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10 FIRE ENGINEERING CASE STUDIES IN FINLAND

Summary

Fire engineering solutions in building industry in Finland vary depending on e.g. the type of building and of resources used in design. The fire protection can be done by using prescriptive rules or by using performance based design. In this paper, the fire solutions of two quite large commercial buildings in Finland are gone through using the guidance paper done within COST-IFER project as a guideline.

The first building introduced is furniture and household store IKEA built in Finland 2010. The fire solution is based mainly on fire protection with automatic water extinguishers. The design is mainly based on prescriptive rules, but during the design and acceptance procedure the solution had to be validated using performance based design, i.e. additional simulations. The design and acceptance procedure of this will be gone through in this paper.

The other building introduced here is a recreational centre, which is locating in the middle of Helsinki, Finland. The building is ready for use in April 2010. The area of the building is 22200 m^2 and the volume is 167700 m^3. The fire engineering was carried out using both performance based and prescriptive design. A variety of fire scenarios was simulated using FDS software and the structural analysis was done using the temperatures from these analyses. The simulations were carried out by VTT and the structural analysis by Tampere university of technology together with the main structural designer Finnmap Consulting ltd. The design procedure and the acceptance procedure will be introduced in this paper.

10.1 IKEA STORE, TAMPERE, FINLAND, 2010

10.1.1 Description

Finland's largest IKEA store was built in 2009-2010 to the district of Tampere. It is the first steel-framed IKEA in Finland. The project made use of Ruukki's structural fire design to ensure fire safety of the steel structures in the event of fire and to choose the most effective fire protection method for the different parts of the construction project. When completed, the largest Ikea store in Finland will have a floor area of 35,000 square metres.

Ruukki Construction is focusing on solutions and systems deliveries that include design and installation. The way of working and technical solutions are cost-effective and speed up the construction process. The building speed plays a big role in the process. Ruukki has earlier been involved in Ikea construction projects in Finland, Sweden, Russia, and Poland.

A consortium of Lemcon Ltd and Rakennustoimisto Palmberg Oy has ordered the frame from Ruukki and Rovakate, which is part of the Icopal Group, has ordered the panels.

Storeys:	1-2
Floor area:	35 000 m2
Steel structures	-Composite steel-concrete columns
	-Tubular steel trusses
	-WQ-welded profiles + hollow core slabs in 2-storey parts
Wall cladding:	-Sandwich panels (rock wool insulation)
Roof structure:	-Corrugated steel sheeting beased solution
Fire requirement:	-R60 for load bearing structures
Fire protection methods:	-Prescriptive and performance based together
	-Automatic water extinquishers
	-Intumescent coating

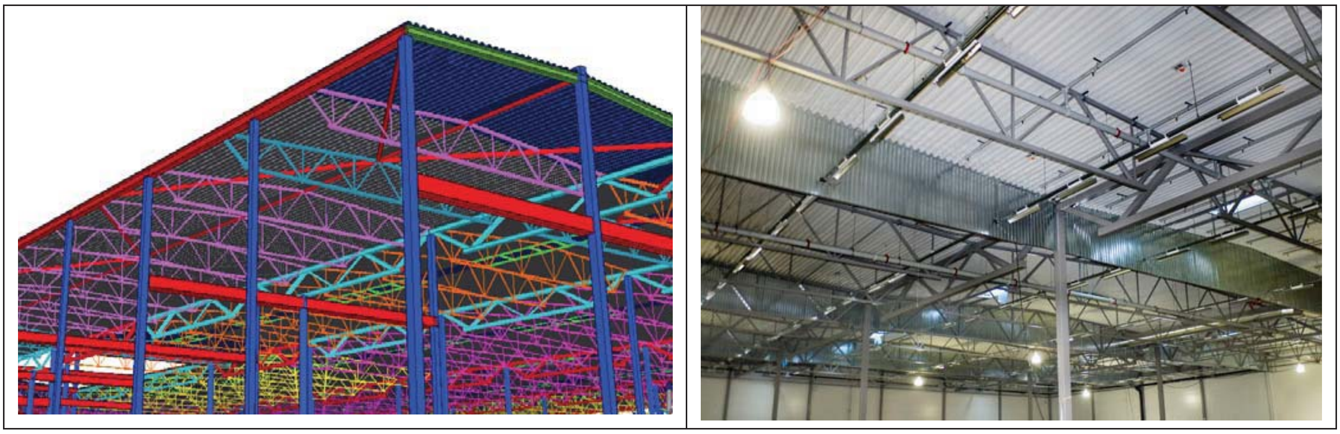


Fig. 10.1 Part of the frame system taken from Tekla Structures model and during the construction

10.1.2 Fire solutions

The building regulations require 60 minutes Fire protection for this case. The Ruukki's national acceptance for "Fire protection of steel structures with automatic water distinguishers" was used as the main fire protection method. With this method one can achieve 90 minute fire protection, having the water flow minimum of 10mm/min. No additional fire protection to steel structures is needed within this system's coverage. The system is optimal for 1-2 storey commercial, large buildings. The approval is based on actual large-scale fire tests and also a large simulation project. The simulation project is still continuing and is carried out by VTT.

Fig. 10.2 Sprinkler protection network on the left. Building site on the right

Part of the structures, especially the bottom chords of the WQ-beams (integrated, welded slimfloor beams) in the intermediate floors were protected by intumescent paint. Also some part of the bracing structures was protected by fire protection materials. This was done in the office area of the building where the spaces are lower, and the water flow from the sprinklers was smaller.

10.1.3 Design and approvals

The fire protection was approved by the building and fire authorities before the building process. Many negotiations were carried out in going into the details of the solution. In Finland the building authorities give the approvals but in this kind of large buildings they always ask statement from fire brigade. So the final solution is done in negotiation with designers and authorities. Also a statement from Research Institute (VTT) was required.

The final installations of sprinklers and also fire protection materials are inspected afterward and documentation is put to the building manual for future inspections and maintenance.

Altogether the fire protection in this case was optimized to different areas using different materials and methods. The performance based design using simulation was used mainly by the 3rd party inspector to ensure that in certain spaces the calculated temperatures of the structures stays at safe level.

10.2 SALMISAARI SPORTS CENTER, HELSINKI, FINLAND, 2010

10.2.1 Description

Salmisaari Sports Centre is located in the middle of Helsinki, Finland. The building will be ready for use in April 2010. The floor area of the building is 22,200 m^2 and its volume 167,700 m^3. The main contractor is YIT Rakennus Oy. The architects and consulting structural and fire engineers are Arkkitehtitoimisto Pekka Lukkaroinen Oy and Finnmap Consulting Oy and L2 Paloturvallisuus Oy, respectively. The load bearing structures were delivered by Ruukki Construction Oy.

The length, width and height of the building are about 136, 35 and 36 metres. There are four stories, each 8-10 metres high. Each storey has a space about 30 m wide supported by 30 m span trusses located at every 5 metres. These trusses are innovative structures used in some Finnish projects: the top chord is made of a welded slim floor box beam that supports pre-stressed hollow core concrete slabs, the braces are of tubular steel and the bottom chord is a flat steel bar. The trusses are about 3 m high. That leaves a lot of space for installations below the floors. The columns supporting the trusses are reinforced concrete filled steel tubes. A general view and the space examined in this study are shown in Fig. 10.3.

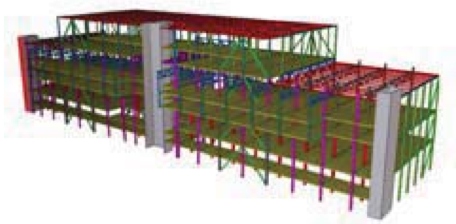


Fig. 10.3 General view and the examined space

Performance based fire design was applied in this project only to trusses. Fire actions were determined for the parts of the building topped by trusses. The intended uses of the spaces below the trusses are:

- First floor: two ice hockey rinks (total area 4200 m^2).
- Second floor: Bowling, martial arts, restaurants (2000 m^2).
- Third floor: Adventure place for children (2000 m^2), beach volley (780 m^2), badminton (570 m^2).
- Fourth floor: dancing (900 m^2).
- Climbing wall, area 170 m^2, max. height 30 m.

Fire actions were determined for the intended uses of the spaces, and for the following special cases:

- Ice resurfacing machine fire,
- Storage fire with flashover,
- Coat-rack fire,
- Plastic slide fire,
- Stage fire (abnormal use),

Stand fire (abnormal use),

- Climbing equipment fire.

The fire safety plan was prepared by the fire engineers of the project. Fire compartments were partitioned using EI60 structures. The fire compartments consist of stairwells, exit areas, storage spaces, offices, saunas, dressing rooms and special facilities. According to the safety plan, the building should have the following fire safety equipment:

- Initial extinguishing equipment, consisting of: one portable extinguisher per 300 m^2 or hose reels.

- Automatic alarm system covering the whole building.
- Smoke extraction, mainly by the fire brigade.
- Automatic sprinkler system.

According to CEA (1998) requirements, the sprinkler system should be able to detect and put out a fire in its early stage, or to restrict the spread of fire until the fire brigade arrives.

Fire actions are determined based on fires which may occur in different spaces (during intended use, special use and abnormal use). The effects of the sprinkler system are taken into account when defining design fires. Traditionally the effects of the actions of the fire brigade and other fire fighting measures are not taken into account in defining design fires. Fire brigade actions are taken into account in the following references: Tillander et al. (2009), Karhula & Hietaniemi (2008), NFPA (1996), Barry (2002) and Hietaniemi (2008).

A summary of the definitions of design fires used in the performance based fire design of this project is given below. More details are given in a report by Hietaniemi (2009). In Finland it is not possible to use Annex E.1 of EN 1991-1-2 (not applicable) to define the fire activation risk due to the size of the compartment and the type of occupancy, which is why probability analysis was used in this study. Fire load densities were determined based on national fire load classifications of occupancies and by conducting a fire load survey using both analysis and synthesis of experimental data as well as modelling and fire simulation.

The fire scenarios and all details of the fire load calculations were approved by the local authorities, the client and the fire safety and structural engineers of the project before fire simulations and structural calculations were done.

10.2.2 Fire actions based on intended uses of spaces

The following properties are supposed to be valid for the sprinklers:

- RTI = 110 $m^{1/2}s^{1/2}$
- Activation temperature is 67 °C
- Protection area A_r of one sprinkler is 12 m^2.

The defect frequency of sprinklers is 3 % according to International Fire Engineering Guidelines (2005). Assuming a floor area of 5000 m^2, and a 12 m^2 protection area, about 500 sprinklers are required on that floor. Then the probability is that one of those sprinkler heads is defective. Let us then suppose that this defective sprinkler head is just above the starting point of the fire. The resulting fire scenario would be a so-called local fire in the sprinklered building where:

- The other sprinklers restrict the fire to the protection area of one sprinkler.
- Fire intensity is defined by the use of the space under consideration, as shown later.

Let us then consider the failure of the entire sprinkler system. That can be estimated by the defect flow of Fig. 10.4. The sources of the initial data are the following:

- Pump defect, Isaksson et al. (1998),
- Duct defect and water source defect, Isaksson et al. (1998),
- Installation defect, Korpela (2002).

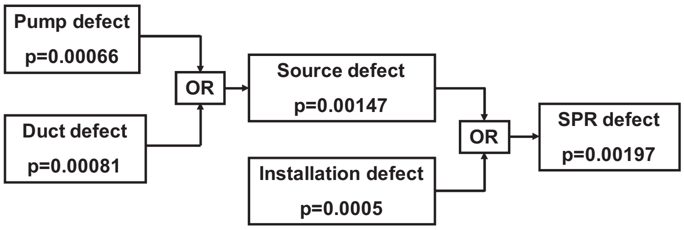


Fig. 10.4 Defect flow of sprinklers

The probability for failure of the entire sprinkler system is about 0.00197 ≈ 0.2 % according to the estimate. On that basis a second fire scenario is created involving a so-called global fire in the sprinklered building:

- After sprinkler activation the fire intensity is doubled from the value defined based on the use of the space at sprinkler activation time and it remains constant. The doubling provides the extra safety required by authorities in this case.

So we end up with two fire scenarios, the first one based on local sprinkler defects and the second one on the failure of the entire sprinkler system. They are graphically demonstrated in Fig. 10.5. In the first case the fire decays either due to a lack of oxygen or combustible material in the space. The fire is local within an area of 12 m^2 and should be applied to the most severe locations in the building. The second fire is not dying down and engulfs the whole floor under consideration.

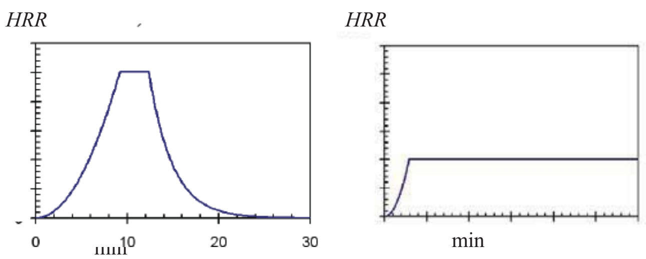


Fig. 10.5 Schematic fire loads (heat release rates, *HRR* in MW), local (left) and global (right) fires

The local and global fires in a sprinklered building defined above were assumed to occure at the most severe locations in the building.

The special uses, including abnormal uses, and corresponding fires were also assumed to occur in the building. The probabilities of these fire activations resulting from the size of the compartments and the occupancies are given in Tab. 10.1. The probabilities were calculated based on Tillander et al. (2009) for a 50 year period. Probabilities for abnormal uses were calculated assuming their occurrence once a month. The probabilities for local and global fires are given in Hietaniemi (2009).

Tab. 10.1 Probability of fire activations and sprinkler defects during 50 years of special uses of spaces.

	First floor		Second floor	Third floor		Fourth floor
	Ice machine	Sto-rage	Coat-rack	Plastic slide	Stand (ab-normal)	Stage (ab-normal)
A_r (m^2)	4200	45	12	2000	260	900
A_r/A_{tot}	0.221	0.002	0.0006	0.10	0.013	0.047
Fire acti-vation	6.8 E-01	1.2 E-02	3.2 E-03	4.2 E-01	5.8 E-03	2.0 E-02
Sprinkler defect	3.3 E-02	3.6 E-04	9.7 E-05	1.6 E-02	1.7 E-04	6.0 E-04

Next we shall consider the fire load intensities q'' [MJ/m^2] for local and global fires.

Finnish regulations (Ympäristöministeriö (2002)) state that the value for stores should be more than 1200 MJ/m^2. For shops, exhibitions halls and libraries its proper range is 600-1200 MJ/m^2. For restaurants, smaller than 300 m^2 shops, offices, schools, sports halls, theatres, churches, and similar buildings the value is below 600 MJ/m^2. Based on the above, the maximum value for sporting areas is 600 MJ/m^2.

