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EVACUATION MODELING OF AN HISTORICAL CASINO IN CASE OF FIRE

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ABSTRACT

This paper describes the strategy used to evaluate the egress of occupants from a casino sited in an historical building. The methodology proposed in this paper keeps the changes to be made to the building to a minimum while at the same time maintaining its safety features in case of fire. Indeed, the adaptation to fire prevention standards of an historical building may be difficult or not possible due to its great architectural value. The proposed methodology considers three different aspects: reduction of the fire growth rate using materials classified for fire reaction, implementation of the safety management level by developing an internal trained team and verification of the occupants egress in case of fire through Computational Fluids Dynamics (CFD) models. The proposed methodology has been supported by laboratory test which investigate the real behavior and reaction of some electronic devices in case of fire and define the HRR curve to be used inside the CFD models. The software FDS has been used to simulate different fire scenarios for determining durability of tenability conditions (ASET). The Required Safety egress time (RSET) has been computed according to analytical data, ISO/TR 16738 and multi-agent continuous evacuation modelling. The evacuation scenarios have been simulated with the software Pathfinder. To guarantee the life safety, the ASET must be greater than RSET. Previous evaluations leaded to minimize adjustment works and maximize the level of safety with considerable benefits in terms of cost/effectiveness risk analysis.

KEYWORDS

Historical Building; performance-based design; Fire Safety Engineering, FDS, Pathfinder; Life Safety; ASET; RSET; HRR; management level

INTRODUCTION

In a life safety analysis, the ability of the occupants to escape from the fire compartment is evaluated normally in the incipient and growth phases of the fire. The phase after flashover or full involvement is relevant to evaluate the fire resistance. This paper analyzes the life safety and the early stages of the fire. Therefore, the measures that should be adopted to increase the human safety will concern these stages.

The speed at which fire can spread over the historical building is a critical factor in fire growth and spread. Due to the high flammability of many materials typically inside the historical building (wood, upholstery fabrics, fabrics, padding material etc.), there is a serious hazard that flames will quickly spread (Huang, 2009). Furthermore, the materials without fire reaction should produce a deeper smoke that reduces the visibility and causes serious problems for a safe evacuation.

The Casino is a public space and its activity is the gambling. The slot machines and game tables represent a “focal point” as like as the stage in a theatre or the screen in a cinema. There is a focal point when the attention of occupants is focused on a central figure (Proulx,2002). Since in a Casino, the occupants are mostly focused on gambling, in case of fire the evacuation might start with an important delay. Furthermore, the occupants are unfamiliar with the layout of the building and the

evacuation might request more time. These aspects increase the egress time and, as a consequence, the likelihood of damages to occupants increases as well.
The presentation of this case study is a useful guide for the design of safety strategies inside an historical building where a great number of people does not have the knowledge of the space. This report emphasizes the safety measures that are not always taken into account in fire prevention projects.

THE BUILDING

This paper takes into account only that part of the building that is open to the public. The casino is housed in a historic multi-storey building, which has a lower ground floor and two floors above ground. Fire prevention regulations usually require a protect egress routes and a smoke control system. However, these solutions are not applied in this case due to the following reasons:

- a monumental stair connects the first floor and ground floor. Enclosing this stair is not possible because of its architectural interest;
- the installation of a smoke control system is not possible, because the building façade cannot be modified. Furthermore, the ground floor has windows that cannot be opened.

Due to these restrictions, alternative safety measures are considered to guarantee the safety of the occupants.

THE METODOLOGY

The fire reaction of materials is the first factor that has been considered. In accordance with the prevention regulations, all materials must be certified as conforming to reaction to fire. A specific analysis has been done for selecting materials that present a fast or medium fire growth rate and consequently, their substitution (with others certified in terms of fire reaction) or requalification (application of varnishes or plasters) have been suggested.-Where the class was unknown or some materials cannot be substituted or certified, these materials have been performed in approved laboratory. Using the certified materials, the fire develops slowly and produce less smoke. The figure 1 shows the comparison between the fire growth slow (blue) and the fire growth of a certified material (red).

