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A STUDY REGARDING HUMAN EVACUATION IN THE CASE OF A FIRE ORIGINATED FROM BUILDING DESIGNED FOR SPORT ACTIVITIES

BY

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Abstract. The aim of this paper is to analyse human evacuation from a building designed for sport activities by means of engineering techniques to approach fire safety.

This case study is based on the assumption of starting a fire in a storage room located near the main evacuation route of the building.

The spread of smoke and hot gases inside the building was simulated using a Computational Fluid Dynamics model of fire-driven fluid flow. The movement of people was fully coupled with the fire simulation using the Helbing social model to describe the human movement and behavior in case of fire.

The European guidelines have been followed for the heat release rate of the fire and for the pre-movement time for humans.

Key words: human behavior in the case of a fire; fire safety engineering; numerical simulations; FDS; FDS+EVAC, HRR.

1. Introduction

This case study analyses the human evacuation process in the case of a fire originated from a building designed for sport activities.

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The building, with a simple layout (Fig. 1), has a timber structure and a timber truss roof. The usable floor area of the building is 200 m^2 and the usable volume is 982 m^3.

The main futures of the building are presented in Table 1.

The windows from the sport hall are 2.40 × 0.90 m at a height of 3.10 m above the floor. All other windows are 1.80 × 0.60 m at a height of 1.50 m above the floor (1.80 m for WC).

The exit doors are 1.50 × 2.40 m. All other doors are 0.90 × 2.10 m (except the sport hall with a width of 1.50 m).

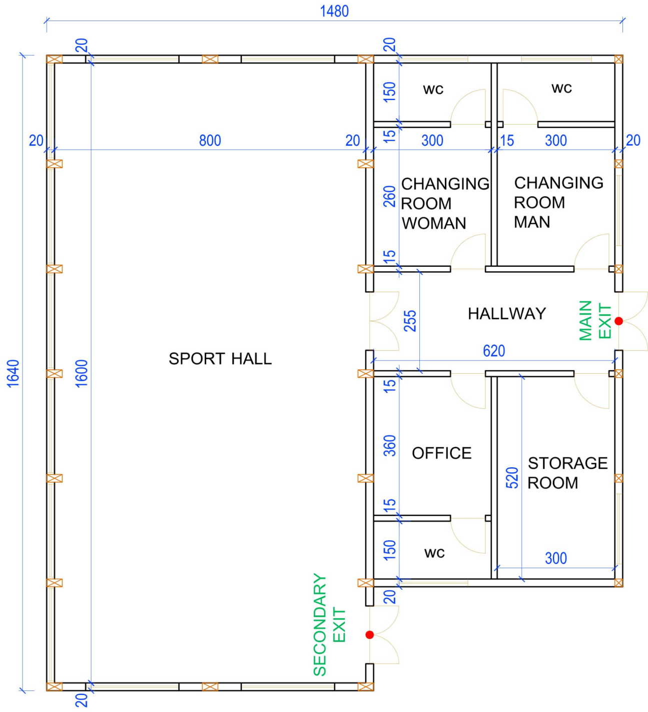


Fig. 1 – Ground floor plan of the analysed building.

Table 1

Main Futures of the Building

	Area, [m^2]	Height, [m]
Sport Hall	128	6.00
Changing Room Woman/Man	7.80	3.00
WC	4.50	3.00
Office	10.80	3.00
Hallway	15.80	3.00
Storage Room	15.60	3.00

2. Fire Scenario

In a wastepaper basket, a fire starts due to a discarded cigarette, which smoulders for several minutes and eventually results in the ignition of the contents and wastebasket in the storage room. The fire has grown enough to ignite adjacent objects that provide sufficient heat to cause the room to flashover.

The storage room has a door of 0.90 × 2.10 m and a window of 1.80 × × 0.60 m at 1.50 m height above the floor.

During fire the storage room door has failed (or is opened) after 15 min. At this moment the fire alarm will be manually trigger and all the occupants start to response (*i.e.* alerting others, investigative behaviour to find source of fire, exit way finding).

At that moment 30 adults were inside the building, two thirds being in the sport hall and one third in the two changing rooms. All the occupants were familiar with the building and they have been trained regarding the emergency procedures during a fire incident.

