ANALYSIS OF THE FLUID DYNAMIC BEHAVIOR OF AN ENCLOSED STAIRCASE UNDER FIRE

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Abstract. The analysis of fire through computer modeling allows the improvement of current legislation, as well as fire protection and fighting techniques. This work presents an analysis of the fluidodynamic behavior of a cloistered staircase (EP) under fire through a computational modeling using the commercial software Fire Dynamics Simulator (FDS), developed by NIST (National Institute of Standards and Technology). The Enclosed Ladder (EP) was dimensioned according to the specifications of the NBR 9077 standard(1). Through the simulation, it is possible to understand the fluidodynamic behavior of (PE) in relation to the aspects of smoke behavior in fire situations and develop mitigating measures for buildings already built. The results showed that the use of (PE) with the dimensions provided for by NBR 9077 (1) is not effective, since it confines the smoke inside the staircase and does not provide the complete escape of the smoke from its interior, being proposed in this worka larger opening dimension dthe windows for smoke escape, as well as the creation of a gap that provides the entry of air inside the staircase in a natural way, providing a better distance of visibility.

Keywords: Enclosed staircase, fire, computer modeling, visibility, temperature.

1. Introduction

Fires are events whose occurrence is influenced by a wide variety of factors, many of which are unpredictable, making each incident unique.(2) Buildings must be designed in such a way as to mitigate fire risks, or minimize the damage caused by them, limiting the effects of heat and smoke spread, allowing sufficient conditions for the evacuation of occupants, and it is important to carry out studies that help the knowledge of the origin and dynamics of the fire. (3)

For this, there is the possibility of study through experimental trials, but these require too much time and involve high costs. The alternative that arises is the study with the use of computer simulations that allow to analyze the dynamics of the fire, as well as the effects caused by it. Through this analysis it is possible to obtain quickly and economically important data such as temperature, gas concentration, burning time, degree of visibility, among others, already considering that materials, such as concrete, have their characteristics of mechanical strength and strain modulus altered when they suffer the effects of high temperatures. The advancement of Engineering has as best resources the adoption of parameters and the creation of computational models. (4) (5)(4)

The proposal of this article is to verify the applicability of a cloistered staircase built in reinforced concrete with mechanical system of provision of independent air intake and outlet by pavement, through thealis and the degree of visibility, which depends mainly on the composition and concentration of smoke.(6) This data was generated by a commercial software, based on mathematical models and fluid mechanics models. The case study is in the UNA College Building in Conselheiro Lafaiete – MG with occupation for teaching services and meeting the provisions of NBR 9077 as to the type of ladder to be used in this type of establishment. (1)

2. Methodology

This article describes two distinct stages: the three-dimensional modeling of the building of the UNA College of Conselheiro Lafaiete and the simulation to determine the degree of visibility.

In the first stage, the theoretical foundations necessary for the elaboration of the work and the understanding of the research theme were developed. Methods of testing and evaluation of damaged structures were carried out as proposed in the bibliography. Based on this data, the modeling of the building was elaborated, taking into account the information available in the projects, including the architectural project "as built". This information allowed the virtual creation of the building through CAD software.

In the second step, the computer simulation to determine the temperature profile was performed by importing the building model from Autocad to Pyrosim. Through the FDS software, a simulation of a randomly estimated fire for the building was performed.

With regard to the computational modeling criteria, the following points stand out:

a) The floors not affected by the fire were not detailed in relation to the internal environments and were considered as a single volume in the modeling.

b) The dimensions of the building correspond approximately to the dimensions of the project.

c) The fire load used follows the definition established by the Brazilian Standard for the type of occupation.

For a deeper understanding of fire behavior on a cloistered staircase, the analysis provided information on how smoke spreads and behaves on a cloistered staircase, including the areas of greatest visibility and the safest routes for evacuation.

For this analysis, it was necessary to use the following items: Notebook; Fire Dynamics Simulator (FDS) software; Smokeview Software; AutoCad Software; and PyroSim Software.

The simulated environment corresponds to the building that houses the Una College in Conselheiro Lafaiete – MG. The building was designed to meet the type of stairs provided for by NBR 9077(1) and Technical Instruction01 of the Military Fire Department of Minas Gerais as to its occupation.

