

Fire Safety Design, Means Of Egress And Fire Modelling With Sprinkler Actuation In A High Multifunctional Sports And Events Hall – Case Study



Judit Rauscher – assistant lecturer at University of Public Service, Institute of Disaster Management, Hungary – rauscher.judit@uni-nke.hu

Csaba Szikra - teacher at Budapest University of Technology and Economics, Department of Building Energetics and Building Services, Hungary – szikra@egt.bme.hu

Lajos Gábor Takács PhD - associate professor at Budapest University of Technology and Economics, Department of Building Constructions, Hungary – ltakacs@epsz.bme.hu



The Multifunctional Sports and Event Hall - MVM Dome



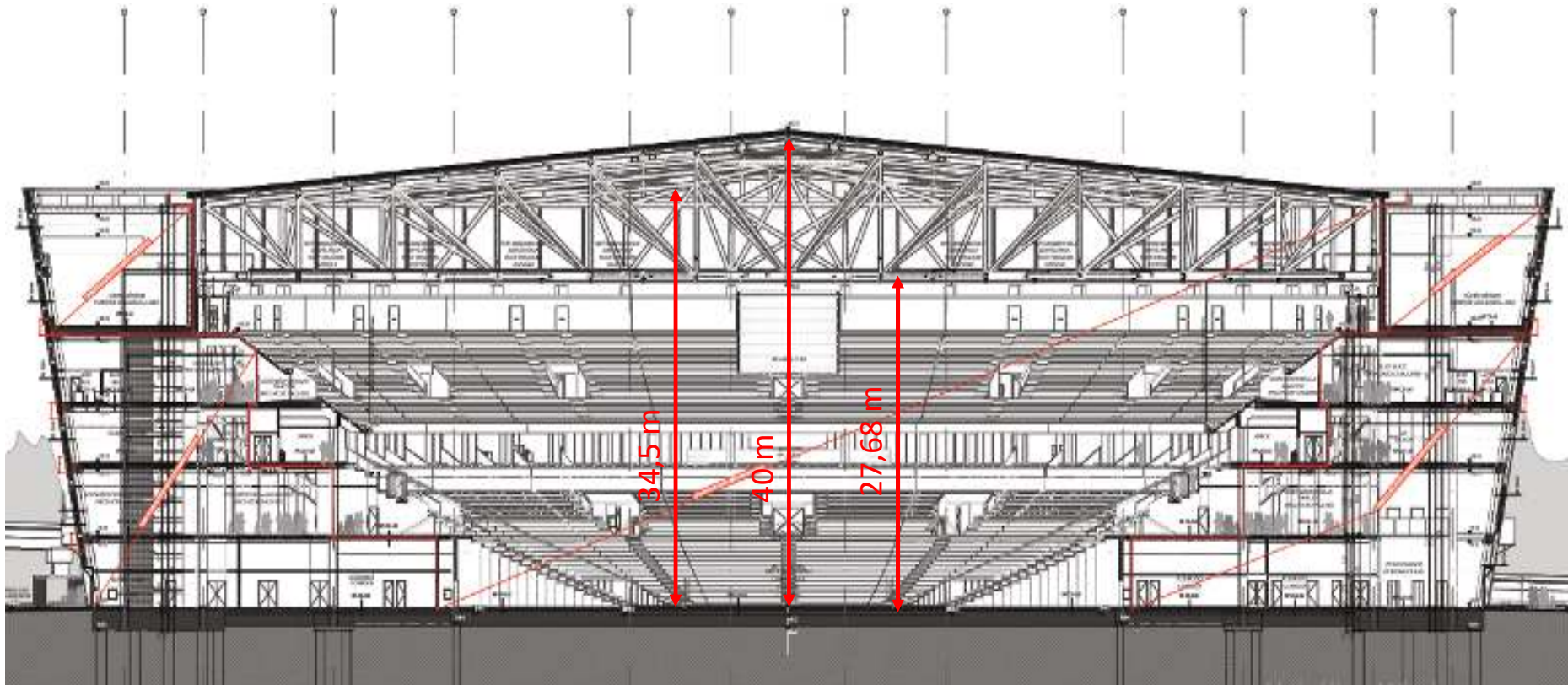
Basic fire safety data of the MVM Dome are the following:

- ground floor + 5 floors + rooftop HVAC level; there is no basement
- the highest floor level is at +23,25 m
- seating area 20.000 people, for events around 24.000 guests
- net floor area 51.750 m², divided to 17 fire compartments
- automatic fire detection and alarm system and a wet sprinkler system
- a public address system
- pressurized staircases and mechanical smoke and heat ventilation with natural air supply in the event hall
- at circulation areas a smoke control system with reversible mechanical smoke exhaust and air supply points

@ wikipedia.hu @ kozti.hu @ authors



Sprinkler actuation problems in the Event Hall



Main problems:

- Clearance is significantly more than 12 m – there are no full-scale sprinkler tests for this clearance
- „skipping” hazard of the sprinklers



Sprinkler actuation problems in the Event Hall

MSZ EN 12845:2015+A1 about sprinklers,

7.7.2.1: authorities shall be consulted for buildings exceeding 12 m.

Hungarian guideline “Planning, Design and Installation of Fixed Firefighting Systems” [2], as follows:

4.2.2. If the ceiling height exceeds 12 m, in any hazard class, a K factor of minimum K115 and quick response ($RTI < 50(m^s)^{1/2}$) sprinklers are recommended.

4.2.3. In case of high hazard (HHP or HHS), when the clearance between the highest intermediate sprinkler levels (f.i. in-rack sprinklers) and the ceiling sprinklers, or without intermediate sprinkler levels the headroom exceeds 15 m, K factor of minimum K160 and quick response ($RTI < 50(m^s)^{1/2}$) sprinklers are recommended as ceiling sprinkler system.

4.2.4. At the hydraulic calculations, requirements of the MSZ EN 12845:2015+A1 standard concerning to the given hazard classification are recommended.

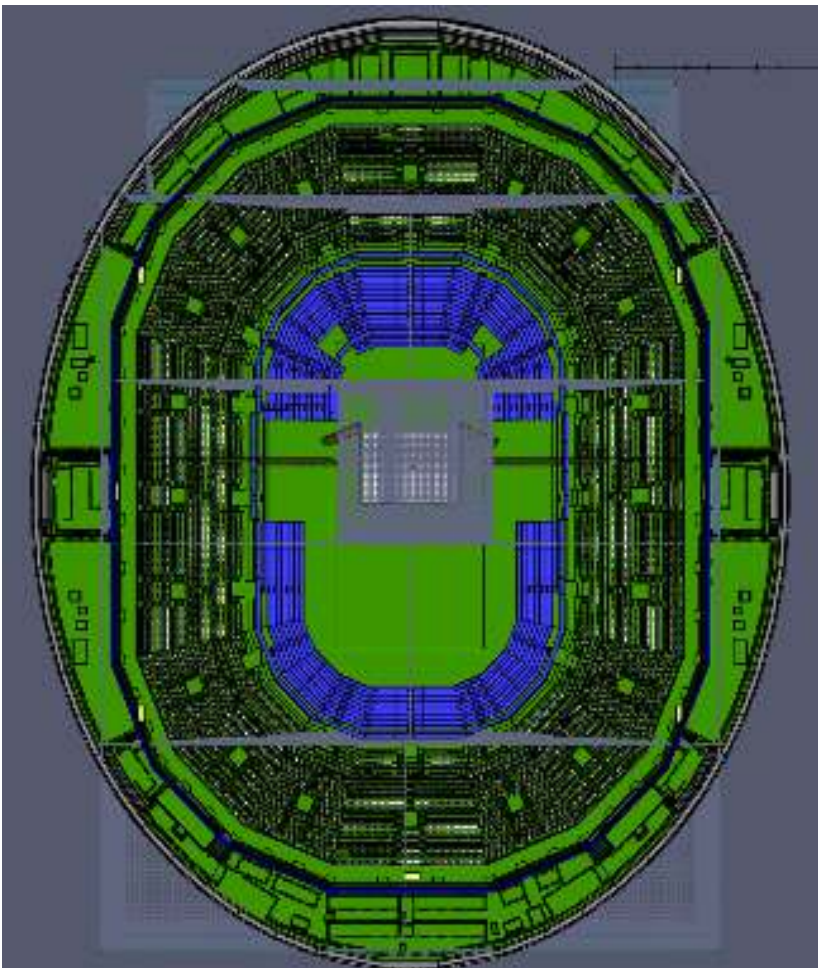
Note:

The above mentioned points are based on full-scale fire tests testing and minimizing the so-called skipping effect at high ceiling areas.

The note refers to full scale fire tests, which are extremely important at validation of the fire modeling results at any jobs.