Measured data (International Fire Engineering Guidelines (2005)) yielded 421 fire load intensities for production spaces, which are clearly higher than in our cases. The mean of the sample was 530 MJ/m^2 and the deviation 540 MJ/m^2. The 3-parameter gamma distribution was used with the following results: 80 % fractile = 600 MJ/m^2 and 95 % fractile = 1100 MJ/m^2, see Fig. 10.6.

Based on these estimations, the following fire load intensities were used in this study:

- 600 MJ/m^2 for the spaces meant for sporting (80 % fractile for generic fire intensity distribution).
- 1100 MJ/m^2 for other spaces excluding stores (95 % fractile for generic fire load intensity distribution).

Next we shall consider the corresponding fire release rates (*HRRPUA*, Heat Release Rate Per Unit Area). Tab. 10.2 draws on data from Hietaniemi (2007). It presents the fire load intensities and corresponding fire release rates. The origin of each data line is given in Hietaniemi (2007).

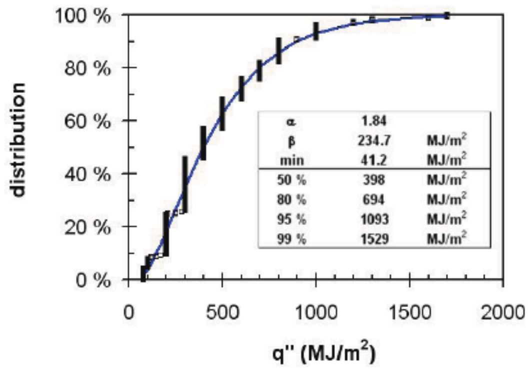


Fig. 10.6 Fire load intensity distribution for production space

Tab. 10.2 Sample of *HRRPUA* and *q''* values

Item	t_g (s)	HRRPUA (kW/m^2)	q'' (MJ/m^2)
Wood pile (4 pieces)	209-409	469-2156	703-1561
Stack of pallets (2 pieces)	600-900	3062-4105	1500-2250
One plastic chair	900	600	160
Stack of plastic chairs	110	7600	1140
Two stacks of plastic chairs	110	4300	1450
Sports bags	420	1324	1829
Fair stand	150	1966	1203
Litter basket (2 pieces)	140-1450	1200-1400	400-422
Carton	150	1966	1230
Work point in office (8 pieces)	115-225	820-1799	376-914
TV		930	500
Washing machine	273	1422	639
Washing machine in cabinet	563	1483	1054
Refrigerator	660	1921	1031
Polyester coat	720	250	40
Coat-rack (2 pieces)	150-210	188-190	90-125
Shoe store	80	2500	1760
Speciality shop	71	2900	2900
Armchair	120	5480	980
Sofa (2 pieces)	110-110	3120-3375	727-940
Unprotected mattress	145	527	126
Protected mattress	360	34	3

The close correlation between fire load intensity and heat release rate per unit area is shown by Fig. 10.7.

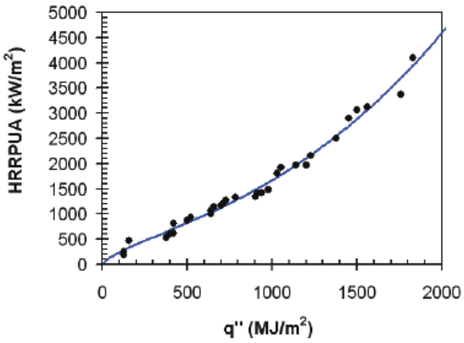


Fig.10.7 *HRRPUA* versus fire load intensity

Thus, fire release rates can be estimated based on fire load intensities:

- For sporting areas the mean fire release rate is 1000 kW/m^2 and its 5 % and 95 % fractiles are 800 kW/m^2 and 1100 kW/m^2 (see Fig. 10.8 a)).
- For other spaces (excluding stores) it is 1900 kW/m^2 and its 5 % and 95 % fractiles are 1600 kW/m^2 and 2100 kW/m^2 (see Fig.10.8 b)).

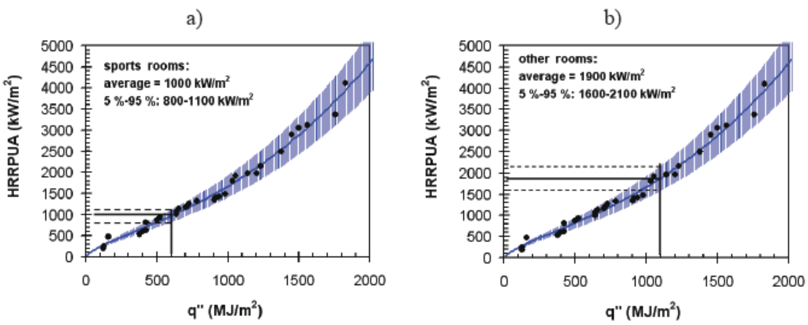


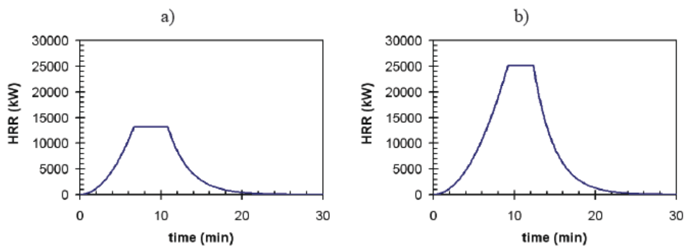
Fig. 10.8 *HRRPUA* for two types of spaces, shading indicates values between 5 % and 95 % fractiles

Next, we fit the local fire (A_r = 12 m^2) curve of Figure 3 to the data above. In the growing phase we use the t^2 curve including the time t_g needed to reach a heat release rate of 1 MW. In the decay phase we use an exponential curve including a creeping factor of 30 % of total heat release based on experimental values. Fire intensity is:

$$Q(t)=\begin{cases} Q_0\cdot\left(\dfrac{t}{t_g}\right)^2 & when \quad 0\le t\le t_1 \quad (growing\ phase) \\ Q_{\max} & when \quad t_1<t\le t_2 \\ Q_{\max}\cdot\exp(-\dfrac{t-t_2}{\tau}) & when \quad t>t_2 \quad (decay\ phase) \end{cases} \qquad (1)$$

where Q_0 = 1 MW, t_g = 150 s, τ is the creeping factor and t_1 and t_2 are the limit times for uniform fire intensity.

The result for the sports area is shown in Fig. 10.9 a) and for other areas in Fig.10.9 b). The maximum *HRR* for the sports area is little below 15 MW and for other spaces little over 25 MW.



a)

fire area A_f =	12	m^2
HRRPUA =	1100	kW/m^2
q' =	600	MJ/m^2
max HRR =	13200	kW
Q =	7200	MJ
t_g =	110	s
t_1 =	400	s
t_2 =	650	s
τ =	160	s

b)

fire area A_f =	12	m^2
HRRPUA =	2100	kW/m^2
q' =	1100	MJ/m^2
max HRR =	25200	kW
Q =	13200	MJ
t_g =	110	s
t_1 =	552	s
t_2 =	740	s
τ =	155	s

Fig. 10.9 Local design fires and their parameters

The *HRR* for the corresponding global fire is shown in Fig. 10.11.

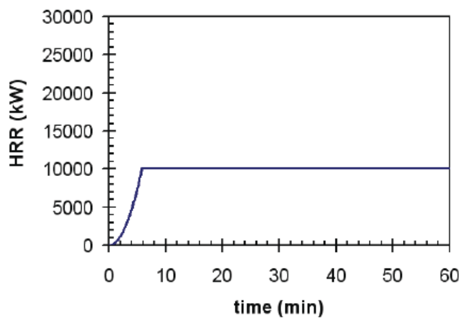


Fig. 10.11 Global design fire

In studying structures above the fire, the simplified geometrical model for modelling the local fire uses a square (3x4 = 12 m^2) at a specific height from the floor, and the fire burns only on the top surface. Special cases where the fire source was supposed to be 5 m above the floor were considered too.

The height H_f of the fire source can be estimated using the equation:

$$H_f = \frac{q''}{\eta \cdot \Delta H_c \cdot \rho_{fuel}} \qquad (2)$$

where q'' is the fire load intensity, ΔH_c is the calorific value of the material (supposed to be within 25-44 MJ/kg), η is the factor that accounts for the solidity of the material (one for a solid material, zero for a loose material) and ρ_{fuel} is the density of the material (supposed to be within 900-1200 kg/m^3).

IF we suppose for simplicity uniform distribution of all the quantities within the ranges shown above and a 10-90 % range for the factor η. Then, based on 1000 Monte-Carlo simulations we find that for 600 MJ/m^2 the value H_f is smaller than about 20 cm (Fig. 10.12 a) and for 1100 MJ/m^2 the value H_f is smaller than about 50 cm (Fig. 10.12 b).

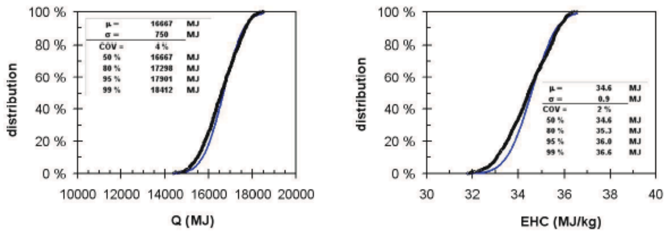


Fig. 10.12 Distributions for the burning item

Traditionally the value H_f = 0.5 m is used for both cases. The fire source area used in the simulations is shown in Fig. 10.13.

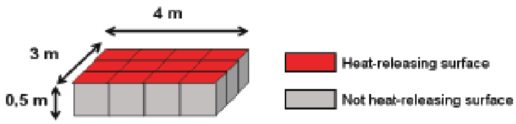


Fig. 10.13 Geometrical model for burning item (local fire)

Next, we shall consider the design fires for special uses.

Ice resurfacing machine fire

Two kinds of approaches were used to define the design fire for this case: simulation with the FDS 5 program and estimation with a general fire model for vehicles (Hietaniemi 2007). The goal was to define the design fire for the ICECAT (2008) machine shown in Fig. 10.14.

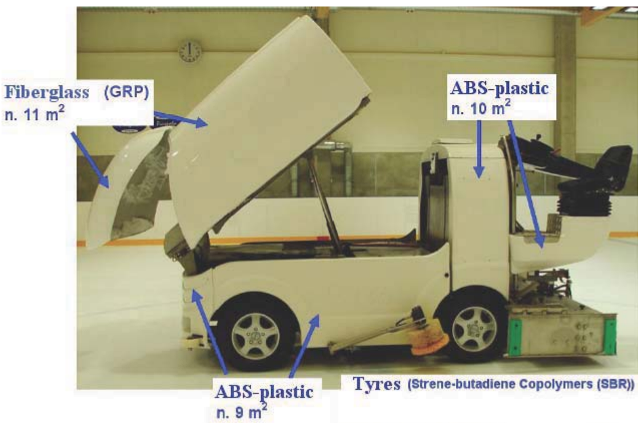


Fig. 10.14 Ice resurfacing machine

The machine contains the following combustible materials: plastics (ABS), glass-reinforced plastic (GRP) and rubber. The properties of ABS were derived from Lyon & Walters (2001) and Scudamore et al. (1991), those of GRP from Mouritz & Mathys (2006) and those of rubber from Iqbal et al. (2004), Chapter 7.

The machine was modelled with FDS 5 using cubes fit to the grid size and amount, distances, total size and mass of the cubes fit to the machine data.

The thermal properties used in the simulation were typical for plastics: density 1100 kg/m^3, thermal conductivity 0.2 WK^{-1}m^{-1} and specific heat 1500 JK^{-1}kg^{-1}. Combustion time is estimated at 30 s and combustion temperature at 320 $^\circ$C. The fire is supposed to reach its maximum intensity in 60 s.

The simulation is based on normal distributed fire load [*Q*, MJ], effective net caloric value [*EHC*, MJ/kg] and heat release rate per unit area [*HRRPUA*, kW/m^2].

In the simulations the following 95 % fractiles were used as input. Their standard deviations are shown in parentheses:

- *Q*: 16700 (750) MJ,
- *EHC*: 35 (1) MJ/kg,
- *HRRPUA*: 700 (70) kW/m^2.

In some cases other fractiles were used to determine the effect of the input on the result. The result of the simulation is shown in Fig. 10.15.

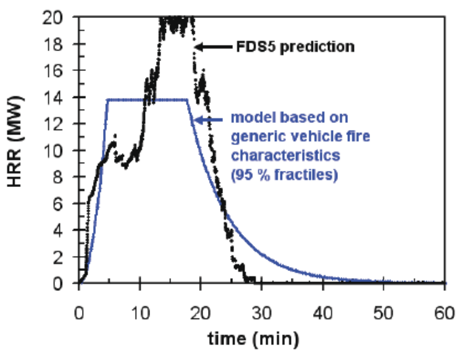


Fig. 10.15 FDS 5 prediction and general vehicle model prediction for the ice resurfacing machine fire

Fig. 10.15 also shows the result based on Hietaniemi (2007) using the 95 % fractiles 2225 MJ/m^2 for the fire load and 1725 kW/m^2 for the heat release rate.

The final design fires for the ice resurfacing machine were determined based on these analyses. They are presented in Fig. 10.16. Fig. 10.16 a) presents the local fire and Fig. 10.16 b) the global fire where after the total collapse of the sprinkler system the heat release rate doubles and then remains constant.

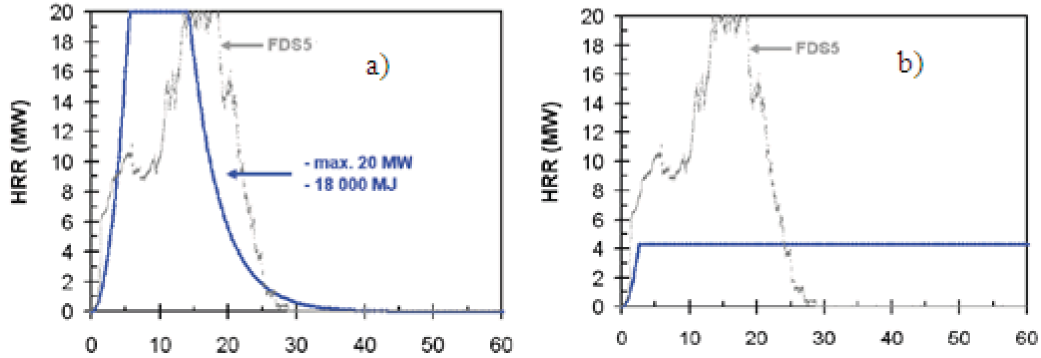


Fig. 10.16 Local and global ice machine design fires. Vertical axis shows time in minutes

Storage fire with flashover

The large compartment comprises storage spaces which should be divided into individual compartments using EI60 structures. However, the doors of the spaces open into the large compartment which is why the scenario where the door is open during the fire was chosen.

