Journal of Civil Engineering and Architecture 18 (2024) 86-91
doi: 10.17265/1934-7359/2024.02.005

The Analysis of Human Behaviour and Evacuation in a Fire Situation in a Building for Higher Education

Dan Diaconu-Şotropa
Technical University "Gh. Asachi", Iassy 700050, Romania

Abstract: The paper presents the analysis of a human evacuation from a higher education building located in Iassy, Romania, by means of engineering techniques to approach fire safety. Because in Romania (as in other European countries) fire safety design of buildings is prescriptive and not performance-based, a fire safety engineering approach arouse great interest in many countries such as the U.S.A., Australia, New Zealand, England, Sweden, Finland, etc. This paper is based on the assumption of starting a fire in the space of a hall for festivities, located on the ground floor of the building, near two human evacuation routes; We consider two building evacuation scenarios: two exits and, respectively, just one exit (assuming that the second would be accidentally blocked).

Key words: CFD (computational fluid dynamics), FDS (fire dynamics simulator), fire safety engineering, smoke, human behaviour, fire simulation, educational building.

1. Introduction

The building, intended for teaching activities in higher education for construction and auxiliary teaching, is an independent building, ground floor + 4 floors (Fig. 1a), located on the edge of a group of buildings from Faculty of Civil Engineering and Building Services area of Iassy (in the vicinity of the Faculty of Architecture).

The building that occupies a ground area of 826.50 m^2, has an usable floor area of 3,340.5 m^2 and a built volume of 12.820 m^3, being a single fire compartment (built surface area is less than 2,500 m^2 [1]). The building can accommodate over 700 people.

The main features of the building are:

• on the ground floor, three halls for teaching activities (accommodating, at the time of the fire, 50 persons each) and a hall for festivities (Fig. 1b) (without people at the time of the fire);

• on the 1st floor, 2nd floor, and 3rd floor, three lecture halls (accommodating, at the time of the fire, 50 persons each) and a laboratory (with 20 computer workplaces each);

• on the 4th floor, a lecture hall (accommodating, at the time of the fire, 50 persons).

The building is a reinforced concrete frame with core walls and it belongs to the 1st degree category concerning fire safety.

The access to the floors (with a height of 3.80 m) is done through two staircases, with two ramps and intermediate landing (Fig. 2):

• the main staircase, centrally located, allows access from the ground floor to the second floor; further, the access to the next floors is allowed through other staircase located at the edge of the hall;

• the secondary staircase, located in the outer limit of the main hall, provides the access from the ground floor to the top floor of the building.

2. Content and Method of Research

The case study analyzes the safe evacuation of people in the building (positioned as specified above) for two possible situations:

• S1, human evacuation through both primary and secondary access;

• S2, human evacuation through the main access (secondary access being accidentally locked).

Corresponding author: Dan Diaconu-Şotropa, research fields: structural analysis, FE analysis.

(a) (b)

Fig. 1 Building for teaching activities: (a) analyzed building; (b) initiation fire area.

The supposed fire starts in the festivity hall, located on the ground floor and close to the main exit of the building (Fig. 2). The interior furniture is specific to the office type spaces and predominantly cellulosic/wood, HRR (heat release rate) = 250 kW/m^2 [2].

We analyzed, by means of the finite volume method, fire development and human evacuation inside the building in both S1 and S2 situations. The types of analysis involved in the case study require the use of a virtual discrete model, with finite volumes.

This research is the result of authors' interest in the use of computer programs to analyze the development of fire and of human evacuation from buildings in fire situation [3-5].

2.1 The Research Instrument

The computer program FDS 5.5.3 (fire dynamics simulator) has been used for the numerical simulations of the proposed circumstances. This program, designed by NIST U.S.A., is based on fluid dynamics (CFD (computational fluid dynamics)) and applied to fire dynamics. It was initially conceived for the analysis of temperature distribution and smoke emissions, and furthermore developed by VTT Finland, to include the possibility of analyzing the human evacuation in fire situation, FDS+Evac 2.2.1.

The FDS software is based on the finite volume method for setting numerical matrix equation of equilibrium flow phenomena such as fire development and evacuation, which involves making discrete virtual models with finite volume.

