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Evaluating the fire safety performance of a building

Introduction to Fire Protection Engineering

Fire Protection Engineering is a developing discipline; it includes material science, structure strength, chemistry, fluid mechanics and touches many other domains such as medicine and psychology ([1], [2], [3]). Its goal is to reduce the number of deaths and injuries in fire accidents, to educate and train firefighters to improve their safety during interventions, and to reduce the cost of property damage. To this end, it is important to develop predictive tools to help engineers with their building designs by simulating complex problems like combustion, heat transfer, smoke spread, human behavior and evacuation. However, despite all these efforts, fire remains one of nature's most hazardous and unpredictable phenomena. The discipline therefore requires continuous research.

During the last decades, building codes have been shifting from prescriptive to performance based, in order to comply with the evolution of modern building design, or to allow using buildings for other purposes than primarily intended to, while still ensuring a sufficient level of safety. This approach strongly relates on the development and performance of Computational Fluid Dynamics (CFD) codes. In this article, the possibility of using the skating hall of Reykjavík (Skautahöllin) for rock concert is investigated, carrying a complete fire safety analysis by coupling results from CFD and evacuation software.



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Example of Fire Safety evaluation

Skautahöllin in Reykjavík was designed to accept 1000 to 1200 people for its regular intended usage. However, the owners now want to investigate the possibility to organize rock concerts, accepting about 4000 people inside the building. This configuration needs a completely new fire safety investigation, especially regarding the evacuation time during the early stage of the fire, when the concern is not yet temperature or structural strength but rather early evacuation and visibility, which can be quickly affected by smoke. Therefore, the smoke production and spread is simulated by using Fire Dynamic Simulator (FDS) [4], the most widely used CFD code within the fire research and engineering community. In parallel, the evacuation under fire is modeled using BuildingExodus [5], a code which is by considerable extent based on statistics, evacuation experiments and psychological studies on human behavior under fire threat ([6], [7], [8]).

Depending on the type of occupancy and the characteristics of occupants, the fire safety engineer determines a certain critical value under which the visibility is considered too poor to ensure acceptable evacuation conditions. In this case, we'll consider as safety criteria a critical visibility level of $V_{crit} = 10$ meters, which is generally admitted as a conservative choice.

Fire scenario and geometry

In this scenario, there is ignition which sets the stage on fire. The 20 m² burning stage creates a fire equivalent to a 10 MW polyurethane fast fire. On the roof are 3 smoke exhaust vents of 1 m² each which trigger after 120 sec. and are in full power (exhaustion flow rate $Q_{exhaust} = 20$ m³/s) after 180 sec. The area of the first floor is close to 2500 m² and the second floor (stand) close to 450 m². There are 9 different escape doors, 4 in the skating hall and 5 close to or at the main entrance of the building.

In order to check the safety in a conservative way, it is necessary to simulate cases when fire safety devices fail or unexpected problems occur. Statistics show that smoke exhaust systems fail to start and to work properly in roughly 20 % of cases. In addition, it often happens that one emergency exit door remains closed. Therefore, the combination of these 2 failures remains a likely scenario which will be simulated.

Results from fire simulation

As discussed earlier, the main concern for evacuation purposes is the visibility. It is important that it remains above V_{crit} at $z = 2$ meters from the floor. In addition, the visibility is also checked at the height of 6 meters for the people standing at the top of the stands. Figure 2 (left) shows the visibility in a cross section containing the fire. It shows a very clear two-layer condition, with fresh air close to the floor and hot smoke above. The visibility remains acceptable after 10 minutes at ground floor level, but is under critical value at the top of the stand. Figure 2 (right) shows a top view of the visibility at $z = 2$ meters from the floor shown after 12 minutes. At this time, the visibility is poor mainly on the left side and above the stand.