The storage space was modelled as a single sprinklered floor area because that represents the most severe situation as flames come out of the storage door. The fire load was modelled using 64 burning units each equalling a cell of the FDS grid. The heat release rate from each surface of each unit was 500 kW/m^2. The net caloric value was 35 MJ/kg and the total fire load 30,000 MJ. The FDS 5 model and an example of the flaming through the door are presented in Fig. 10.17.

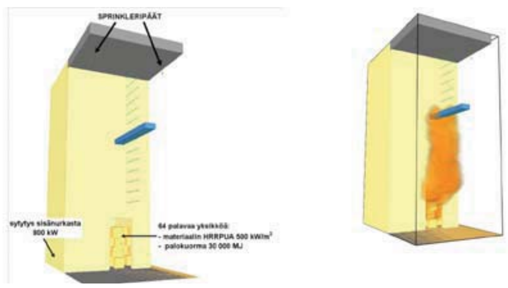


Fig. 10.17 FDS 5 model for predicting the storage fire load and an example of flaming through the door

The design fire for this case is shown in Fig. 10.18.

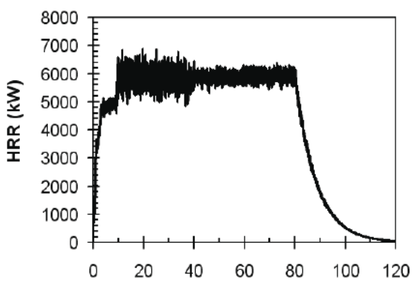


Fig. 10.18 Design fire for storage with flashover (time in minutes)

Coat-rack fire with local flashover

The definition of the design fire for this case started by modifying the FDS 5 model to simulate closely the experiments of Hadjisophocleous & Zalok (2004). The *HRRPUA* was 160 kW/m^2 and the *EHC* was 30 MJ/kg. The geometrical model, the FDS 5 model and examples of the fire are presented in Fig. 10.19.

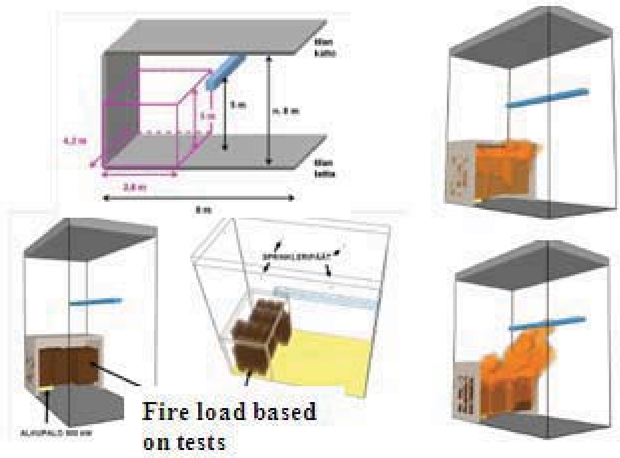


Fig. 10.19 Geometrical model, FDS 5 model and examples of fires to predict the coat-rack fire

The fire loads for the basic case and two variations are presented in Fig. 10.20. The first variation is calculated using double the *HRRPUA* [kW/m^2] value of the basic case. The second variation is calculated using double the fire load intensity [MJ/m^2] of the basic case.

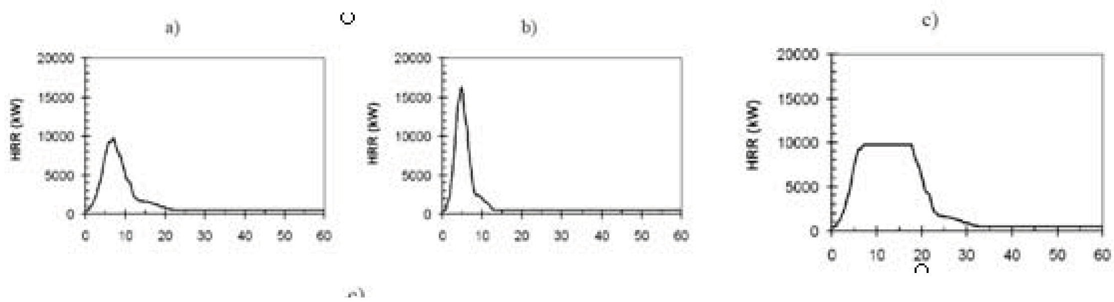


Fig. 10.21 The basic case (a) and two variations: doubled heat release rate (b), and doubled fire load intensity (c).

The fire of Fig. 10.21 c) was used in the final simulations of the building fires.

Plastic slide fire

The most hazardous object in the adventure space for children in case of fire is the plastic slide which is high and contains a lot of combustible materials. The slide and its simplified model are presented in Fig. 10.22.

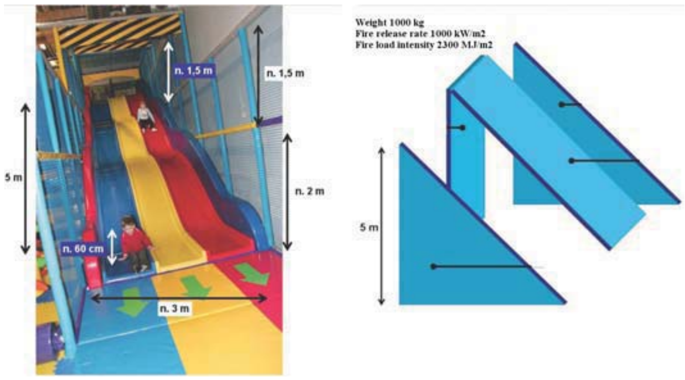


Fig. 10.22 Plastic slide and its simplified geometrical model

The design fire presented in Fig. 10.23 was used for global fire.

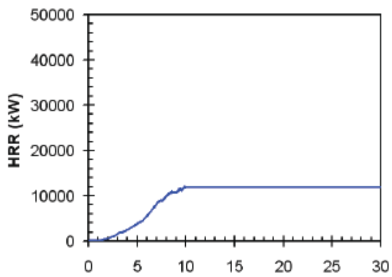


Fig. 10.23 Global design fire for plastic slide (time in minutes)

The design fire used in this case was much larger than the doubled fire load after sprinkler activation (about 5 minutes in Fig. 10.27).

<u>Stage fire</u>

The stage is not a permanent structure and is not normally in use. However, it may be needed in the dance, which is why this scenario was also considered. Stage load was defined for the area of one sprinkler (12 m^2). The geometrical representation of the stage and the quantity data for calculating the fire load are given in Fig. 10.24.

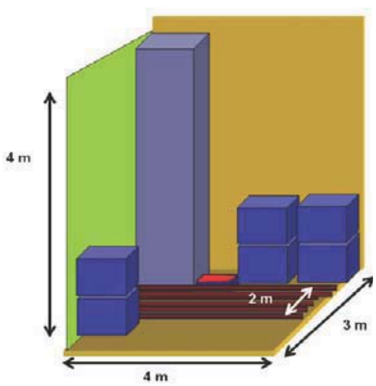


Fig. 10.24 Stage model

The quantity data and the corresponding fire are shown in Tab. 10.3.

Tab. 10.3 Quantity data of stage fire

	Density [kg/m^3]	Heating value [MJ/kg]	HRR [kW/m^2]	V [m^3]	A [m^2]	Weight [kg]	Fire load [MJ]
Speaker	200	30	1000	0.96	8.24	192	5780
Amplifiers	200	30	1000	0.86	8.40	173	5184
Cables	1200	40	450	0.72	60.84	144	5760
Platform	700	15	1000	0.30	12.35	60	900
Back wall	700	15	1000	0.40	16.40	80	1200
Curtain	1200	40	1000	0.01	12.01	2	96
Total							18900

The attributes of the single homogeneously burning stage material for the whole area are:

HRRPUA = 1000.0 kW/m^2

THICKNESS = 0.05 m

DENSITY = 1200.0 kg/m^3

HEAT_OF_COMBUSTION = 30.0 MJ/kg

The fire load of the stage is presented in Fig. 10.25 with the fire load of a global fire (red line).

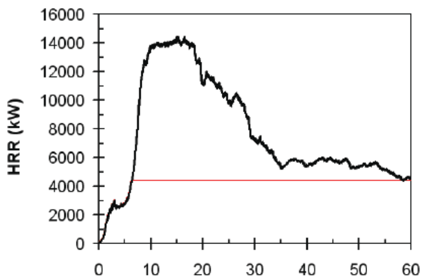


Fig. 10.25 Stage design fire loads, local and global (red)

Stand fire

The stand is not a permanent structure. Temporary stands are needed for spectators of beach volley and badminton matches. The stand is made of plywood and plastics. Its geometrical model is given in Fig. 10.26. The quantity data and corresponding fire load calculations are shown in Tab. 10.4.

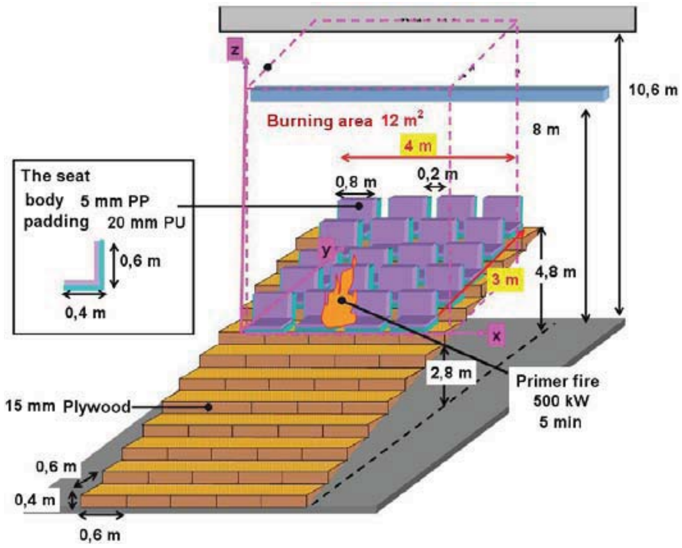


Fig. 10.26 Geometrical fire model of the stand

Tab.10.4 Quantity data of one seat in the stand

	Density [kg/m^3]	Heat value [MJ/kg]	HRR [kW/m^2]	V [m^3]	A [m^2]	Weight [kg]	Fire load [MJ]
Plywood	700	15	150	0.0072	0.72	5.04	75.6
PP	1200	40	1200	0.0024	0.72	2.88	115.2
PU	100	25	400	0.0096	0.72	0.96	24.0
Total							214.8

The size of the burning area is 12 m^2. The attributes of the single homogeneously burning stand material are:

HRRPUA = 583.0 kW/m^2

THICKNESS = 0.2 m

DENSITY= 52.0 kg/m^3

HEAT_OF_COMBUSTION = 24.2 MJ/kg

Local and global design fires for this case are given in Fig. 10.27.

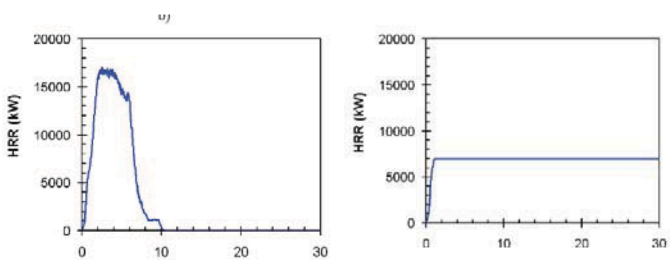


Fig. 10.27 Local and global design fires for the (time in minutes)

10.2.3 Estimations of errors in results

Some error estimations concerning the proposed design fires should be done before any fire simulations on the building. The selected fire scenarios meet the requirements of Finnish regulations (Ympäristöministeriö (2002), Chapter 1.3.2) and, thus, cover all fires that probably could take place in the building. They do not represent the average situation, but a rare situation which can be considered to represent 99 % of the cases. This means that one fire out of 100 can be worse than expected. That is a very small number, which means that in this study the possible uncertainty of the fire scenarios will be attributed to the uncertainty of the design fires.

The uncertainty of design fires consists of the uncertainty of our knowledge and our ignorance (epistemic and aleatoric uncertainty) such as:

- The values used in calculations, e.g. *HRRPUA* values, always include noise originating from non-ideal tests arrangements, measurements and analysis models.
- Possible systematic errors in the values used in calculations originating e.g. from the hypotheses made to simulate the real situation.

The uncertainty of fire technical measurements is of the order of 20 % as are model uncertainties. Assuming that systematic uncertainties are of the same order (20 %), the uncertainty $\Delta\dot{Q}$ of the fire load is

$$\Delta\dot{Q} \approx \sqrt{20\%^2 + 20\%^2 + 20\%^2} \approx 34\% = \pm 17\% \tag{3}$$

According to fire plume models, gas temperature T_g rises in proportion to ambient temperature to the power 2/3 as shown by Heskestad (1984) and Hostikka (1997).

$$T_g \propto \dot{Q}^{2/3} \tag{4}$$

so the uncertainty ΔT_g of the temperature rise is

$$\Delta T_g \propto \frac{2}{3}\dot{Q} \tag{5}$$

This means that the relative uncertainty of the estimations of temperatures can be described as a normal distribution with a mean of 1 and a standard deviation of 10 %:

$$\frac{\Delta T_g}{T_g} \propto N(1;10\%) \tag{6}$$

10.2.4 Fire simulations

<u>The simulation environment</u>

The aim of the simulation was to estimate endurance of structures to natural fire. The structural product model was used as the basis of simulation. Beams, columns, roof and floor slabs, and concrete stairwells were incorporated in the model. The data content of the structures of that model was more complete than that of the architectural model. The building parts were not assumed to be involved the fire since all the burning material was assumed to be included in the fire packages. The material properties of structures were not needed in fire simulation.

The structural model was complemented based on drawings. The airspace where the fire burned was bounded by slabs or wall panels. All doors were modelled as openings in the walls assuming that evacuated persons had left them open. Other vents were for the most part not modelled. If there were any openings, the airspace where the fire burned could also be modelled by the properties of the edge of the calculation grid. The used modelling program was Tekla Structures version 15.0.

The NIST Fire Dynamics Simulator (FDS) version 5.2.5 was used for simulation. The calculation method is based on CFD (computational fluid dynamics) which uses a three- dimensional, rectilinear computation grid. All the modelled objects must be modified into cubes in some phase of the data transformation process.

