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# The modeling, simulation and numerical analysis of a fire in a construction with light structure

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Summary

*This paper presents a numerical simulation of a light construction structure by using of the high level dedicated software Fire Dynamics Simulator (FDS). The important temperatures, Heat Release Rate, Total Heat Flux were computed along with the numerical fire visualization.*

Keywords: Fire Model, Fire simulation, Numerical simulation, Heat Release Rate, Fire visualization.

## 1. INTRODUCTION

The present study refers to the modeling, simulation and numerical analysis of a fire developed in a construction with a light structure. The research had as starting point a practical requirement the realization of a prototype with a light structure resistant to fire. In this idea tests were made on the structural model chosen, on a numerical way with the help of the advanced platform “FIRE DYNAMICS SIMULATOR” (FDS) and also experimental (by ICECON S.A.) by the effective building of a scale model and the preparing of it for the fire test.

The experimental results obtained were concretized by temperature measurements in divers points on the burning structure. The measurements were executed at ICECON S.A., in the context of a mutual research contract with a part of the staff from The Firefighters Faculty.

## 2. THE MODELING, SIMULATION AND THE NUMERICAL ANALYSIS OF THE FIRE

The numerical analysis was made on a geometry with a light structure identical with the one obtained experimentally, observing the way of fire behavior of it and the underlining of 20 numerical monitoring points of the temperature on a determined time interval. The structure and the calculus network utilized for the discretization of differential equations of the fire is shown in figure 1.

For the numerical modeling of the fire the "field zoning" type was adopted or more precise the tridimensional discretization of the transitory characteristically equations. The 3D modeling of the fire can be shown in principal by the input values and the output values:

Input values:

- The detailed form of the structure, the construction of the chambers, including walls, the ceiling and the floor, the number of air vents and their sizes (if necessary, etc;
- The characteristics of the furniture (if necessary), the characteristics of the fuel, the parameters of buoyancy and radiation.

Output values:

- The thermal flux, the movement and speed of smoke;
- Temperatures measured in divers points of the structure;
- Previsions on the time until sprinkler and heat detectors activation (if necessary), the time to flashover;

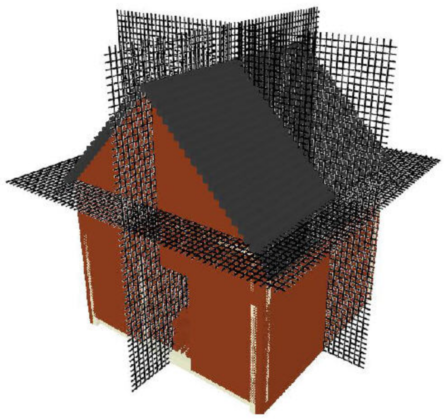

Figure 1. The geometry of the light structure and the calculus network

A FDS simulation determines the thermal behavior of the whole structure by calculating the thermodynamically quantities in each cell of the discretization. The number of quantities previsioned is greater then the number of quantities that are normally measured in validation experiments.

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The following is a list of thermodynamically values that will be obtained for every cell, list that can be compared with the experimental measurements. Their order underlines their importance.

- The temperature of the gas;
- The speed of the gas;
- The concentration of major gases ;
- The concentration of smoke/ obscurization;
- The pressure.

For solid surfaces, the FDS results are usually:

- The surface temperature;
- The total thermal flux (by conduction, convection and radiation).

These global quantities are used to evaluate the total energy budget, the confirmation of the conservation of the total energy in the model, and the evaluation of the incertitudiny of the values obtained experimentally.

FDS resolves the mass conservation equations, of the momentum and energy for a multi-component, thermal expandable mixture of ideal gases, like:

Mass conservation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho u = 0 \tag{1}$$

Component conservation (species)

$$\frac{\partial}{\partial t}(\rho Y_l) + \nabla \cdot \rho Y_l u = \nabla \cdot \rho D_l \nabla Y_l + \dot{m}_l''' \tag{2}$$

Momentum conservation

$$\rho\left(\frac{\partial u}{\partial t} + (u \cdot \nabla) u\right) + \nabla p = \rho g + f + \nabla \cdot \tau \tag{3}$$

Energy conservation

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot \rho h u = \frac{Dp}{Dt} - \nabla \cdot q_r + \nabla \cdot k \nabla T + \sum_l \nabla h_l \rho D_l \nabla Y_l \tag{4}$$

