FIRE SAFETY IN HOSPITAL BUILDINGS, with PERFORMANCE-BASED ANALYSIS

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INTRODUCTION / MOTIVATON

The risk of fire in an Hospital building is a topic of extreme importance for the safety of the population in general, and for the safeguarding of the occupants and equipment in that building.

The publication of Fire Safety Regulations aim to improve the conditions for preparing buildings in the event of a fire. In this sense, it is important to analyse the fire safety conditions in existing buildings, so that safety is not only verified in new buildings.

Particularly, in Hospital buildings, special care must be taken to safeguard them, mainly due to the difficulty in evacuating bedridden people and people with limited mobility needing medical assistance.

Current regulation prescribes the performance of fire drills with a certain frequency. There are buildings in which, due to their characteristics, performing drills may imply the suspension of services, as the level of difficulty of doing them, for example in health units with users with reduced mobility, including bedridden, will be very high.

OBJETIVES

- Validate the Regulatory Requirements on Fire Safety measures to apply on medical buildings, with occupants with reduced or limited mobility.
- Analyze the Emergency Plan of a Medical Building, to access the safety of all occupants during the evacuation on a fire situation, eventually to improve it.
- Carry out a performance-based analysis of the building in case of fire.
- Test the possibility of increasing the installed efficiency of the smoke extraction in case of fire.
- Attempt to limit the CO concentrations to values in such a way to prevent human harm.

CASE STUDY AND NUMERICAL MODELLING

Hospital da Luz Private Clinic in Coimbra

Figure 1: Lateral facade of the Hospital da Luz Private Clinic

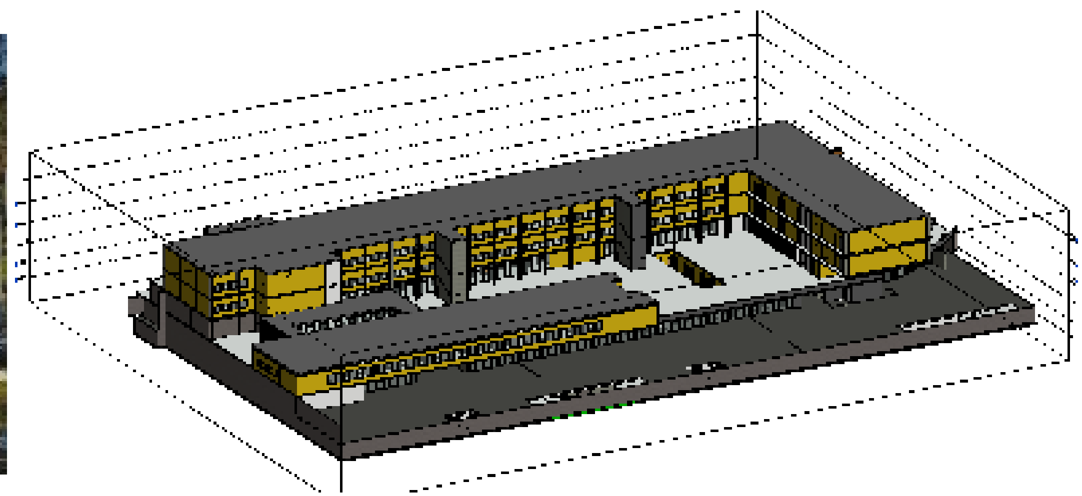
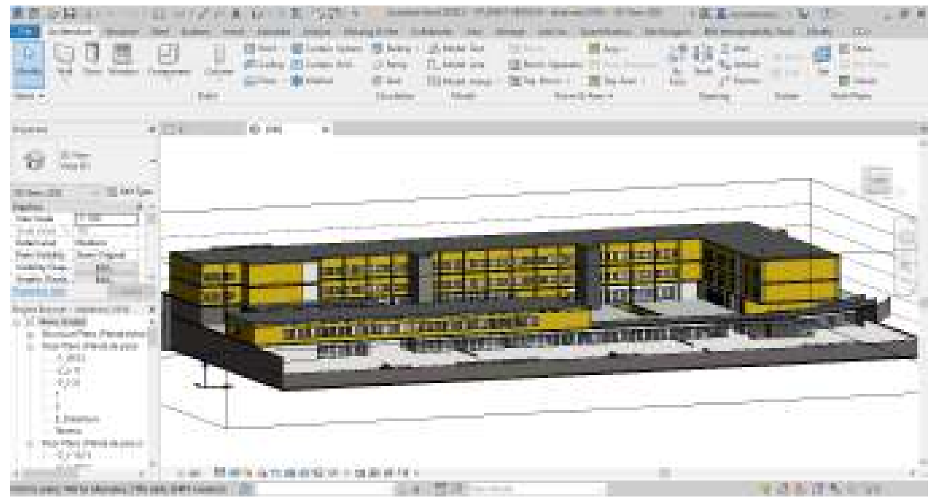


Figure 2: View of the 3D model of the building in REVIT.