A special data transformation program was used to transfer the structural model data to the FDS input file. At the same time, all needed material data were stored to the same input file. The process is described more accurately by Laasonen (2010).

Selection of the grid cell size

The size of a single cell of the calculation grid affects the following three important factors given in order of importance: 1) the reliability of simulation, 2) the minimum size of the objects that can be incorporate in the fire model, and 3) the computer time needed for calculations.

Heinisuo et al. (2008a) have discussed the required cell size. Heskestads's correlation is used to estimate the reliability of calculation. It uses the density of fire [kW/m^2] and the burning area to calculate the so-called Resolution factor (R) for defining the sizes of cells. Heinisuo et al. (2008a) recommended that the sizes of cells should be selected so that the value of R is at least 10 (or inverse value r not more than 0.07).

As presented in the previous chapters, the used special fires are not planar but involve three-dimensional objects which may burn on many faces. Then, the acceptable limit for the Resolution factor is not known. Two Resolution factors have been calculated based on simulated fires: a lower value when only the fire on the top face is included in the burning area, and the higher value when all the burning faces are included in the area.

To limit calculation time, the model was divided into the several grids. A calculation environment where every grid can be calculated by a different processor was used. However, the hottest area was not divided between several grids because that could cause problems to the stability of calculation. Also, if a larger number of processors are needed, the starting of calculations could be severely delayed.

Coarser grids were used for the colder parts. Alpert's correlation was used to approximate the width of the hot area. A distance from the plume centreline where the temperature should be less than 100 ˚C was calculated. This distance is always smaller than the distance to the edge of the coarse grid.

In the simulation environment the co-ordinates of modelled objects were not changed in the transformation to the fire simulation program. The simulation program was allowed to locate every co-ordinate to the nearest cell corner using normal mathematical rounding rules. If all the corners of an object are rounded to the same cell corner, it will vanish from the fire simulation. Because of rounding, the thickness of some objects may be zero. As long as the rounding cause any unwanted holes in the simulation model, it should not affect the calculation. The simulation program reads the real thickness of objects from their attributes.

The effect of rounding was observed by two methods. In the simulation environment the calculation grids were also added to the structural model. At least one edge of the grid could be located according to modelled structures. All the added geometry could also be located to the grid cells. For example, holes less than two cells in size were not used.

The other method involved visual checking of the fire simulation model. The checking was carefully done before calculation when most of the problems could been noticed. After calculation, smoke animation could indicate unwanted air flows.

To minimise calculation time, the biggest possible cell size was usually selected. Then the rounding of co-ordinates may cause structures to be lost in the fire simulation model. Profiles whose both dimensions are less than the cell size will probably be lost if not successfully located between cell corners. Profiles exactly the size of a cell can be lost if the cell corner is located exactly in the middle of the profile. That is highly improbable.

Heinisuo et al. (2008a) have tested the effect of different sizes of obstacles in a fire model. They noticed that if the obstacle height versus corridor height is below 0.1 in a ceilinged space, and the obstacles are not located close to each other (less than three times their height), it is not essential to model them in a fire simulation. Consequently, slender profiles do not change substantially the flow of air. The height of the modelled spaces was typically between 4 and 10 metres. Then it can be assumed that ignoring of obstacles smaller than 400 mm has little effect on simulation.

In the hot area the upper limit of cell size was 200 mm. Outside the hot area, the flow of air is even slower and bigger obstacles can be ignored in the fire model. There the upper limit of the cell size was 400 mm. The end result of the investigation of the effects of rounding was that profiles smaller than the cell size could be freely rounded off. The pictures of the fires in Chapter 5.5 show that, for example, all diagonal members of trusses have vanished from the fire models.

Modelling of fires and grids

The previously presented fire packages were used in simulations. The properties and behaviour of burning materials were converted to FDS language. The HRRPUA, CONDUCTIVITY, SPECIFIC_HEAT, HEAT_OF_COMBUSTION and DENSITY values were given. The slope depicting the development of the fire as a function of time was given. The material data of the fire were linked to the model so that the name of the FDS fire was included in the name of the geometrical object describing the fire.

The fire was modelled in the form of cubic geometry which follows the cells of the calculation grid. The location of the fire was selected for maximal temperatures of structures. Then the flames should reach the structure or just underneath. The other rule was that there should be enough air for the fire since the area around the opening is the severest.

The finest grid was located around the fire. One edge of the grid was aligned with the bearing structures. The exact location of the fire was fine-tuned accordingly. Then the other fine grids where located around the first one. Finally, the rest of the model was filled by coarser grids.

Output of temperatures

Air temperatures were output at certain points during fire simulation. The location of the points must be entered by co-ordinates to the input file of fire simulation. The middle point of every steel member was selected as a control point. That allowed reading the co-ordinates automatically from the structural model. Temperatures at different locations of long and vertical rods varied sometimes. The safe solution in such instances is to assign critical members the highest calculated temperature of the surroundings. In some cases extra control points above the fire were also included in the calculation.

The air flow near the flames and plumes is turbulent. The programs can simulate this when output temperatures vary a lot between successive calculation steps. In an intense fire the difference could be about 100 °C. If we wish to know the temperature at one point at a certain time, it is not advisable to take a single value from the time-temperature curve because of the turbulence. It is better to use the so-called 'sliding window' with the mean of several successive calculation steps.

One simulated second may involve several steps of calculations. That would make the amount of output data huge. The temperature of structures corresponds closely to the temperature of air. For these reasons, all the calculated steps are not used in post processing. Hostikka et al (2001) have presented an equation to calculate the width of the sliding window. In the output diagrams of simulations they reduced air temperatures to 10 seconds wide time steps. That value was considered suitable in all cases.

The temperature of a steel part can be calculated by integration from the time-temperature curve of air. Heinisuo et al. (2008b), among others, have presented examples of such calculations.

In the following, only the air temperature curves are given. These temperatures were used by the structural engineers of the project to check the resistance of the structures in fire.

Simulated cases

The calculations of the fire cases presented in Chapter 3 were done to determine the worst-case scenarios. The cases involving the highest temperatures are presented in the following. Results are presented mainly for those control points where air temperatures were over 400 °C. That is a critical limit because the yield stress of steel decreases at temperatures above it.

Tab. 10.5 lists the documented cases. The Resolution factor (R) is output as told in Chapter 5.2. An exception is the coat-rack fire where the relative area of the top faces was very small and the top of the coat-rack was closed as shown in Fig. 10.34. The R value of the top faces in the coat-rack fire has not been output. All calculated values are at least near the minimum target value 10. The worst R value was calculated for the storage fire, but there only the top faces of the fire elements were burning.

The number of grids of both used cell sizes is given. The total number of grids of the fire models was between 7 and 16.

Tab.10.5 Documented simulations

	Resolution factor R		Number of grids		
	Burning faces		Size of cells [mm]		Σ
	top	all	200	400	
Ice hall, ice machine	9.6	13.9	3	6	9
Ice hall, storages	9.2	-	4	6	10
Restaurant, coat-rack	-	11.4	4	5	9
Fun park, slide	13.9	30.6	6	10	16
Dance hall, stage	13	23.8	6	2	8
Volleyball hall, stand	10.4	12.8	7	0	7
Climbing hall, climbing wall	13.4	25.6	8	0	8

The initial simulation time was one hour. In cases where the combustible material burned away, the simulation was stopped earlier. The output temperatures should have settled down before the stopping.

Tab. 10.6 shows the calculation times of simulations. The maximum numbers of cells in one grid and simulation time were output to compare different cases. As stated earlier, it is advisable to avoid dividing the grids around the fire to keep calculation times short. A long, intense fire also lengthens the calculation time in addition to the wideness of the grids.

Tab. 10.6 The simulation and the calculation times

	Maximum number of cells of grids	Simulation time	Calculation time of simulation
		min	hh:mm
Ice hall, ice machine	109824	33	33:47
Ice hall, storages	109824	60	41:02
Restaurant, coat-rack	100000	60	33:51
Fun park, slide	83200	60	41:01
Dance hall, stage	72000	50	86:13
Volleyball hall, stand	52000	25	16:33
Climbing hall, climbing wall	190256	23	55:28

The ice hall was modelled in actual size bounded by the designed walls. The space was so large that the fire qualities of the walls did not matter in the simulation. The fire was situated near a door so as to provide enough air. The burning part of the machine was at the actual level.

Fig. 10.27 is an example of the visualisation of simulation. The door openings are white and the green points indicate where temperatures were output. Only a few bottom flanges of the trusses were included in the fire model while all other parts were rounded off.

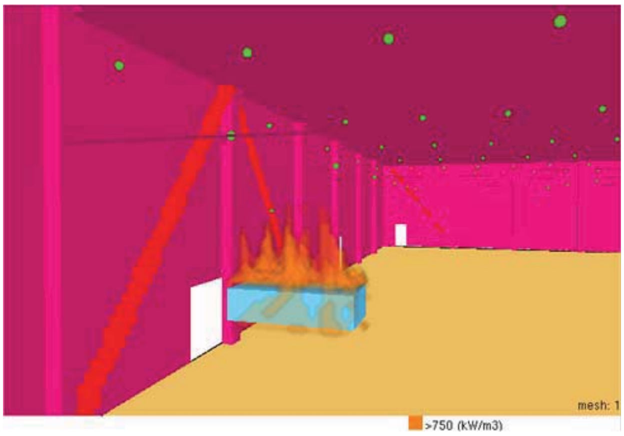


Fig. 10.27 The ice resurfacing machine fire

The time-temperature curve of Fig. 10.28 shows that the fire was decaying rather quickly. The control points are indicated by the letter ‘B’ followed by the consecutive number of the corresponding member.

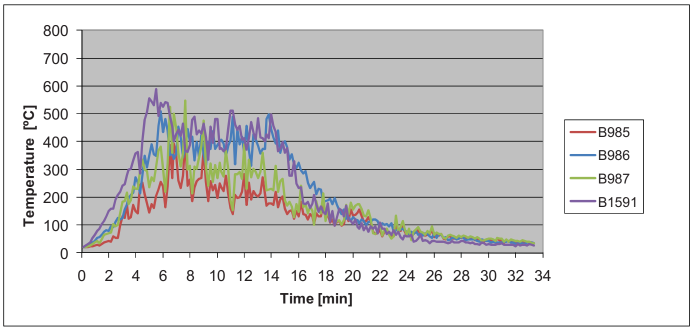


Fig. 10.28 The highest air temperatures above the ice resurfacing machine fire at various control points

In the case of the storage fire, burning objects filled the space and flames shot out of the open door. The structures most endangered by the fire were those above the door opening. In Fig. 10.29 air temperatures are represented by a coloured slice. The other colours of the slice only visualise temperatures while the red objects are structures. The figure shows that the ceiling above the door spreads the heat so that the air at the ceiling level is not very hot. On the other hand, the temperatures at the platform just above the door and the column are rather high.

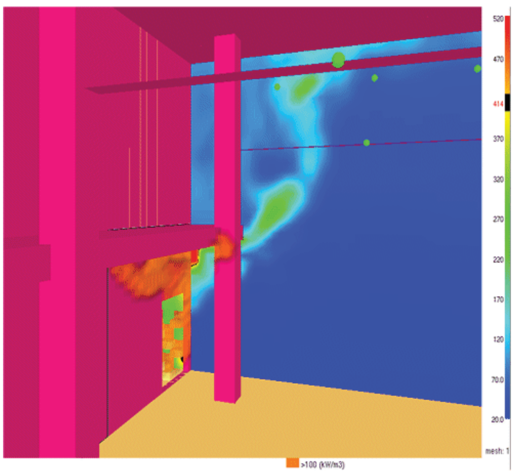


Fig. 10.29 Storage fire in the ice hall

The restaurant was modelled in actual size as an open space with all the doors open. Thus, the lack of air did not limit the fire. The burning coat-rack was situated according to architectural drawings. The fine tuning of its position was done by testing when the flames reached the bottom flange of a truss. The fire is visualised in Fig. 10.30. Air temperatures at control points were not raised above 400 °C.

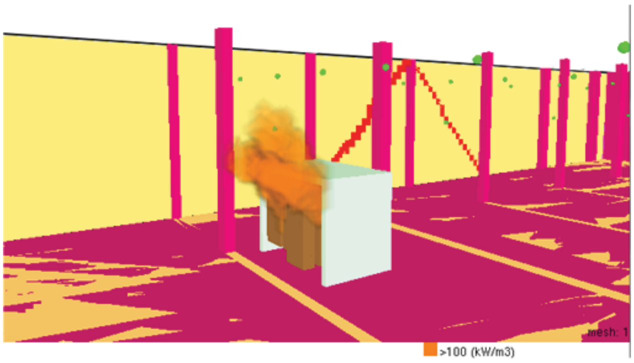


Fig. 10.30 Coat-rack fire in the restaurant

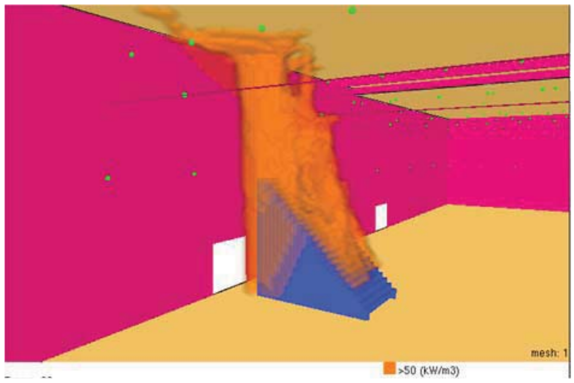


Fig. 10.31 The plastic slide fire

The plastic slide fire was situated in an open hall near an open door. No other equipment or possible separating walls were modelled. The fire is visualised in Fig. 10.31.

The plastic slide fire was very severe although the structure of the slide was thin. Thus, the combustible material was consumed quite quickly as shown by the time-temperature curve in Fig. 10.32.

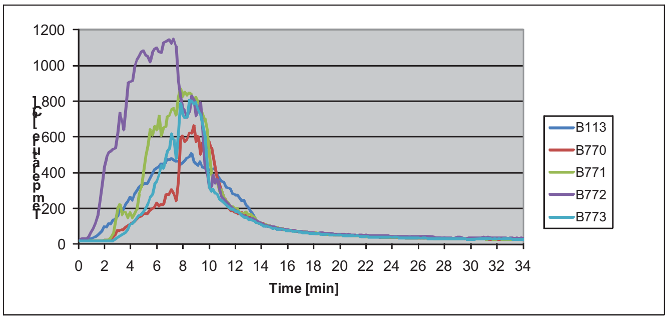


Fig. 10.32 The highest air temperatures above the slide fire at control points

In the dance hall model, the entire space was left open. The separating walls were left out of the model in order to produce simulation results on the safe side as the lack of air could not limit the fire. The fire was located near the emergency exit which was modelled open.