The building has 12 floors consisting of reinforced concrete structure formed by pillars, beams and slabs.

The fire simulation was conducted using the information about the shape of the construction described in the project. It was reproduced the sixth floor of the building, which is a standard floor.

In order to create the representation of the fire, the architectural plans of the building were employed. These plants were later imported into Pyrosim, a software that translates CAD files into a graphical interface compatible with the FDS language. This approach enabled the development of a complete three-dimensional building project.

Fig. 1 illustrates the floor plan type. This plant contains the location of the initial fire outbreak to be generated for study purposes.

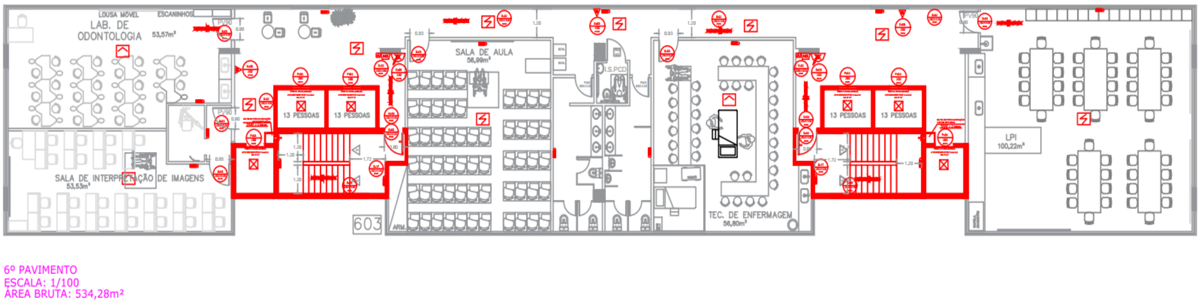

Figure 1: Floor plan type
Source: (Authors, 2023)

At Una College, the main occupation is that of teaching services, classified as E-1, Schools in General. The NBR 14432 standard establishes the (7)specific fire load of 300 MJ/m², which is the energy available and released in the combustion of building elements. (8)

Within the software, it is possible to add "burners", which have the possibility to start the fire. In this particular simulation, the fire started and progressed only by burning the fire load. One of these "burners" was placed exclusively in the hallway of the sixth floor of the building, as evidenced in red in Fig. 2.

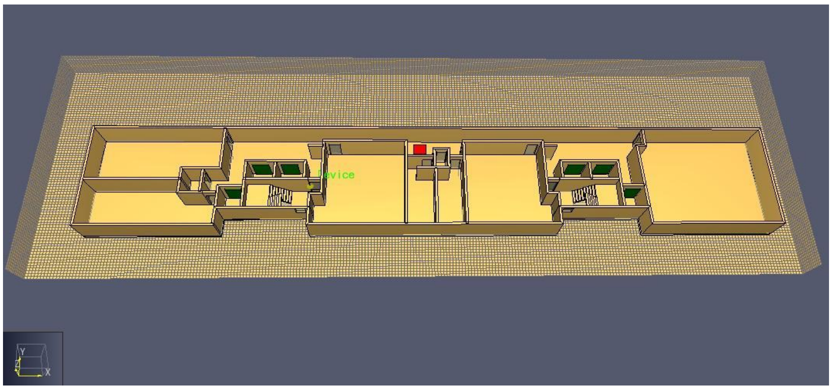

Figure 2: Location of the burner on the 6th Floor
Source: (Authors, 2023)

It is important to be careful when defining the values to be applied to the burner, as very high values can impact the development of the fire. For this specific burner, a fire load was assigned that represents approximately 0.01% of the load defined for the place where the accident starts.

(8)According to Rodrigues, it is necessary to apply the value established by standard of the specific fire load according to Equation 01, for the transformation of the units from MJ/m² to MW, for a simulation time of 300 seconds of total duration.

$$Q= (Af \times q)/300 \quad (01)$$

Where:

Q= the fire load, in MW;

Af= the area of the floor reached, in m²;

q= the fire load, in MJ/m².

Through the Equation 01 mentioned earlier, it is possible to convert the values of fire load by the standards to the units used by the FDS software. All the materials present in the building were considered inert, ensuring the stability of the walls in relation to heat variations. This was done in order to focus on the observation of smoke dynamics and evaluate the effectiveness of ventilation of the enclosed staircase of the building. In addition, it was established that the elevator doors would remain closed during the fire, indicating that they would not be used.