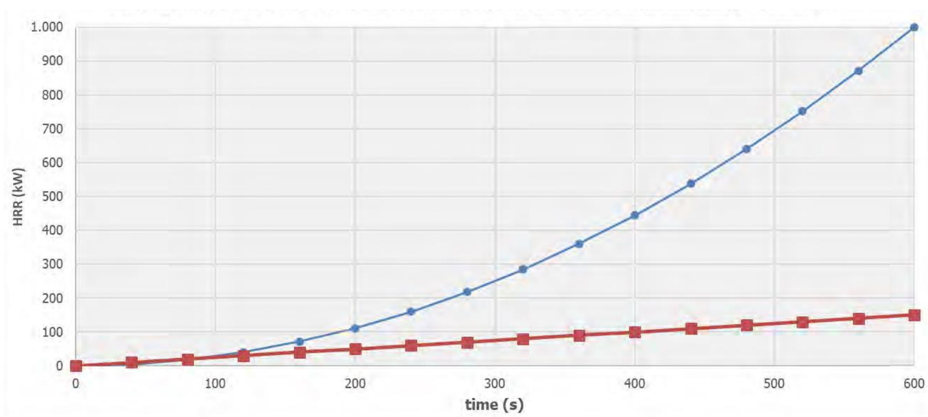


Figure 1: Curve Slow VS fire growth certified material

This aspect influenced positively the ASET and these parameters were used in FDS simulations. Furthermore, the laboratory test has been used to determine the HRR Curve that defines the design fires of slot machine rooms. The fire growth rate of slot machine is lower than the curve with slow and medium growth rate. Figure 3 shows the comparison between three curves.

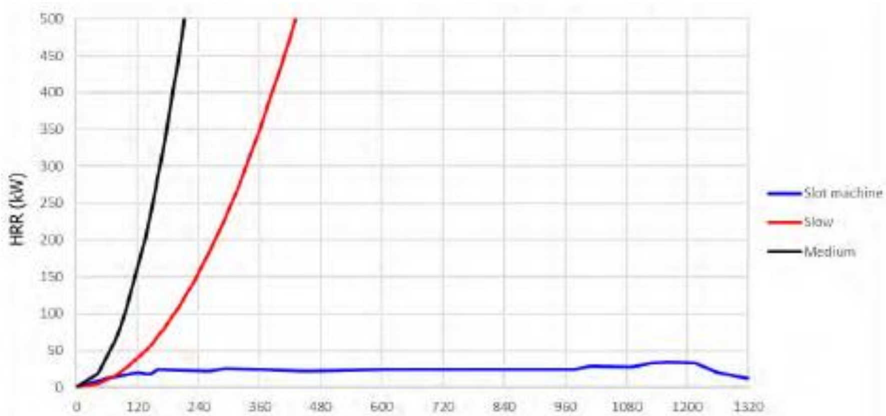


Figure 2 : Comparison HRR curve of slot machine

In a public space, the pre-movement has a very important role in the request time to egress from the building due to unfamiliarity of the occupants. The level of safety management is a fundamental measure in order to reduce pre-movement time and accidents in case of emergency. A new safety management plan has been developed and its main features are:

- the appointment of emergency team coordinator;
- presence of a Building Evacuation Team: group of trained people in fire extinguishment and coordination of fire evacuation;
- a plan to reduce the property damages;

The level of safety management was considered in an evacuation modelling, that was used to determine the travel time of occupants.

FDS SIMULATION

To determine the ASET the software FDS has been used. The Figure 3 shows the model used to simulate the fire inside the Casino.

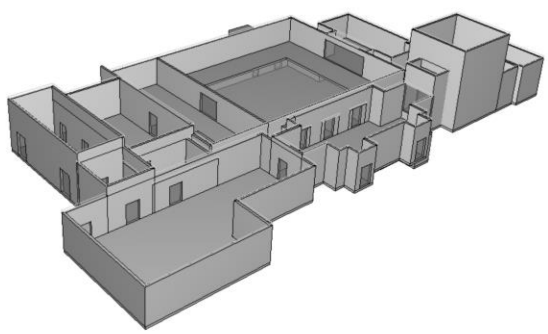


Figure 3: FDS model of the Casino

The design scenarios take into account maximum occupancy and immediate difficulty in evacuating the occupants due to the harmful effects of combustion products during the fire. The scenarios have been positioned within the slot machine rooms on the ground floor (S4B, S4C) and the HRR curve has been determined in the laboratory. The characteristics of these fire case studies are presented in Table 1.