The overview of the results from FDS and FDS+Evac, is achived by the postprocessor software Smokeview 5.6.

FDS and SmokeView have been run on a computer with two Intel (R) Xeon E5240 Quad Core 2.66 GHz, 16.00 GB DDR2 ECC, 64-bit Operating System Windows XP; the runtime for the analysis of the S1 situation (460 s) is 23 h and for S2 situation (526 s) is 26 h.

2.2 Discrete Model for Fire Development

The numerical simulation of the spread of smoke and hot gases inside the building used a virtual model with the following dimensions (Fig. 3a):

- main mesh: 29.60 m in *X* direction (from 0.00 to 29.60), 28.60 m in *Y* direction (from 0.00 to 28.60), 19.38 m in the *Z* direction (from -0.38 to 19.00);
- secondary mesh (for R1 amphitheater): 7.2 m in *X* direction (from 7.60 to 14.80), 16.60 m in *Y* direction (from 11.00 to 27.60), 6.08 m in *Z* direction (from 19.00 to 25.08).

The size of a finite volume is 0.20 × 0.20 × 0.38 m.

The heat release rate was determined for a building with offices, HRR = 250 kW/m^2.

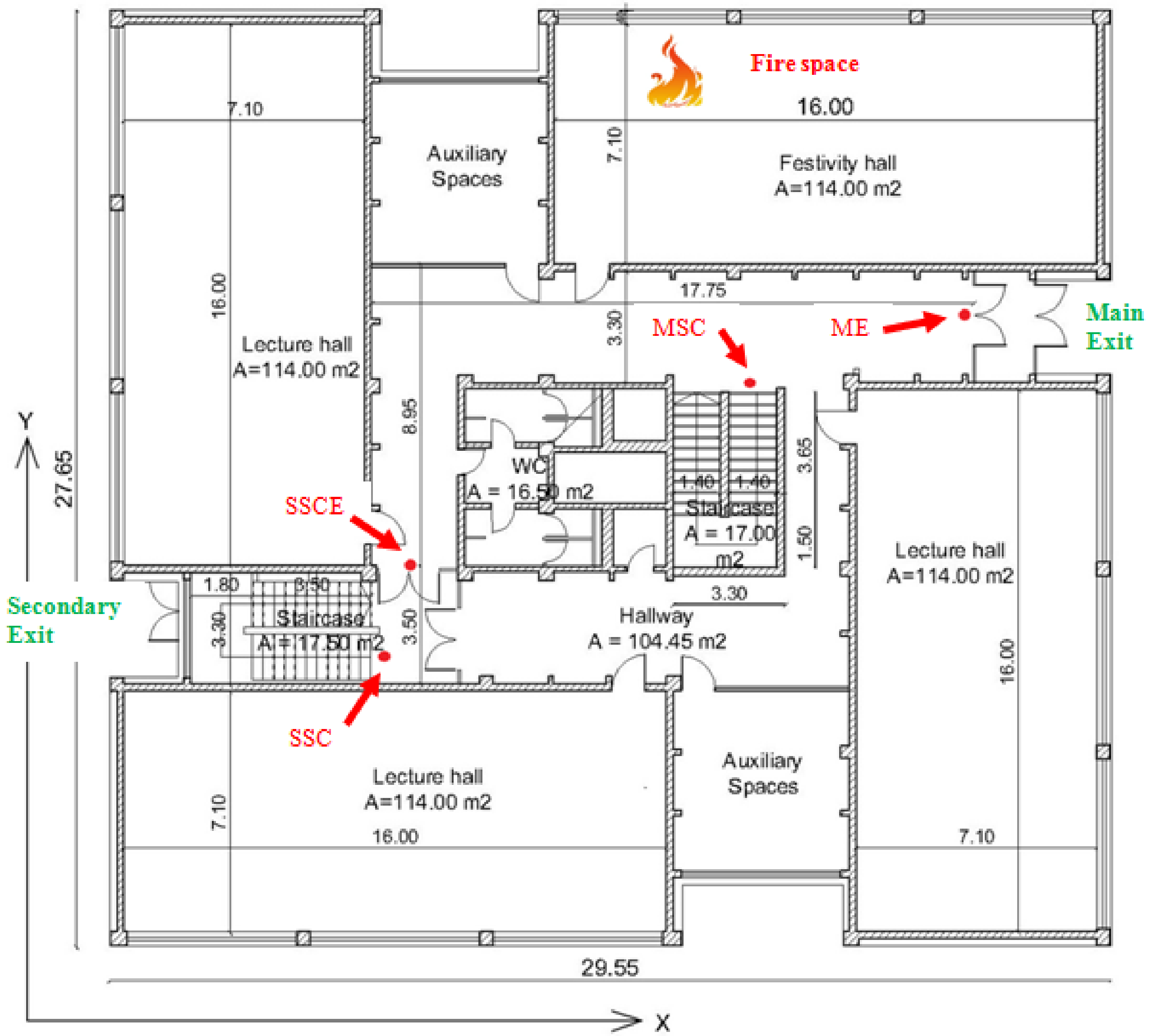


Fig. 2 Ground floor of the building (approximately for 1st and 2nd floors).