Test calculations were made to determine the most severe situation of the stage fire. It was noticed that that tallest speaker caused the highest and longest-standing flames. At the time, the speaker was located under the truss.

Fig. 10.33 shows the geometrical model of the storey where the volleyball hall is located –without the walls. The calculation grids can be seen as darkened areas on the floor. The thinner grids are indicated by the darkest colour. The perimeters of the grids follow the walls of the hall. The gray doors and ventilation opening are also pictured.

According to Chapter 3.8, only the upper part of the stand is assumed to burn. Therefore, only the seats of the upper part of the stand are modelled.

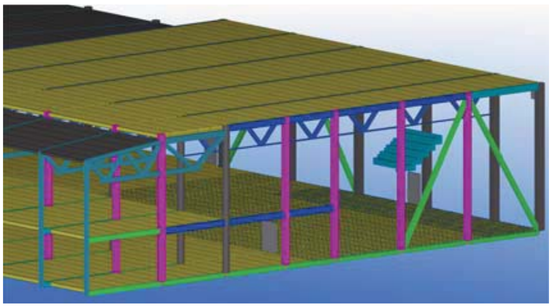


Fig. 10.33 The geometrical model of the volleyball hall

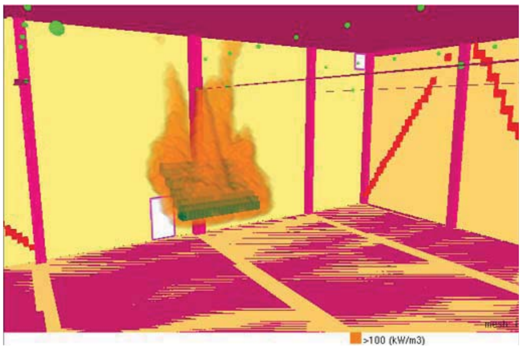


Fig. 10.34 The stand fire in the volleyball hall

The highest point of the flames varied across the stand. The locations of the highest temperatures varied correspondingly. Thus, it was difficult to determine the single most critical spot of the fire. Therefore, the highest registered temperature should be used for all structures above the fire. Fig. 10.34 also shows how the diagonal braces modelled in green in Fig. 10.33 have been modified into cubes in the fire model.

The air temperatures near the structures were high because the fire spread up towards the ceiling. The duration of the fire was, again, short as can be seen from Fig. 10.35.

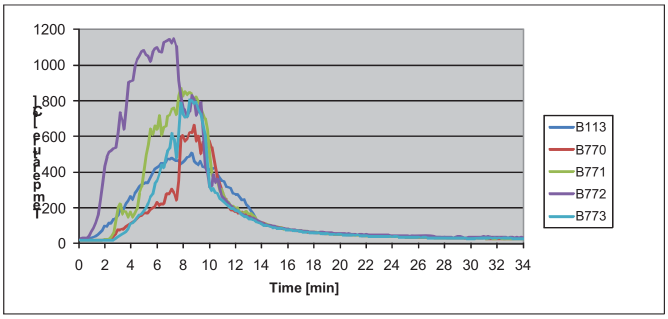


Fig. 10.35 The highest air temperatures above the stand fire at control points

The climbing hall was modelled as a three-dimensional multistorey space. Three trusses supported the ceilings. The climbing equipment and plywood based climbing wall were assumed to catch fire. A temperature slice was output also for the climbing wall fire of Fig. 10.36.

All simulation data were delivered to the structural engineer of the project. That allowed him to visualise the simulation results using all temperature histories of all control points. Using this information he could check the resistances of the trusses of every store.

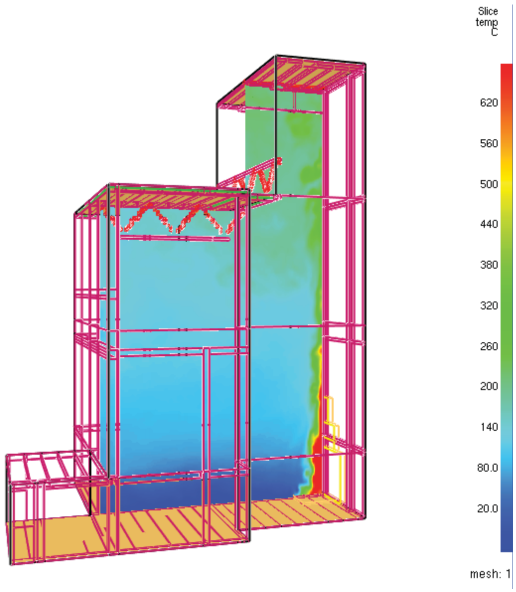


Fig. 10.36 The climbing hall fire

10.3 CONCLUSION

Performance based fire engineering is increasingly used in projects not only for evacuation, smoke control and exit design, but also to determine the resistance of structures in fire. It is not used just to minimise or reduce fire protection, but to enhance the fire safety of structures. In some cases it provides better fire protection than traditional fire design.

Performance based fire design is not suitable only for large projects, but for all projects

Lot of work will be required in Europe to bring fire design to the same level in different countries, which would make the market for products subject to the same regulations wider. Fire design has been typically incorporated in different sections of national codes as structural codes. In many countries national rules have been changed to allow applying Eurocodes to fire design as required in EU regulations.

The lack of experience and confidence of authorities and design fire definitions seem to be the largest challenges to performance based fire design in projects. The checking of design calculations is a major challenge to authorities.

The article presented one simple case study using water extinquishers and a case study on how to define the temperatures of fire compartments. Only the fire scenarios and the definitions of the design fires were given. The structural design of the project was done by others.

Fire scenarios for all the parts of the building were defined in close co-operation with the client, the authorities and other designers of the project. In this kind of performance based design co-operation between all partners to the project is essential and leads to a thorough survey of the worst-case scenarios. The authors believe that the end result is a very high level of fire safety for buildings.

This kind of design requires first rate fire engineering skills and good computing facilities. The developed integrated fire engineering tool was used in the project. In this case a module was used to transfer the data between the product model (Tekla Structures) and the fire simulator (FDS). Careful grid sizing, fitting the obstacles and fire packages to the right locations, etc. require experience from the end user of the system.

Similar integrated systems, in fact the same simulator, FDS, can be used e.g. in evacuation design and other design tasks. High unused potential lies in the integration of design procedures. However, the expertise of skillful engineers cannot be substituted by computers.

Performance based design should be incorporated in design at an early stage of the project. In the case study it was done by the steel contractor at a rather late stage. Earlier introduction could result in improved fire safety over the life cycle and bigger savings during the building phase compared to this project.

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11 FIRE IN A LARGE-AREA SHOPPING CENTER

Summary

The paper presents an analysis of a fire in a large-area shopping center. Although the building was equipped with fire protection measures, their activation has not proved to be effective. The fire took place at night without need to evacuate customers. It was found that the direct cause of the fire flashover was short circuit in the electrical wiring and improper use of the shelving containing parts made of combustible materials. In this report, the authors suggest, however, many indirect causes, needlessly generating significant fire hazard. They are characteristic for the whole group of such facilities. The primary risk factors included, among others are: the applied fire protection system which was satisfactory from the legal point of view but not uniform throughout the building, defective, and easygoing manner of use and lack of professional training of personnel. In final remarks, there are given recommendations to investors and managers of large shopping centers on the design and implementation of new structures and on maintenance of the fire protection systems providing required level of safety in buildings already in use.

11.1 INTRODUCTION

In the first half of the nineties of the last century a new category of buildings - large shopping centers emerged in Poland as a side effect of the political and social changes. Initially, these were mainly single-story buildings, in later years they were dominated by multi story malls. These objects relatively quickly replaced the traditional department stores where the floor area did not exceed several thousand square meters. The area characterizing the largest of the newly created centers is now almost fifty times bigger. They are, therefore, the places where thousands of people, employees and customers are gathered in a limited space, in the midst of a huge range of goods. The specific usage carries the challenge of providing the necessary level of security through developing appropriate rules of protection against fire flashover. However, this cannot be a simple adaptation of the general rules, applicable generally in the typical public buildings.

The need for refinement and continuous improvement of a variety of specific recommendations, that take into account all possible scenarios and fire hazards, was indeed noticed relatively quickly, especially in the case of the considered shopping centers. A catalyzing factor in this field was a series of fires that have occurred in such facilities in recent years. At the beginning the applied solutions for fire protection were yet consistent with the law in force at that time, however, they were incoherent with the modern safety requirements. An investor not obliged to use relatively expensive solutions generally choose those being inexpensive and ineffective if only they satisfied the current low requirements. An example was a legal rule allowing for refraining from installing fire alarm system if the object was protected only by permanent firefighting equipment. Foreign investors were also surprised by no obligation to separate fire compartments for storage facilities. Considered objects at the time of use were modernized several times. The way the commercial space was used also changed, mostly due to acquisitions by new tenants. Any such change was associated with other safety requirements, effective at the time of modernization. As a result, today we have complex objects with parts not fully congruent to each other and with quite different levels of fire protection. In many cases, spaces used in a similar way have different limitations, for example regarding the maximum height of storage or kind of goods accepted for the trade.

Published recently in Poland a set of rules recommended for operation in this field (Skaźnik, 1999) is the practical help, particularly useful for investors, managers and users of large retail stores, but also for all interested on requirements, systems and procedures for fire protection of buildings of this type.

11.2 BUILDING DESCRIPTION

An example of the facilities described above is a large-area shopping center where the fire took place in December 2008. It was built and handed over for use in the late autumn of 1999. The total building area was approximately of 48 000 m^2, and the usable area was about 50 000 m^2. The whole building was divided into three main fire compartments of the areas 10 400. m^2, 22 000 m^2, and 14 200 m^2, respectively. In the zones II and III the main tenants occupied from 2/3 to 3/4 of the total area, which consisted of sales room and warehouse facilities, separated by fire-break divisions with the increased fire resistance. The remaining area of each compartment was occupied by a strip of the retail outlets and the other service facilities. Additionally, the separate fire compartments were designated for the sprinkler central units and for some technical rooms. In May 2005 the fire compartment III was expanded by 1 600 m^2. Finally at that time the sales room was an area close to 9 000 m^2 and the largest warehouse facilities in this part had 700 m^2 and 1 300 m^2.

The superstructure of the considered object was represented by reinforced concrete columns, steel beams and steel purlins. The curtain walls to a height of 3.5 m were made of prefabricated elements, and above that height - as a layered wall, consisting of two layers of sheet steel, internally insulated with mineral wool. Interior walls were made of brick or plaster - cardboard. The roof was made of corrugated steel sheeting, insulated from the top with self-extinguishing polystyrene, sealed with vapour barrier foil on both sides and coated on the outside with topcoat coverage foil. The entire building roof was classified to the Class E of fire resistance (which means no special R, E, or I reqirements according to Rozp., 2002) with particular elements belonging to the non-spreading fire category. On the other side, two-story part of the building structure was classified to the class D, more restricted in relation to the required fire resistance. Furthermore, the whole storage zone separated in considered shopping center was qualified also to the class E. In addition, all members and all materials applied in its structure could not spread fire. Finally, the elements separating fire compartments had fire resistance of at least 120 minutes.

11.3 EXISTING FIRE PROTECTION SYSTEM

Before the enlargement of the building took place, it was equipped with all the fire equipment required by the contemporary law regulations (Rozp., 2002, Rozp., 2010), including:

- protection sprinklers covering the entire space of the shopping center, excluding such facilities as the electrical switchgears, monitoring rooms, air units, sprinkler systems, refrigerators, etc.
- alarm-signaling installation, consisting of the smoke detectors built-up in the passage and the spaces adjacent to commercial premises - services (excluding the sales floor), the manual fire alarms located in the entire facility, the fire control central connected directly to the city fire department,
- smoke extraction system, covering the entire site, including storage rooms, and consisting of the windows and smoke vents, pneumatically and electrically operated. The smoke extraction at the passage was secured by the system of windows operated by the signal from the fire central, upon detection of smoke by fire detectors. The passage space under roof was divided into 11 sectors by smoke curtains with the supply of fresh air in the passage provided by the escape sliding doors, automatically opened in case of fire, and revolving doors operated manually by the staff, the selling rooms were equipped with smoke dampers operated automatically or remotely from a set of points distributed in several places at the object,
- battery powered emergency lighting central.

After the expansion in 2006, the following changes were applied:

- in the refurbished store new sprinklers designed as a single level, supplied from the existing sprinkler pump, were installed with the resulting intensity of the spray 15 mm/min,
- fire alarm system was installed in the main hall of the sale, the linear smoke detectors were used with the time delay between the discovery of fire and switching on the central fire alarm of the second degree set at 3 min.,
- the extended part of the store was equipped with a device containing of the smoke vents controlled by the fire alarm system.

The range of the exhibited goods in the main hall included goods with very different susceptibility to inflammation, since made of metal, through wood and plastic up to the acrylic enamels and solvents. In the electrical section on the shelves there were exhibited among others wire coiled on spools made of plastic and wood.

11.4 COURSE OF FIRE

The course of fire has been reconstructed on the basis of information recorded in the fire control unit, at the alarm receiving center and fire monitoring system, and based on the analysis of footage from the cameras of the object. It looked as follows:

- Thirteen minutes before midnight, the lights go out at the racks in the electric department,
- After 10 seconds in the view of one of the cameras flame appears at the top of one of the shelves in the electrical department - This point was taken as time 0,
- 2.5 minutes from time 0 – there are visible flaming droplets sinking on the lowest part of the shelf, where there is a second outbreak of fire,
- 8 minutes - the first fire detector signals the fire, and immediately after, the next one, both alarms are deleted by the shop service,
- 9 minutes – the fire covers the second portion of the rack, at the time when the third detector signals the fire alarm, also cleared by the shop service,
- 10 minutes - the fire spreads over the full height of the whole wall of the unit, and at the same time the sprinkler is opened, causing visible suppression of the fire and smoke rise, at the same time the fire appears on the other side of the rack on the floor, the opening of the sprinkler transmits the alarm to the municipal fire brigade,
- 10 minutes 20 seconds - the fire covers two segments to the entire height of the rack, followed by rapid development of fire - probably due to ignition of the insulation of cables stored in that location,
- 13 minutes - the sprinkler built across the shelf gets on but the fire is still rapidly evolving,
- 17 minutes - the first units of the state fire service arrives,
- 18 minutes - the fire is spreading over the roof of the object.
- Extinguishing action ends after 108 hours of fire brigade activity. As a result of the fire almost the entire fire zone of several thousand square meters was destroyed. The fire also spread to the back warehouse store. The extent of the damage in shown in the photography (Fig. 11.1).