Table 1: The characteristics of fire case studies

Parameter	**Value**
Fire Growth Rate	< 600 s (slow)
HRRMAX	34 kW
Soot Factor	0,07 kg/kg [*]
CO Yield	0,10 kg/kg [*]
ΔHc	20 MJ/kg [*]
[*] according to Italian prevention rules for civil occupancies	

The casino is usually characterized by a huge number of slot machines, all positioned side by side, therefore four burners were inserted into the model to simulate the fire spread. The FDS simulations determined the ASET considering the following parameters throughout the egress routes:

- visibility;
- temperature;
- fractional effective dose (FED);
- radiation.

The value of ASET has been compared to value of RSET, that has been computed according to analytical data, ISO/TR 16738 and multi-agent continuous evacuation modelling.

COMPUTATION OF RSET

Escape time depends upon detection, warnings and a range of parameters related to occupant evacuation behavior and movement. The basic formula used for determining RSET is given in equation (1)

$$t_{RSET} = t_{det} + t_a + t_{pre} + t_{tra} \quad (1)$$

The detection time (t_{det}) is the time between ignition and detection of fire signals by an automatic system or the first occupant. The alarm time (t_a) is the time from detection to a general alarm. The pre-movement time (t_{pre}) is the time that elapses between activation of the occupant notification system and the time at which occupants make the decision to begin evacuating. Depending on the type of occupancy, the pre-movement time may be a few seconds or a few minutes. Finally, the travel time (t_{trav}) is the time it takes for the occupants to reach a protected exit or the outside of the building once they decide to evacuate the building and start moving towards the exits (Pauls, 1980).

The prediction of detection time tdet

Some studies through computer fire modeling compute the activation times of smoke detectors for different fire growth rates. The material in the casino are certified or are characterized by a slow fire growth rates. The studies (Raavi, 2011) pointed out that smoke detector activation times lie between 22 seconds and 56 seconds. In this case the detection time has been considered 80 seconds.

The prediction of alarm time

The automatic detection throughout the building providing a pre-alarm to management or security, with a manually activated general warning system sounding throughout affected occupied areas and a general alarm after a fixed delay if the pre-alarm is not cancelled (two stage alarm system). The alarm time has been considered 20 seconds This value has been verified by a simulation of smoke detector activation.

The prediction of pre-movement time

The pre-movement time is a function of the management level (M1, M2, M3), building level (B1, B2, B3) and alarm level (A1, A2, A3) according to ISO TR 16738.

In this case study, the pre-movement for occupants that are in fire compartment has been considered 0 seconds. It is supposed that after detection time the smoke is visible and the evacuation starts immediately. Instead, the pre-movement time for other occupants been provided according to ISO TR 16738.
The factors that influence the t_{pre} are presented in the following table.

Table 2: The characteristics of fire case studies

Parameter	Value
Occupancy types	**B** – Awake and Unfamiliar
Alarm System	**A2** – Two Stage alarm System
Building Complexity	**B2** – a simple multi-enclosure (usually multi-storey) building, with most features prescriptively designed and simple internal layouts.
Management level	**M1**: The normal occupants (staff or residents) was trained to a high level of fire safety management with good fire prevention and maintenance practice, floor wardens, a well-developed emergency plan and regular drills.