The main exit door and all the windows of the building are opened during this fire scenario. All other doors are closed.

A two-minute pre-movement time is considered (CFPA-E No 19:2002) for all occupants because:

a) all occupants are awake and familiar with the building and they are trained to emergency situations;

b) the building has a simple rectangular geometry with few enclosures, short travel distance and exists leading directly to the outside of the building;

c) the building has a low occupant density.

After the pre-movement time the occupants start evacuation to the exterior of the building and they open the doors to evacuate.

3. Research Method

The research instruments used in this case study were special software used both by fire protection engineers and fire researchers.

The development of fire from the storage room was described using a wood fuel and the heat release rate according to the European legislation.

3.1. FDS 6.0.1

FDS (Fire Dynamics Simulator), is a Computational Fluid Dynamics (CFD) model of fire-driven fluid flow. FDS solves numerically a form of the Navier-Stokes eqs. appropriate for low-speed ($Ma < 0.3$), thermally-driven flow with an emphasis on smoke and heat transport from fires (McGrattan *et al.*, 2013).

The partial derivatives of the conservation eqs. of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid. Thermal radiation is computed using a finite volume technique on the same grid as the flow solver. Lagrangian particles are used to simulate smoke movement (McGrattan *et al.*, 2013).

3.2. FDS+Evac 2.4.1

FDS+Evac (Fire Dynamics Simulator with Evacuation) is the evacuation module of FDS; this software allows simultaneous simulation of fire and evacuation process and consider the analogy between fluid and particle motions (including interactions) and crowd movement.

FDS+Evac treats each evacuee (or agent) as a separate entity, which has its own personal properties and escape strategies (Korhonen & Hostikka, 2010). The movement of the agents is simulated using two-dimensional planes representing the floors of building. The basic algorithm behind the egress movement solves an eq. of motion for each agent in a continuous 2-D space and time. The forces acting on the agents consist of both physical forces, such as contact forces and psychological forces exerted by the environment and other agents. The model behind the movement algorithm is the social force model introduced by Helbing & Molnar (1995).

Each evacuee observes the locations and actions of the other evacuees and selects the exit through which the evacuation is estimated to be the fastest.

For exit selection the algorithm takes into account the visibility of an escape route and the toxic effect of gases.

The movement algorithm can incapacitate the agents considering the toxic effect of gases.

3.3. PyroSim 2014.1.0331 and Smokeview 6.1.5

Both FDS and FDS+Evac don’t have a user interface; all input data is entered using command lines. PyroSim is a graphical user interface for FDS and FDS+Evac that helps to quickly create and manage the details of complex fire models.

Smokeview is a software tool designed to visualize numerical calculations generated by FDS and FDS+Evac. It can display contours of temperature, velocity and gas concentration in planar slices. It can also display properties with iso-surfaces that are three-dimensional versions of a constant value of the property.

3.4. Combustion Using the Heat Release Rate

The fire load density was considered according to the European legislation (EN 1991-1-1-2 Annex E), 780 MJ/m^2, corresponding to dwelling occupancy (common objects can be found in the storage room).

For this case study the design value of the fire load density was 11,560 MJ/m^2 (Grigoraş & Diaconu-Şotropa, 2014).

The total energy released by the combustible materials from the storage room was 184,900 MJ and the maximum heat release rate was 4,831 MW.

According to Grigoraş & Diaconu-Şotropa (2014) the heat release rate of the design fire considered in the fire scenario was represented in Fig. 2.

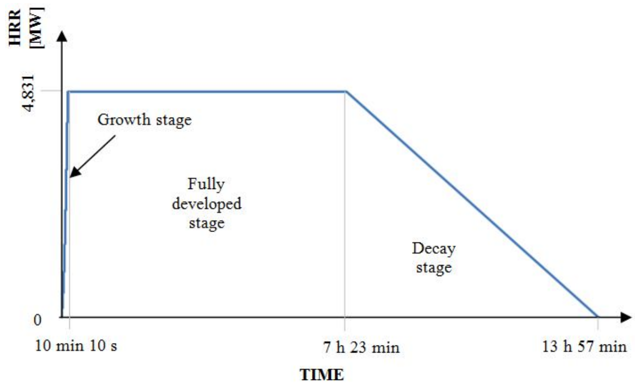


Fig. 2 – Development of the ideal fire (obtained by simplification) used for calculation.