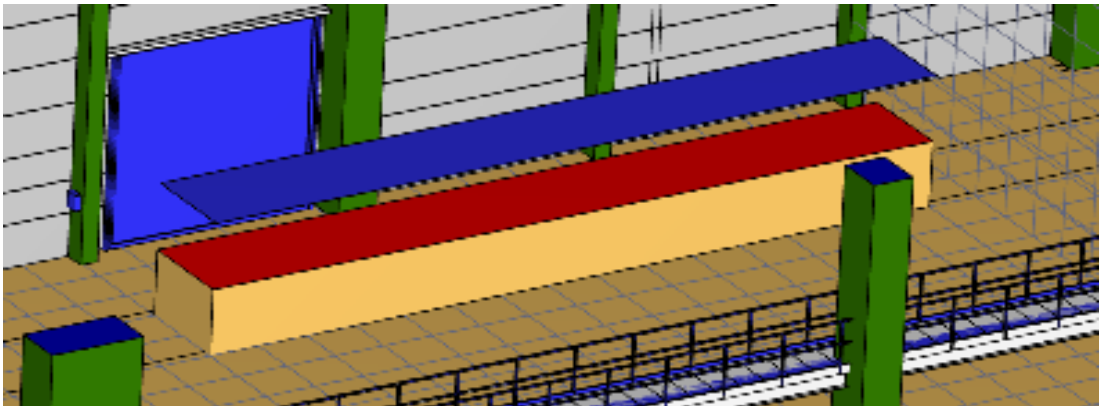
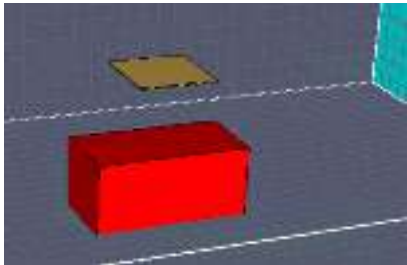
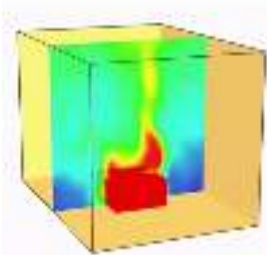


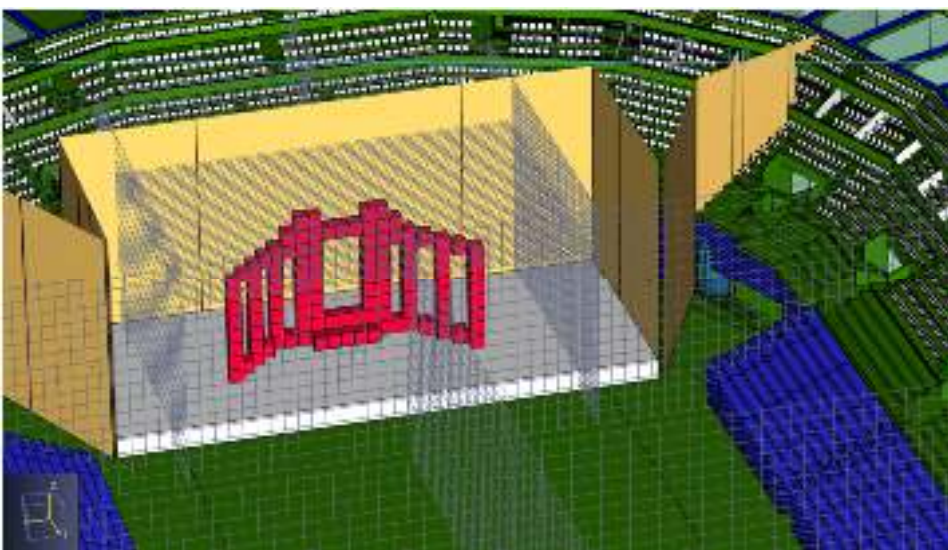
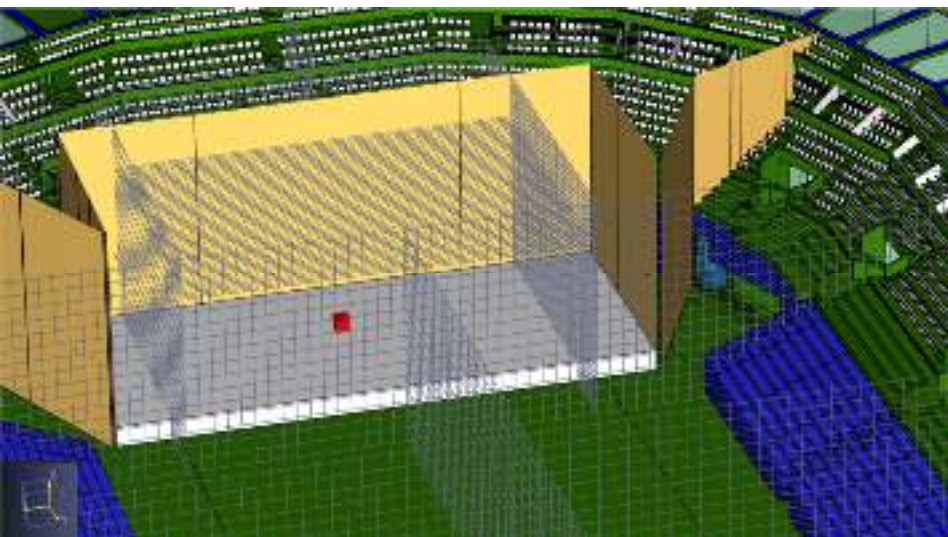
Sprinkler actuation problems in the Event Hall



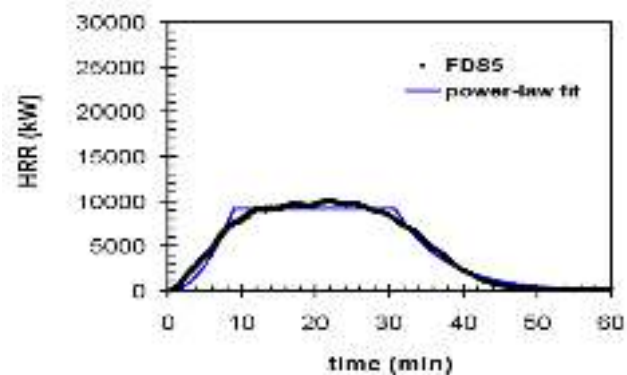
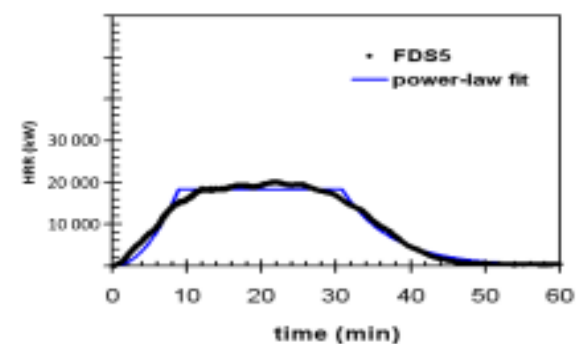
Sprinklers used in the Event Hall:
quick-response extra-large-orifice (QRELO)
K factor 160, activation temperature 68 °C, RTI28.

Fire sources at pre-determined fire scenarios are usually represented by rectangular objects





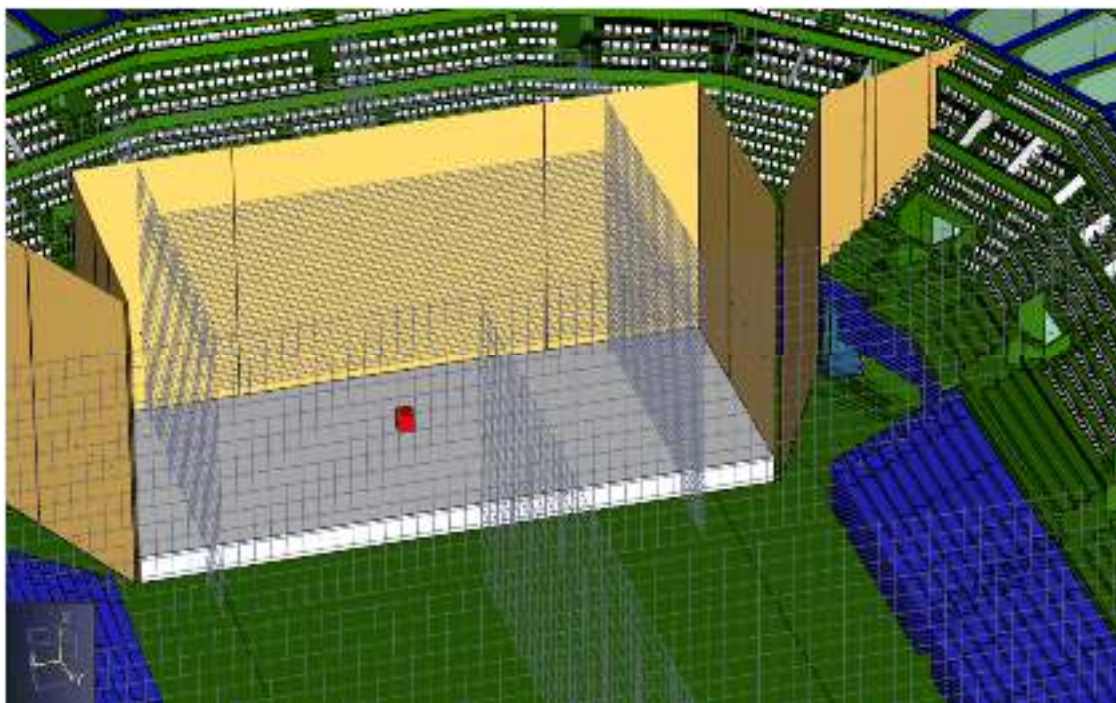
Fire scenarios in the Event Hall



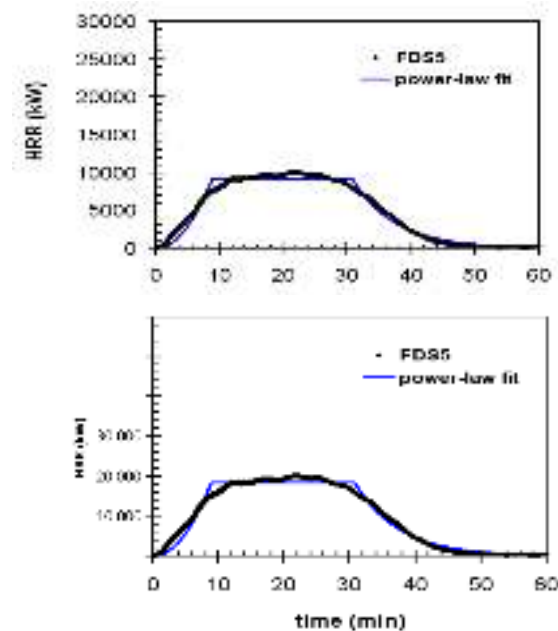
Fire scenarios:

- 1,8 MW in the spectator's area
- 10, 20, 25 and 30 MW on the stage – represented with simple or complicated obstruction



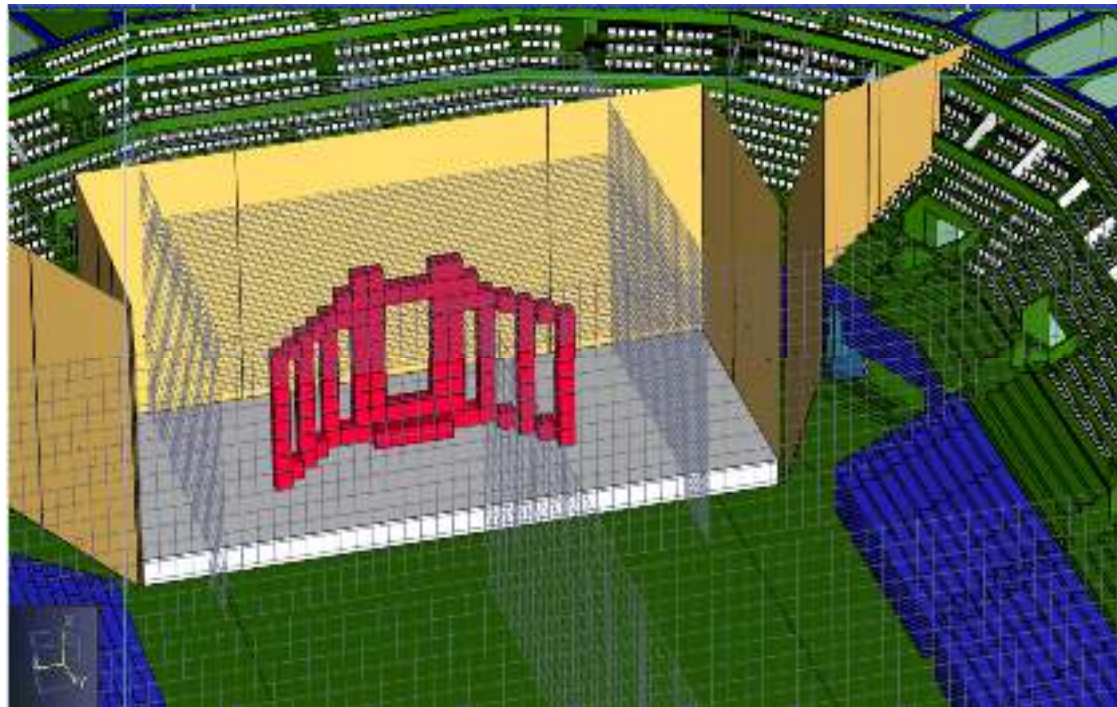


Fire scenarios in the Event Hall

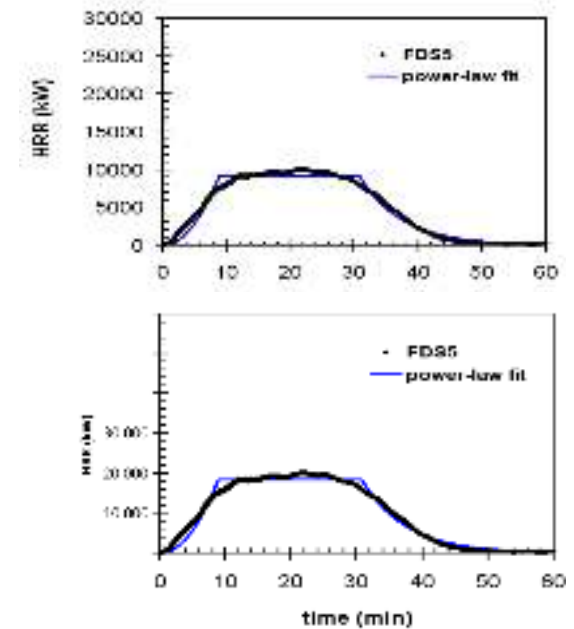


Fire scenario	Peak heat release rate	Activated sprinklers	Sprinkler activation time	Fire scenario	Peak heat release rate	Activated sprinklers	Sprinkler activation time
19/A (end stage)	10 MW	3	422,7- 438,2 s	23/B (end stage)	20 MW	6	422,5- 485,6 s
21/A (side stage)	10 MW	1	432,0 s	23/B (side stage)	20 MW	10	402,2-706,0 s
23/A (center stage)	10 MW	1	426,8 s	23/B (center stage)	20 MW	6	400-973,3 s
25/A (2/3 stage)	10 MW	1	811,2 s	25/B (2/3 stage)	20 MW	6	449,5- 509,7 s



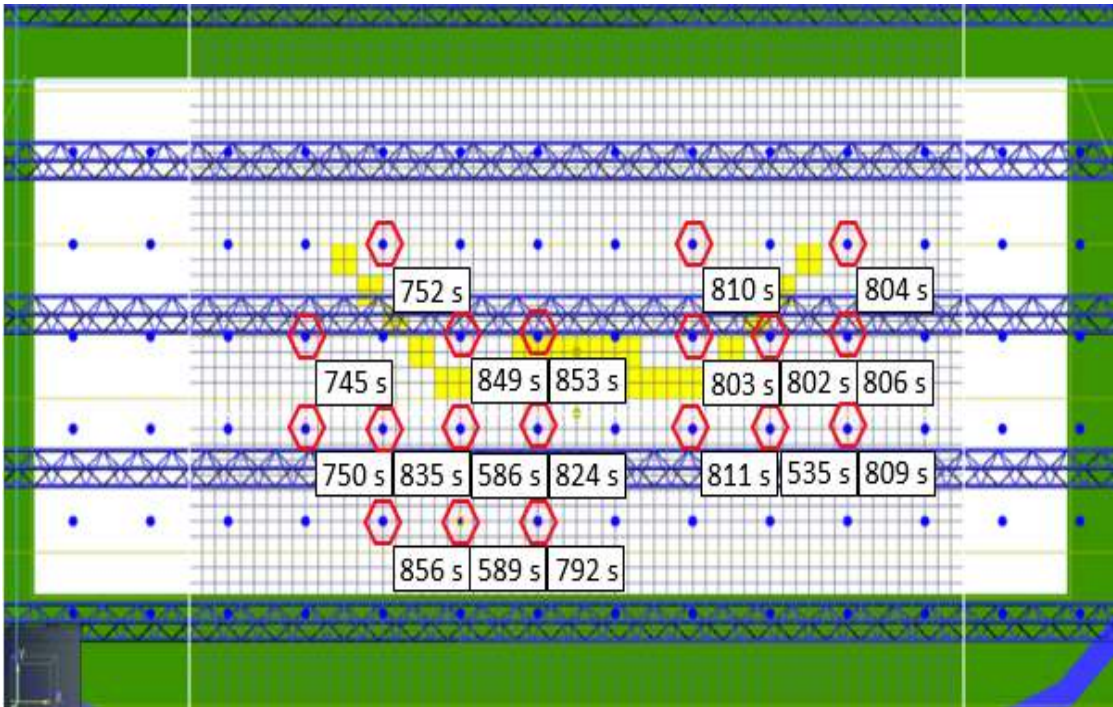


Fire scenarios in the Event Hall



Fire scenario	Peak heat release rate	Activated sprinklers	Sprinkler activation time
19/A (end stage)	20 MW	-	-
19/A (end stage)	25 MW	4	862-1009
19/A (end stage)	30 MW	18	535,3-856,6





All the above mentioned design goals can be tested only with fire modelling; prescriptive standards, guidelines cannot provide methods for the proper design.

Consequences

- **multifunctional use:** several kind of fire scenarios are possible so a wide range of design fire scenarios must be tested (HRR, fire source form)
- **sprinkler activation time** strongly depends on the heat release rate curve: at higher peak HRR, more sprinkler heads are activated; when the peak HRR is less than 10 MW, in the Event Hall no sprinkler activation happened due to the high clearance; fire fighting intervention possibilities must be always provided - fire brigades can extinguish small and middle size fires while large fires are controlled by sprinklers providing conditions to the fire brigades to extinguish the fire;
- to avoid extensive **sprinkler skipping**, sprinkler activation times and patterns must be checked at every fire scenario and if there are skipping problems, sprinkler design or even the smoke and heat ventilation must be modified.