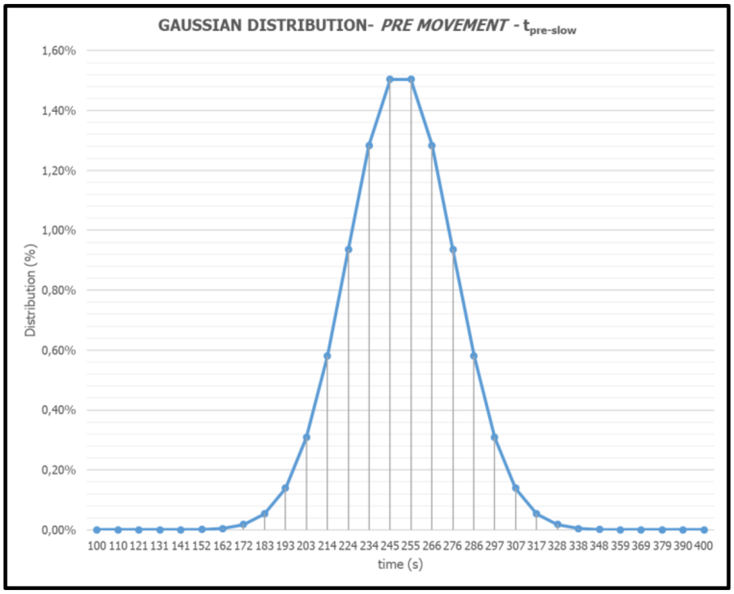


Figure 4: Gaussian Distribution of t_{pre}

In according to this classification, the trend of pre-movement time follows the Gaussian curve (see Figure 4):

<u>The prediction of travel time</u>

Evacuation movement time can be simulated and computed through the Pathfinder software, developed by American Thunderhead engineering company. This software is a simulator that takes into account people evacuation movement. This paper uses the Pathfinder software to compute the travel time of the occupants.

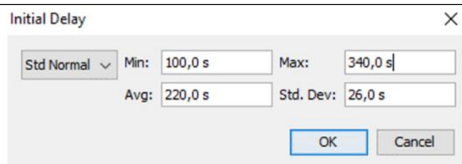
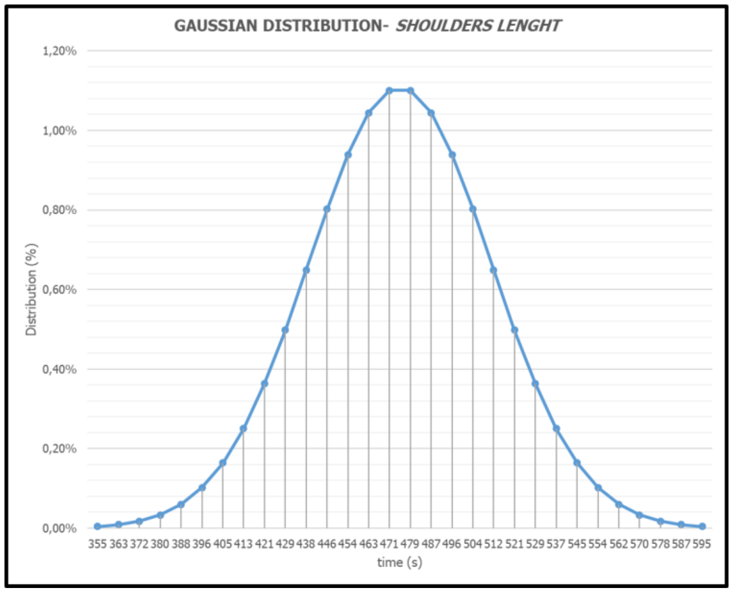
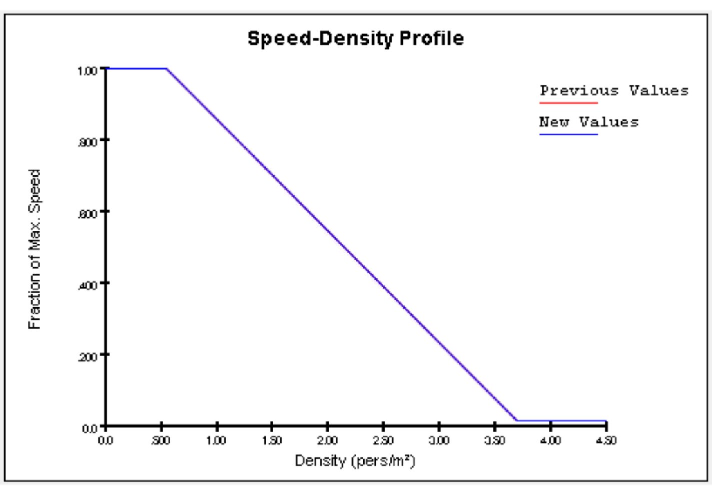
PATHFINDER SIMULATION