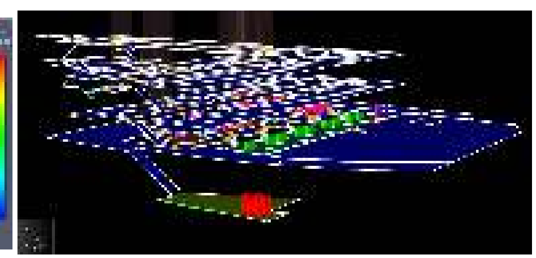
CASE STUDY AND NUMERICAL MODELLING

Numerical modelling with Pyrosim and Pathfinder



The software PYROSIM, along with Smokeview, developed in the National Institute of Standards and Technology of the United States of America (NIST) and the Technical Research Center of Finland (VTT). (courtesy of Thunderhead Engineering).

The software calculates and simulates the evolution of the fire, that is, the propagation of flames and smoke. Along with PATHFINDER, it was possible to simulate the egress of the building (courtesy of Thunderhead Engineering).

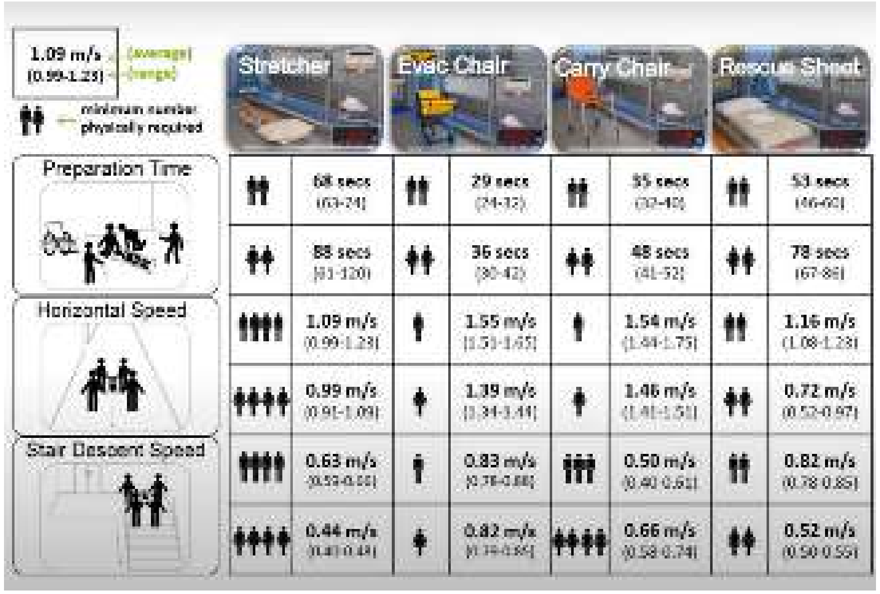


CASE STUDY AND NUMERICAL MODELLING

Evacuation times

The evacuation times were considered

according to Aoife Hunt (2013).



	Stretcher	Evac Chair	Carry Chair	Rescue Sheet
Preparation Time	68 secs (63-74)	29 secs (24-33)	35 secs (32-40)	53 secs (46-60)
	88 secs (61-120)	36 secs (30-42)	48 secs (41-52)	78 secs (67-86)
Horizontal Speed	1.09 m/s (0.99-1.23)	1.55 m/s (1.51-1.65)	1.54 m/s (1.44-1.75)	1.16 m/s (1.08-1.28)
	0.99 m/s (0.91-1.09)	1.39 m/s (1.34-1.44)	1.46 m/s (1.41-1.51)	0.72 m/s (0.52-0.97)
Stair Descent Speed	0.63 m/s [illegible]	0.83 m/s (0.78-0.88)	0.50 m/s (0.40-0.61)	0.82 m/s (0.78-0.85)
	0.44 m/s [illegible]	0.82 m/s [illegible]	0.66 m/s (0.58-0.74)	0.52 m/s (0.50-0.55)

Hunt, A., Galea, E., Laurence, P., (2013) "An analysis and numerical simulation of the performance of trained hospital staff using movement assist devices to evacuate people with reduced mobility", Fire and Materials,, https://doi.org/10.1002/fam.2215

CASE STUDY AND NUMERICAL MODELLING

Efects of the fire in humans

Particular attention was paid to the Carbon Monoxide Concentration during evacuation According to Stephen Marsar, (2009).

Table 1. Effects of Hypoxia[8] (Reduced Oxygen)

Oxygen Percentage Available	Symptoms
21	Normal conditions, no effect.
19.5	OSHA oxygen-deficient atmosphere.
17	Muscular impairment, rapid breaths.
12	Dizziness, headache, rapid fatigue.
9	Unconsciousness.
7 to 6	Death within a few minutes.