The calculation cells, known as "mesh" in the software, determine the refinement parameters for the simulation. They represent the number of cells where they will be applied, defining the size of the finite volumes to be simulated. The maximum amount of calculated cells used in a simulation depends on the configuration of the computer hardware performing the test and the characteristics of the system under study.

Simulations that aim to evaluate the temperature on the surface of the materials and the dynamics of the fire not waiting for a large number of cells. Factorable values of 3, 4 and 5 are assigned to the cells to perform these simulations in the software.

A cell size of 25 centimeters was defined. These calculation cells were applied in an area larger than that occupied by the building, allowing the evaluation of the development of smoke in the environments and its exit to the external area.

To simulate the oxygen supply to the fire in the simulated environment, openings called "open vents" were created. These openings allow communication between the internal and external environment, and their area of occupation in the model has a direct relationship with the calculated volume performed by the computer during the simulation of the claim. In order to visualize the visibility at each moment, a blade called "slices" was created. It was positioned on the pavement under study, where the main damage was felt.

Below are the main parameters configured for characterization of the material and the characteristics of the environment to be simulated in the software, already meeting the units of measurement used by the Pyrosim system:

Characteristics of the Material used: concrete
- Density: 452 kg/m³
- Specific Heat: 1,758 kJ/(kg. K)
- Conductivity: 13.956 W/(m.K)
- Emissivity: 0.9
- Absorption coefficient: 5.0×10^4 1/m

Characteristics of the Simulated Environment:
- Ambient Temperature: 20 °C
- Ambient Pressure: $1{,}01325 \times 10^5$ Pa
- Relative Humidity: 40.0%

A simulation was performed with a maximum time of 300 seconds. The various interactions performed by the application until the end of the entire simulation reached a time of approximately 60 hours, performed on a computer with two processing cores and 2.0 Gigahertz.

3. Results and Discussions

After the simulations performed, it was possible to obtain the images demonstrating the visibility of the burned area along with the entire environment, both according to the current norm and also according to the proposal of the work. These images were obtained with times of 60 seconds and 300 seconds, these being the minimum and maximum times, respectively, of pre-movement for various types of environments, presented by Gouveia and Etrusco. (9) Two different heights were also analyzed, 1.50 meters and 2.50 meters. In this context, subsequent Fig. 3 and Fig. 4 were acquired according to NBR 9077, with a window area in the staircase of 0.80 m², where it was proposed to (1)an opening of 1 m x 0.80 m.

Fig. 3 represents the results obtained in the simulation for 0, 60 and 300 seconds respectively, at a height of 1.50 m, in which it can be noted that in 0 seconds there was no variation in visibility, since the fire had not yet started. With 300 seconds it was possible to observe a minimum visibility in most areas of the floor. The best visibility rates were found in the central classrooms and the one farthest to the right, which does little to help evacuate people down the stairs. The two staircase boxes are very low in visibility, which implies that the opening dimension used is not a satisfactory opening area for the exit of the volume of smoke necessary for a safe evacuation.