To note that the extern force of the fluid, represented by the term **f** in the above equations, is the friction exercised by the water drops from the sprinklers and by other external forces. The term $\frac{Dp}{Dt} = \frac{\partial \rho}{\partial t} + u \cdot \nabla p$ represents a material derivate. The conservation equations are accompanied by a state equation that links the thermodynamically quantities. It is used an approximation of the characteristically equation of the ideal gas by decomposing the pressure in a “background” component, a hydrostatic component and a perturbation induced by the flow:

$$p = p_0 - \rho_\infty gz + \tilde{p} \qquad (5)$$

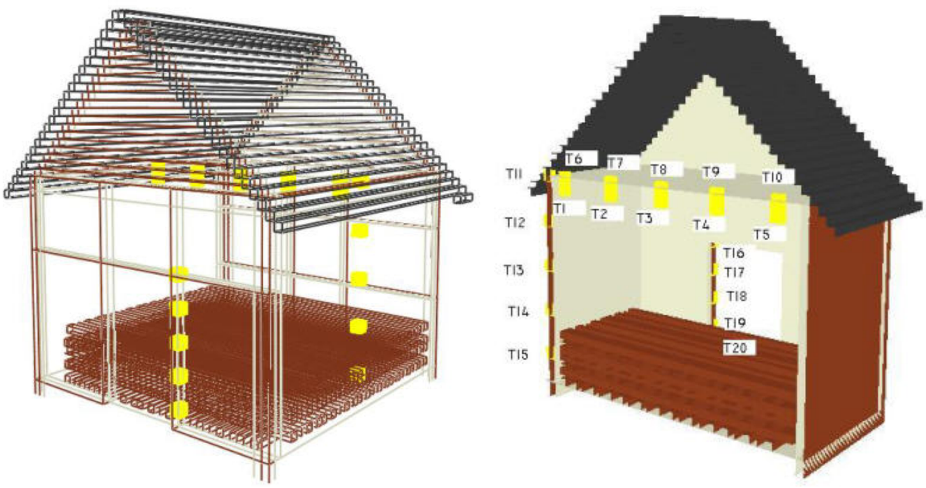
For application $p_0$ is a constant and the other two components are relatively small. This assumption can be modified if the pressure rises due to the fire in a small an isolated compartment, or when the height of the domain is very high and $p_0$ can no longer be considered a constant and must by considered a function of altitude.

The scope of decomposing the pressure is that for the flows with a small Mach number the temperature and density can be approximated with the state equation:

$$p_0 = \rho TR \sum (Y_i / M_i) = \rho TR / M \qquad (6)$$

These equations (1-6) are simultaneous resolved in time (transient regime) for all the calculus cells assimilated to the light structure.

The geometry of the structure together with the location of the 20 point where the temperature is measured is shown in figure 2:

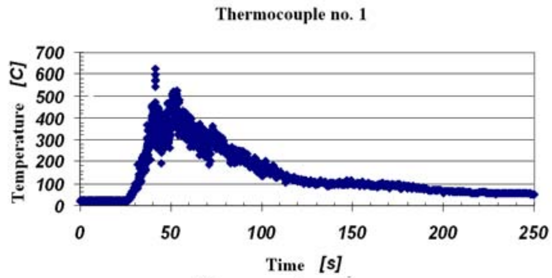


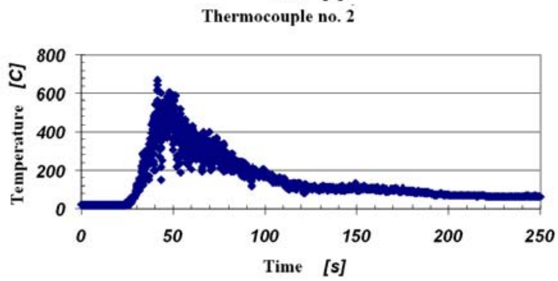

a) b)