FDS simulation – Hungarian regulation – detailed requirements

Fire-, smokespread and evacuation modelling”, Fire Protection Technical Guideline, TvMI 8.5: 13-06-2022

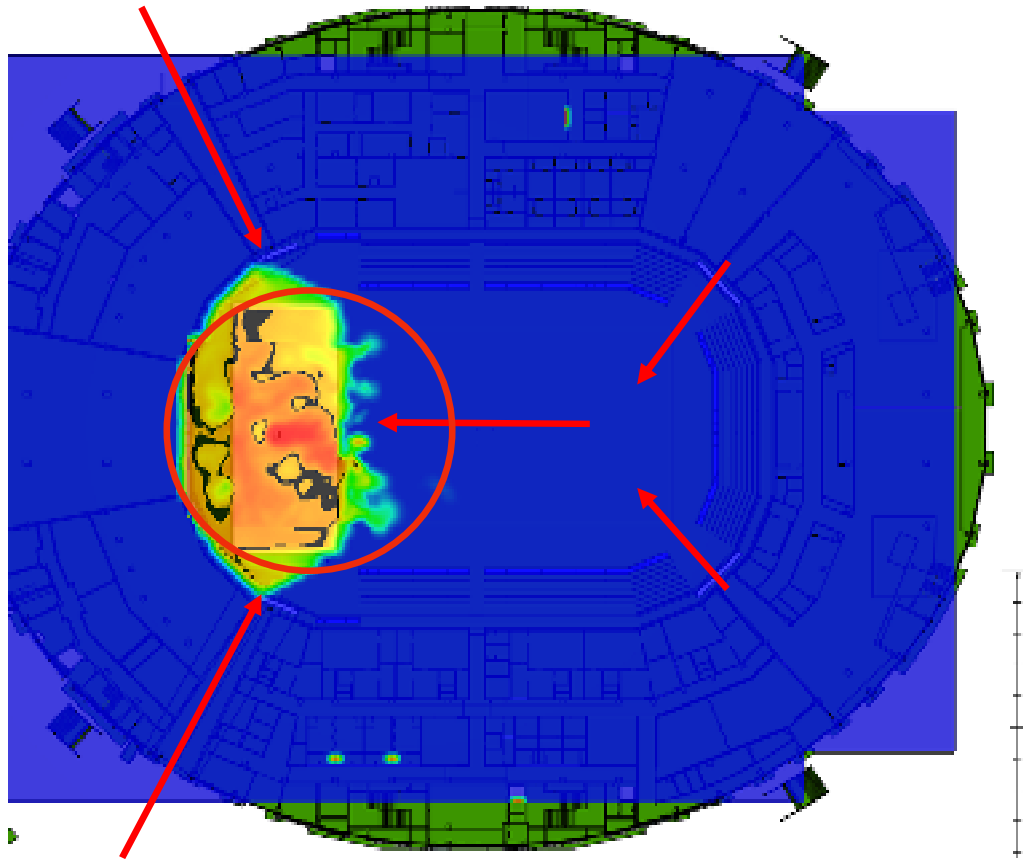
Total emergency response time must be precisely calculated

Leaving the fire department:	2,0 mins
Travel time with average speed of 30 km/hrs (0,5 km/mins)	≈ 5,0 mins
fire reconnaissance, setting time:	3,0 mins
building that is above 5000 m ² ground area	extra 1,0 min
more time is needed in case of a different level of the building level:	
first floor (lower concourse area):	extra 1,0 min
second floor (VIP level):	extra 3,0 mins
third floor (upper concourse):	extra 4,0 mins
fourth floor (HVAC level):	extra 5,0 mins
Total response time calculations:	
ground floor fire scenarios:	12,0 mins (720 s)
first floor fire scenarios:	13,0 mins (780 s)
second floor fire scenarios:	14,0 mins (840 s)
third floor fire scenarios:	15,0 mins (900 s)
fourth floor fire scenarios:	16,0 mins (960 s)



FDS simulation – Hungarian regulation – detailed requirements

Fire-, smokespread and evacuation modelling”, Fire Protection Technical Guideline, TvMI 8.5: 13-06-2022



Within the total firefighting response time:

- Further distance than 25 meters measured from the fire source the visibility shall not be lower than 5 meters at that exact moment when the firefighter intervention begins. 25 m radius is represented with a circle around the fire source.
- To ensure the conditions of the intervention visibility slice should be set in case of every fire locations at $Z = 2$ m height.

Slice
VIS_Soot
m

31.5

28.4

25.3

22.2

19.1

16.0

12.9

9.80

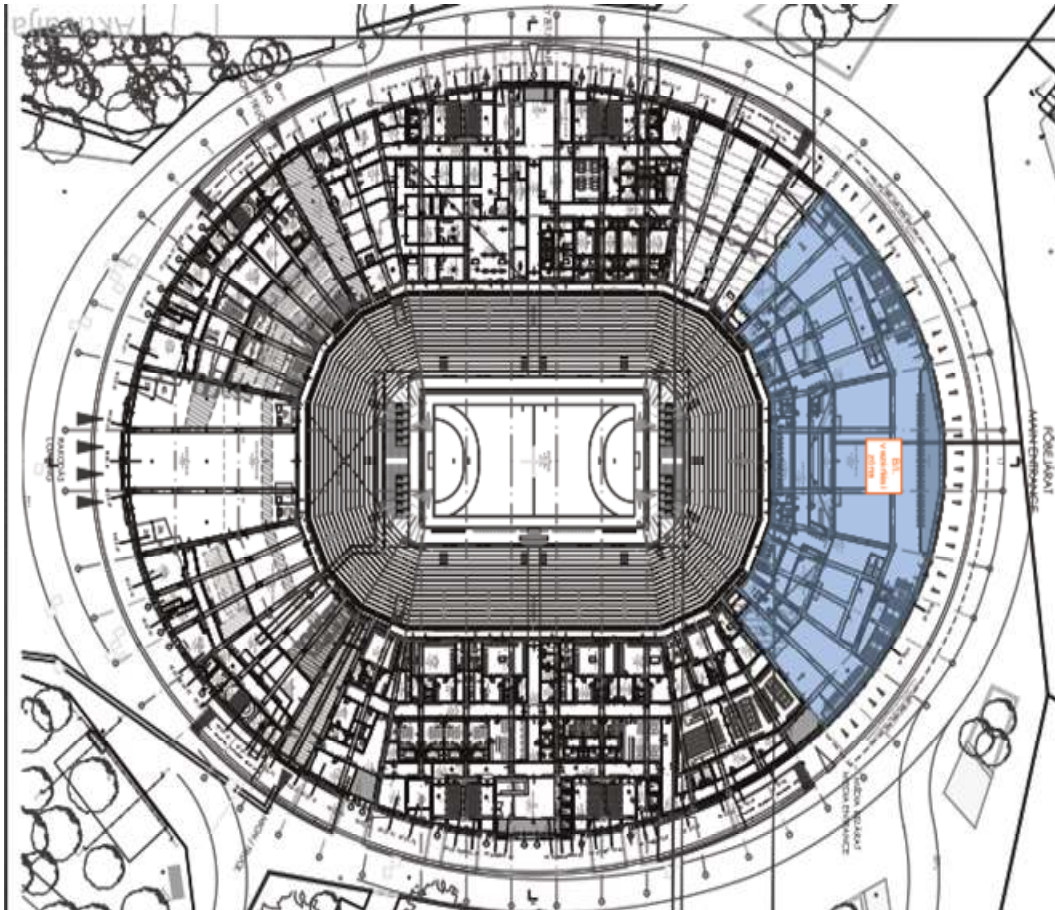
6.70

5.00

0.50



Smoke and heat control system – concourse areas



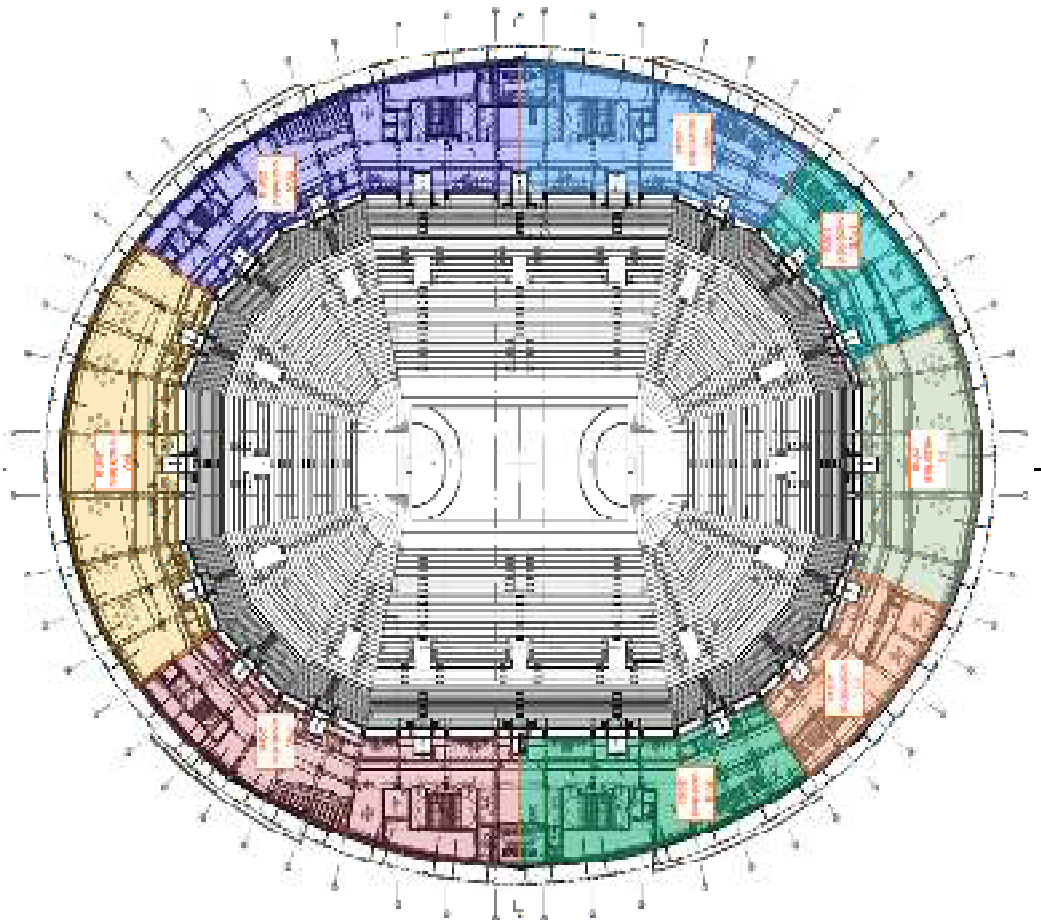
Virtual smoke compartments are designed with reversible mechanical smoke and heat exhaust and air supply points in every control zones; vent points have 27.000 m³/h, 54.000 m³/h and 60.000 m³/h exhaust or supply capacity.