Fig. 11.1 General view of burned commercial building

11.5 DIRECT CAUSE OF FIRE

The preliminary analysis showed that the probable cause of the fire could be overheating of so called couplings used in electrical connections supplying lighting fixtures for shelving. Under normal lighting conditions, it should be turned off after trading hours, however that day, for unexplained reasons there was no such exclusion. The spread of fire was possible due to the specific design of the racks. Across the hall the selling goods were exposed on the shelves made of non-combustible materials. These racks were combined in bilateral rows, and the rear walls were made of perforated sheet metal. However, in some areas of the room, particularly in the electrical department where the fire broke out, there were additional wood panels made of combustible material to which in turn some electrical equipment and lighting fixtures were mounted.

11.6 FACTORS GENERATING FIRE RISK

11.6.1 Consistent with legal requirements but nonuniform fire protection

As mentioned above, the facility was put into operation in 1999. The fire protection system used at that time satisfied all the requirements of the current building law (Rozp., 2002 - in the previous version from 1994, Rozp. 2010). In 2006 the object was extended. In the new part of the building more modern and efficient protective devices were installed, in accordance with already more restrictive law (Rozp., 2002, and CEA, 2003). Thus, there was a situation where in one room there were sprinkler sections designed according to different standards, and imposing different conditions for storage of goods. Moreover, according to the project documentation, all the smoke vents in the new part of the store should be controlled by fire alarm system. Finally, as a result of savings, much of the vents were operated by individual thermal triggers. It should be also mentioned that the fire protection project made in 1999 did not set out in principle any conditions for storage of goods. Such requirements were given only in 2006 and only for the modernized part of a building.

11.6.2 Faulty operation of the building

The analysis made after fire showed numerous disagreements with the conditions contained in the standards that were adopted as the basis for the design of the existing sprinklers, especially considering requirements for the display of goods. Particularly improper height of storage, use of full shelves containing parts made of combustible materials, storage of cables and electrical wires without sprinkler protection, multilevel shelving, as well as too small distance between the shelves. Although goods intended for sale were laid, only to the height of 2.4 m, but the space above, to the height of up to 3.5 m, was used to store supplies of these goods, stored generally using combustible, paper packaging.

A separate issue, which also drew attention during the analysis, was numerous marketing campaigns carried out by the shop and intensified in the pre-holiday periods, to improve the economic result. The events led to installation of a variety of additional lighting, organized demonstrations, etc. The safety considerations in such situations often descended into the background, sometimes with many potential risks completely ignored.

The issue of paramount importance is to maintain the fire protection system capable of full readiness. The reports developed by fire departments for large retail stores, show that considered object was no exception. In many cases after installation the technical fire protection systems functioned correctly but after two or three years of operation it was turned out based on the individual opinions of the managers and was simply forgotten. Common practice is incomplete design documentation, missing operating manuals, maintenance reports, etc. This is ultimately the realty for many managers who in many cases run facilities with a collection of random documents, even mutually exclusive. In general there is a luck of information on the required maintenance practice. There was even a reported case of the modern large space trade building where the poorly maintained fire protection system at all did not work and the building burned completely. In the economical battle field, the owners and managers of such facilities generally are aware of their incompetence just in case the object of control by firefighters or representatives of insurance companies.

11.6.3 Lack of professionalism of technical staff

The described fire occurred after business hours. The facility was not occupied by customers or vendors. There were present only the security and maintenance staff. Must arouse astonishment, however, that there was no rescue action in the early stages of the fire. Particularly surprising is turning off several times the alarming devices activated at the appearance of fire. This behavior can be explained only by an illusory belief in the wrong message coming from the warning system. Undoubtedly, the staff was not prepared to undertake professional activities. Specialized safety training was carried out very rarely and was not effective. Besides, with the high turnover of the staff in this type of facilities, many workers by nature are subject to only to a typical amount of training at the adoption to work.

11.7 POTENTIAL EVACUATION FROM THE BURNING FACILITY.

The considered fire took place at night when the facility was without customers. However, on 14 fires that have occurred recently in this type of objects, 9 were in the daytime, occupied by the customers who need to be evacuated. In large sale-halls such evacuation involves large groups of people, usually composed of several hundred and often several thousand people. This can cause uncontrolled reaction and thus carries imminent risk of panic. It is not important in this case whether the fire became part of the roof insulation, shelving in the warehouse or exhibit at the show. Customers watching smoke spreading inside the sales floor or passage, and maybe even a fire, have the right to be concerned. On the one hand they are mindful of the sometimes overly dramatic media coverage of the other fires, and on the other hand without seeing any effective action against fire not only from employees but also be aware of not to the end efficient fire protection systems.

11.8 FINAL REMARKS

The statistics on major fires in large commercial buildings have been gathered in Poland for 36 years. It is very curious that for the first 32 years of observation there was only 4 such fires, while since 2008 already more than a dozen. This worrying trend is clearly related to the significant increase in this type of objects used in the country. Its explanation is not quite so simple. Certainly, the first raises the idea about the diminished alert. In practice, until 2008, the unwavering long-term operation of shopping centers has strengthened all: from investors to the owners and designers, and even the State Fire Service firefighters, in the belief that they found the right way to ensure a high level of safety of people and property at these facilities. Yes, from time to time, you could hear reports of fires in hypermarkets (for example Biuletyn, 1968), but always they took place quite far from Poland, and usually from Europe too. Yet surprisingly similar events began to appear also in our country, first sporadically, but then their frequency increased markedly. This increase was so pronounced that it was necessary to look for systemic causes, even though they do not always directly generate a fire hazard. It seems that the base problem is a change of investment strategy and practice. It is obvious that the primary criterion in this field is the project cost account. However, it should always be complemented by a credible risk assessment, taking into consideration the safety of people first. The more comprehensive shopping facility - service, the greater degree of difficulty in determining the method of its fire protection. So, it should not be uncritically accepted that the winners are the project teams that offer the cheapest service. The basis for selection should be experience in the design of such facilities and achieved results. Construction projects for hypermarkets should not be treated as completely reproducible projects. Despite many common features of their approach to the way of fire protection they should always be individualized. Must take into account not only the investor's objectives, but also local conditions, determining even the possibility of taking effective firefighting action. A reference list of designed and built objects should play a great importance in this case. A reasonable assessment of the protection system can be designed by independent auditors specialized in the provision of such services.

Very much prudence and discernment requires the use of appropriate solutions for the modernization of in-use facilities - those that will not only properly secure a new part of the building, but also unify, within reasonable limits, the level of fire protection in the whole store. One should not lead to a situation where not only in one fire zone, or in one passage but even in the sale room, there will be different operating conditions, valid for the same usage, such as different height of storage of goods. When designing an object one cannot forget about the next user who will not be required to have an expertise in fire protection and the resulting operating conditions. Hence there is a conclusion that the solutions should be transparent functional and friendly, not only for the owner and staff, but also for the firefighters themselves. One should also take into account the possibility of errors committed during the operation of the building and limited practical knowledge of those responsible for maintaining the facility and its protection system in good condition. On the other hand, facility personnel should be prepared so as to be able to execute any command related to the firefighting action, the technical infrastructure, yet provide a detailed explanation in this regard. This implies the need for periodic training, both in theory and in the form of practical exercises, designed to provide knowledge about the functioning of fire safety systems in the facility. To be effective in such training it is important to limit the scope with the knowledge to only that is needed for their position and required to properly perform their duties. Entrusting this type of training to carry out for random entities or individuals is pointless. The trainer should have full knowledge about the object and its fire safety system.

The last issue is how to make any changes in the facility, especially in the arrangement of its equipment. In shopping centers such situations occur, in principle, on an ongoing basis and you need to factor them in the safe operation of the system. Particular attention should be paid to the changes in land surface of the sales rooms and passages, how to display and store goods, including the type of shelving, changes in the communication system, the range of goods sold, etc. An important role should be assigned to monitor all kinds of marketing campaigns linked to the organization of temporary stands. The basis should be on the field to submit a project manager building the planned activities. This document should always be evaluated by a person competent and adequately prepared for that task.

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12 PERFORMANCE BASED DESIGN OF CENTRUM GALERIE DRESDEN

Summary

In this case study for a large shopping center it is demonstrated how escape routes can be optimized by a performance-based design with simulation of smoke propagation and evacuation analysis based on the fire safety concept of hhpberlin. The design for a superstructure of a road between two parts of the shopping center building was established with the natural fire method. In this way it is shown unprotected steel is feasible for the superstructure.

12.1 SCOPE

Large shopping centers imply a special challenge for the strategy of fire safety. Due to the manifold use (shopping, assembly hall, office, garage etc.), the individual demands of the users and the expansion of the building as well, fire safety concepts cannot be created only on a prescriptive way, for there are many deviations from the requirements of the building codes.

In fact such buildings require a performance-based fire safety concept. In this way an adequate safety level is to be proved by engineering methods.

In this case study for a large shopping center it is demonstrated how escape routes can be optimized by a performance-based design with simulation of smoke propagation and evacuation analysis based on the fire safety concept of hhpberlin. The design for a superstructure of a road between two parts of the shopping center building was established with the natural fire method. In this way it is shown unprotected steel is feasible for the superstructure.

The Centrum-Galerie Dresden dimensions are:

- max. length (direction East-West) 180 m
- max. width (direction North-South) 125 m
- max. height of the floor of a habitable room 20 m

Besides the actual shopping areas, there are planned garages, catering, offices, storage areas, plant areas and a center management.

12.2 PERFORMANCE BASED DESIGN FOR THE ESCAPE ROUTES

In the course of planning it emerged that the prescriptive substantial requirements concerning the widths of the rescue routes and the direction of the emergency routes were no realizable with the design for the “Centrum Galerie” in Dresden, Germany. To show this two examples are named:

- For shops with less than 100 m² the German Building Regulations for retail uses allows to lead both emergency escape routes over the mall. Shops with more than 100 m² sales area require a second escape route independent from the mall. On the 1st floor, the mall was shaped widely. Within the mall, covered shops were ordered which sometimes have a sales are of more than 140 m^2.
- In accordance with the German Building Regulations for retail uses for exits to the outside and stairwells designed for shops with more than 500 m² net area a width of at least 0.30 m is required in relation to each 100 m² of sales area.

The implementation of these requirements would have meant a number of additional staircases in the considered building and the conception of the central Mall would not have been realizable.

To meet the safety target requirements of "facilitating the rescue of people", a performance-based approach was chosen by way of deviance from the prescriptive design.

12.2.1 Simulation of smoke propagation

Using a simulation of the smoke propagation with the CFD model FDS (McGrattan, 2009) based on fire scenarios agreed upon with the approval authority, it has been demonstrated that the target criteria with regard to a low-smoke layer formulated in the German vfdb-guideline can be met for a sufficiently long period. Due to this document, the routing of both emergency escape routes via the mall could be approved of for shops smaller than 100 m².

The air space of the mall, for which the simulation of the smoke propagation was carried out, extends from the basement to the 4th floor, which is flush with the roof of the mall.

In the basement there is a ventilation opening for supply air of a total 5 m², the openings are arranged above the corridor doors and are automatically controlled by the fire detection system in the case of fire. On the ground floor, three arms of the main Mall branch off. On the ground floor, more than 40 m² of supply air ventilation openings are available, which are formed by the access doors. The branches are not separated from the main mall by smoke protection curtains. On the 1st floor, an amount of air of 15 m³/(h * m²) is blown from the shops into the Mall as mechanically driven supply air. The mall ends in the 1st floor. The air space of the 2nd and 3rd floor of the mall is separated from the garage. A total of 12 exhaust fans arranged in the longitudinal walls of the roof of the mall on the 4th floor exhaust a total air flow of 350,000 m³/h.

The results of the decisive fire scenario in the basement of the mall are shown below. Because the mall of the ground floor partly covers the mall in the basement, the fire in the simulation was placed so that the fire plume come up against the ceiling above thus covering the worst case scenario. The heat release rate was determined due to the t^2-approach with t[illegible] = 300 s. A constant lapse of the heat release rate was assumed after the sprinkler had been activated (see Fig. 12.1).

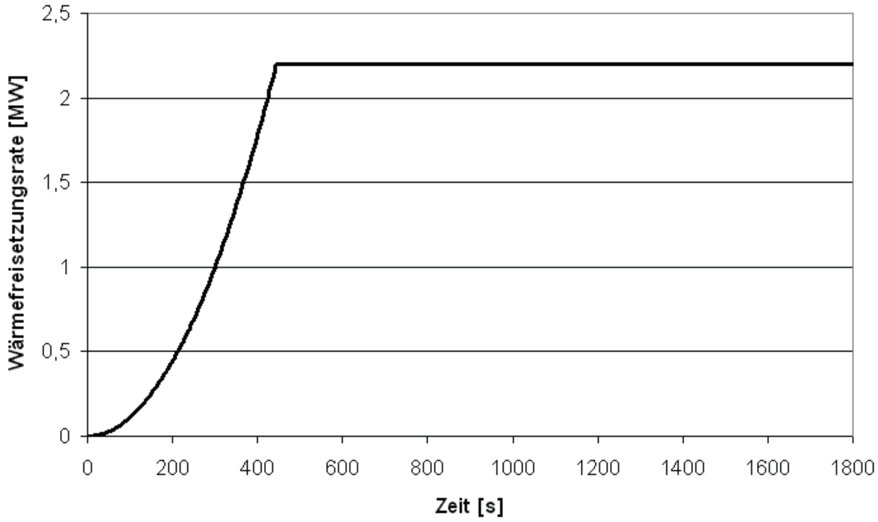

Fig. 12.1 Heat Release Rate for simulation of smoke propagation

The values of the visibility range after 1800 s on the first floor at a height of 2.50 m are shown below as an example.