For this analysis a user-defined fuel was used. It is assumed that the burning objects from the storage room are predominantly cellulosic/wood. According to Rinne *et al*., (2007), a wood fuel has the properties presented in Table 2.

Table 2
Fuel Properties

User input data	Value	Description
Carbon atoms	3.4	The fuel chemical formula.
Hydrogen atoms	6.2	
Oxygen atoms	2.5	
Critical flame temperature, [°C]	1,427.0	The critical flame temperature for this fuel.
Heat of combustion, [kJ/kg]	17,500	The heat of combustion for wood.
Soot yield, [kg/kg]	0.015	The fraction of fuel mass converted into smoke particulate.
Hydrogen Fraction	0.1	The fraction of atoms in the soot that are hydrogen.

3.5. Grid Cell Size, Meshes and Boundary Conditions

For the fire simulation that involves buoyant plumes, a measure of how well the flow field is solved is given by the non-dimensional expression $D^*/\delta x$, where D^* is a characteristic fire diameter and δx is the nominal size of a mesh cell (McGrattan *et al.*, 2013).

Generally the $D^*/\delta x$ values ranged from 4 to 16 (Stroup & Lindeman, 2013).

In this analysis it was considered a 0.30 × 0.30 × 0.30 m cell size corresponding to a course grid size:

$$\frac{Q^*}{\delta x} = \frac{1.80}{0.30} = 6\,, \tag{1}$$

For the evacuation mesh the same cell size has been used to align this mesh to the fire mesh.

Corresponding to Korhonen & Hostikka, (2010), in some cases, a finer grid does not always mean a better guiding field for agents. Usually grid sizes are equal or less than the dimensions of a human body and the accuracy of the fire information in the evacuation meshes is fine enough for the accuracy level of the evacuation calculation (Korhonen & Hostikka, 2010).

For the spread of smoke two “fire” meshes were used (one for the sport hall and another for the rest of the building). Both meshes were extended with 0.90 m from the building and their boundaries were declared “open” to better capture the spread of smoke through windows and doors.

For human evacuation one mesh was declared at a height of 0.90 m above de floor.

3.6. Occupants Properties and Tenability Criteria

Default settings (Figs. 3 *a* and 3 *b*) were used for agents properties (Korhonen & Hostikka, 2010).

The main objective of smoke hazard management in buildings is to enable the occupants to move to a place of safety before the evacuation routes become untenable due to smoke.

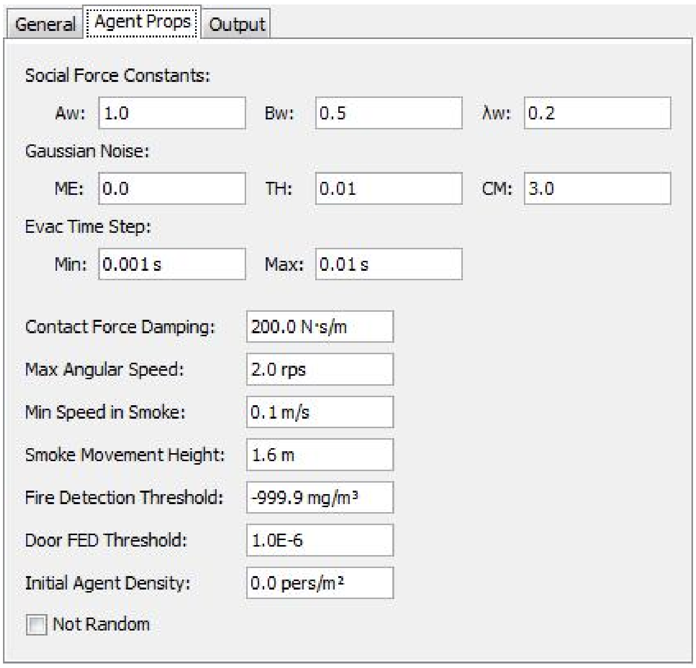
During the analysis the next tenability criteria was considered at a height of 2 m above the floor (Poh, 2011):

a) radiant heat ≤ 2.5 kW/m^2;