Effects of Hypoxia

Table 4. Human Response to Carbon Monoxide at Different Concentrations[2]

Carbon Monoxide (CO) in Air	Human Response
0.2 %	Headache after 10 minutes, collapse after 20 minutes, and death after 45 minutes.
0.3 %	Maximum "safe" exposure for five minutes and danger of collapse in 10 minutes.
0.6 %	Headache and dizziness in 1 to 2 minutes and danger of death in 10 to 15 minutes.
1.28 %	Immediate effect, unconsciousness after 2 to 3 breaths and danger of death in 1 to 3 minutes.

Human Response to Carbon Dioxide

Marsar, Stephen, (2009) "Survivability Profiling: How long Can Victims Survive in a Fire? ", Fire Engineering.com

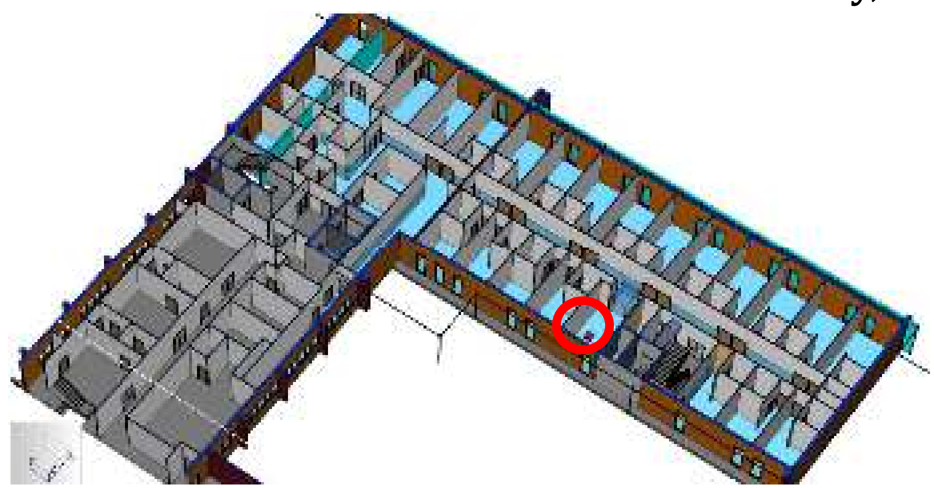
CASE STUDY AND NUMERICAL MODELLING

Fire Scenarios

Two fire scenarios and corresponding evacuations were studied. The scenarios consider ignition points in internment ward and external consultation areas. The alternatives aimed to optimize the smoke removal systems in order to reduce the evacuation times of the sectors under study, as well as the danger to the occupants.

Scenario A

Fire scenario A was considered on the 2nd floor of the internment ward. In this case the location of the fire source is in a living room in the middle of the hallway.



CASE STUDY AND NUMERICAL MODELLING – Fire scenario A

The following tables show the definition of the existing and proposed fire extraction systems for the scenario A fire site.

Clinic Smoke Control System

Table 1: Summary table with insufflation and extraction flow rates existing in the building

Place	Number Fans Extraction	Extraction Flow (m3/s)	Total Extraction Flow (m3/s)	Number Fans insufflation	Insufflation Flow (m3/s)	Total Insuflation Flow (m3/s)
Main Corridor	1	3	3	3	0,9; 1; 1,5	3,4

Proposed Smoke Control System

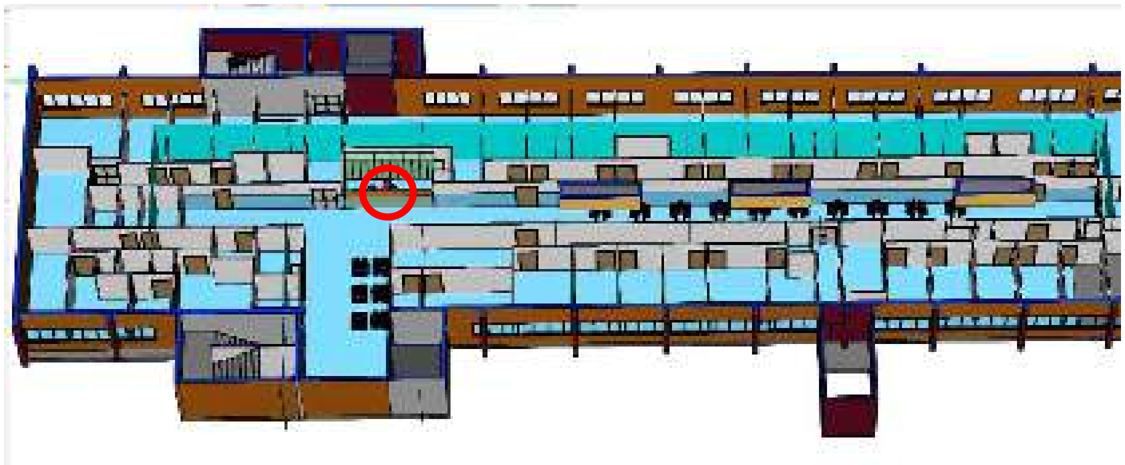
Table 2: Summary table with proposed insufflation and extraction flow rates

Place	Number Fans Extraction	Extraction Flow (m3/s)	Total Extraction Flow (m3/s)	Number Fans insufflation	Insufflation Flow (m3/s)	Total Insuflation Flow (m3/s)
Main Corridor	1	6	6	3	2,0; 2,5; 2,5	7,0

CASE STUDY AND NUMERICAL MODELLING

Scenario B

Fire scenario B was considered on the 2nd floor, in outpatient consultations. In this case, the location of the fire source is at the reception, next to the waiting room, in the main lobby.