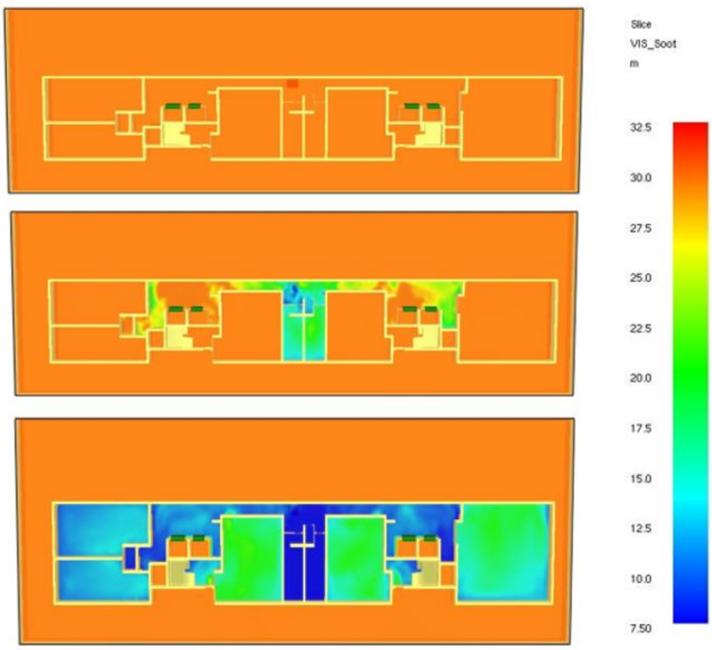

Figure 3: Result of the Global Visibility Analysis of the analysis made by the FDS with 0, 60 and 300 seconds of simulation and height of 1.50 meters
Source: (Authors, 2023)

In Fig. 4 it was possible to perceive some differences regarding the results found with the height of 1.50 meters. From these differences it can be highlighted that the speed of smoke spreading and loss of visibility is higher at a higher height, since the smoke is less dense than oxygen, where the smoke tends to occupy spaces higher up the environment. It is also possible to see that visibility worsened in all environments when compared between the analyses of 1.50 meters and 2.50 meters.

In relation to the staircase boxes, they also followed the same dynamics of the rest of the environments, where with 2.50 meters the visibility decreases drastically. In addition, it was possible to better perceive the exit of the smoke through the opening of 0.80 m² made, since the opening is within the height of 2.50 meters. Thus, it is perceived the exit of the smoke in the external part of the building.

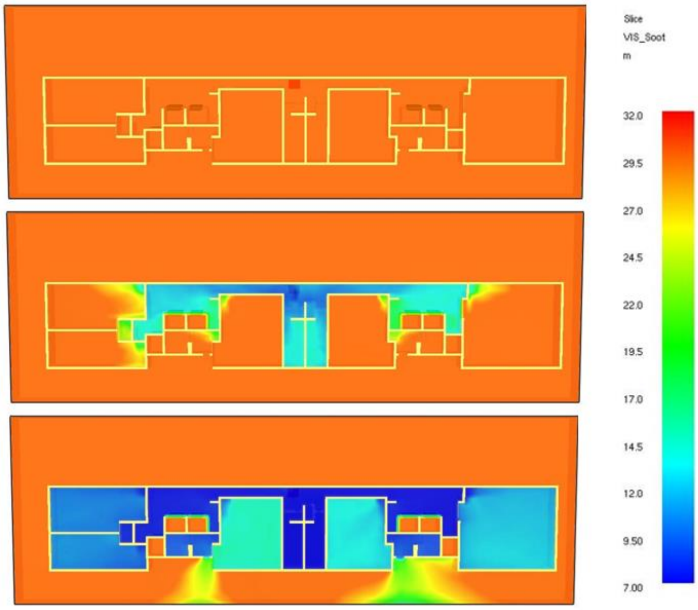

Figure 4: Result of the Global Visibility Analysis of the analysis made by the FDS with 0, 60 and 300 seconds of simulation and height of 2.50 meters
Source: (Authors, 2023)

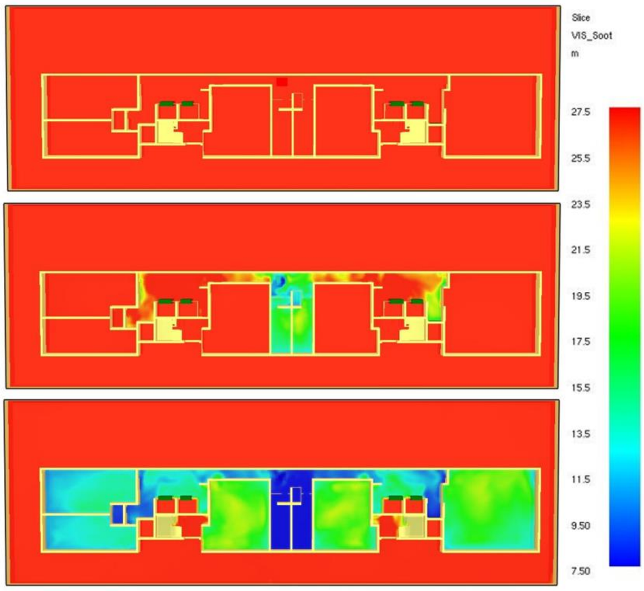

Figure 5: Result of the Global visibility analysis of the analysis made by the FDS with 0, 60 and 300 seconds of simulation, height of 1.50 m and aperture proposed by the authors
Source: (Authors, 2023)