ME: main exit, SE: secondary exit, MSC: main staircase, SSC: secondary staircase, SSCE: secondary staircase entrance.

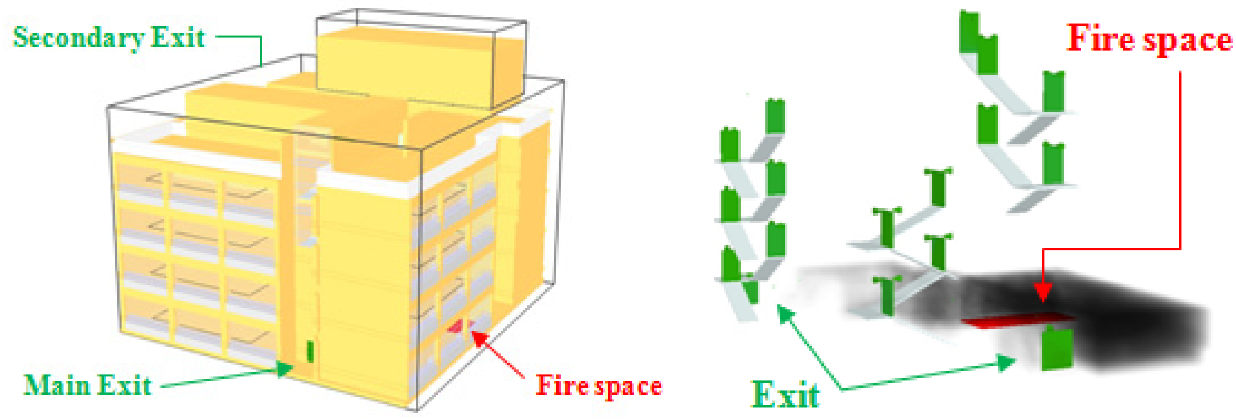
2.3 Discrete Model for Human Evacuation

The numerical simulation for human evacuation of the building was performed on a virtual model with the following dimensions (Fig. 3b):

- Six (6) main meshes corresponding to each level, and 7 secondary meshes corresponding to stair landings, 107,230 volumes.
- A finite volume size is 0.20 × 0.20 × 0.38 m.

The author used the following data for analysis (the same are used in Exemple 3-Atrium, official site of FDS+Evac):

- the movement speed for an adult person model is a uniform distribution with the values: minimum 0.95 m/s and maximum 1.55 m/s;
- the detection time (the time interval between the alarm activation and the moment when the occupants of the building start to move towards the exits) is established to 120-180 s with a uniform distribution [6];
- the reaction time is set to 5 s and a triangular distribution, with a minimum value of 1 s and maximum of 9 s.



(a) (b)

Fig. 3 Discrete finite volume model used for analysis: (a) general view; (b) evacuation routes view.