CASE STUDY AND NUMERICAL MODELLING – Fire Scenario B

Clinic Smoke Control System

Table 3: Summary table with insufflation and extraction flow rates indicated installed in the building

Place	Number Fans Extraction	Extraction Flow (m3/s)	Total Extraction Flow (m3/s)	Number Fans Insufflation	Insufflation Flow (m3/s)	Total Insuflation Flow (m3/s)
Main corridor	3	4; 4; 4	12	3	4; 4; 4	12
Hallway	-	-		-	-	

Proposed Smoke Control System

Table 4: Summary table with proposed insufflation and extraction flow rates

Place	Number Fans Extraction	Extraction Flow (m3/s)	Total Extraction Flow (m3/s)	Number Fans Insufflation	Insufflation Flow (m3/s)	Total Insuflation Flow (m3/s)
Main corridor	3	4; 4; 4	16	4	4; 4; 4;4	16
Hallway	1	4		-	-	

RESULTS

Scenario A

The table below shows the number of occupants per compartment. It is important to understand that the entry of each element to aid evacuation is counted as an occupant. Given the length of time it takes to evacuate bedridden users compared to the evacuation times of autonomous users, only the compartments where bedridden users are found were considered.

Table 5 – Number of occupants in the compartments - Comparative Graphs

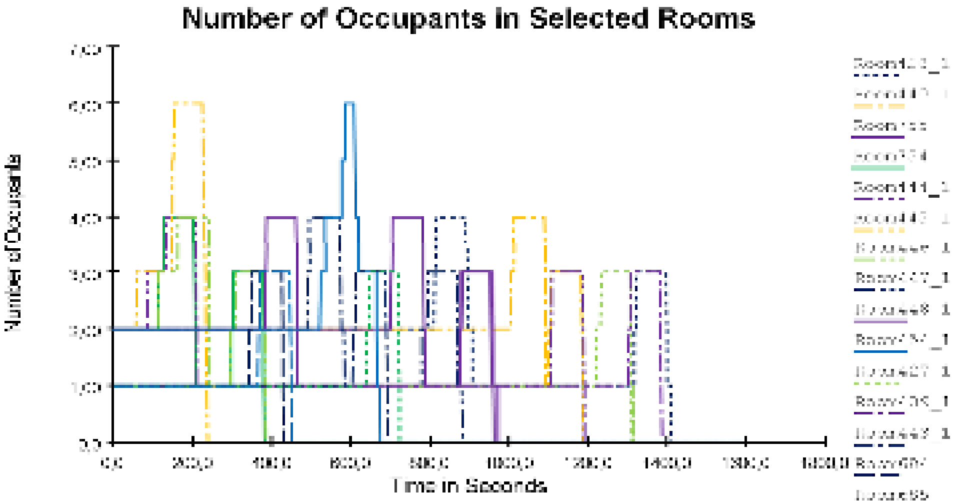
Compartment:

- **Double inpatient rooms – 2.138; 2.140; 2.142; 2.144; 2.146; 2.148; 2.150; 2.152; 2.154; 2.156**
- **Individual inpatient rooms – 2.160; 2.162; 2.164; 2.170; 2.174; 2.178**

Occupants at start: 26 bedridden occupants (two per double room and one bedridden occupant in each single room); 10 medical staff; 10 additional staff (may be firefighters, arriving 8 minutes after the alarm)
Occupants at the end: 0

