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# PRACTICAL DESIGN AND PERFORMANCE BASED REGULATIONS

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## ABSTRACT

The paper 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 design with a sprinkler system. The objective was to demonstrate different design strategies and still comply with the performance based Swedish building regulation. Mostly, only the safety to people has 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.

Keywords : fire safety, evacuation, building regulation, safety comparison, fire safety engineering

## 1. INTRODUCTION

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

A 4-storey office building was designed with respect to fire safety, for three conditions:

- 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.

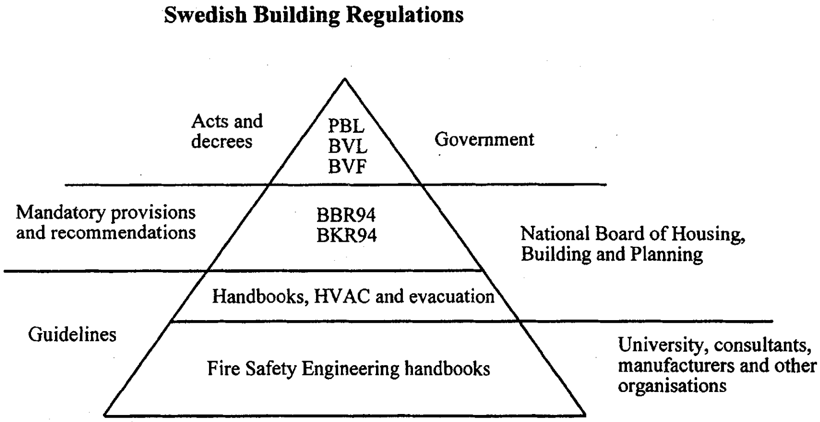
Sweden has since 1994 had performance based building regulations. The performance based regulations are in line with the decision made by the Parliament in 1985, to use more scientific based solutions in building fire safety design and not rely so much on "rule of thumb" and old experiences from building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

At the same time there has been a change in the Planning and Building Act were 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 structure of the Swedish building regulation system is shown in figure 1.

One of the major improvements in the new building code (BBR94) [1], 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.

## 2. BUILDING DESCRIPTION

The general conditions for the building were specified by CIB/SFPE but two extra features have been added to meet the building tradition in




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 structure of the Swedish building regulations.

Sweden. An assembly room at ground level for about 400 people and a glassed-over outdoor yard (atrium) have been added to the original building specification. The reason for having the atrium is because all office rooms must have access to daylight according the building code. Building drawings are included in Appendix A.

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. The threat of fire spread to neighbouring buildings is not considered.

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. 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 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.

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.

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). An office building of 3-4 storeys is classified Br1, which is the highest class. The level of fire compartmentation, class of surface materials etc. are depending on the building class. 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 classifications 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/m$^2$ (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.

## 3. STANDARD METHOD

The fire protection reported below in this section, is designed according to standards and recommendations in building codes [2], guidelines and handbooks without using calculation models.

### Fire spread

Stairways and lifts are separate fire compartments. Each storey is kept separate. Office floors are 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, if it is their wish.

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.

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 in other parts than in the escape routes and the assembly room, may be made in a lower class (class Ⅱ), without wood in the surface layer material.

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.

### 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. In other places, 0.9 m wide escape routes are accepted.

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.

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.

**Installations**

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.

The four stairways are provided with smoke 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 because 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. 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.

**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 the atrium, forms a separate fire compartment. The premises on all 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. The glass roof has to be protected in EI 60.

## 4. FIRE ENGINEERING DESIGN METHOD - UNSPRINKLED BUILDING

As the building code is based on performance 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 design procedure is to start with a standard method in accordance with section 3, and then do an analysis of what could be optimised with regard to fire resistance and cost, using calculation methods and alternative solutions [2].

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.

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

In addition to the calculations presented it is also necessary to determine what happens if some technical installations do not respond correctly. If human safety is very much depending on the proper operation of smoke vents, the reliability of those vents must be high. But, it is still necessary to evaluate the consequences if the vents do not open, and to see if that could be accepted. Other types of sensitivity studies were also made. Examples of variables subjected to alternative values are fire growth rate, maximum heat release, maximum number of occupants and human response time. The results of the sensitivity analysis is not presented.

**Fire resistance classification**

Radiation calculations show that a simpler and 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. The design fire consisted of a burning sofa with a peak heat release rate of 2.5 MW. The shield effect of the E 60 glass was considered to be 50%. The calculations made it necessary to introduce a restriction distance of combustible materials of approx. 2 m close to the glass wall.