Operation of the smoke and heat ventilation:

- mechanical smoke and heat ventilation starts in the closest virtual smoke compartments to the fire source;
- mechanical air supply ventilation is activated in two virtual smoke compartments next to the smoke compartments where the smoke exhaust had been started,
- emergency exits on the ground floor serving as natural auxiliary air supply openings are always activated.



Smoke and heat control system – concourse areas



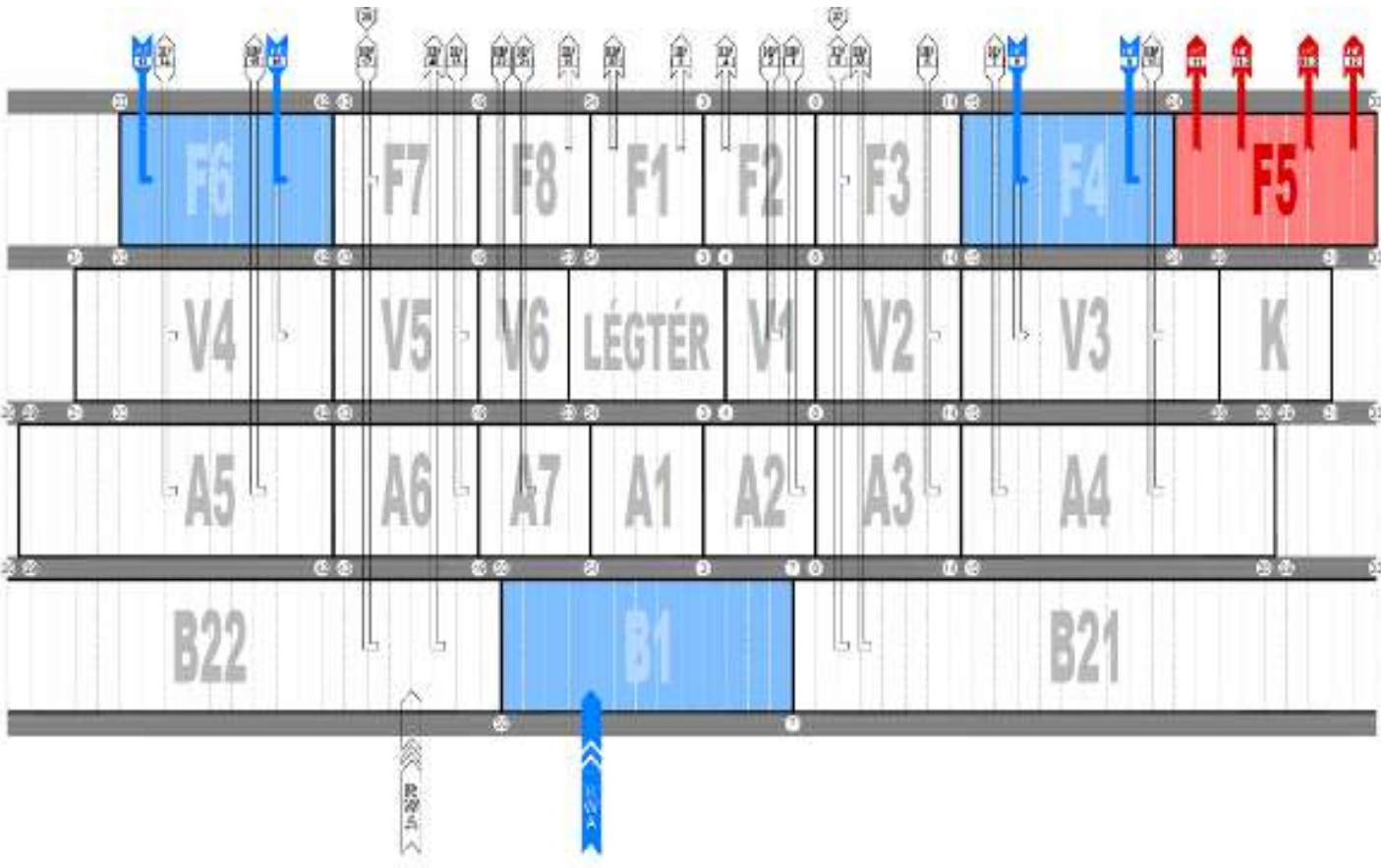
Virtual smoke compartments are designed with reversible mechanical smoke and heat exhaust and air supply points in every control zones; vent points have 27.000 m³/h, 54.000 m³/h and 60.000 m³/h exhaust or supply capacity.

Operation of the smoke and heat ventilation:

- mechanical smoke and heat ventilation starts in the closest virtual smoke compartments to the fire source;
- mechanical air supply ventilation is activated in two virtual smoke compartments next to the smoke compartments where the smoke exhaust had been started,
- emergency exits on the ground floor serving as natural auxiliary air supply openings are always activated.

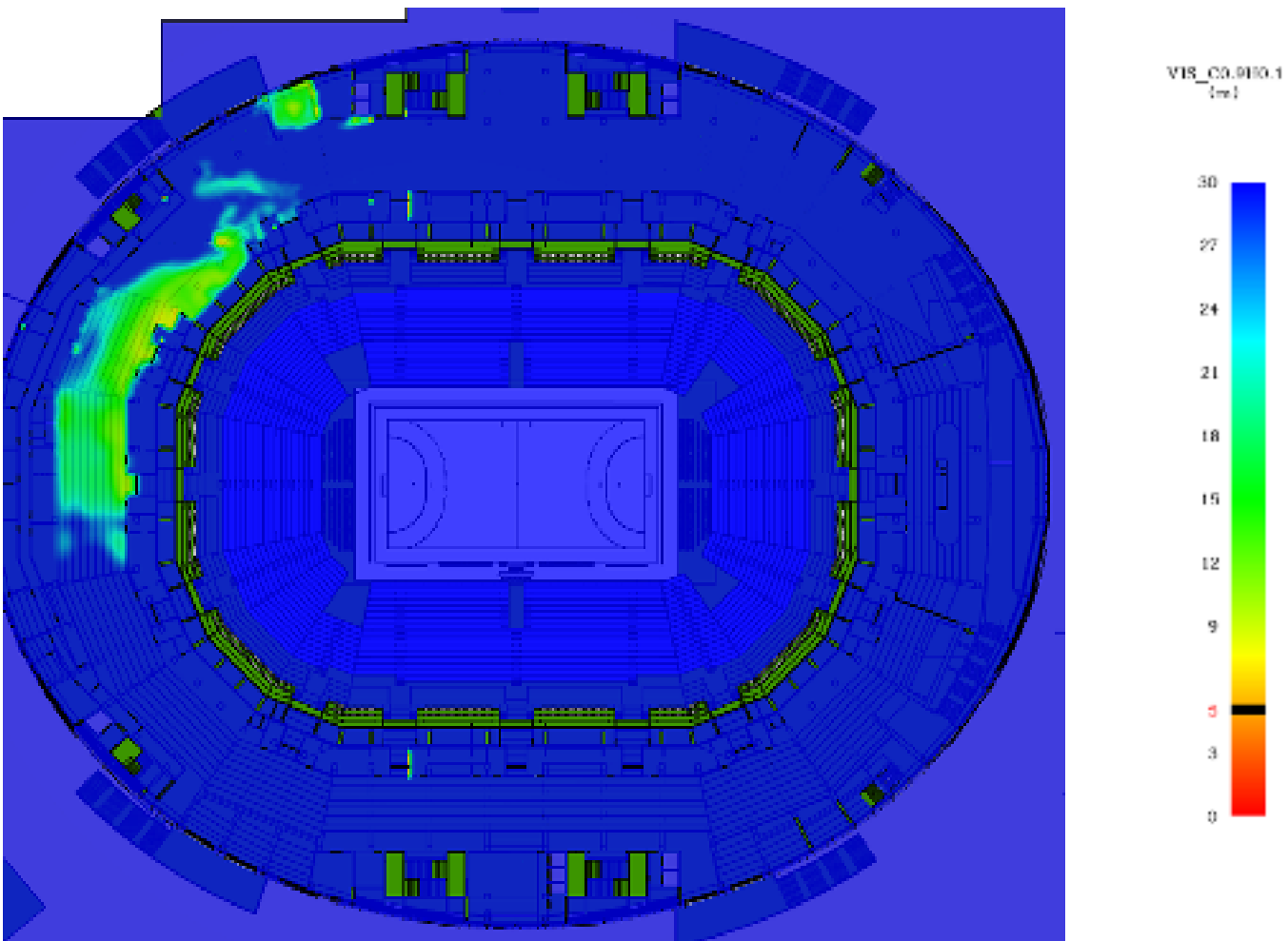


Smoke and heat control system - concourse areas



- there are no smoke barriers just virtual smoke zones
- fires under 1 MW can be controlled with the designed system
- where larger fires expected (f.i. in buffets)
 - despite of the sprinkler system - were separated from the concourse area with active fire curtains