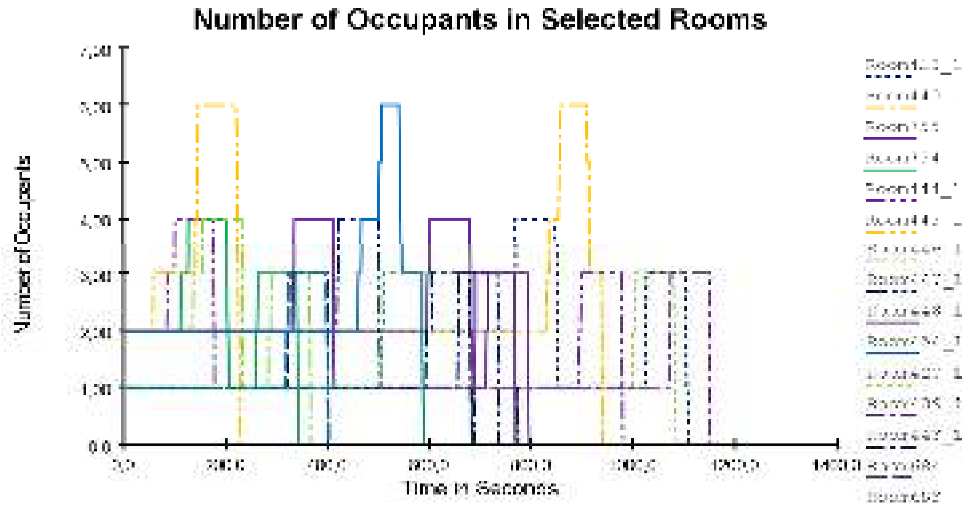
RESULTS – Fire Scenario A

Evacuation with the Building Smoke Control System



Evacuation of spaces occurs in seconds: 1444

Evacuation with the Proposed Smoke Control System



Evacuation of spaces occurs in seconds: 1160

RESULTS – Fire Scenario A

Description of the evacuation (scenario A with proposed smoke extraction system)

At 60s the Evacuation Alarm is given. The smoke extraction system starts and opens the skylight in the waiting room. The evacuation of bedridden users begins. Comparing each of the parameters with those of the building's smoke removal system, it can be seen that in this simulation: Visibility is better with the lowest value of about 5.40 m; Oxygen Concentration is similar and Carbon Monoxide Concentration is lower being about half in the Corridor.

At 230s, the first bedridden occupants arrive at the Concentration Zone in the Refuge Sector. Visibility continues to increase, with minimum visibility being between 6 and 7 m. The temperature does not increase in the corridor and the concentration of Carbon Monoxide is maintained.

At 480s the firefighters arrive and begin the evacuation operation to the outside of the bedridden occupants. There are 10 bedridden occupants in the Concentration Zone. In part of the corridor, visibility is above 18m with a minimum of about 6.5m. The maximum value of concentration of Carbon Monoxide is in the ceiling next to the fire source and at about 0.6%.

At 550s, firefighters begin removing bedridden occupants. In part of the corridor, visibility is greater than 18m, with a minimum value of about 6.5m. There are 15 bedridden occupants to be removed from the rooms.

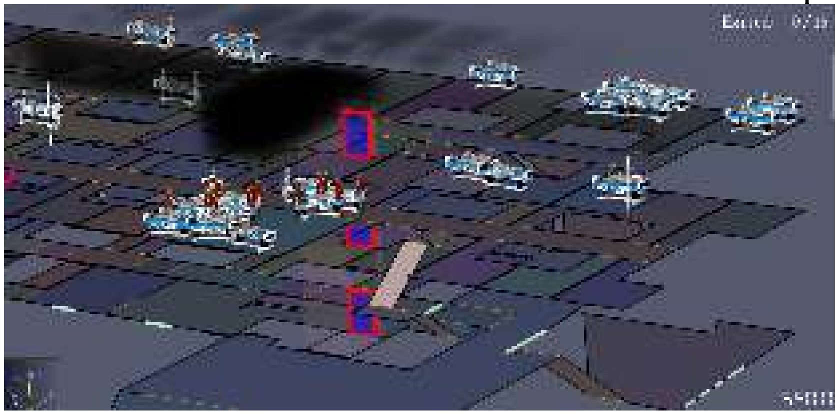


Figure 5: Evacuation simulation at 550 s

At 1160s the last bedridden occupant is removed from the 2nd floor. (In the simulation with the building's ventilation system this moment occurred at 1444s)
Visibility is maximum in half of the corridor (matching with the very low CO concentration value) and around 9m in the remaining corridor. 28 occupants have already left.
At 1251s, the last bedridden occupant who was in the Concentration Zone is removed.

RESULTS

Scenario B

Table 6 shows the number of occupants per compartment for scenario B. The graphs depict the evolution of number of occupants in each compartment, along the time. Both situations are represented: one with the building ventilation system and the other with the proposed ventilation system.

Table 6 – Number of occupants in the compartments - Comparative Graphs

Compartments: Endoscopy Exams – 2.016; Recovery Room – 2.016; Exam Room – 2.012; Office – 2.012; Exam Room – 2.023; Allergology Exams – 2.039; Sleep Cabinet – 2.041; Room – 2.042; Room – 2.042; EMG – 2.046; ECG – 2.047; Recovery – 2.081; **Occupants at the beginning: 16 bedridden occupants; 201 Occupants (Health Technicians and External Users); 10 additional staff (may be firefighters, arriving 8 minutes after the alarm)** **Occupants at the end: 0**

<u>Scenario B</u>

Description of evacuation (scenario B with existing smoke extraction system)

Between 20s and 30s the Health Technician will check out what is happening and returns to the room and contacts the Security Post. The corridors are practically filled with smoke, as both visibility levels are reduced and CO levels are increasing.

At 60s, the occupants were checked to exit via the emergency stairs to the North and South. The evacuation alarm is given, the smoke extraction system starts and the skylights in the main corridor are opened. Visibility is practically null in the corridors. There are 12 occupants left. Health Technicians will evacuate bedridden occupants.

