# FIRE DESIGN OF INDUSTRIAL AND COMMERCIAL BUILDINGS BUILT WITH STEEL STRUCTURES UNDER NATURAL FIRE

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## 1. Project objectives and goals

One of the major limitations associated with steel structures in large compartments is the compliance with fire resistance. The conventional method of fire protection is the application of intumescent paint since it is the most practical method and the one that offers an aesthetically pleasing solution. This solution implies a large investment, and in some cases, it can reduce the competitiveness of steel structures.
The existing calculation software for the design of a structure in a fire situation essentially uses the standard ISO 834 curve, which is not suitable for large rooms, such as commercial and industrial buildings [1]. These calculation simplifications lead to potentially unrealistic fire scenarios, not guaranteeing safety proportional to the invested capital.
The present work focuses on the evaluation of the design methodologies of steel structures in a fire situation, to allow a cost reduction. It is intended to obtain, through numerical studies, curves closer to the real development of temperature, thus optimizing the fire protection to be applied to the structure, providing a more sustainable application of steel.
Two types of evaluations were made in the first phase, two-zone models were used, simulating various fire load density scenarios and ventilation conditions. In a second phase, the most relevant scenarios were also simulated using computational fluid dynamics models.

## 2. Description of the case study

The commercial and industrial building that is intended to serve as a case study has 30 m x 20 m (plan) and a height of 6 m to the top of the columns (Fig. 1). The structural solution is generally characterized by pinned supports at the base and column-beam and beam-beam rigid connections.
The safety check at room temperature was carried out by the EN1993-1-1 [2], using the steel class S275 JR (EN 10025-2) for all the structural elements. The actions considered correspond to the self-weight of the structural elements, permanent loads, live loads, temperature and wind. The HEA 300 steel profile was selected for the columns and the IPE 360 steel profile was selected for the beams.
The safety check in a fire situation was carried out in the temperature domain. The design effect of actions for the fire situation was obtained through the accidental combination, using the value of $\psi_{1,1,}$ as stipulated in the Portuguese National Annex of the EN1990 [3]. The critical temperatures obtained are 622.5 ºC for the columns and 591.1 ºC for the beams.

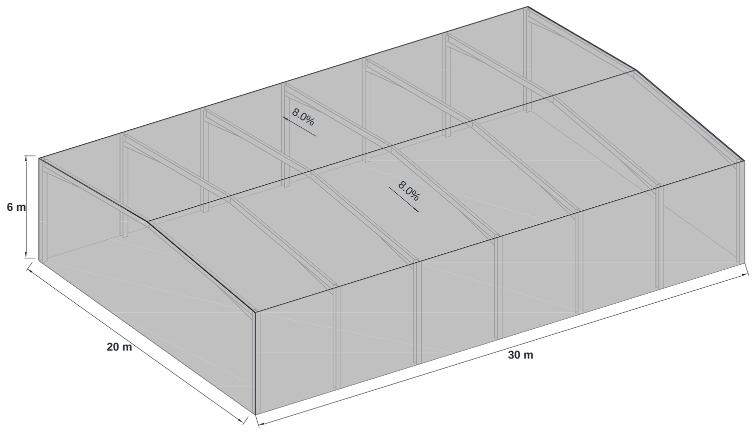


**Fig. 1:** Dimensions of the commercial and industrial building intended to serve as a case study

## 3. Description of methods and results

Concerning to the temperature development in the fire compartment, numerous scenarios were simulated varying the fire load density, heat release rate, compartment height, ventilation conditions and ignition location. Advanced calculation models were used, namely two-zone models with the software CFAST [4] and computational fluid dynamic models, using the Fire Dynamics Simulator [5].
In these parametric studies, five groups were created and combined to generate 72 fire scenarios by selecting one case from each group.
In the first group, two fire scenarios were defined, corresponding to de 2nd category of risk and the 3rd category of risk, according to the Portuguese Technical Regulation on Fire Safety in Buildings (RT-SCIE) [6] for the worst use (type XII, industrial, workshops and warehouses). For the scenario that includes the 2nd risk category, a fire load density of 730 MJ/m$^2$ was considered, according to Annex E of the EN1991-1-2 [7] for occupancy of a shopping centre. For the scenario relating to a 3rd risk category, a fire load density of 15000 MJ/m$^2$ was considered. The maximum value established for the duration of combustion was 120 minutes because the most relevant in these analyzes is to obtain the temperature in the compartment instead of the duration of the fire.
For the second group, three fire area scenarios were considered, depending on the expected occupancy: 9 m$^2$, 20 m$^2$ e 36 m$^2$ [1,8]. The fire growth rate corresponds to fast growth and the maximum rate of heat release per square meter corresponds to 250 kW/m$^2$, according to the Annex E of EN1991-1-2 [7] for occupancy of a shopping centre.
The ventilation conditions in the compartment were defined in the third group. 12 roof openings were used, simulating the existence of skylights, with an area of 1.5 m$^2$ each. For the second case, only two openings on the facade of the compartment were used, with an area of 9 m$^2$ each, simulating the existence of gates. For the third case, openings in the facade and roof were admitted. The openings previously defined in the roof were maintained and openings were added to the facade corresponding to one-third of the area of the original gates.
The influence of the compartment height was considered in the fourth group.
In the fifth and last group, the two most unfavourable ignition locations were considered: ignition next to a column at a corner of the building and ignition in the center of the building, which corresponds to an unfavourable scenario for the beam.
For the evaluation of flashover in the compartment, the procedures described in the literature [9,10] were used: temperature in the ceiling of the compartment below 600 ºC and heat flux at a height of 1 m from the floor below 15 kW/m$^2$.
Due to limitations in the time required for the simulation in the FDS program, only 12 scenarios were simulated, which correspond to the most unfavourable combinations of fire area (36 m$^2$ e 20 m$^2$). Table 1 summarizes the maximum temperatures obtained in all the simulations carried out, taking into account

the occupancy and fire area described in the literature [1,8]. In the simulations with FDS, the temperatures were considered using the 80% fractile. The risk categories and occupancies defined according to the fire area are taken into account, disregarding the temperature profile of the CFAST plume model.