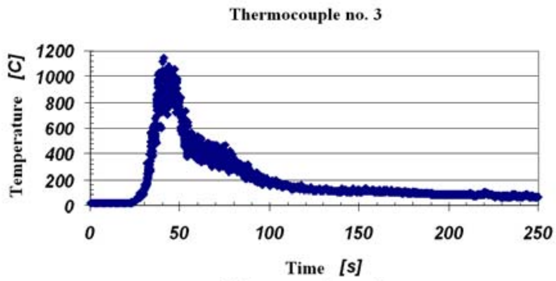
Figure 2. a)-b) The geometry and the positioning of the points of numerical evaluations of the temperature

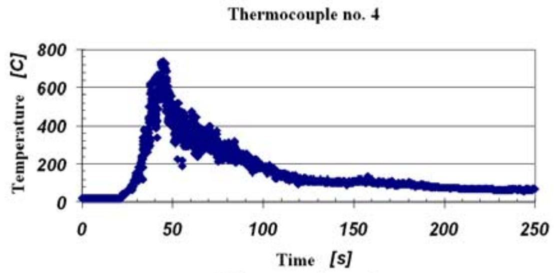
The location of the 20 calculus points of the temperature can be easier represented by groups of 5 points, in Figure 3:

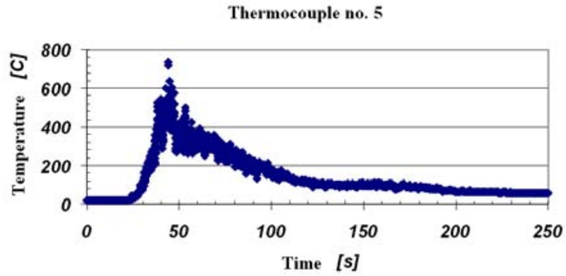
a) T1 ÷ T5 Thermocouples interior ceiling:



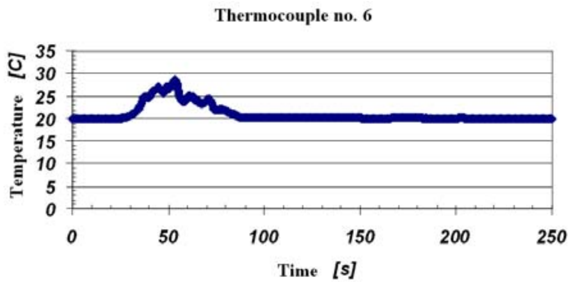



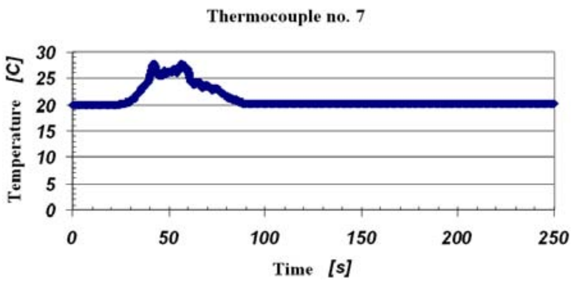



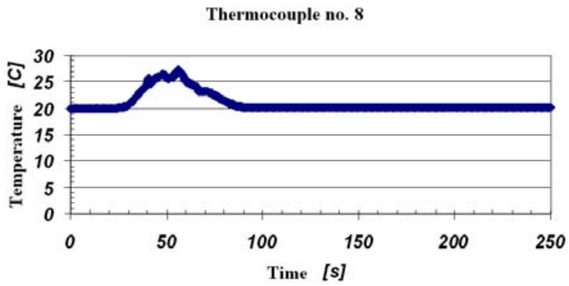



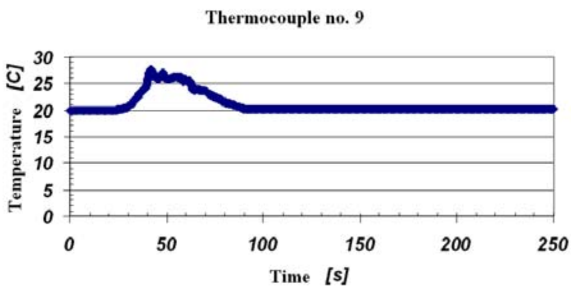



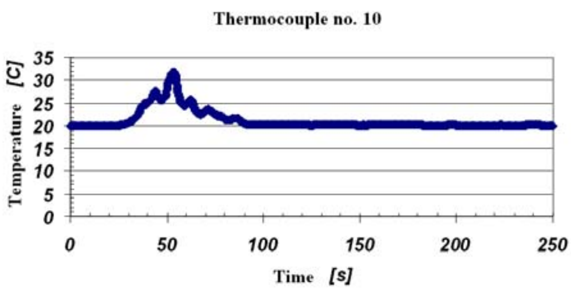

b) T6 ÷ T10 Thermocouple ceiling:


Thermocouple no. 6
Temperature [C]
35
30
25
20
15
10
5
0
0
50
100
150
200
250
Time [s]

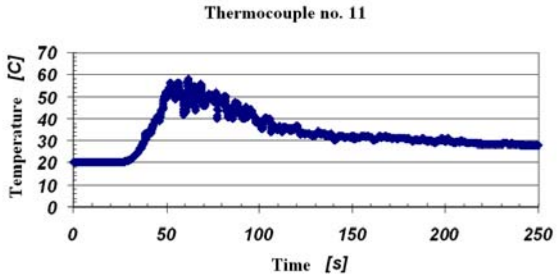

Thermocouple no. 7
Temperature [C]
30
25
20
15
10
5
0
0
50
100
150
200
250
Time [s]

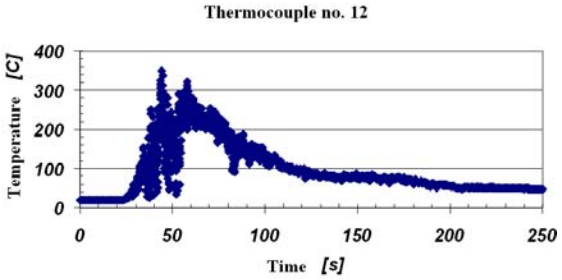

Thermocouple no. 8
Temperature [C]
30
25
20
15
10
5
0
0
50
100
150
200
250
Time [s]

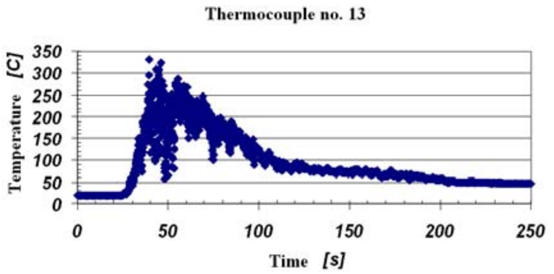

Thermocouple no. 9
Temperature [C]
30
25
20
15
10
5
0
0
50
100
150
200
250
Time [s]

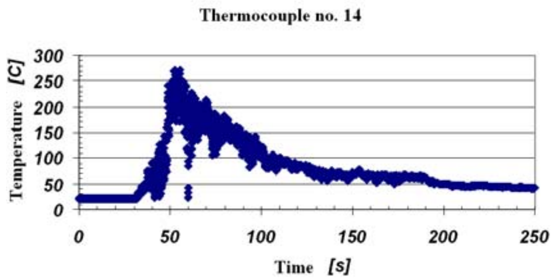

Thermocouple no. 10
Temperature [C]
35
30
25
20
15
10
5
0
0
50
100
150
200
250
Time [s]

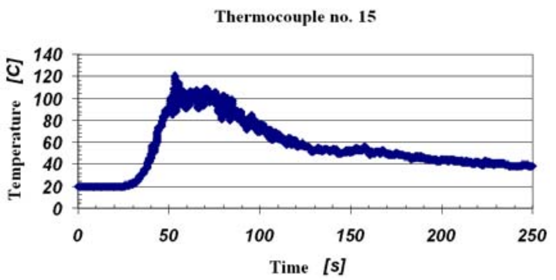
c) T11 ÷ T15 Thermocouples walls:



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d) T16 ÷ T20 Thermocouples door:

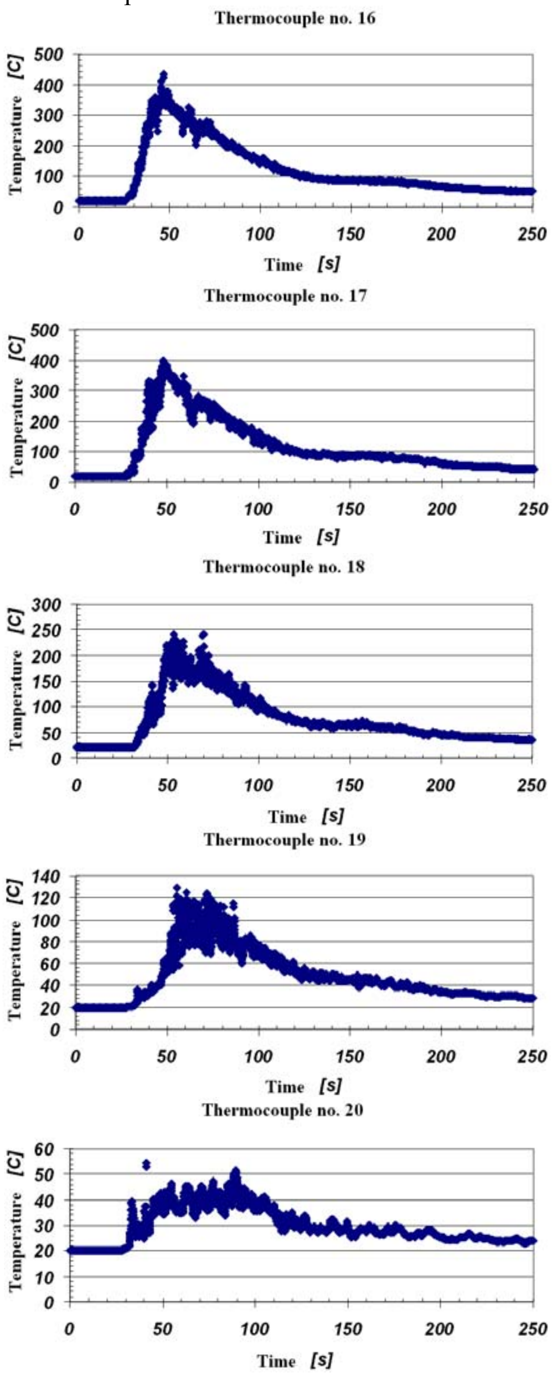


Figure 3. a)-d) The variation of temperature in the 20 considered points

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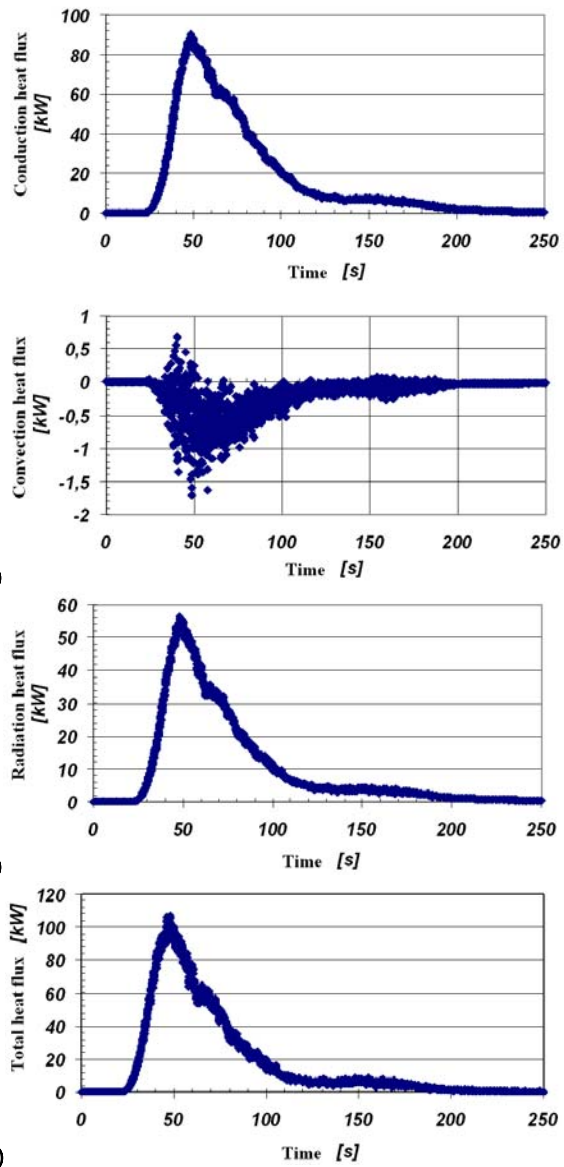
It is observed that for all the thermocouples the value of the temperatures at that location was calculated, in the interval 0...250 [s] and the graphics of temperature variations were created. The obtained values indicate a very high level of the temperature on in inside ceiling and that it drops in order: wall, door, and ceiling.