In addition to visibility slices, visibility probes are positioned in the center of the hall and above the stand. They give the time evolution of the visibility at certain heights (see Figure 3), allowing the determination of the time when the visibility becomes critical at $z = 2$ m and $z = 6$ m above the floor, shown in Table 1. The visibility is also calculated in the case the smoke exhaust system fails to start and vents do not open.

As shown by these results, the visibility becomes critical after 12:30° minutes on the ground floor and after 5:30° minutes at the top of the stands, when the smoke exhaustion system works properly. When the vents remain closed, these critical times fall to 8:30° and 4:40°

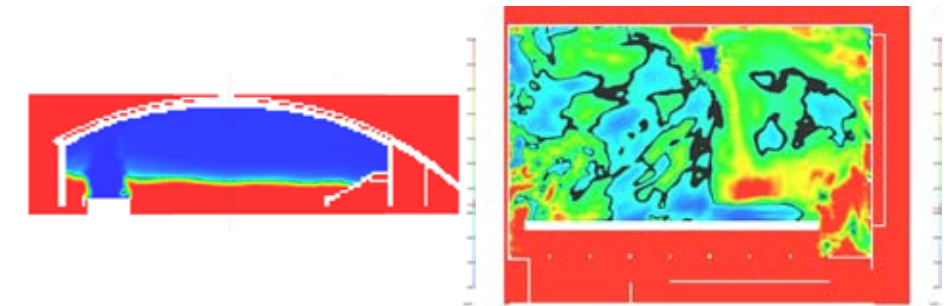


Figure 2: Visibility slices – Transversal view at $t = 10$ min. (left) and top view at $z = 2$ m after 12 min. (right).

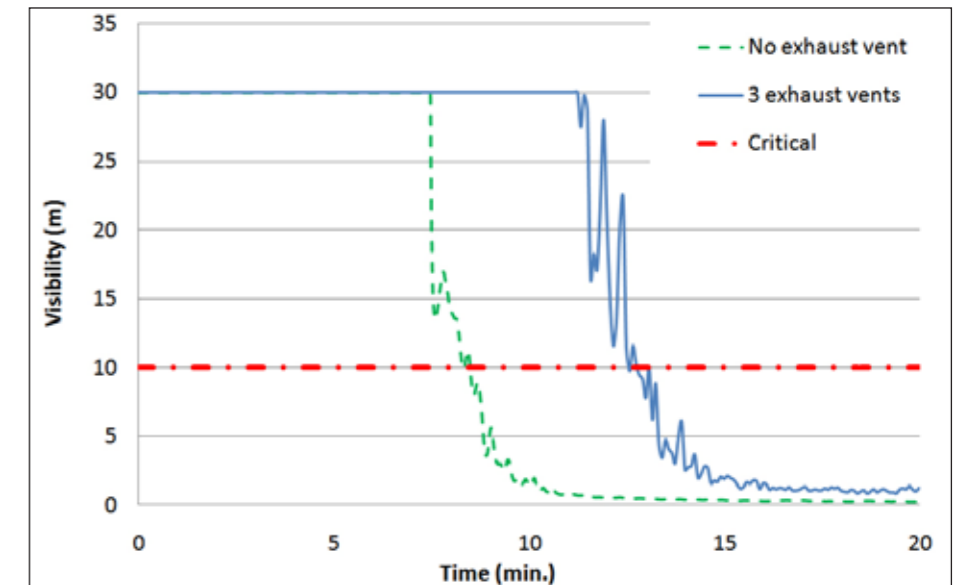


Figure 3: Time evolution of the visibility at the center with and without smoke exhaustion system working.

4:40° minutes respectively.

Evacuation simulation

The fire and smoke spread simulation has allowed the determination of the critical times, when complete evacuation must be achieved. The owner wishes to accept 3500 people on the skating ring (zone 1) and 600 on the first

floor (zone 2). Characteristics of the occupants, such as walking velocity, size and agility are set to be consistent with a young population from 20 to 35 years, who are most likely to attend a rock concert.