**Table 1:** Summary of the maximum temperature obtained in the simulations according to the expected occupation and risk category

| Ocupancy | Maximum temperature 2nd risk category (ºC) | Maximum temperature 3rd risk category (ºC) |
|---|---|---|
| Atrium on Office Building<br>Hotel Reception Hall<br>Picture Gallery<br>Station Hall<br>Aerogare Hall<br>Sport Hall | 175.7 | 190.5 |
| Church<br>Multi-use hall<br>Restaurant Room | 318.2 | 392.4 |
| Supermarket<br>Shopping Gallery<br>Offices (Large Area)<br>Exhibition Hall | 490.7 | 568.8 |

Based on the temperature curves generated through the various simulations in the two programs used, a temperature curve was created with the most unfavourable values (Fig. 2). Conservatively, no distinction was made between the temperature curves for beam elements and column elements, since the results obtained in CFAST result from the average temperatures of the upper layer of a compartment that encompasses the two elements, and it is not possible to have a clear temperature distinction between them. To guarantee the fire resistance of an element, it is necessary that the calculation value of the temperature in the element at the required instant is less than or equal to the critical temperature of the element. To calculate the temperature in the structural elements, the equations and methodologies present in EN1993-1-2 [11] were used, conservatively considering the structural elements exposed on the 4 sides. The required fire-resistance time was 60 minutes, as required by Portuguese legislation for single-storey buildings with the occupancy VIII to XII [6].
Given the results obtained, it was verified that the maximum temperature reached by the structural elements is 566.5 ºC. Taking into account that the critical temperature determined for the columns is 622.5 ºC and 591.1 ºC for the beams, it is concluded that the structural elements of the case study do not need additional fire protection, since their critical temperature is higher than the design value of the temperature in the elements at all times.

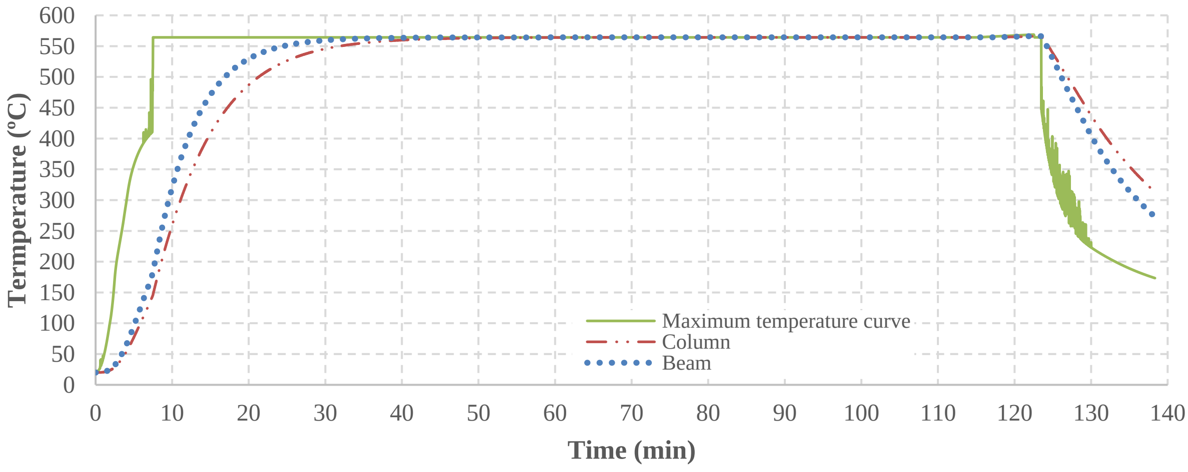


**Fig. 2:** Temperature obtained in the structural elements from the maximum temperature curve generated through the various simulations

## 4. Potential for application of results

In the study presented, advanced calculation models such as two-zone models and computational fluid dynamic models were used to obtain temperature curves closer to the real development of a fire in a building. Five groups were created and combined to generate scenarios with variations in fire load density, fire area, openings locations, compartment height and ignition location. These variations made it possible to acquire sensitivity to the various admitted characteristics, being relevant for future studies or comparisons with an equivalent design situation and to serve as an improvement to new knowledge about the subject.

The occurrence of generalized combustion (flashover) in the compartment was considered unlikely since the temperature measured at the ceiling of the compartment was less than 600 °C and the heat flux was less than 15 $kW/m^2$ at the fire load level.

The results obtained are quite promising in terms of maintenance and cost reduction in passive fire protection. The structural elements for the analyzed case study do not need additional protection against fire, having as thermal action the most unfavourable temperature curve obtained by simulation. It was thus verified that the determination of curves closer to the real development of fire allows to optimize the costs of industrial and commercial buildings built with steel structures, reaching relevant steps in the range and competitiveness of them. The performance in sustainability is also relevant, leading to a reduction in the environmental load that triggers a smarter application of steel and its capabilities to society.

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