A tridimensional numerical study of the FLUMILOG warehouse fire experiment

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A TRIDIMENSIONAL NUMERICAL STUDY OF THE FLUMILOG WAREHOUSE FIRE EXPERIMENT

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1. INTRODUCTION

At national scale, every consumer society needs to significantly rely upon warehouses for storage purposes. The French case is not an exception, with great warehouse activity throughout all the territory. In order to prevent human harm and guide the right course of action for firemen, numerical simulation of warehouse fire is of great importance and is constantly in need for model improvement. However, validating the numerical models is often hindered due to lack of experimental data and actual accidents are analysed *a posteriori* for that matter, yet only with limited amount of features to be compared to. The recent FLUMILOG experiment performed in 2008 was designed for bringing such experimental insight. The purpose of the present work is to perform the FLUMILOG warehouse fire simulation using FDS6[1] simulation code.

2. THE FLUMILOG WAREHOUSE FIRE FULL-SCALE EXPERIMENT

2.1. General experimental features

The experiment consisted in triggering fire within a 864 m² warehouse which was designed for study purpose. The warehouse was filled with racks holding stacked wood pallets, a storage designed for optimal fire propagation. The experiment was heavily instrumented with thermocouples and heat flux gauges, and the warehouse contained all the key features of a standard warehouse, including walls, roofs, rack storage and smoke exhausts. Fire propagation was filmed inside and outside the building and precise timing was thus observable e.g. for fire propagation inside the building or opening of smoke exhausts. Smoke behavior is also available since outdoors cameras tracked the whole burning process. Finally, wall behavior pushed to their ultimate resistance limit under thermal aggression is also a key feature available for analysis. Figure 1 shows an overview of the experimental set-up from outside and from inside the warehouse.

Outer view of the warehouse | Inner view of wood storage

Figure 1: Outer and inner view of the experimental warehouse facility

As illustrated on the outer view in Figure 1, one of the cells of the warehouse doesn't include any wall. The beams and pillars of this cell are intended to bring structural stability to the adjacent concrete fire-resistant wall (see also Figure 2).

2.2. Mechanical structure and storage configuration

The warehouse is built upon IPE steel beam and pillar structures and is surrounded by steel-cladding on three sides and fire-resistant concrete wall on the 4th side as shown in Figure 2. Roof is in profiled steel sheets with an insulation of 50 mm of mineral wool in-between. 4 smoke exhausts of 3 m by 2 m dimension are included on the roof. Their opening is automatically triggered when the temperature of the thermal sensors associated with the smoke exhaust reaches 140 °C.

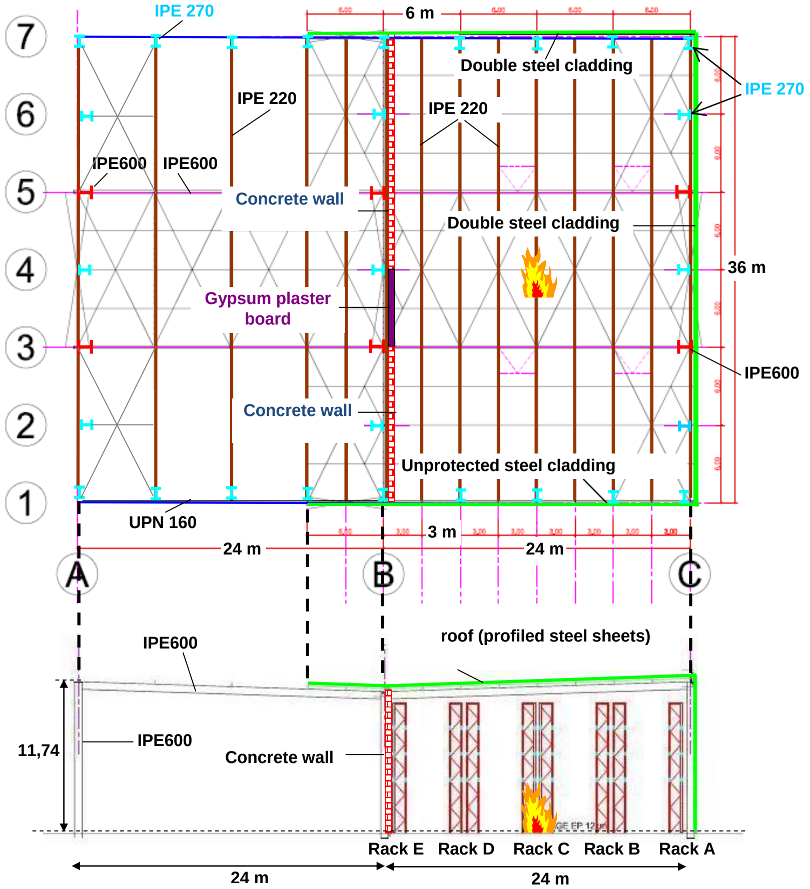


Figure 2: Structural scheme of the experimental warehouse (top and side view)

The storage is composed of 310 tons of wooden pallets and cages disposed across 30 m long and 10 m high racks.