After the identification that the proposed opening area of NBR 9077 would not be sufficient to have a satisfactory visibility for the evacuation in the staircase boxes, two openings in the staircase boxes were proposed in this article, one near the floor (0.10 m from the floor) for air intake, with dimensions of 2.65 m x 0.60 m, and another opening higher up, starting at 0.10 m from the slab, for smoke exit, with dimensions of 2.65 m x 1.20 m. In view of this proposal, the same analyses were performed with the area indicated in the NBR, according to Fig.5 and Fig.6.

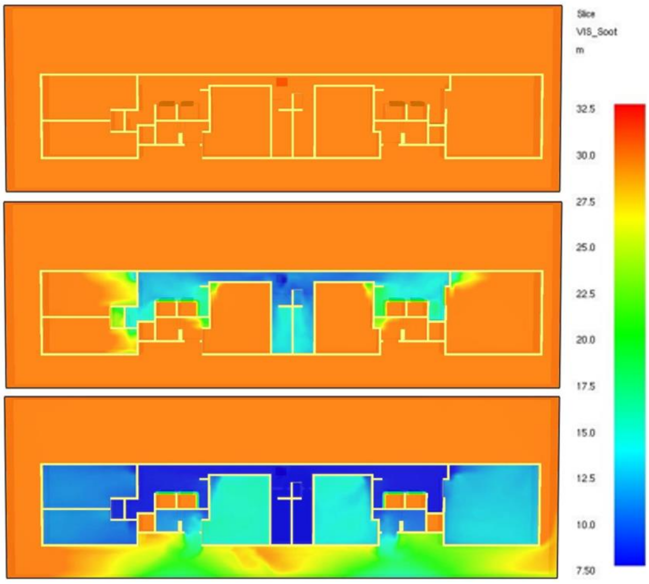

Figure 6: Result of the Global visibility analysis of the analysis made by the FDS with 0, 60 and 300 seconds of simulation, height of 2.50 m and aperture proposed by the authors
Source: (Authors, 2023)

According to Fig. 5, in comparison to the same results presented with the opening proposed by NBR 9077 in (1) Fig. 3, it was possible to identify that in 60 seconds, before the smoke meets the exit in the staircase, the visibilities are very similar in any of the proposals. With 300 seconds, where the smoke already meets the exit, it is possible to notice that the staircase maintains its initial visibility, and if compared to the opening of the NBR, the rest of the environments are with better visibility, excluding only the bathrooms closest to the focus of the fire.

The interpretations described with the new openings proposed in the staircase boxes and with 1.50 meters, are also possible to perceive at 2.50 meters with some observations, according to Fig.6.

4. Conclusions

The results of this research prove that the opening area for smoke exit of 0.80 m² recommended by the NBR 9077 standard (1) presents a small flow of smoke, influencing poor visibility in the environments, including in the staircase boxes. On the other hand, the two openings proposed in this article, the upper one of 3.18m² and the lower one of 1.59m², cause greater smoke flow to the external environment, causing greater visibility in the staircase. The analyses performed with heights of 1.50 meters and 2.5 meters showed that the difference is more noticeable in the height of 1.50 meters.

It is noted that with these analyses, there is a need to review NBR 9077 (1) regarding the prescriptions for sizing the Enclosed Ladder, since it does not guarantee effectiveness when in situations of fire and panic in a building

These findings are of utmost importance for the safety and efficiency of escape routes in buildings, since adequate visibility is essential for a quick identification and orientation of occupants during accident situations. The use of the openings proposed in this study can contribute to a better evacuation and minimization of risks to human life.

It is of great importance to encourage research in this additional area, seeking to further improve solutions to improve visibility in staircase boxes in the event of a fire. In this way, it will be possible to ensure an effective and safe evacuation in buildings, preserving the integrity of the occupants and minimizing the damage caused by fires.

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Authorship statement. The authors confirm that they are solely responsible for the authorship of this work, and that all material that has been included herein as part of this work is the property (and authorship) of the authors, or has the permission of the owners to be included herein.

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