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.

**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 persons/$m^2$ x 288 $m^2$). 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 reach untenable conditions
D = time to detect the fire
R = time for human response and behaviour
M = movement time to safety

The calculations of the time to untenable conditions are done using the model CFAST from NIST [3] and the model used to calculate the detection times is the DETACT-T2 model [4]. 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 $m^2$ openings at roof level, which are opened by smoke detectors, give the necessary extension of time.

However, 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 ventilation.

### 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. Windows below the interface do not have to be protected. The calculations were performed according to the procedures in [5].

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 $m^2$ 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℃ (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.

## 5. 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 compared to the engineering method presented in the previous section. In office situations, these two bodies of regulations are relatively similar. Fast response sprinklers are normally used, (68℃ and RTI $<50\sqrt{ms}$).

### 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'. The term 'smoke compartment' is not included in the Swedish building code but can be accepted if the hazard is low.

Walls with wooden surfaces in offices etc., and to a certain extent, corridors, are permitted when sprinkler are installed. This is, however, not accepted in the escape routes.

**HVAC System**

Insulation in ducts in fire compartment wall lead-ins can be omitted if the fire compartment temperature does not rise above 200℃ 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℃ for at least 30 minutes (class 300/30), instead of E 30-glasses which have a resistance temperature of 800-1000 ℃. The smoke ventilation areas are 10㎡ at 7 metre smoke height above floor level, according to the cost analysis.

## 6. 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 in table I, 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%.

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

Natural fire (N) 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/㎡. In the case of sprinklers 60% of these values are used.

The fires are located in a conference room (C), - 9.5 m x 10.5 m or in an office room (O), - 3.2 m x 4.5 m or in the assembly room. These rooms have been chosen to be the most representative in the building.

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

Table Ⅰ. Minimum required insulation thickness of the gypsum plaster sheet in mm.

| | Fire condition | | |
|---|---|---|---|
| Structural member | (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. INSPECTION AND MAINTENANCE ROUTINES

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 for this type of building, so it is the responsibility of the building owner.

### 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.

### 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.

### 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.

## 8. FIRE CLASSIFICATIONS AND FINANCIAL COMPARISON

No full financial or fire engineering analysis which compares the three cases has been done. Only a brief comparison was made to see if a financial benefit could be achieved by using performance based regulations. The prices are in 1995 monetary level.

The atrium- and the radiation-calculations are estimated to reduce the building costs of 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.

The paper is a condensed version of the full description presented in reference 10.