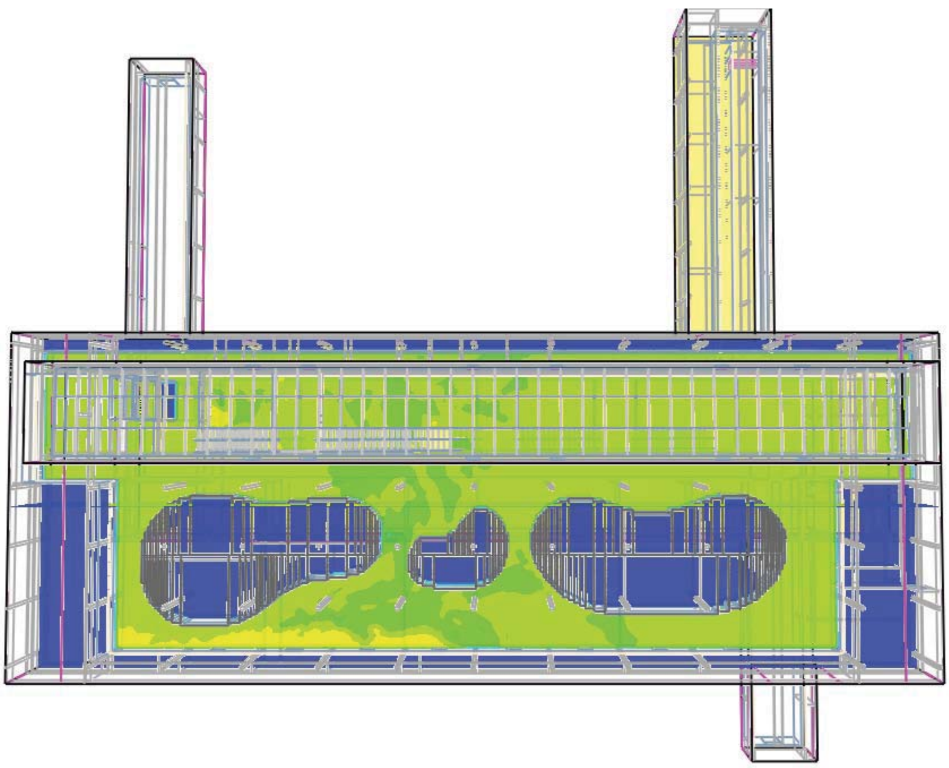

Fig. 12.2 Visibility on the first floor at H = 2.50 m after 1800 s

In a stationary condition visibility ranges on the first floor are still between 10 m to 15 m after 1800 s. Only in locally limited areas the visibility is slightly below 10 m.

12.2.2 Evacuation Analysis

The occupancy was determined in accordance with German vfdb guidelines (vfdb-Leitfaden TB 04/01) as follows:

- Ground floor 0.5 persons/m²,
- Remaining floors 0.3 persons/m²,
- Office areas 0.2 persons/m².

This results in an overall occupancy of 14,510 people for the evacuation scenario of the entire shopping centre (excluding the garage).

The reaction time is calculated to be 2-5 minutes following Purser (vfdb-Leitfaden TB 04/01).

The proof of a sufficient capacity of the emergency exits was led with an evacuation analysis (buildingEXODUS V4.06, 2006).

In the first minutes of the evacuation, short-term congestion may arise in the area of the exits (see Fig. 12.3).

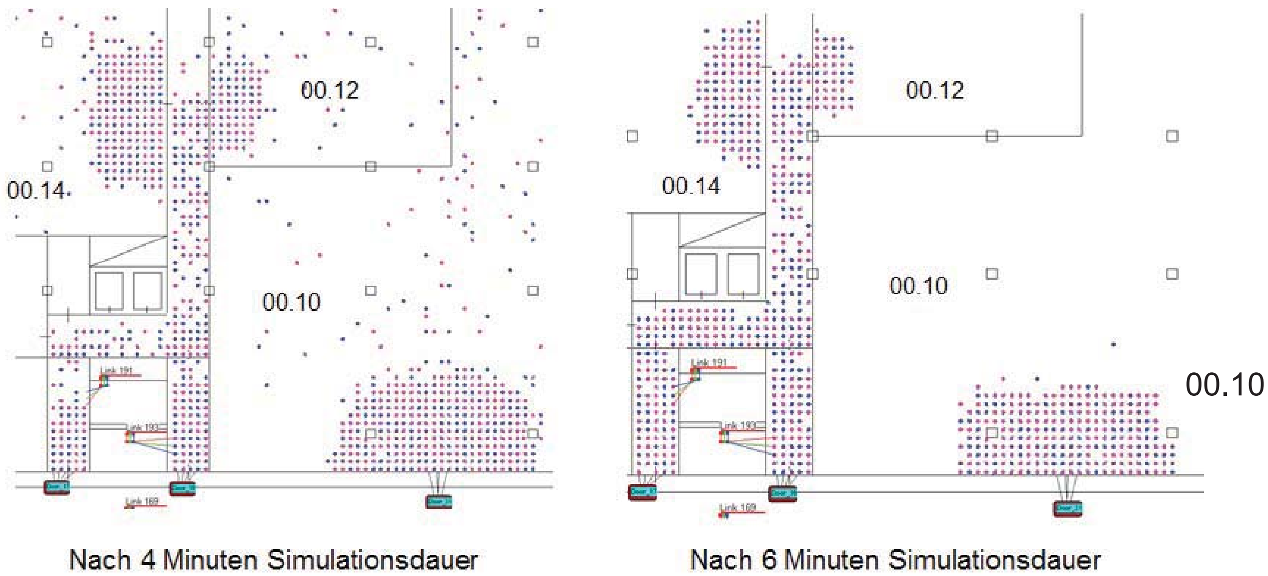

Fig. 12.3 Short-term congestion at ground floor exits

A total of 10 simulations were carried out. On average there were the following results:

- The whole building evacuated after 17 minutes,
- Most of the shops evacuated after 14 minutes,
- Last floor evacuated after 15 minutes.

The safety objective to avoid waiting times in the shops longer than 3 minutes, agreed upon with the approval authority, is achieved. Congestions on escape and rescue routes from the entrance onwards to the staircases only occur to a limited extent. A tailback into the flight of stairs does not happen.

The evacuation is completed 17 minutes after the start of the fire. The simulation of the smoke propagation has shown that for a sufficient period of time (> 20 minutes) the safety objective criterias according to (vfdb-Leitfaden TB 04/01) are fullfilled so that the performance based verification of the sufficient capacity of the rescue routes and the routing of both emergency escape routes from shops > 100 m² via the mall could be supplied.

12.3 PERFORMANCE BASED DESIGN OF THE SUPER-STRUCTURE OF THE TROMPETERGASSE

The Trompetergasse is located between part 1 and part 2 of the Centrum Galerie in Dresden. The Trompetergasse should be roofed over to allow customers and visitors to stroll between the two buildings also in bad weather.

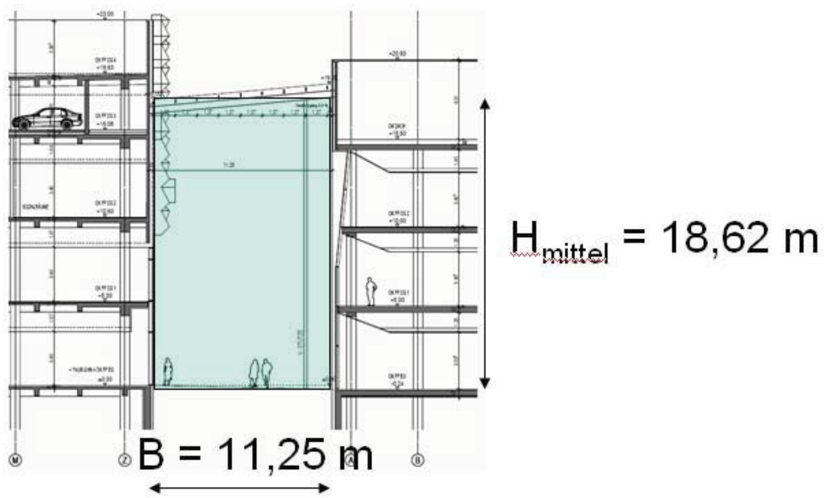

Fig. 12.4 The superstructure of the Trompetergasse

The roof is supported by the outer walls of the two adjacent buildings as well as a steel column. The roof itself consists of a steel structure with glass elements.

The area under the roofing is to be treated similar to the open. Therefore it remains to be proven that it is safe when people flee from the adjacent buildings into this street or when windows of staircases open in the direction of the Trompetergasse.

Generally, the area below the roof is only intended as a public thoroughfare. But because it cannot be ruled out that this area might be used with vehicles occasionally or that it is temporarily used in the course of specific events and the Trompetergasse will be used as access for the fire brigade, it should be verified by a performance based design that in case of a fire neither smoke will fill the Trompetergasse nor will the stability of the supporting steel structure fail.

In agreement with the approval authority a design fire with 15 MW rate of heat release was taken as the relevant fire scenario.

The following ventilation openings are present:

- At the junction of the roof and part 2 of the building a non-closed gap of 20 cm was taken into account
- Both facing surfaces of the covered area were assumed to be open across the full width.

The structural fire safety design of the superstructure was carried out by the simplified natural fire model following Eurocode 1 part 1-2 annex C (Heskestad plume) resp. the German vfdb guideline (vfdb-Leitfaden TB 04/01).

For the design of the superstructure the following assumptions were assumed:

- height of the fire above the ground: 2.50 m,
- minimum height of the superstructure above the ground: 17.40 m,
- maximum rate of heat release: $\dot{Q}_{max}$ = 15 MW.

The temperature of the plume is calculated according to (vfdb-Leitfaden TB 04/01) as follows:

$$T_P = T_\infty + 25{,}5 \frac{\left((1-\chi_r) * \dot{Q}\right)^{2/3}}{z^{5/3}} \qquad (1)$$

with:
T_∞: ambient temperature [K],
χ_r: radiative fraction of the heat release rate [-],
$\dot{Q}$: rate of heat release [kW],
z: height [m].

Using a rate of heat release of 15 MW, a radiative fraction of 30% and a height z of 17.40 m - 2.50 m = 14.90 m, the plume centerline temperature can be calculated to 155 °C

Because the plume mass flow does not form unobstructed and contrary to the basic assumption hot gas instead of cold gas is mixed into the layer of hot gas after entering the mass flow, in (vfdb-Leitfaden TB 04/01) a suitable method is presented to determine the corrected temperature of the hot gas. The calculation is done by adding a plume temperature difference to the temperature of the layer of hot gas.

After the calculation a temperature difference of ΔT_{Plume} = 50.3 K has to be added to the hot gas temperature. The maximum hot gas temperature of 140 °C was calculated using the multi room zone model CFAST. Thus the corrected temperature of the plume is calculated:

T_{Plume} = 140 + 50.3 = 190.3 °C.

The corrected temperature of the plume of 190.3 °C is higher than the uncorrected temperature of the plume and is therefore decisive for the calculation.

The determined temperature of the plume of 190.3 °C lies significantly below the critical steel temperature of approx. 500 °C. Thus, no special measures are required to protect the steel sub-structure of the superstructure.

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13 FIRE SAFETY DESING WITHIN RETAIL - BUYING 'MORE' FOR 'LESS' BY MAKING INFORMED DECISIONS

Summary

One of the most crucial aspects of fire safety design, is ensuring that this can be effectively implemented and managed during the buildings occupation. Having expensive and complex systems may solve a particular design issue, but ongoing maintenance and management involvement may result in this system being worthless or misunderstood by the buildings operators. This case study outlines one particular example where fire engineering has played a crucial role in improving the overall safety of an existing supermarket. In utilising a straight, forward-thinking approach an argument was created to remove an unwanted, existing and problematic natural smoke ventilation system in the roof where this did not work as intended. This system didn't provide any fire safety benefit, but caused continued problems with water tightness and heat loss.

13.1 INTRODUCTION

This case study focuses on one particular project where an existing supermarket was being modernised, and extended. The overall floor plate was being increased from around 7,700m² to 8,100m² with a new mezzanine floor containing a coffee bar, and back-of-house areas. One of the main aspects of this building was the existing system of manual smoke ventilation located within the ceiling space. This was installed within the original building some 10 to 15 years previously due to a local county building code. The code requested that to facilitate firefighting operations, a certain percentage of the floor space should be provided with natural ventilation for smoke clearance. These had been successfully installed within the roof space, but due to the lack of staff training and understanding of how the system should operate these were left to slowly fall into a state of disrepair.

This concern was addressed within the newly written fire safety strategy, and a new qualitative approach was adopted which took into consideration management capabilities, onsite fire safety equipment, the internal height of the store and Fire Service access provisions to, and around the building. UK's most recent fire safety design code, BS9999, was applied throughout the building. This code is written in a such a way, that it allows the extension of travel distance, optimisation of stair and exit widths when taking into consideration additional fire safety features which may be present within the building such as:

high ceiling heights which would act as a smoke reservoir; a higher standard of automatic alarm and detection; management levels which may be in place.

13.2 FIRE STRATEGY OUTLINE

The main purpose of the fire strategy was to create an 'easy-to-use' end product, which could be implemented into the day-to-day running of the supermarket. By adopting this, there would be a greater degree of certainty that the fire strategy would work as intended when required.

13.2.1 Legislative Requirements

A number of guidance documents had to be consulted during the fire safety design process. The main guidance document which was used to design the fire strategy was BS 9999: 2008. This document was the preferred choice, as it takes into consideration a risk profile made up of the fire growth rate and occupancy type associated with the building. This risk profile was then used to determine items such as travel distances and exit widths. Travel distances were extended by almost 30% further than the previously applied method which used an older standard, Approved Document part B.

Due to the location and size (containing a volume greater than 7,000m^3) of this supermarket, a local building act also applied. The primary reason for this local act is to reduce the risk of fire spread within large 'warehouse' type buildings, and to increase provisions for Fire Service operations. It was this legislation which originally called for the provision of natural roof ventilators within the roof space.

Lastly the supermarket's own fire safety requirements had to be considered. This set of minimum design standards had to be incorporated, including items such as: minimum fire alarm classifications; automatic suppression, and the incorporated of compartmentation to specified areas.

13.2.2 Means of Escape

A full means of escape assessment was carried out on the proposed building, with the aim to make provisions more efficient and easier to manage. The existing supermarket relied heavily on occupants escaping through back-of-house areas to meet the original 45m travel distance limit from front-of-house areas. This is not a desired method of design as it relies heavily on each staff members' ability, ensuring that goods are not stored within dedicated escape routes - at all times. In addition to this, it is known that occupants have a higher degree of reluctance to escape through back-of-house areas where they are normally forbidden to enter – adding to the risk associated with escaping through staff only areas.

During a site visit and a meeting with the supermarkets management, it was clear that maintaining clear routes through back-of-house areas was difficult to implement due to continual stock rotations, lack of staff responsibility and general shortage of storage space.