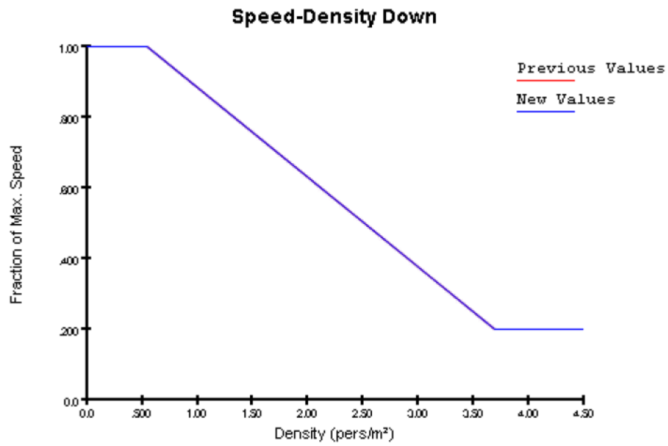
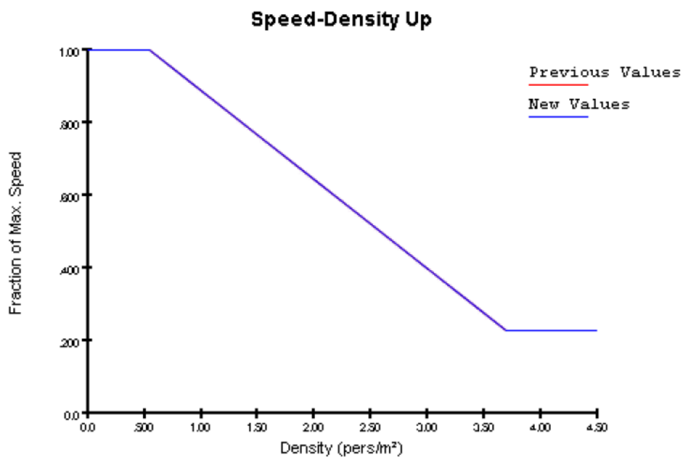
The fundamental parameters have been inserted into the software. These data have been determined analytically and the following table shows their values.

Table 3: Parameter of Pathfinder simulation

Parameter	Pathfinder settings
BLw	A parameter that influences the walking speed is the boundary layer width (BLw). In this case, the value of BLw equal to 20 cm has been assumed. This value is typical of the corridors. It is conservative: in the real case the spaces is very wide.
Knowledge of places	Pathfinder is based on hydraulic models and does not control directly the behavior of the occupants. However, the possibility for the occupants to change the egress route due to the crowd has been considered. In this study, the likelihood of 30% to change the chosen egress has been considered.