At 132s, the evacuation of bedridden occupants begins (4 practically simultaneously). Visibility in the main corridor is practically restored. In the other aisle, visibility is practically null. 63 occupants have already left. Occupants continue to exit via the North and South stairs.

Scenario B

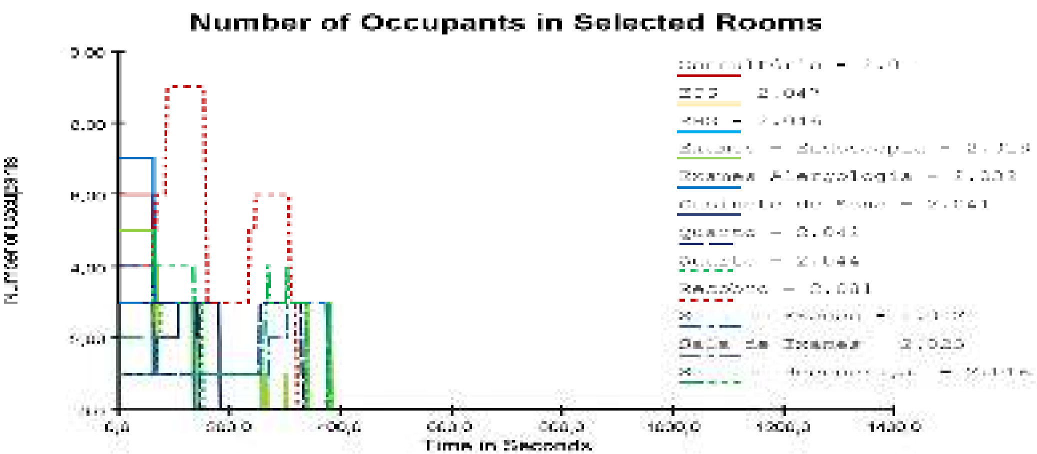
Description of evacuation (scenario B with existing smoke extraction system)

At 456s, the last bedridden user is removed from the sector to be evacuated. Visibility in the other aisle visibility is less than 3m. An increase in the concentration of Carbon Monoxide can be observed. The concentration of Carbon Monoxide (Figure 6 – t=456s) reaches values between 1% and 2%, above 0,2%, which already causes symptoms in humans (headache after 10 minutes, collapse after 20 minutes and death after 45 minutes). 197 occupants have already left. The fire reaches temperatures above 500°.

At 480s the fire crew arrives. The last bedridden user evacuated from the floor enters the concentration area on the 1st floor. 199 occupants left. In the secondary corridor, the concentration of Carbon Monoxide continues to increase, as well as the temperature. The flame is crossing the corridor (Figure 7 – t=480s).

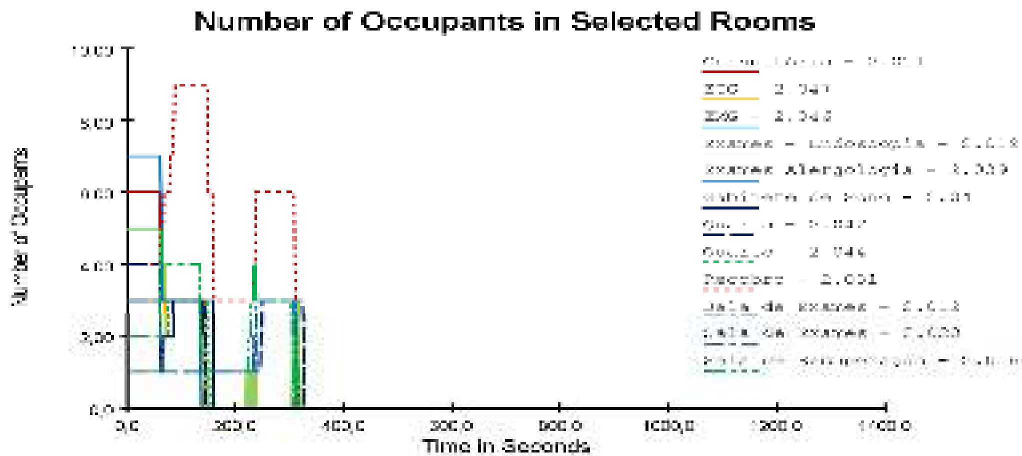
RESULTS – Fire Scenario B

Evacuation with the Building Smoke Control System



Evacuation of spaces occurs in seconds: 383

Evacuation with the Proposed Smoke Control System



Evacuation of spaces occurs in seconds: 330

Description of evacuation (scenario B with existing smoke extraction system)