Smoke and heat control of the concourse areas - results



- There are no smoke barriers just virtual smoke zones
- fires under 1 MW can be controlled with the designed system
- where larger fires expected (f.i. in buffets)
- despite of the sprinkler system - were separated from the concourse area with active fire curtains



Means of Egress – Hungarian regulation

A scenario is defined by the following characteristics:

- the usage layout
- initial agent number and their distribution
- geometry
- characteristics of the agents
- duration before evacuation
- characteristics and effects of the fire



Hungarian legislation [3] says:

„only that the worst case scenario needs to be checked...”



we believe that with an engineering approach this may not be enough (without testing)

Options for verification of egress process:

1. observing geometric parameters
2. calculations
3. evacuation simulation



Prescriptive code

- legal requirement for the period of movement for event hall 90 s
- pre-movement time 0 s
- for calculations walking speed 0,67 m/s

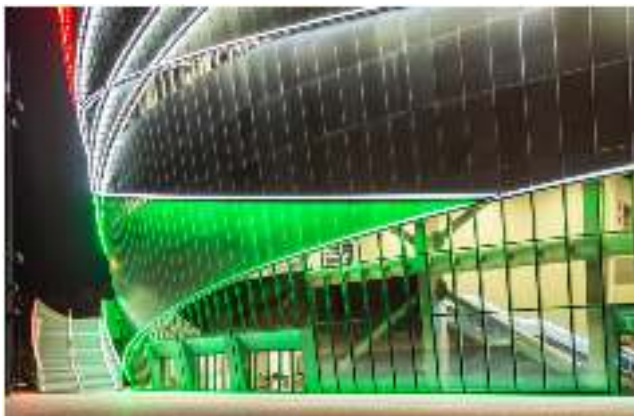


Evacuation simulation

- determining the ASET time by FDS simulation
→ visibility > 15 m, 2 m above floors
- determining the RSET time by Pathfinder simulation
- pre-movement time 30 s (approved by authority)
- walking speed 0,59-1,19 m/s



Circulation areas and evacuation routes



external escape stairs



main entrance lobby



circulation area



main stairs in the lobby



staircases



Event Hall - grandstand



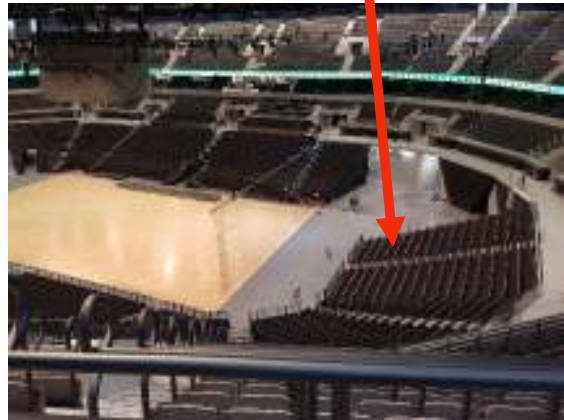
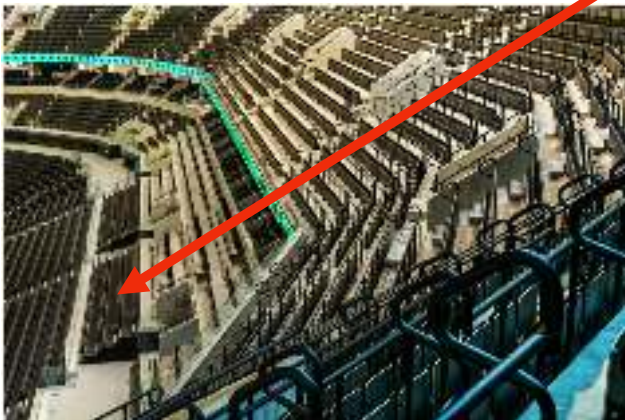
full grandstand



view from 3 m high steel beams



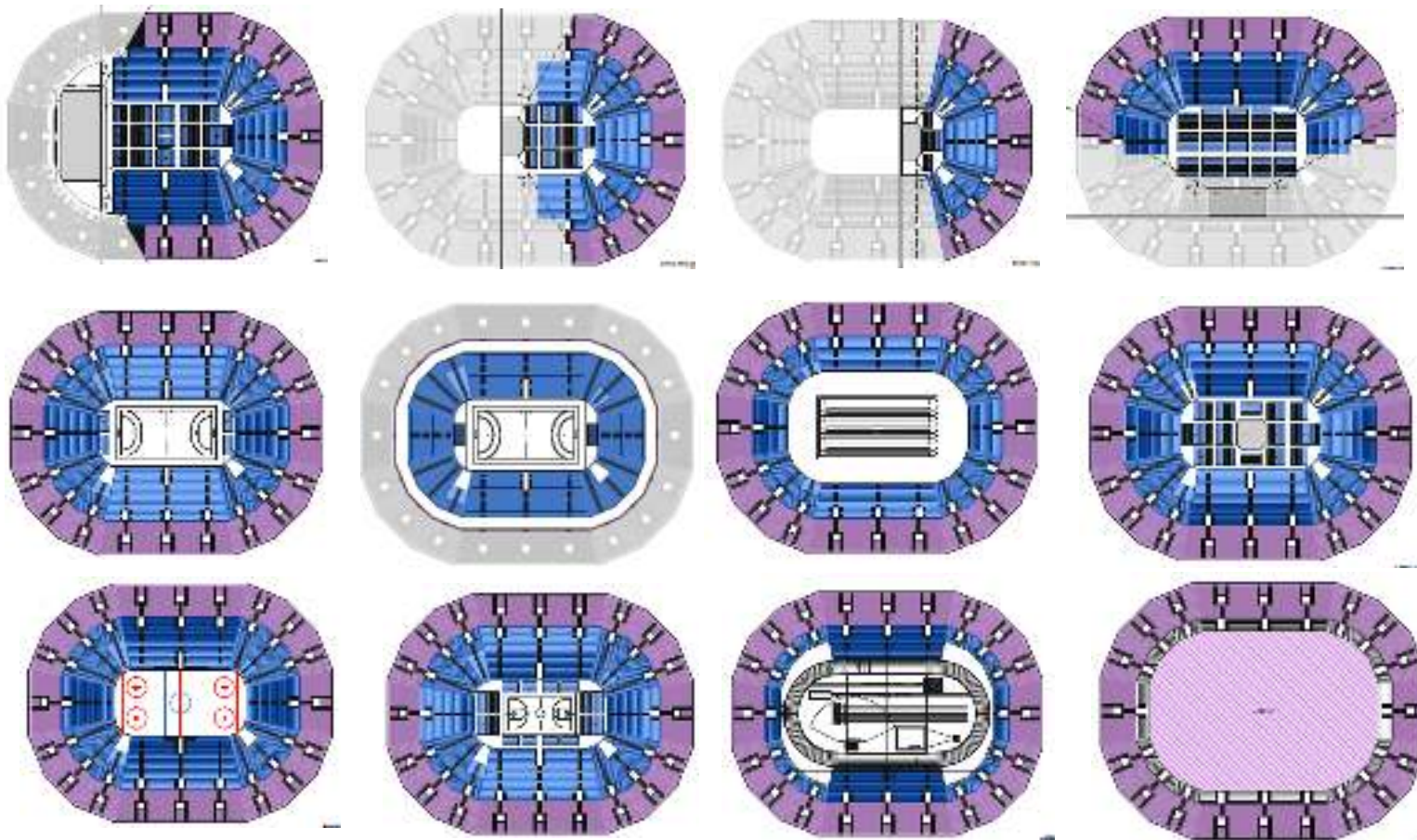
lower grandstand



mobil stands



Multi-functional event hall – evacuation scenarios



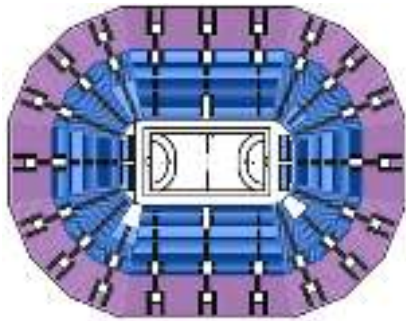
CONCEPTUAL PLAN

12 USAGE LAYOUT
planed by the
architect

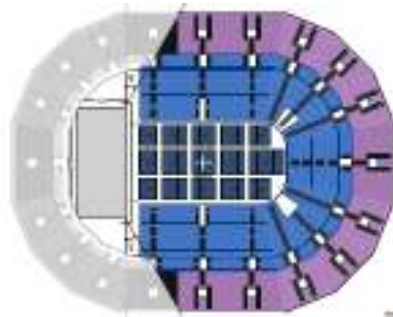


Multi-functional event hall – evacuation scenarios

PERMIT PLAN



CONSTRUCTION PLAN



only basic layout, tested with fireplaces, but so it is not "multi"

1 usage layout (handball with full grandstand) + 6 fire scenarios » 3 merged simulation results

must be "multi"
...
full lower grandstand mobile

SPORTS

handball, basketball, futsal, volleyball, tennis, badminton, athletics, gymnastics, boxing, wrestling, dodgeball, fencing, weightlifting, archery, roller-skating, rsg, dance, swimming, ice hockey, curling ...