Table 3: Parameter of Pathfinder simulation

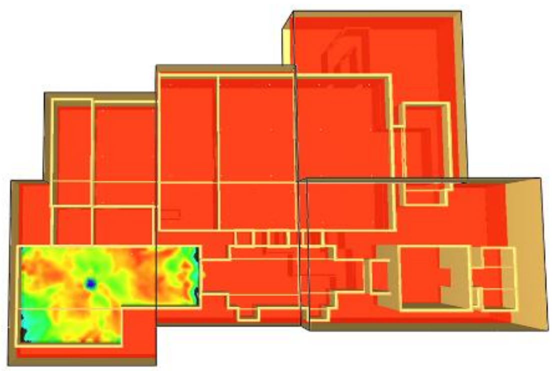
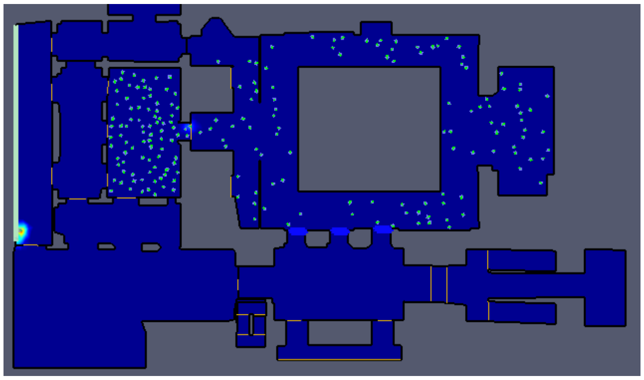
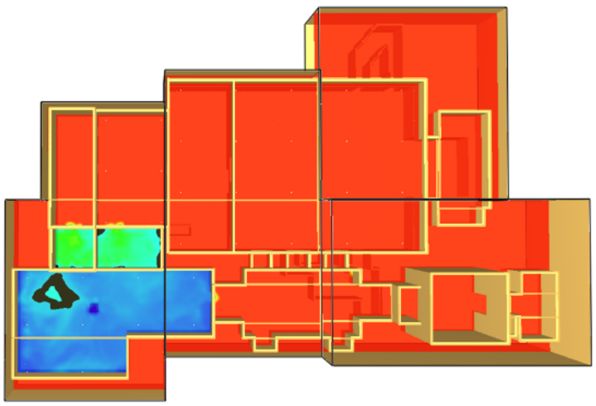
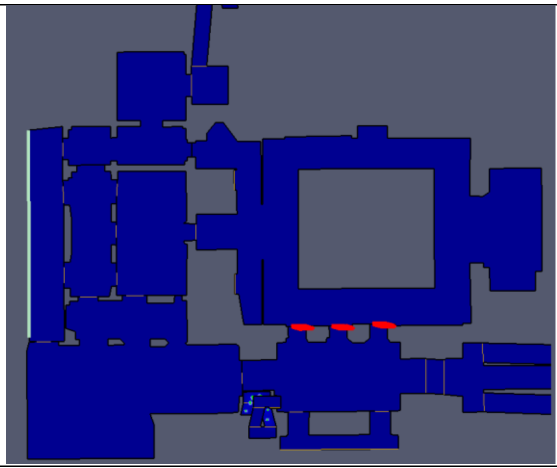
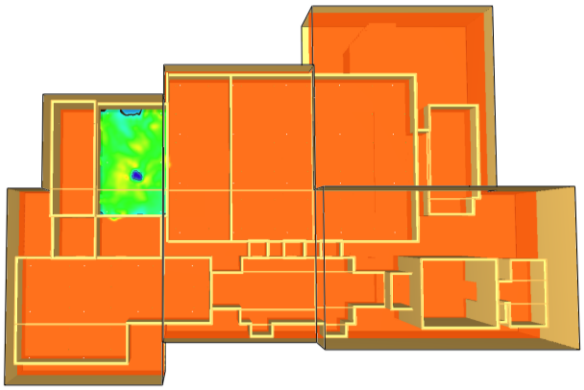
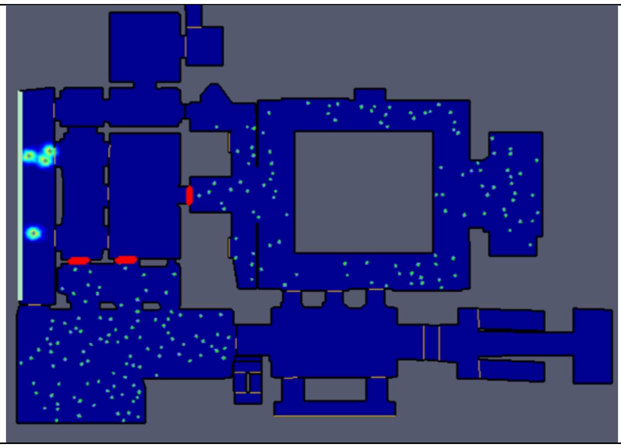
Parameter	Pathfinder settings
t_{pre}	 The trend of pre-movement time follows the Gaussian distribution
	It is important to evaluate the physical constitution of occupants. A research of University of Florence provides this parameter that follows a Gaussian distribution (see Figure 5).  *Figure 5: Gaussian distribution of shoulders length*
t_{trav}	The walking speed has been determined in accordance with ISO/TR 16738. For horizontal travel, the value of the unimpeded walking speed is 1,19 m/s.
	ISO/TR 16738 quoted unimpeded velocities on stairs of about 0,8 m/s (0,67So) for travel downwards and 0,7 m/s (0,59So) for travel upwards. These parameters were inserted in the software.
	 The crowd reduces the walking speed I accordance with the following relation: $S = k - akD$ With: S = walking speed (1,19 m/s) D= density in person/m2 (0,54 ≤D≤3,8) k= 1,4 for horizontal travel a= 0,266