The time to be aware of the fire t_{aw} is estimated to be 50 sec. and the reaction time t_{react} to be 50 sec. Therefore, a total response time will be $t_{resp} = t_{aw} + t_{react} = 100$ sec.

The safety can be assessed by considering the

$$K_{safe} = \frac{t_{crit}}{t_{evac}}$$

factor K_{safe} , defined as the ratio between the evacuation time and the critical time:

If $K_{safe} < 1$, the safety level is not sufficient.

If $K_{safe} > 1$, the safety level is sufficient. However, it is necessary to consider a certain security delay to take into account unexpected problems such as panic or longer reaction time, and how familiar the occupants are with

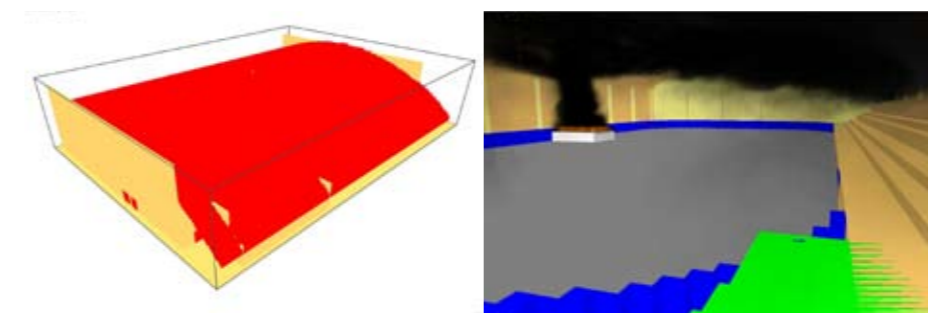


Figure 1: FDS model of Skautahöllin (left). Fire and smoke visualization after 3 minutes (right).

	Probe position	t_{crit} (min.) [Visibility < 10 m]
3 vents (3x1 m ²)	$z = 2$ m, middle of hall	12:30°
	$z = 6$ m, above stand	5:30°
No vents	$z = 2$ m, middle of hall	8:30°
	$z = 6$ m, above stand	4:40°

Table 1: Time to critical visibility

Case	Population	Evacuation time t_{evac} (min.)		3 vents		K_{safe}		No vents	
		2 nd floor	1 st floor	2 nd floor	1 st floor	2 nd floor	1 st floor	2 nd floor	1 st floor
1	4200	3:30 ^{o**}	7:50 ^o	1.57	1.60	1.33	1.09		
2	3700	3:30 ^{o**}	7:10 ^o	1.57	1.74	1.33	1.19		
2*	3700	3:30 ^{o**}	9:20 ^o	1.57	1.34	1.33	0.91		
3	2500	3:30 ^{o**}	5:20 ^o	1.57	2.34	1.33	1.59		
3*	2500	3:30 ^{o**}	7:00 ^o	1.57	1.79	1.33	1.21		

Critical times t_{crit}		
3 vents	5:30 ^o	12:30 ^o
No vents	4:40 ^o	8:30 ^o

(*) 1 exit blocked
(**) estimated time

Table 2: Population, evacuation times and safety factors for various configuration cases.

the evacuation routes. Therefore, engineers should take a safety factor higher than 1. How high depends mainly on how conservative were the choices made by the engineer for the simulation.

The evacuation is simulated for different number of occupants (see Table 2) in zone 1 (see Figure 4), but with fixed number of occupants in Zones 2 and 3 (100 and 600). The corresponding evacuation times are compared to the critical times defined earlier, and K_{safe} is calculated. As recommended by guidelines, tests with one of the exit doors blocked are also simulated (case 2* and 3*).

The results show that the safety is not sufficient

in the worst case ($K_{safe} = 0.91 < 1$) for 3700 people if vents are not functioning and one exit door closed (case 2*). For 2600 people, the safety level is sufficient ($K_{safe} > 1.2$), even with the 2 failures in the safety system.