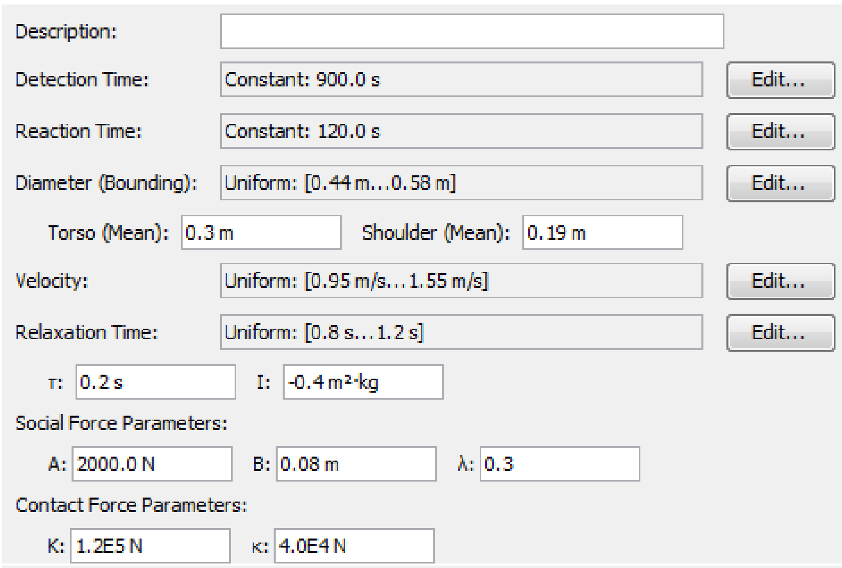
b) air temperature ≤ 100°C;

c) FED ≤1 (the Fractional Effective Dose is a commonly used measure of human incapacitation due to the combustion gases, Purser, 2002);

d) visibility ≥ 10 m (large enclosures) or ≥ 5 m (small enclosures).



a



b

Fig. 3 – Agents properties.

4. Results

Following numerical analysis the timeline of events is presented in Table 3.

Table 3
Timeline of Events

Time, [s]	Description	FDS+Evac time, [s]
0	The fire starts in the storage room (the door is closed and the window is opened). The occupants of the building unaware and continue their normal activities.	t_{det} = 900
660	The fire reaches the fully developed stage at a maximum heat release rate of 4,831 MW	
900	The door from the storage room fails. The fire alarm is trigger and the occupants are aware of the danger.	
1,020	The occupants start moving to the two exits.	t_{reac} = 120
1,022	First occupant leaves the building	t_{trav} = 20
1,040	Last occupant leaves the building.	

The visibility and the air temperature at a height of 2.1 m (in FDS a slice can be placed only between two mesh cells) at the end of the evacuation process is shown in Figs. 4 and 5.

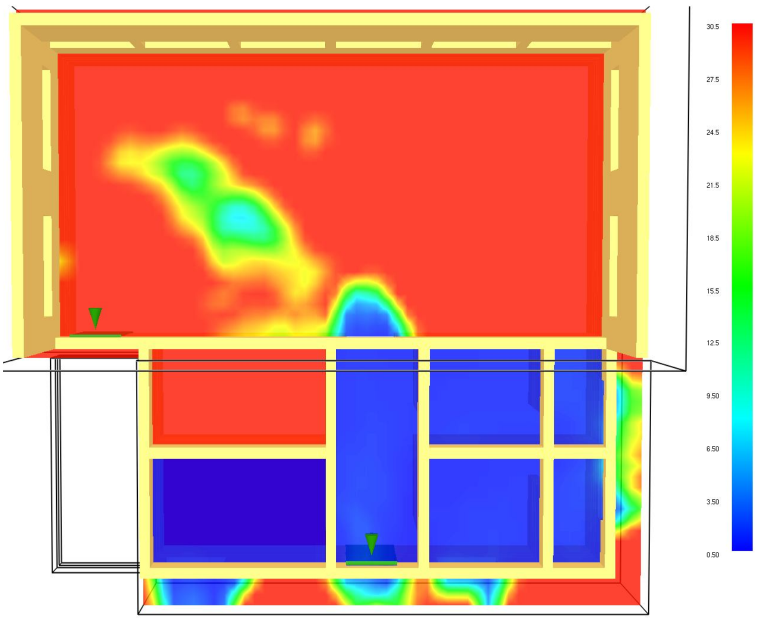


Fig. 4 – The visibility at 2.1 m above the floor at the end of the evacuation process.