3. Results of the Numerical Experiment

The main tenability criteria in the occupants-effluents interaction, considered in the analysis for safe evacuation during the supposed fire, are [7, 8]:

- the radiant heat (T_{cr}), measured by the maximum permissible value for radiant heat flux from the upper layer of smoke which is 2.5 kW/m^2 and/or the maximum permissible temperature at the bottom of the top layer of smoke is 200 °C;
- the visibility through smoke layer (V_{cr}), quantified by the minimum visible distance which is 10 m (for large rooms);
- FED_{cr} (fractional effective dose), quantified by the maximum value of 1 (a non-lethal environment for adults).

During the research, we considered the stipulations of the technical regulation [9], which states that, throughout the evacuation of persons, the clean air layer on the evacuation route, must be maintained at a minimum height of 2.5 m in the case of civil buildings (public).

The requirement of monitoring critical ($_{cr}$) and effective ($_{eff}$) values for some fire parameters (temperature: T, visibility: V, FED) imposed placing virtual recording devices at the height of 2.50 m (above entrances/exits for stairs and the exits of the building), shown in Fig. 2 and Table 1.

The maximum values for FED are 0.04 for S1 and 0.06 for S2, far below the limit 1. The dangerous conditions for human evacuation on the 3rd and 4th floors are not met.

Table 2 presents the effective values of T_{eff} and V_{eff} in two situations of human evacuation, for specific area of the building (exits from floors, the staircases and the building).

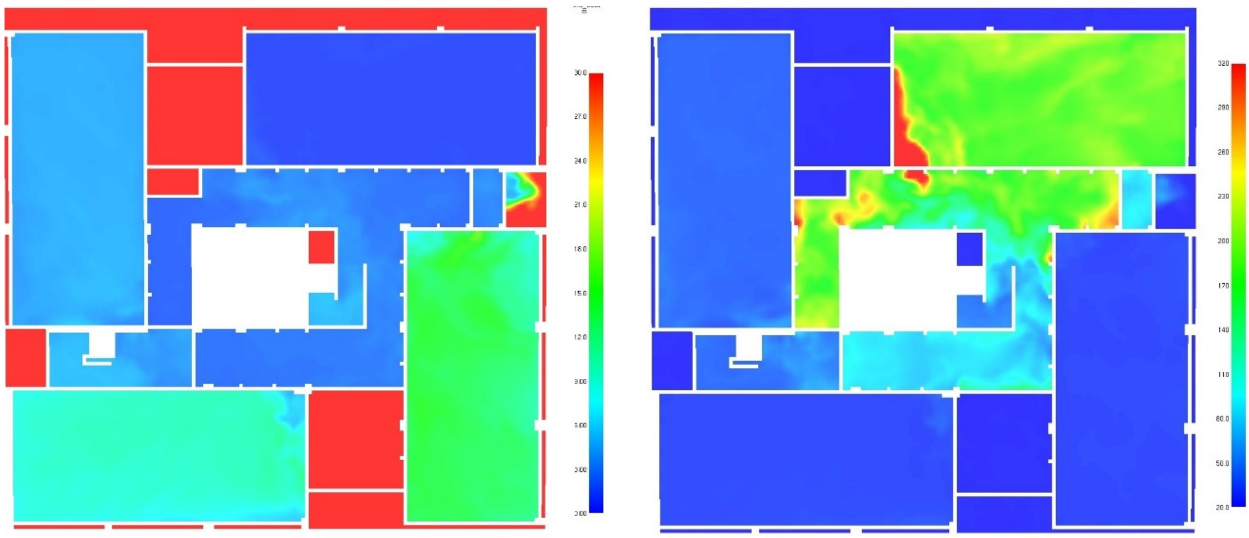
Table 1 Time steps at which the critical values of the fire parameters are reached.

Parameters	Ground floor						1st floor				2nd floor			
	ME		SE				MSC		SSC		MSC		SSC	
			SSCE		SSC									
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
T_{cr} 200 °C	212	271	213	266	*	*	*	*	*	*	*	*	*	*
V_{cr} 10 m	24	24	30	31	158	174	151	169	194	193	253	277	312	277

ME: main exit, SE: secondary exit, MSC: main staircase, SSC: secondary staircase, SSCE: secondary staircase entrance, *: no critical values.

Table 2 Effective values of the fire parameters at the evacuation time t_{ev}.