Prescriptive based methods based on recommendations from building regulations [9] allow calculating the maximum number of people as a function of the size and number of emergency exits. Applying this method to the skating hall gives a maximum close to 1800 people.

Conclusion

In this article, we have described the fire safety investigation process for new or existing

building, using both CFD and evacuation models. As an example, the fire safety of the skating hall in Reykjavik is tested in a very different configuration than the intended use was, with a rock concert hosting about 3 times the normal population of the hall.

The fire and smoke simulation carried out using the CFD software FDS gave the critical time for evacuation, which was then compared to results from an evacuation model built with BuildingExodus, tested for various populations and exit conditions. It appeared that the evacuation time remained smaller than a critical time based on visibility conditions, showing that both the smoke exhaustion system in the roof and the emergency routes created a sufficient level of safety in the case safety devices work properly. However, failures must be considered while assessing the safety of a building, and authorities and fire safety engineers should always make conservative choices and carry out sensitivity analysis to account for possible unexpected problems. The performance based evacuation simulation suggested that the level of safety wasn't sufficient for 3600 people (case 2) in the likely case of 2 failures in the system. The prescriptive method suggested a significantly lower value close to 1800 people, but the safety level for 2600 people ($K_{safe} < 1.2$; 1½ minute safety delay) was confirmed to be sufficient considering the conservative choices made during the simulations.

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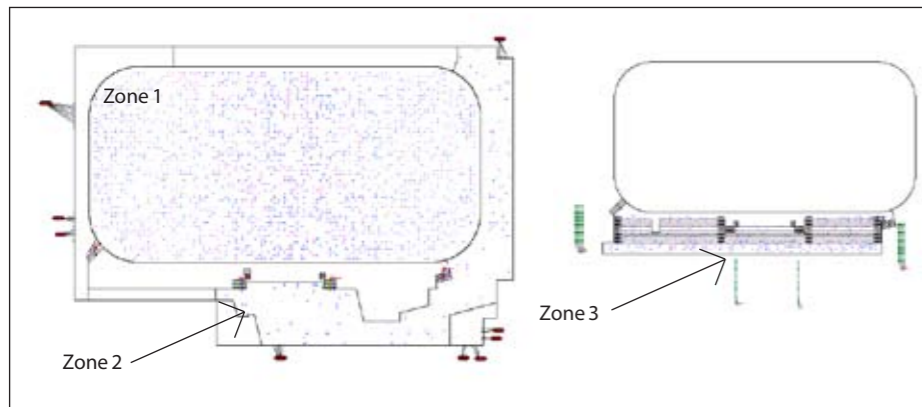


Figure 4: Evacuation modeling in case 2: population at t=0 on 1st (left) and 2nd floor (right).

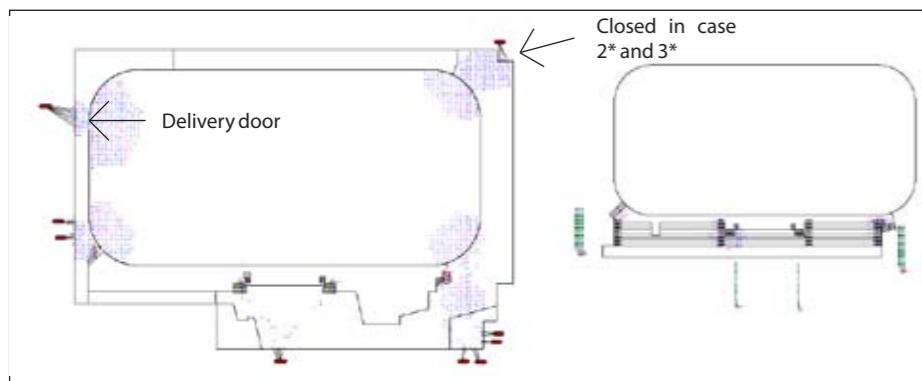


Figure 5: Evacuation modeling in case 2: population at t=3 min. on 1st (left) and 2nd floor (right).



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