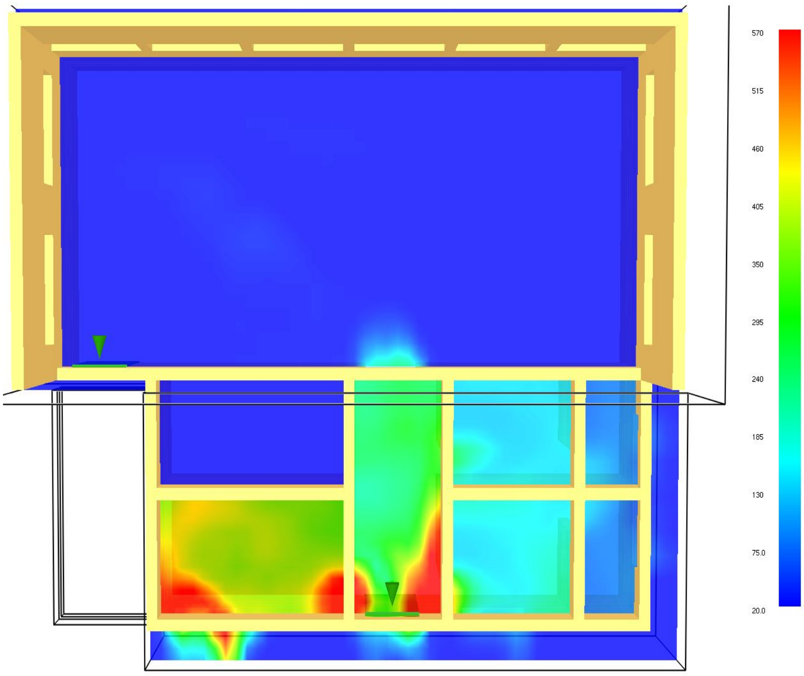


Fig. 5 – The air temperature at 2.1 m above the floor at the end of the evacuation process.

The variation of air temperature (Fig. 6), visibility (Fig. 7), radiant heat (Fig. 8), and FED (Fig. 9) at a height of 2 m above de floor at the main and secondary exits (red dots from Fig. 1) are shown next.

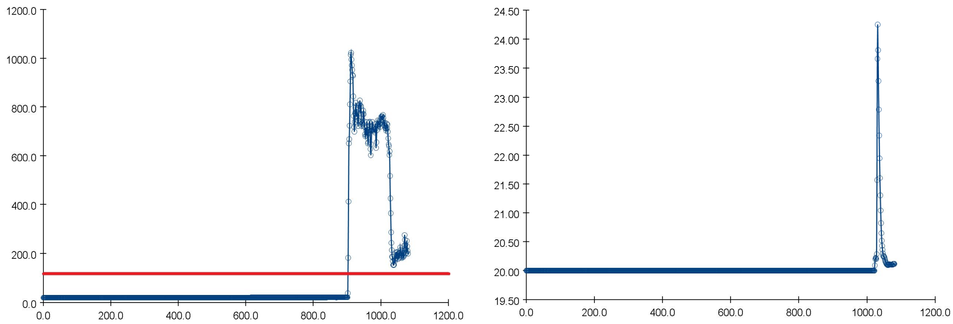


Fig. 6 – Air temperature, [°], variation at 2 m above the floor (left – Main Exit, right – Secondary Exit).

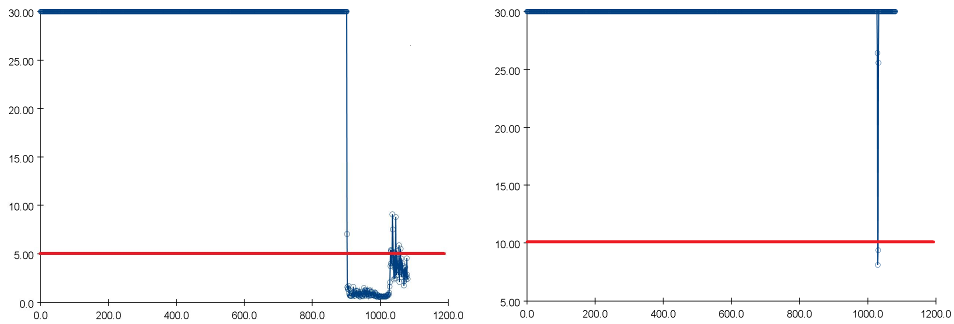


Fig. 7 – Visibility, [m], variation at 2 m above the floor (left – Main Exit, right – Secondary Exit).