Parameters	Ground floor						1st floor				2nd floor			
	ME		SE				MSC		SSC		MSC		SSC	
			SSCE		SSC									
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
t_{ev} (s)	460	526	200	196	410	374	427	478	382	358	360	384	340	317
T_{eff} (°C)	173	254	127	122	58	41	72	72	47	52	43	45	42	35
V_{eff} (m)	2.6	2.4	3.0	2.8	4.4	6.7	4.3	3.9	6.1	5.8	7.6	7.3	7.7	10



(a) (b)

Fig. 4 The distribution on grund floor of: (a) visibility; (b) temperature.

Fig. 4 presents the visibility and temperature parameters for the final moment of evacuation at the ground floor.

4. Conclusions

The Romanian specific prescriptive regulation [1] states that the evacuation times, for higher education buildings (excluding high and very high buildings or crowded halls) that belongs to the 1st degree category concerning fire safety is 125 s, for two different directions of evacuation and 63 s, for one direction of evacuation.

The current case study, following the performed numerical simulations, shows that the times for evacuation are 460 s for the S1 situation (evacuation through the main and the secondary exit) and 526 s for the S2 situation (main exit evacuation only). Consequently, it can be seen that these times, including the pre-movement time, are higher than the norm prescriptive times [1] and it is possible that the engineering approach to human evacuation in case of fire is closer to reality.

In both S1 and S2 situations, the critical condition for human evacuation of the building occurs within a very short time, 24 s (from the condition of visibility) and they are not significantly influenced by the way people exit the building.

As a continuation of the research presented in this paper, we intend to extend the analysis, by means of numerical simulation, in order to improve the fire protection solutions of the building. Possible solutions are to: supplement the passive protection measures (the ventilation of smoke and hot gases to the exterior of the building) and/or the active ones (by placing water curtains in critical areas of the building).

References

[1] I.T.R.D. 1999. *Code of Fire Safety for Buildings—P 118-99* (2nd ed.). Bucharest, Romania: I.T.R.D.

[2] European Commission. 2002. "Eurocode 1: Actions on Structures—Part 1-2: General Actions—Actions on Structures Exposed to Fire."

[3] Diaconu-Şotropa, D., Roşu, D., and Robu, D. 2012. "Case Study Referring to the Evacuation Caused by Fire of Person Groups from Museum 'Vasile Pogor' of Iasi, Romania." In *Proceedings of the 5th International Symposium Human Behaviour in Fire 2012 119p.(6p)+CD Downing College-Cambridge-UK, Interscience Communication Ltd. West Yard House Guildford Grove*, London, England.

[4] Diaconu, D., Vrabie, M., and Ibănescu, M. 2011. "Modern Technologies for the Analysis of Fire Action in Closed Compartments." In *Proceedings of the 15th International Conference Modern Technologies, Quality and Innovation Volume I, ModTech, New face of TMCR*, 25-27 May, Vadul lui Vodă-Chisinau, Republic of Moldova.

[5] Cavaropol, D. V., Roşu, D., Diaconu-Şotropa, D., and Burlacu, L. 2010. "Optimizing the Construction Elements of Underground Parking through Temperature Distribution Analysis in Fire Situations." In *Proceedings of the International Conference on Development, Energy, Environment, Economics (DEEE 10)*. Athens: WSEAS Press, pp. 212-6.

[6] Purser, D. 2009. *Human Fire Behaviour and Performance Based Design.* Glasgow: Institution of Fire Engineers.

[7] Spearpoint, M. 2008. *Fire Engineering Design Guide* (3rd ed.). Christchurch, New Zealand: New Zealand Center for Advanced Engineering.

[8] Hirschler, M. M. 2005. *ISO TS 13571-2002: Life-Threatening Components of Fire—Guidelines for the Estimation of Time Available for Escape Using Fire Data*. Al Barsha: GBH International.

[9] National Standards Authority of Ireland Glasnevin. 2005. "Smoke and Heat Control Systems—Part 5: Guidelines on Functional Recommendations and Calculation Methods for Smoke and Heat Exhaust Ventilation Systems." https://www.intertekinform.com/preview/98696239340.pdf?sku=857666_SAIG_NSAI_NSAI_2040314.