The thermal flux by conduction, convection and radiation, respective the total thermal flux is given in figure 4 a)-d):




a) b) c) d)

Figura 4. a)-d) The thermal flux (conduction, convection, radiation, total)

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The rate of burning is shown in figure 5.

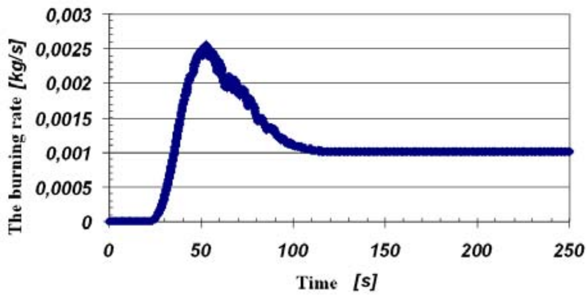


**Figure 5.** The burning rate

In figure 6 some instantaneous numerical visualizations of the evolution of the fire in the light structure are shown:

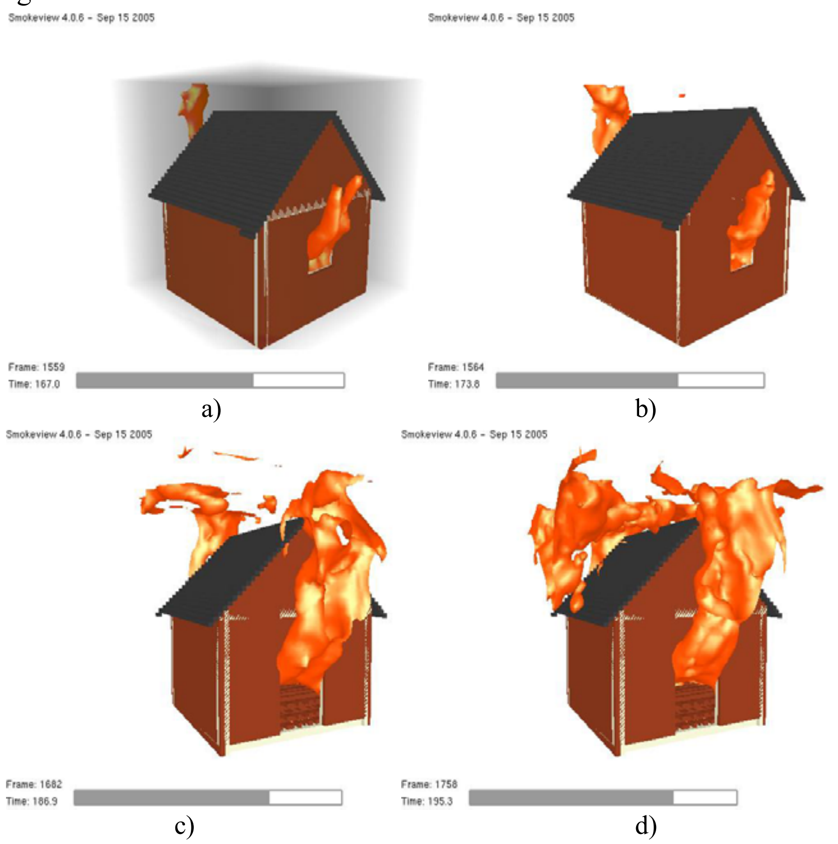


Figure 6. a)-d) The numerical visualization of the fire at diverse moments in time

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## 3. CONCLUSIONS

In this paper the modeling, simulation and the numerical analysis of the fire behavior of the small scale model of a construction with a light structure. The values of the temperatures obtained, the thermal flux, the burning rate and the numerical visualization of the fire were later compared with the experimental ones, obtaining very good accordance.

The modeling, simulation and the numerical analysis of fires can be utilized with success in the following sub- domains of fire security engineering:

- Regenerates of some fires based on the fire's print, the cause of the fire and other data (the characteristics of the materials, the way the firefighters approached the localization and extinguishing of the fire);
- The electronic resolve of the tactical situations;
- The building of fire security scenarios for buildings;
- Providing the necessary parameters for the fire intervention through numerical modeling.

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