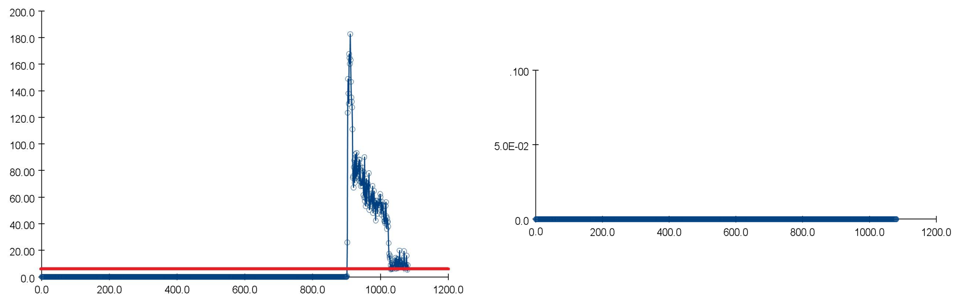


Fig. 8 – Radiant heat, [kW/m^2], variation at 2 m above the floor (left – Main Exit, right – Secondary Exit).

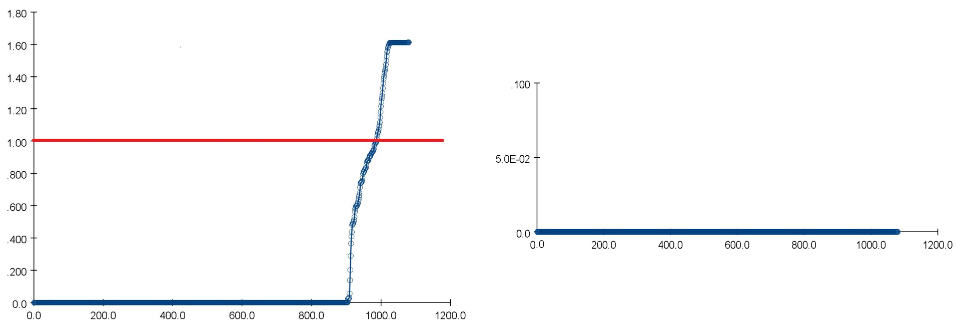


Fig. 9 – FED variation at 2 m above the floor (left – Main Exit, right – Secondary Exit).

5. Conclusions

The current case study, following the performed numerical simulations, shows that the travel time for occupants were 20 s.

It has been seen that only 7 people from the changing rooms will chose to evacuate through the main exit and the other 3 have chosen to evacuate through the secondary exit crossing the sport hall.

Considering the exposure to smoke and hot gases the occupants from the changing rooms will suffer skin burns.

The evacuation process can be improved if the door from the storage room is located outsite of the building.

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STUDIU PRIVIND EVACUAREA UMANĂ ÎN CAZUL UNUI INCENDIU IZBUCNIT ÎNTR-O CLĂDIRE DESTINATĂ ACTIVITĂȚILOR SPORTIVE

(Rezumat)

Scopul acestui articol îl reprezintă analiza evacuării umane dintr-o clădire destinată activităților sportive folosind metode inginereşti de abordare a siguranței la incendiu.

Acest studiu de caz se bazează pe ipoteza inițierii unui incendiu într-un spațiu de depozitare amplasat în apropierea căii principale de evacuare din clădire.

Împrăştierea fumului şi gazelor fierbinți în interiorul clădirii au fost simulate folosind o analiză numerică a dinamicii fluidelor aplicată incendiilor. Comportamentul persoanelor a fost cuplat cu simularea incendiului folosind modelul social Helbing care descrie deplasarea şi comportarea umană în caz de incendiu.

Prevederile legislatiei Europene au fost urmate atât pentru debitul de căldură degajată cât şi pentru timpul de pre-mişcare al persoanelor.