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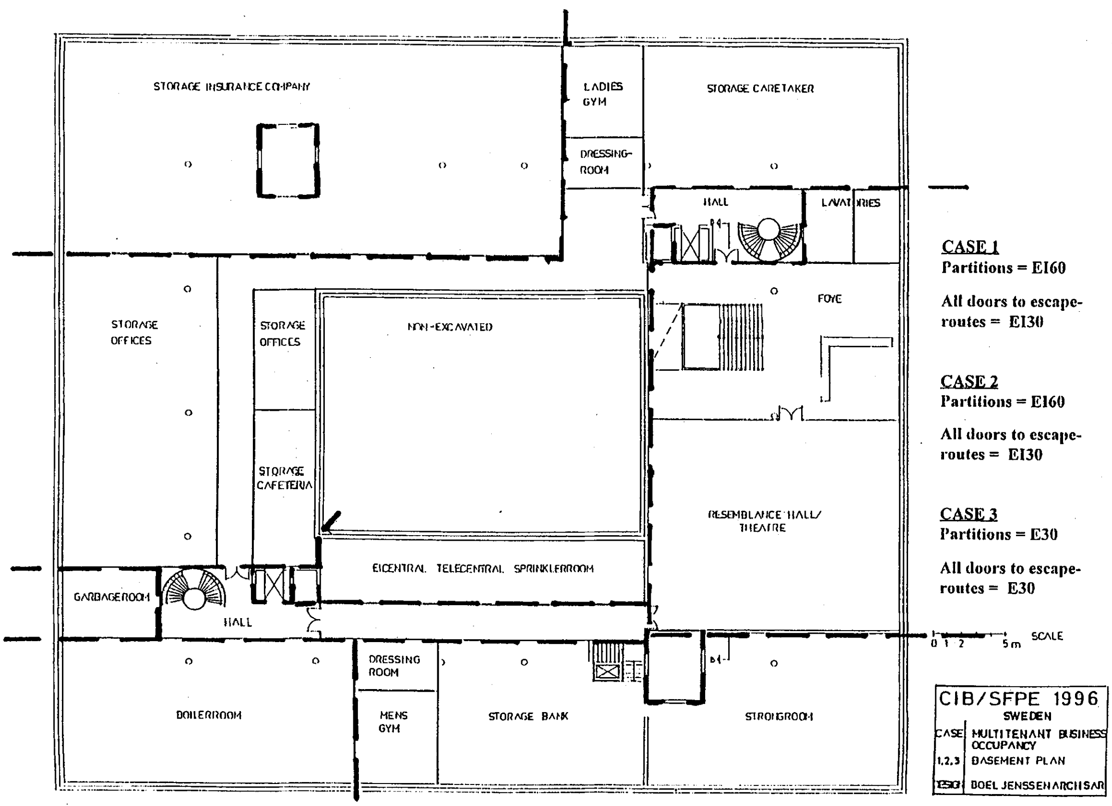
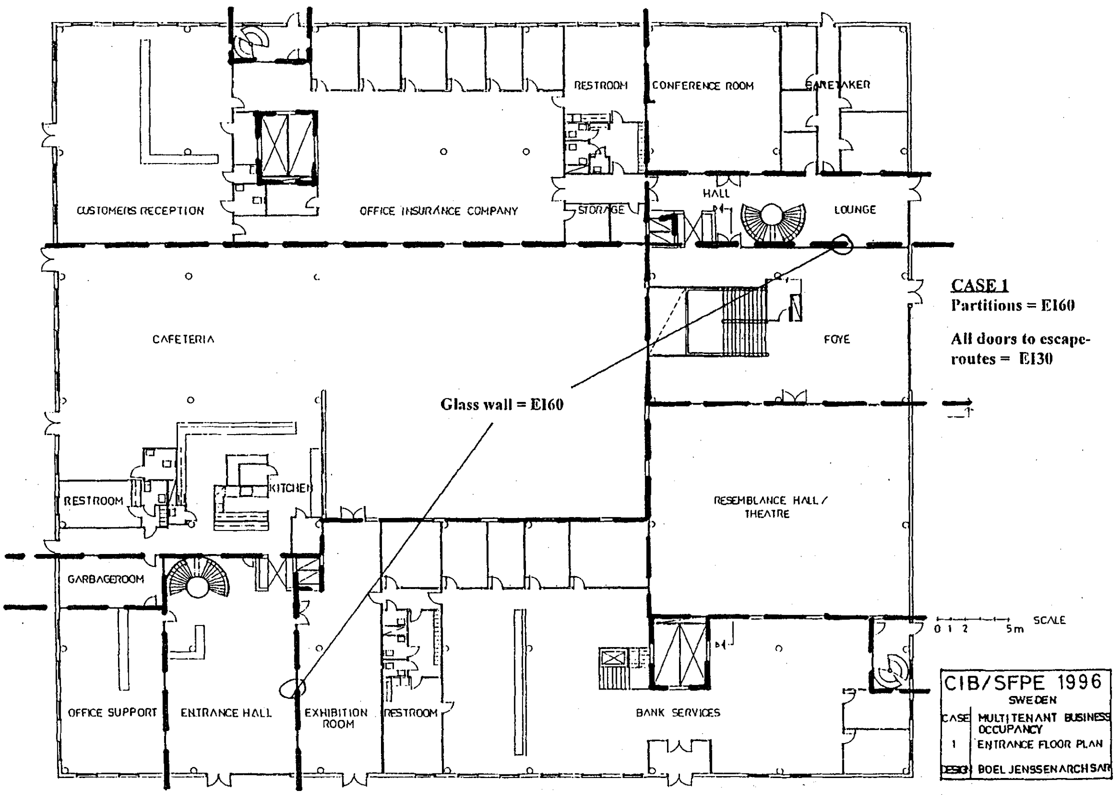
## APPENDIX ( BASEMENT PLAN, FLOOR PLAN )