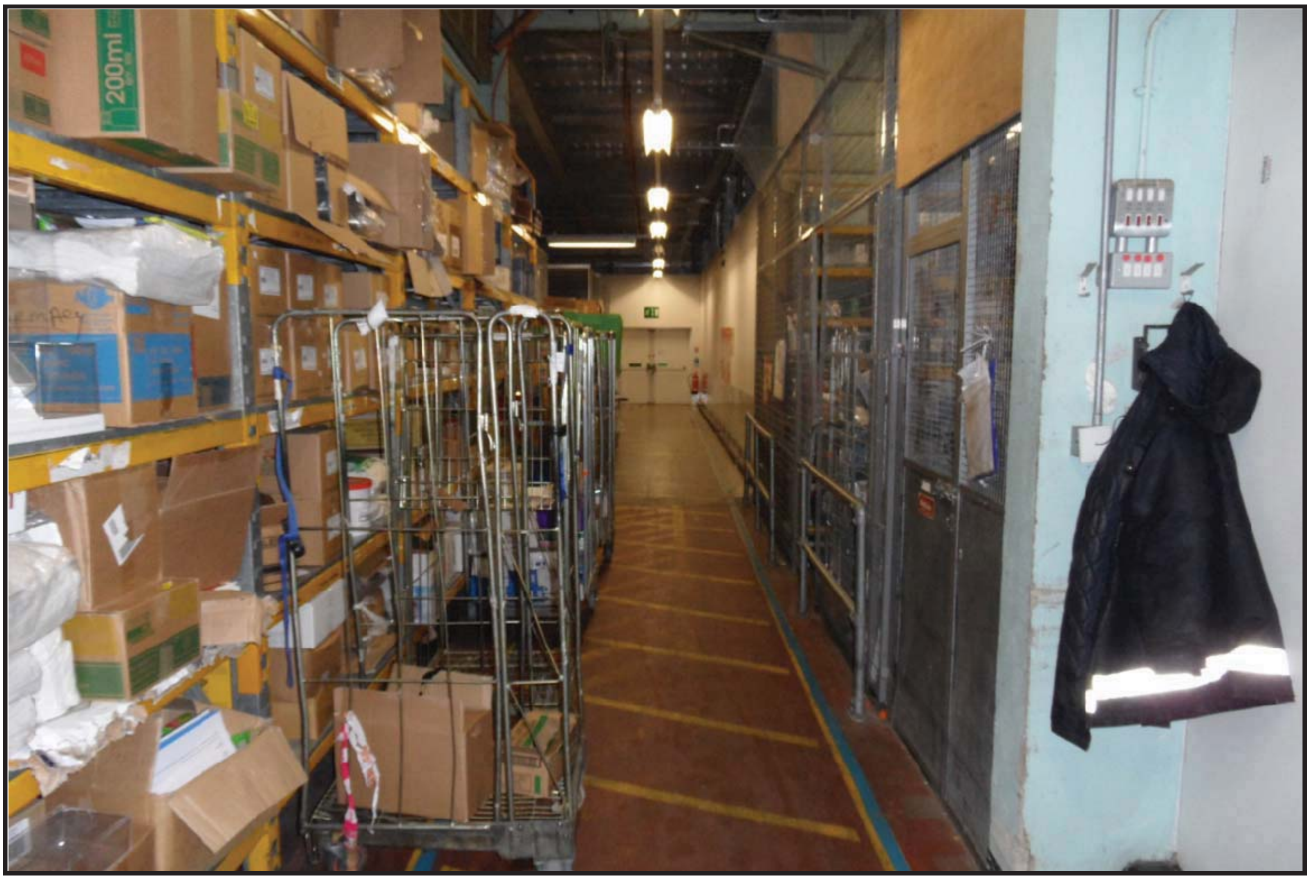

Fig. 13.1 Back-of-house

It was one of the main aims to remove these escape routes from the new design, and an assessment was carried out in accordance with BS 9999: 2008 to study any alternatives. Taking into consideration: ceiling heights; a high level of alarm category (incorporating a spoken instruction system); an automatic sprinkler system being upgraded throughout the building, travel distances were increased to a maximum of 60m where two means of escape were available. This is a vast improvement on the original design, as the means of escape routes could now be diverted away from the back-of-house areas where existing final exit doors were wide enough for the proposed occupant numbers.

In Fig. 13.2, travel distances through back-of-house areas are indicated in blue, where these are restricted to a maximum of 45m when designing to Approved Document, part B. The red lines indicate where travel distances have now been designed to a maximum of 60m enabling means of escape to be possible without travelling through staff only (back-of-house) areas.

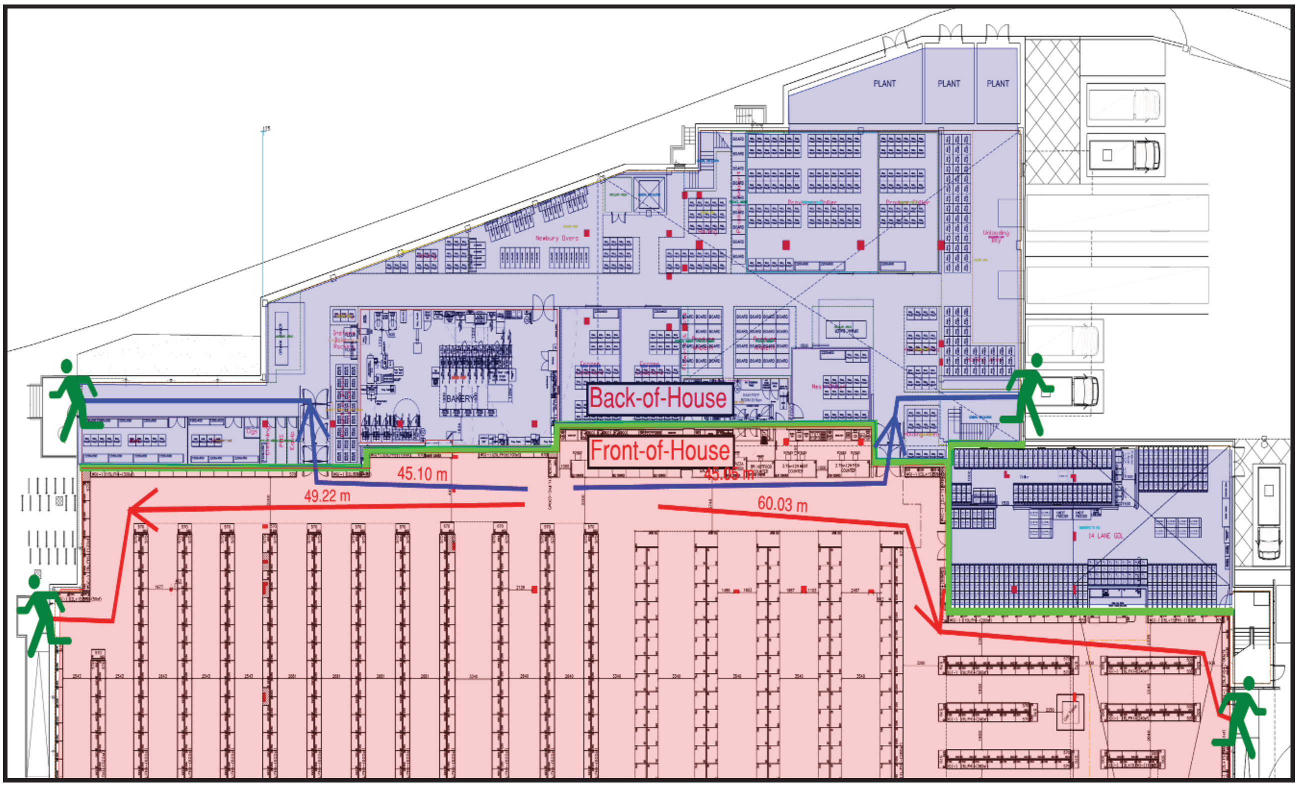

Fig. 13.2 Escape routes diverted away from BOH areas

13.2.3 Fire Service Access

Fire Service access to (and around) the building is a crucial factor, as the building should be easily accessible allowing the fire to be fought in an efficient and realistic manner. One of the main benefits of this supermarket was its location relative to surrounding access roads. These roads provide just over 90% perimeter access around the buildings' circumference enabling the local Fire Service to gain access around, and into each elevation via suitably positioned access doors.

Fig. 13.3 Perimeter access - image sourced from Google Maps

Fig. 13.4 Areal view of supermarket including perimeter access (red) - image sourced from Google Maps

13.3 REMOVAL OF SMOKE CLEARANCE VENTILATION

The existing smoke ventilation system located on the roof was primarily intended for use by the Fire Service to clear smoke during firefighting operations. This system of natural smoke vents caused substantial problems for the supermarket, and was never fully understood. Over time, this system began to leak allowing rain water to fall through spoiling products below at a considerable cost to the supermarket.

The supermarkets management made the decision to install a series of rain catching plastic sheets, and associated water drainage pipes to stop products from being spoiled during every rainfall. This decision ultimately deemed each of the vents as ineffective, as they had in some areas been fully blocked-up.

To further complicate matters, the store was in breach of the law by not maintain their fire safety equipment. In accordance with the Regulatory Reform (Fire Safety) Order 2005, the responsible person i.e. the supermarket manager was at serious risk of being prosecuted.

Fig. 13.5 Roof ventilation covers

Due to the failure of this system, it was seen as a necessary step to review the entire smoke ventilation strategy within the building. It was known that these ventilators were not required for life safety, however a further argument had to be developed providing evidence that Fire Service operations would not be compromised should these be removed.

By developing a qualitative argument that considered the overall on-site Fire Service provisions, consent was gained from the approving authority that these smoke vents were not required for firefighting purposes.

The building had an excellent degree of Fire Service vehicular access where a perimeter road was available to at least 90% of the buildings perimeter. This is compared to 50%, which is the minimum as recommended within BS9999:2008. The existing building was also provided with an automatic sprinkler system; in its original arrangement the sprinkler system was fed of the town main which is not current practice as this supply is not guaranteed to provide a minimum water flow and pressure. By upgrading the water supply to a full capacity tank to fully comply with BS EN 12845:2004 and extending this to all areas within the building which were previously not covered, this system was being brought up to a modern day standard. The presence of an automatic sprinkler system with this supermarket offers a major benefit in terms of controlling a fire in its early growth stages, and restricting the spread of this within the building. This sprinkler system would inherently present the Fire Service with a smaller fire size in comparison with an unsprinklered fire, where access to the building may not even be possible due to the severity of a fast fire growth rate associated with retail.

The layout of this supermarket shelving was also considered in relation to the overall building height. The standard shelving system has a height of around 1.8m with a distance between shelves of no less than 2.7m. This shelving configuration would offer a restriction on the possibility of fire spread. One of the major benefits of this supermarket renovation was the proposals to increase the floor-to-ceiling height throughout.

A false ceiling was being removed, increasing the floor-to-ceiling height from around 2.5m to 3.4m. In addition to this a new double height space was being created towards the front of the supermarket offering a new entrance space. This space was up to 8.2m in height offering a larger volumetric space for smoke to accumulate within.

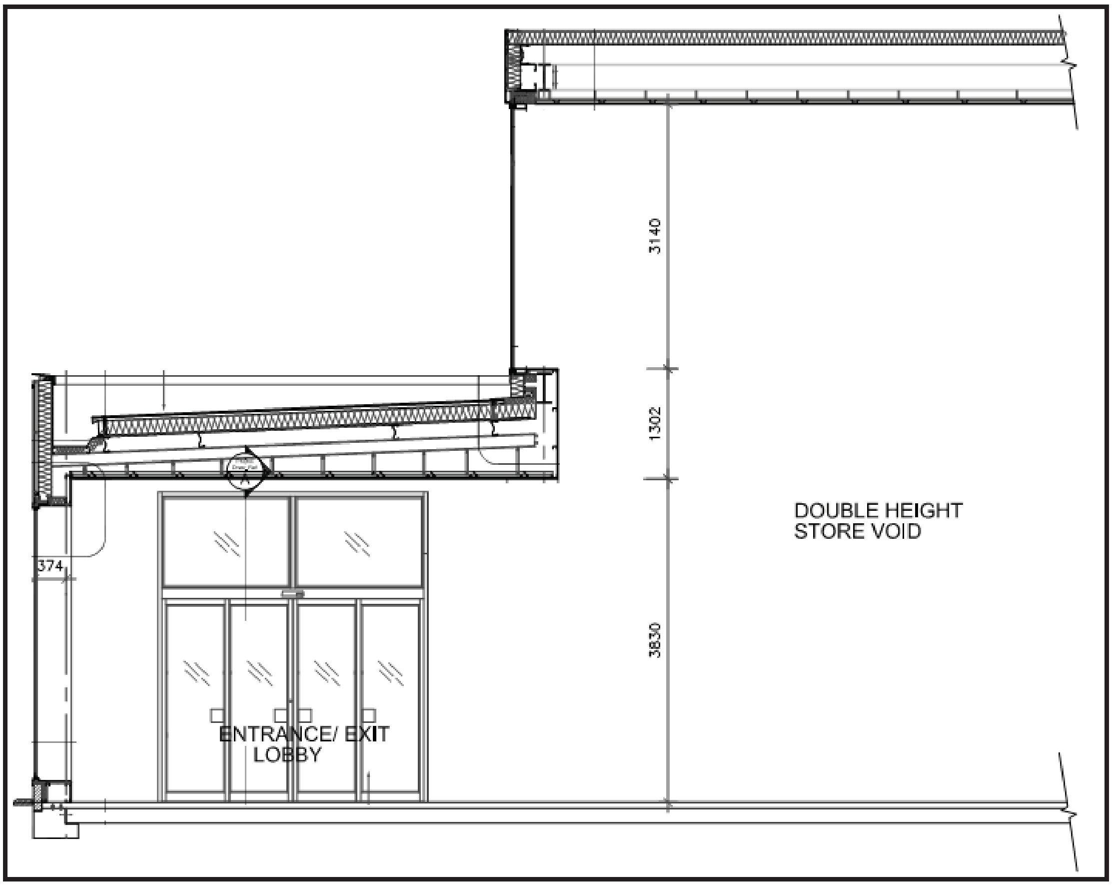

Fig. 13.6 New double height entrance space

13.4 CONCLUSION

By selecting a modern code that considers fire safety systems including: the internal floor-to-ceiling height; automatic fire alarm category and management levels, it was possible to redesign the means of escape provisions to make these more efficient and easier to manage on a day-to-day basis. In addition to this, it was also possible to design out the leaking natural smoke ventilation system by compiling a qualitative argument.

Maintaining clear exit routes and maintaining the smoke ventilation system proved very difficult to manage, and put the responsible person and the supermarket at risk of prosecution under the UK's Regulatory Reform (Fire Safety) Order which controls fire safety in occupied premises.

The means of escape assessment did not require complex numerical models and extensive parametric studies to address uncertainties within the design. The selected code which dealt with this (BS 9999: 2008) is sufficiently flexible, and offers clear benefits when taking into consideration aspects such as extensive ceiling heights which act as smoke reservoir space. As such, the uncertainty associated with deterministic modelling was avoided and a significant improvement implemented by removing complexity from the fire safety management scheme, at very reasonable cost to the client.

Acknowledgement

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