EVENTS

end, half, third stage, side stage + standing and/or seated auditorium

OTHER

exhibition, fair, monster truck show ...

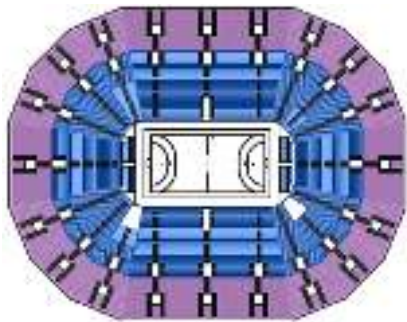
checking typical or extreme situations

14 usage layouts + 39 fire scenarios » 29 merged simulation results



Multi-functional event hall – evacuation scenarios

END OF BUILDING PROCESS



14 usage layouts + 19 fire scenarios » 16 merged simulation results

BUILDING OPERATION

LOWER GRANDSTAND	STAGE POSITION	VISITORS
full	end stage	seats only
3 rows pushed in	half stage	seating and standing areas
8 rows pushed in	third stage	seating and standing areas, with priority standing area
11 rows pushed in	side stage	
	center stage	

for events at least $4 \times 5 \times 3 = 60$ usage layouts
+ 8-10 more layouts for sport events
+ check of special cases

at least 60 usage layouts + 15 fire scenarios »
??? merged simulation results



Evacuation simulation parameters

REGULATION

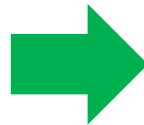
- minimum visibility 15 m
- 2 m height above floor

PRE-MOVEMENT TIME

- spectators, visitors 30 s
- staff 30-60 s
- *simplification in agreement with the authority*

NUMBERS

- worst case in each layout – maximum visitors and staff
- wheelchair user – as designed place (12-60)
- visually impaired – 0,83%



AGENTS			
agent type	size (cm)	speed (m/s)	note
spectator, attendant, player, staff	45,58	1,19	default
independent wheelchair users	70/120	0,79	size and form by ISO 7193, speed based on domestic measurment
assisted wheelchair user	70/120	1,19	The internationally published speed for wheelchair users exceeds the commonly used default setting and is therefore not used.
person with reduces mobility	66,00	0,59	Speed based on domestic measurment
visually impaired person	45,58	1,19	The internationally published speed for wheelchair users exceeds the commonly used default setting and is therefore not used.

