutes. During a fire, the upper exit will be blocked after about 1.5-2 minutes. Critical condition in this case is when level of fire gases are lower than 1.6+(0.1x H) metre, where H is the height of the room.

If 490 persons are to be permitted to be in the premises, some action is needed to prolong the time to critical conditions.

Roof ventilation in the form of 8-10 m² openings at roof level, which are opened by smoke detectors, give the necessary extension of time.

Office

The objective of the office-calculation is to look for the possibility of eliminating one of the staircases in each fire compartment which would be required following the standard method. The difference in distance between the "allowed" distance and the actual most remote distance is very small, 10 m.

Calculations are aimed at demonstrating that an extra 10 metres to the nearest escape route can be compensated by an automatic evacuation alarm. The extra walking distance gives a walking time of 10 seconds, which should be put in relation to the "gain" offered by an automatic evacuation alarm.

The "gain", in the form of reduced detection time and response time would be considerably greater (1-2 minutes) than the 10 seconds entailed by the extra walking distance.

The automatic evacuation alarm in the office thus means that only two staircases are enough, instead of four for a office storey.

Atrium

The objective of the atrium-calculation is to design the smoke management system in the atrium for the design solution where smoke extraction is required. The design area of the smoke vents will be

optimised so that the cost for the smoke venting system and the glazing of the floors above the smoke interface level will be minimised.

By installing smoke vents which are automatically opened by smoke detectors, the smoke temperature falls and a smoke-free height is achieved which facilitates extinguishing. It is therefore assumed that it will not be possible for flashover to occur. The windows facing the atrium from stories 2-4 can then be made by glass with a fire-rating of E 30, which is a lower classification than EI 60.

The design burning rate is 7000 kW which can be represented by the amount of furniture allowed in the atria. The design fire for the fire located in the coffee-shop will be 1000 kW if a sprinkler system is installed and 7000 kW without the sprinkler system.

A smoke ventilation of 30 m² is required, which will result in fire-rated glass sections in floors 3 and 4 is the alternative which show to be the most cost effective.

A 7000 kW fire in the cafe, which was used for design, results in a smoke temperature of 80°C (350 K). This size of fire gives the smoke enough buoyancy to allow non-mechanical smoke ventilation to function. At lower temperatures, the buoyancy of the smoke is less. On the other hand, it is not hazardous to either fire-separating glass partitions or evacuating people.

4. BUILDING WITH SPRINKLER, FIRE ENGINEERING DESIGN METHOD

Sprinklers shall be made in accordance with the rules of the Swedish Insurance Companies Association (RUS 120) [6] or in accordance with NFPA 13 [7]. If a sprinkler system is installed, further simplifications in the design can be made [5]. The differences are compared to the solutions in the previous section.

Fire resistance classification

Fire compartment separating floor structures, partitions and doors can be made to class E 60 instead of EI 60. If the building is regarded as being "light hazardous", the fire resistance can be reduced so that E 30 is sufficient. (Smoke compartmentation).

Walls with wooden surfaces in offices etc., and to a certain extent, corridors, are permitted when sprinkler are installed.

HVAC System

Insulation in ducts in fire compartment wall lead-ins can be omitted if the fire compartment temperature does not rise above 200°C because of the sprinkler installation.

Fans, shutters and cable installations for these devices which are to function during a fire, would be subject to considerably lower temperature requirements than in an unsprinkled building.

Atrium

Windows in the smoke layer shall be made to resist temperatures of 300°C for at least 30 minutes (class 300/30), instead of E 30-glasses which have a resist temperature of 800-1000 °C. The requisite smoke ventilation areas are 10 m² at 7 metre smoke height above floor level.

5. FIRE ENGINEERING DESIGN OF THE LOADBEARING STRUCTURE AND PARTITIONS

A structural engineer has designed the building in a simplified manner. The structural system will not be described in detail.

The calculations show that it is possible to save some insulation materials when using the real temperature - time process in the fire compartment as the design fire (natural fire sequence), instead of the standard ISO 834 fire curve. In the examples gypsum plaster sheets have been chosen as insulation material, and as shown the savings are not that great because the gypsum board only comes in certain sizes (9 and 13 mm). If some other insulation material would have been used, the savings would have been greater. Another fact added to this is that the steel columns are not used to their fully extent because of the simplified design.

In all the calculations the design manual "Fire Engineering Design of Steel Structures", from 1976 [8] is used. In the case where sprinklers are installed the recommendations in Eurocode ENV 1991-2-2 [9] are used. There it is recommended that the fire load density is reduced to 60%. A better approach, depending of the design of the sprinkler system, is to use a temperature - time curve for a fire taking into account the effect of the sprinkler.

The partitions, steel stud wall insulated with gypsum plaster sheets, can resist real fire conditions. This is due to the fact that the acoustic insulation criteria demands for a "better" wall than would have been required if only the design has been according to the fire requirements of 60 minutes. This means that the partitions will resist a fully developed fire until the danger is over. This fact adds extra safety into the building. The partitions not being part of the fire cell enclosure will also have this fire resistance unless they have cable penetrations etc. with no fire resistance.

The following cases have been studied:

Standard fire temperature curve according to ISO 834, 60 minutes. **(S)**

Natural fire, as described in reference [1], with a fire load density of 644 MJ/m^2 total floor area. For the resemblance hall/theatre the fire load is restricted to 320 MJ/m^2 **(N)**. In the case of sprinklers 60% of these values are used.

Conference room - $9.5 \text{ m} \times 10.5 \text{ m}$ **(C)**, and an office $3.2 \text{ m} \times 4.5 \text{ m}$. **(O)**. These rooms have been chosen to be the most representative in the building.

For the above combinations one beam centrally located, and one column in the entrance floor are used for the calculations.

Results: Minimum required insulation thickness in mm.

		Fire:	(S)	(N)	(N) with sprinkler
Beam	(C)		12	9	5
	(O)		12	5	3
Column	(C)	10	7	4	
	(O)		10	4	<2
Resemblance hall/theatre (only one beam)			8	6	<6

6. FIRE CLASSIFICATIONS AND FINANCIAL COMPARISON

The Atrium- and the Radiation-calculations are estimated to reduce the building costs for about SEK 700 000 (about 100 000 US Dollar), because of cheaper windows in fire compartment walls. The calculation-time costs correspond to about 3% of the "design-gain". The profit because of the reduction of two stairways are more difficult to judge, but there is no doubt it is a considerable factor.

The sprinkler cost for the building in question is estimated to be about SEK 2.0 million (about 285 000 US Dollar). Given the choices of materials, it is estimated that the reductions in cost would not be able to "finance" a sprinkler installation if only the building construction costs are considered.

From the fire classification point of view, it is not open to doubt that the sprinkler alternative would give lower fire damage costs.

Insurance companies in Sweden do not give any direct reductions in premiums, merely on account of a sprinkler installation. For this reason, the cost of the sprinkler installation must be reduced, or a sufficient number of tenants must demand that their operations must not be affected if a neighbouring company suffers a fire. Only in this case, can a building of this type be given satisfactory fire protection, as regards both personal safety and property.

The examples in this report clearly demonstrates the benefits of having a performance based building code. The design can be done more cost effective using fire engineering methods and still having the same safety in case of fire in the building. This would not have been possible with a prescriptive regulation. Still, most of the design is according to standard solutions which, of course, also are permitted in the performance based building code.

7. REFERENCES

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