RESTROOM
CONFERENCE ROOM
CARETAKER
HALL
LOUNGE
CUSTOMERS RECEPTION
OFFICE INSURANCE COMPANY
STORAGE
CAFETERIA
FOYE
CASE 1
Partitions = EI60
All doors to escape-routes = EI30
Glass wall = EI60
RESTROOM
KITCHEN
RESEMBLANCE HALL / THEATRE
GARBAGEROOM
OFFICE SUPPORT
ENTRANCE HALL
EXHIBITION ROOM
RESTROOM
BANK SERVICES
SCALE
0 1 2 5m
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SWEDEN
CASE
MULTITENANT BUSINESS OCCUPANCY
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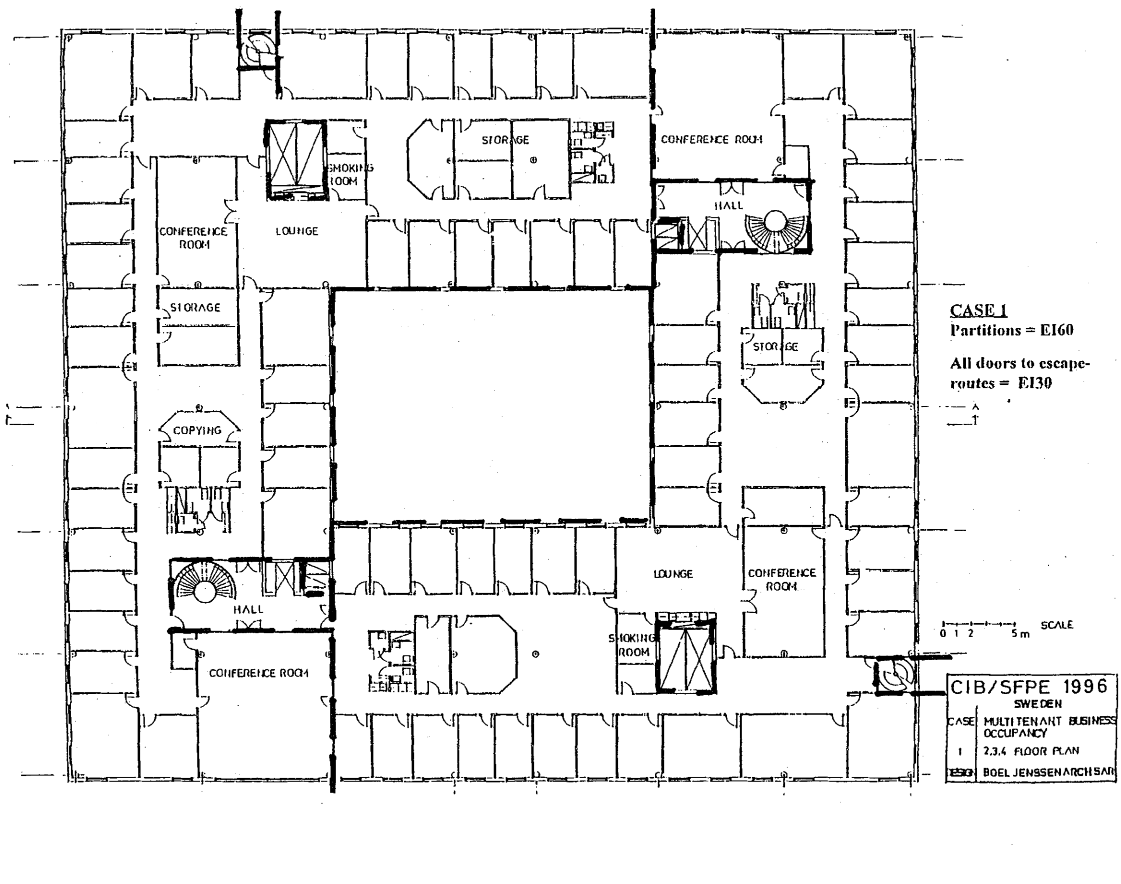
ENTRANCE FLOOR PLAN
DESIGN
BOEL JENSSENARCHSAR


STORAGE
CONFERENCE ROOM
SMOKING ROOM
HALL
CONFERENCE ROOM
LOUNGE
STORAGE
STORAGE
CASE 1
Partitions = EI60
All doors to escape-routes = EI30
COPYING
LOUNGE
CONFERENCE ROOM
HALL
SMOKING ROOM
CONFERENCE ROOM
SCALE
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CIB/SFPE 1996
SWEDEN
CASE
MULTITENANT BUSINESS OCCUPANCY
1
2,3,4 FLOOR PLAN
DESIGN
BOEL JENSSENARCHSAR