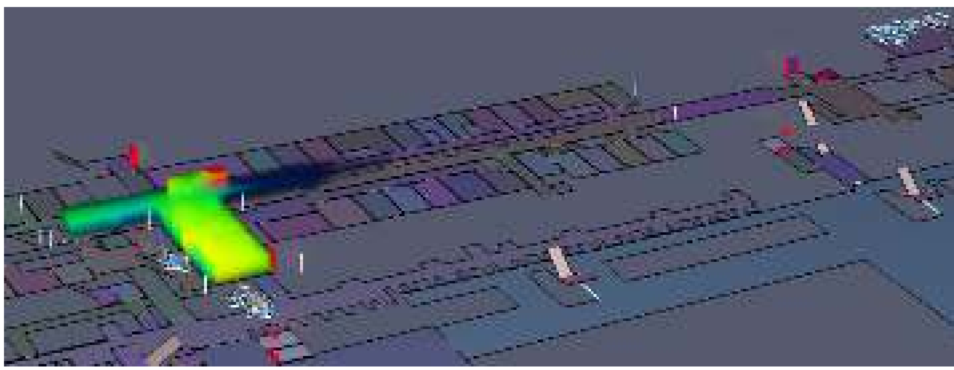
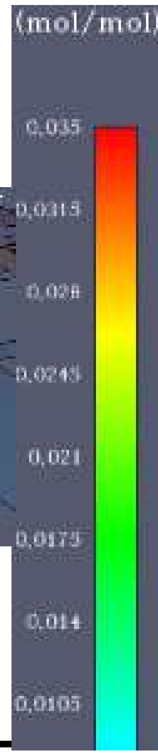



Figure 6 – Carbon Monoxide Volume Fraction (3D) t=456s

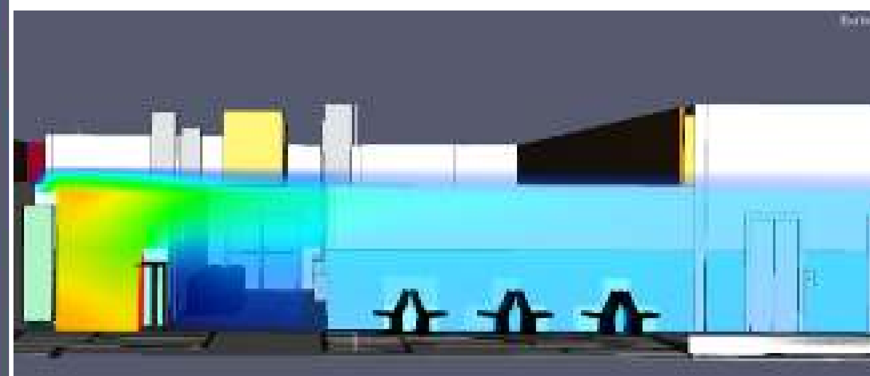



Figure 7 – Reception Temperature (3D) – t=480s

Description of evacuation (scenario B with existing smoke extraction system)

Eventual traffic jam

These simulations allow the analysis of eventual traffic jams of beds or tretchers, to check if the concentration zones are adequate.

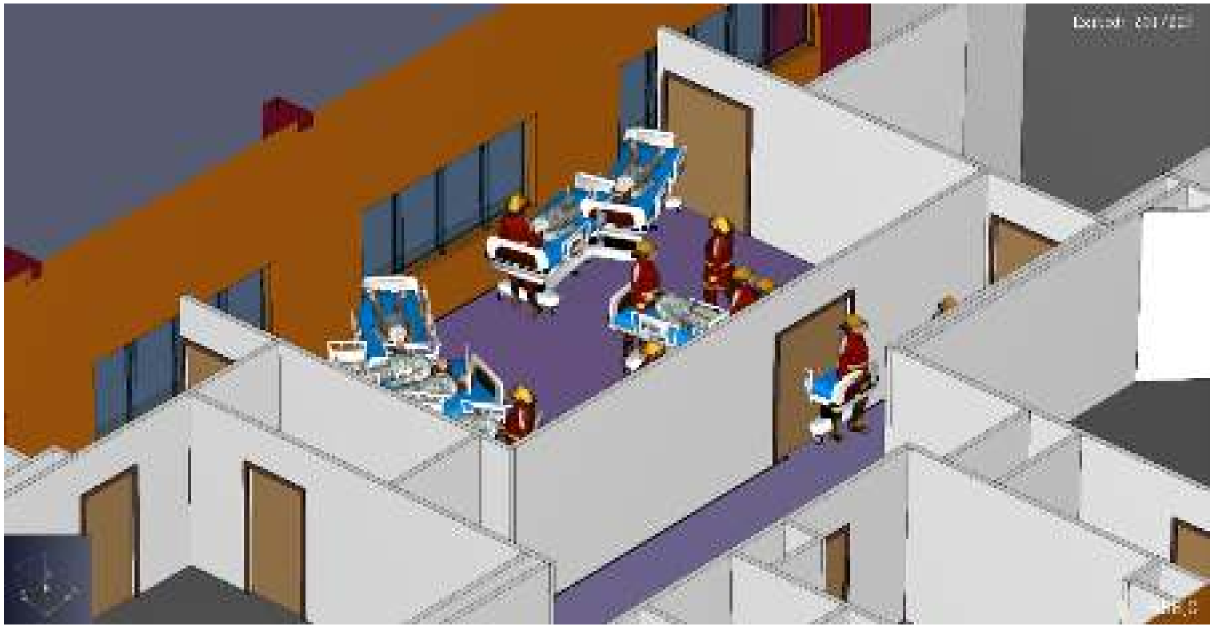


Figure 8: Evacuation of the Concentration Zone

Synopsis

Table 7 shows the evacuation times of bedridden occupants to the outside of the building.