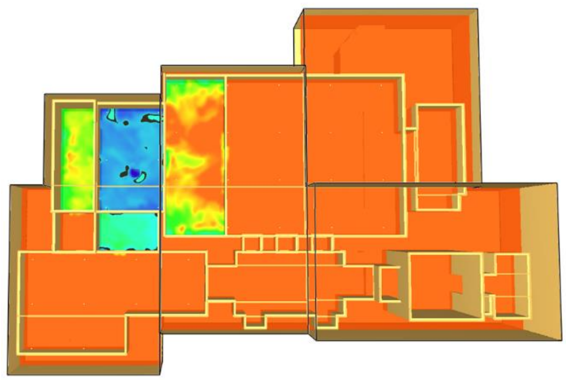
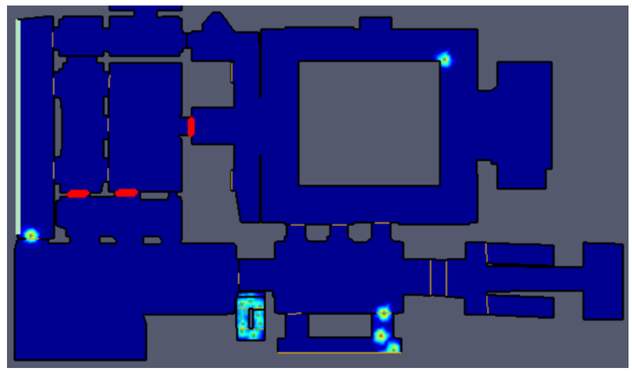
Parameter	Pathfinder settings	
t_{trav}	 	To characterize the reduction of walking speed, the previous formula has been used. A value of k equal to 1 is assumed.

RESULTS

This section shows the results of the modelling of the design fire scenarios: the comparisons between the ASET values calculated with FDS and the identified performance thresholds will be reported for each design fire scenarios and for the place adjacent to the room of first ignition.

Table 4: Result of computer modelling

Comparison between FDS and Pathfinder – Assessment ASET/RSET	
FDS – ASET	PATHFINDER - RSET
S4B	
t = 300s	T = 152 s
 Visibility - m	
	
t =700 s	t =320 s
	
S4C	
t=250 s	t = 140 s
	

Comparison between FDS and Pathfinder – Assessment ASET/RSET	
FDS – ASET	PATHFINDER - RSET
S4C	
t=540 s	t=290 s
	

CONCLUSIONS

Base on the information above, the following conclusion can be drawn:

- the safe egress of occupants is guaranteed and the tenability criteria are met. This study shows that it is possible to ensure the safety of occupants in a historic building by taking alternative measures even if prevention rules are not respected;
- the fire growth rate and ASET has been reduced using the materials classified for fire reaction;
- the laboratory tests are fundamental to know the real characteristics of the material in case of fire.
- the computer modelling is an important tool to lead more in-depth analysis;
- an high level of safety management can reduce the time request to evacuate the building, reducing the accidents. The management measures leaded to minimize adjustment works and maximize the level of safety with considerable benefits in terms of cost/effectiveness risk analysis.

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