basic layout (handball) ≈20.460 visitor + 1.540 staff

end stage ≈16.500-17.600 visitor + 1.300 staff

side stage ≈12.500 visitor + 1.350 staff

central stage ≈24.100 visitor + 1.350 staff

ice hokey ≈19.400 visitor + 1.540 staff



Evacuation videos



ISO SURFACE

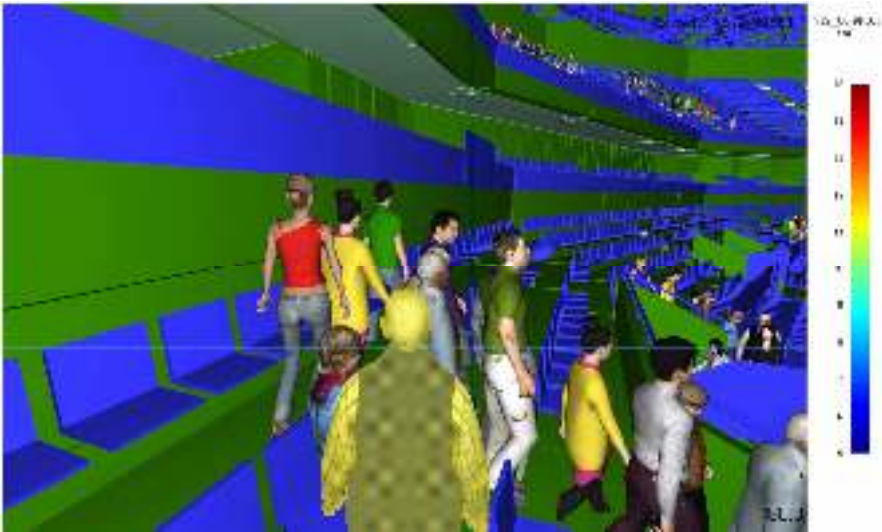


Evacuation videos



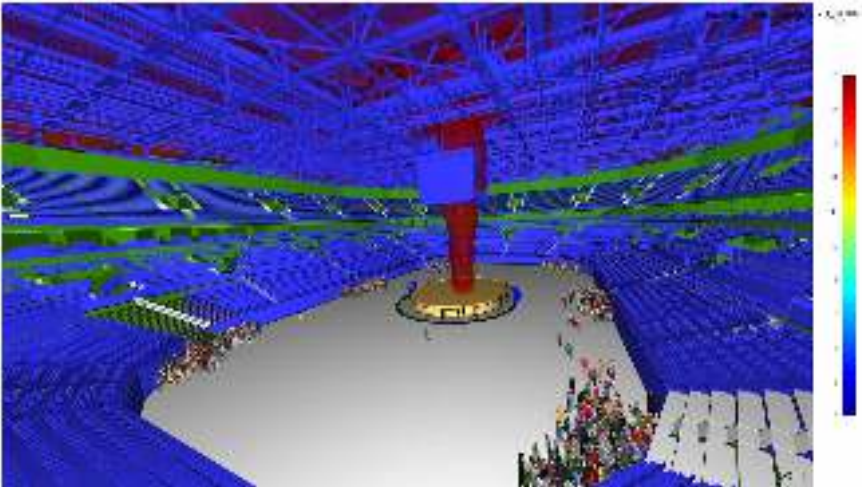
ISO SURFACE or
3D SMOKE

environment perceived
by people

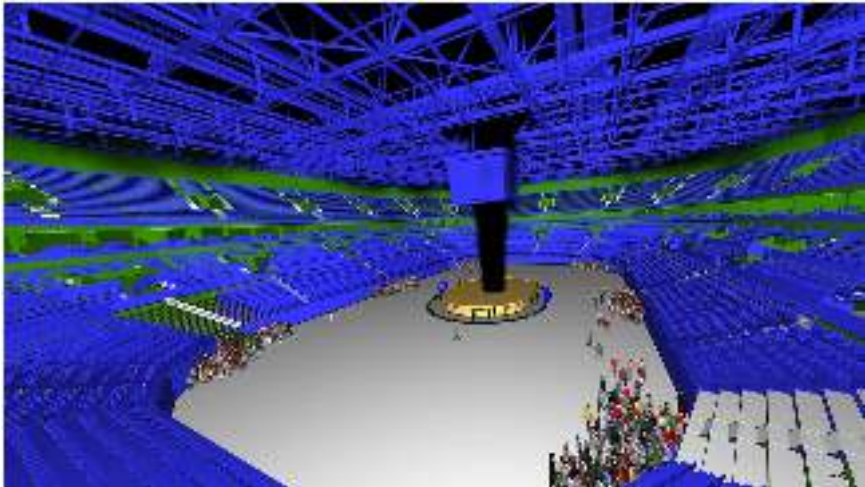


Evacuation videos

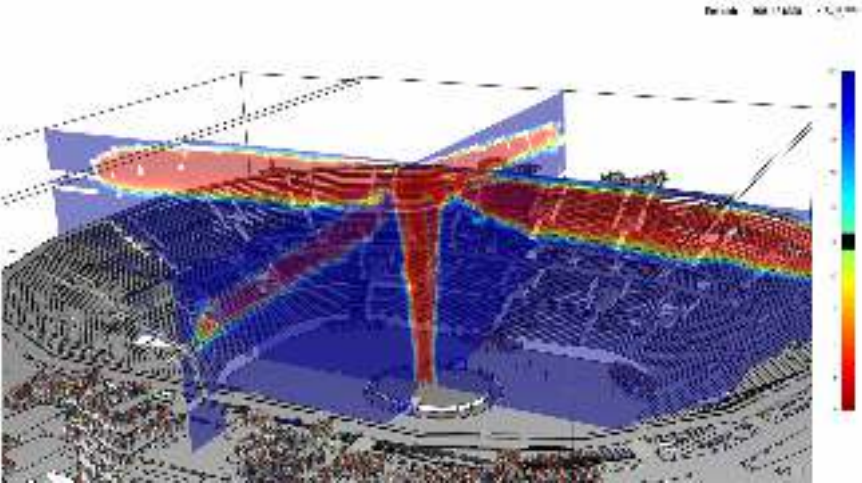
ISO SURFACE



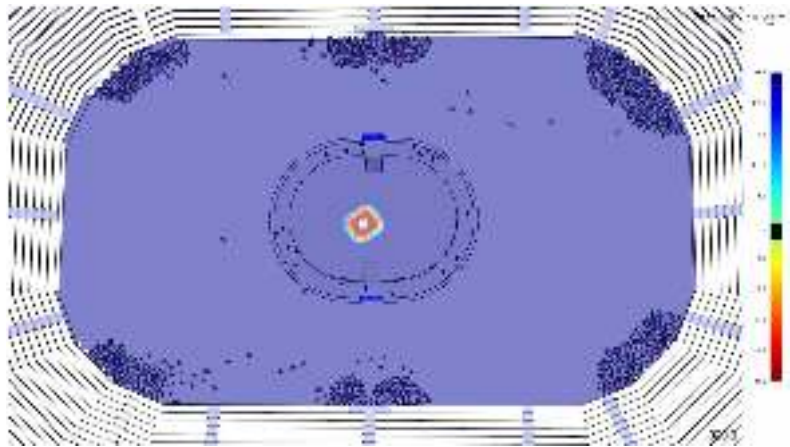
3D SMOKE



visibility

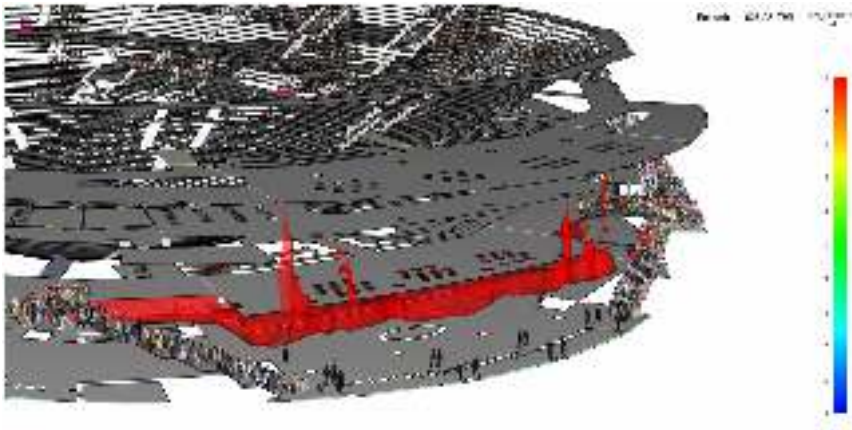


visibility



Evacuation videos

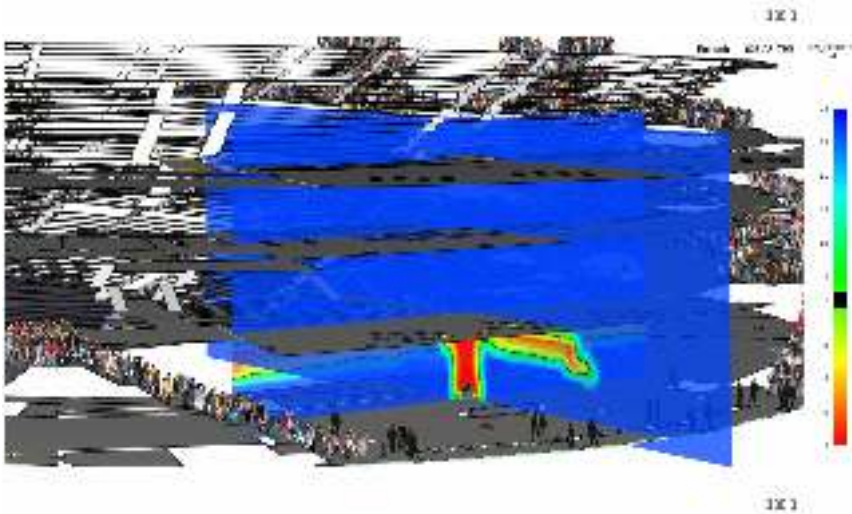
ISO SURFACE



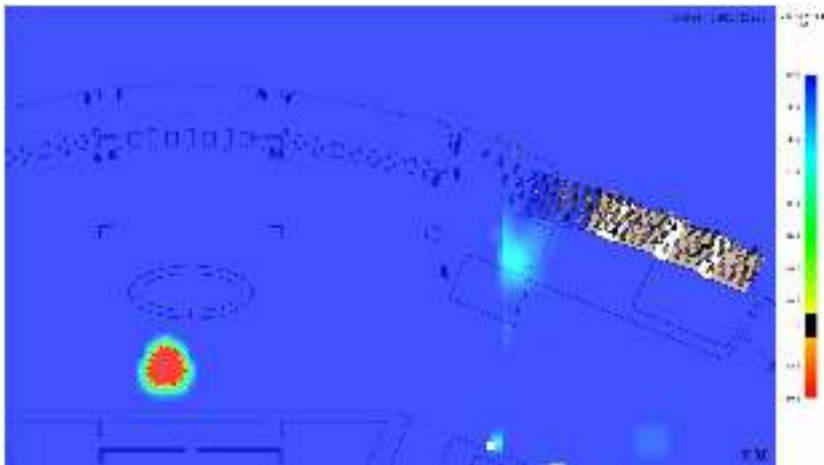
3D SMOKE



visibility



visibility



Merged simulation results

Possibilities to determine the time available for evacuation using simulations:

Method	Accuracy	Time	Application
FDS simulaion by itself – (with test slices)	+	+	Industrial, storage and agricultural buildings, interiors with large air spaces
Merged simulation result from FDS and Pathfinder – <i>real RSET and ASET</i>	++	+++	Public buildings, complex interiors



- TIME FACTOR - many and difficult to predict
- NON-LINEAR - difficult to link to other planning phases
- RELATED WORK - very long hours, many re-runs, rehearsals
- EXPENSIVE - many hours of work, practice and expected benefits...



- this is the most REAL - IF it's done right
- there are many ways to examine the conditions that have developed



Why don't we always do
this way???



CONCLUSIONS - SUMMARY

- The aim of fire safety design is to ensure the highest possible safety for everyone, all the time, but there are no guarantees! It's useful to be able to participate in the whole design process in a complex way and to be able to follow it through with simulations.
- In case of multifunctional use, several kind of fire scenarios are possible so a wide range of design fire scenarios must be tested, both in terms of heat release rate curve and form of the fire scenario (simple forms, complex forms representing a stage setting).
- To avoid extensive sprinkler skipping, sprinkler activation times and patterns must be checked at every fire scenario and if there are skipping problems, sprinkler design or even the smoke and heat ventilation must be modified.
- Combined (merged) fire- and smokespread, and evacuation simulations give the most complete picture of the complex (fire) operation of the building during the design process. They are a good tool, but you cannot, and should not, "solve" everything with them - you need background knowledge, which we are constantly developing.
- Buildings are always used in many different ways, and this must(should) be reflected in their design for safety reason! Our conclusion was that there are always many more usages than the designer thinks of at the beginning...



Thank you for your attention!



Judit Rauscher – assistant lecturer at University of Public Service, Institute of Disaster Management, Hungary – rauscher.judit@uni-nke.hu

Csaba Szikra - teacher at Budapest University of Technology and Economics, Department of Building Energetics and Building Services, Hungary – szikra@egt.bme.hu

Lajos Takács PhD - associate professor at Budapest University of Technology and Economics, Department of Building Constructions, Hungary – ltakacs@epsz.bme.hu



Sources, referencies

- [1] Fixed firefighting systems. Automatic sprinkler systems. Design, installation and maintenance
- [2] "Planning, Design and Installation of Fixed Firefighting Systems", Fire Protection Technical Guideline, TvMI 6.4: 13-06-2022
- [3] Ministerial Decree 54/2014 (XII.05.) BM on the National Fire Safety Code
- [4] Nam, S. (2004), "Actuation of Sprinklers at High Ceiling Clearance Facilities", *Fire Safety Journal*, **39**, 619-642.
- [5] SFPE Handbook of Fire Protection Engineering, 4th Edition, *National Fire Protection Association*, Quincy, Massachusetts.
- [6] Hietaniemi, Jukka & Mikkola, Esko. (2010). "Design Fires for Fire Safety Engineering", *VTT Working Papers*, 139.
- [7] Nam, S., Braga, A., Kung, H.C. and Troup, M.A. (2003), "Fire Protection for Non-Storage Occupancies with High Ceiling Clearances", *Fire Safety Science - Proceedings of the 7th International Symposium*, IAFSS, 493-504.
- [8] Croce, P. A., Hill, J.P. and Xin, Y. (2005), "An investigation of the Causative Mechanism of Sprinkler Skipping", *Fire Protection Engineering*, 15:2.
- [9] "Fire-, smokespread and evacuation modelling", Fire Protection Technical Guideline, TvMI 8.5: 13-06-2022
- [10] "Evacuation", Fire Protection Technical Guideline, TvMI 2.4: 13-06-2022
- [11] RiMEA e.V. Richtlinie für Mikroskopischer Entfluchtungsanalysen, version 3.0.0, 10. Marz 2016
- [12] Veres György (2018), "Evacuation in the event of fire in institutions for people with mobility impairments" doctoral thesis, Óbudai University Doctoral School on Safety and Security Sciences