Scenario	Time required for Evacuation Occupants (s)	Time required for Evacuation Occupants (min:s)
A	1565	26:05
A - Proposal	1297	21:37
B	1019	16:59
B - Proposal	1019	16:59

In this table, the times for scenario B and with the existing ventilation system and with the alternative system are identical. The reason for these values has to do with the fact that in the two simulations the bedridden occupants are placed in the concentration area in a time shorter than the time of entry of the firefighters (480s) and therefore the two scenarios from that time on, are identical (evacuation of bedridden occupants and firefighters to the outside).

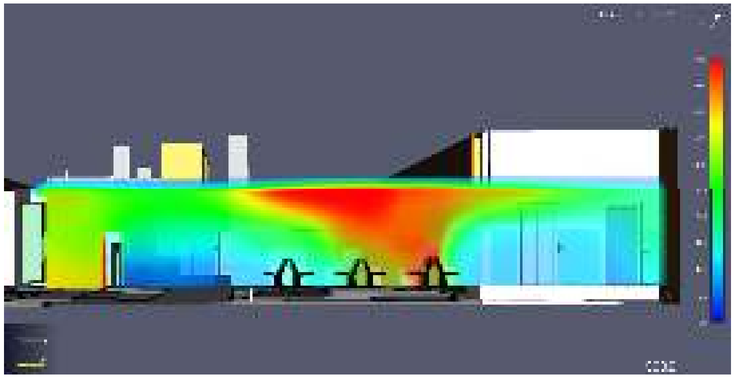
CONCLUSIONS

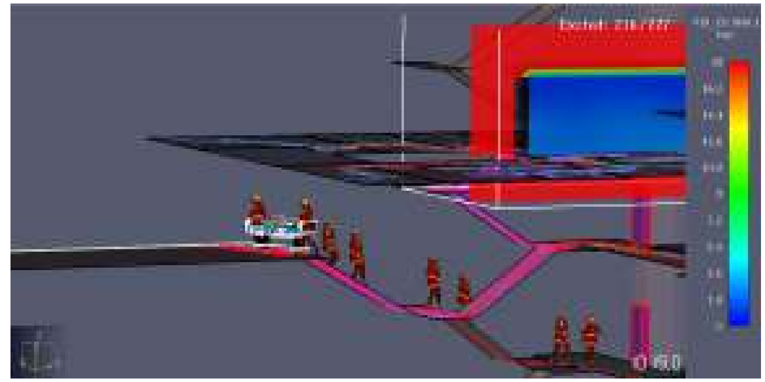
- In scenarios A and B, alternatives were carried out in order to reduce the amount of smoke in the horizontal evacuation routes, so that shorter evacuation times were achieved. From the analysis of the graphs, it was noticed that the increase in ventilation caused better smoke removal and resulted in the intended reduction of evacuation time, mainly in scenario A. The present study allowed to achieve the conclusion that an improvement of the ventilation system is effective in scenario A, and not so much in scenario B.

- It was concluded that depending on the part of the building, it is possible to optimize the ventilation systems, with the objective of reducing evacuation times due to the higher evacuation speeds of users. It is also important to compare the results of real fire evacuation drills, with the results of the computer simulations, to calibrate the virtual models, when it is difficult or impracticable to carry out real evacuation exercises as in areas of occupants with reduced mobility.

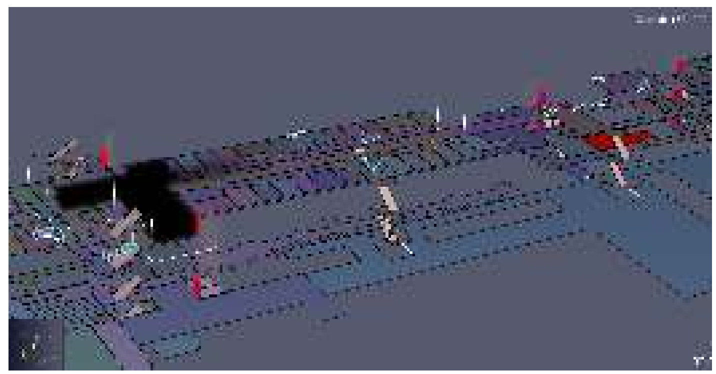
- Another important conclusion is that the firefighters aid in evacuation occupants in beds, may be of great importance to prevent them to be exposed to high levels of Carbon Monoxide. The emergency plan could also be improved (number of staff involved).

CONCLUSIONS


Temperature evolution in the waiting room


Last patient being evacuated


Oxygen Volume Fraction (3D)


Global view of evacuation and smoke propagation

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