2.3. Key features of the fire experiment from outside

The cell and the building components were heavily instrumented with about 200 thermometers for both ambient and steel structure temperature and 14 plate thermometers. Several video cameras and infra-red cameras as well as heat flux meters were also positioned in and around the building. Figure 3 shows several pictures of the experiment at different times.

11 minutes after ignition : opening of the first smoke exhaust, opening of the second exhaust 1 min later

18 min after ignition : roof starts collapsing

30 min after ignition : the structure collapses toward the inside

61 min after ignition : the structure of the cell submitted to fire has totally collapsed except for the fire-resistant concrete wall

Figure 3: Some of the key features of the fire experiment from the outside

The features depicted above can be used for comparison with numerical simulations. The time for smoke exhaust activation will be compared to the one obtained through numerical simulation.

2.4. Key features of the fire experiment from inside

Among the many temperature and heat flux variations with time available for this experiment, only a few are depicted on Figure 4 which will be compared to the numerical simulation presented in part 3.

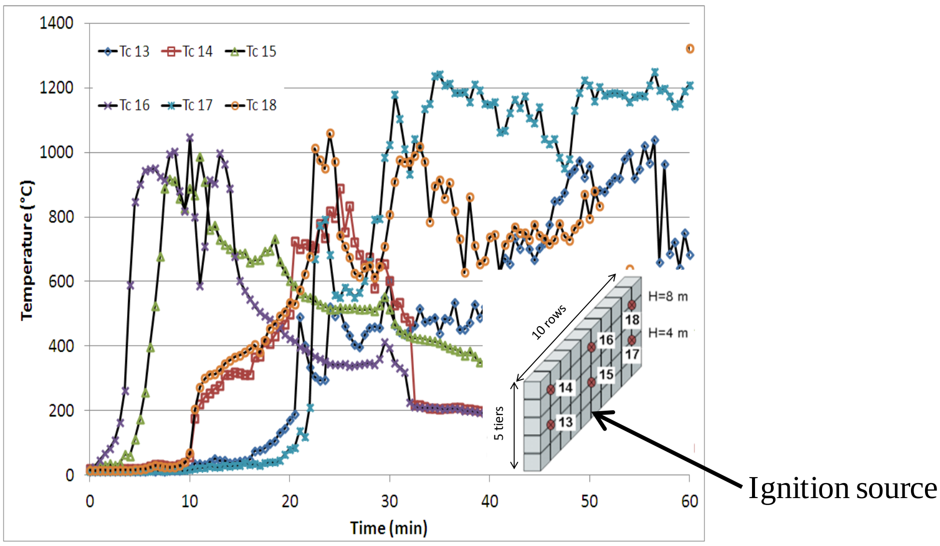


Figure 4: Temperature variation around the ignition source during the experiment

The temperature of the thermocouples 15 and 16 which are located above the ignition source rise faster than the standard ISO 834 curve.

3. NUMERICAL SIMULATION OF THE FLUMILOG WAREHOUSE FIRE

3.1. Physical model and numerical calculation set-up.

The FDS simulation is based on 2nd order finite-difference-discretized Navier-Stokes equations. Turbulence model consists in Large Eddy Simulation with Smagorinsky sub-grid model. Two different grid sizes have been tested, the overall size of the computation domain being 36 m long by 24 m wide by 18 m high. The coarse grid includes 1 944 000 cells which are divided into 108 domains, with 20 cm square cells. The fine grid includes 15 552 000 cells which are divided into 864 domains with 10 cm square cells.

The mixture-fraction model is used to describe combustion, with a prescribed heat release rate (HRR) to model wood pallet pyrolysis. The prescribed HRR for each commodity including a total mass of 225 kg of wood pallets is presented in Figure 5. Such HRR was derived from experiments at INERIS yet remains uncertain and needs further improvement, which will be the subject of future works.

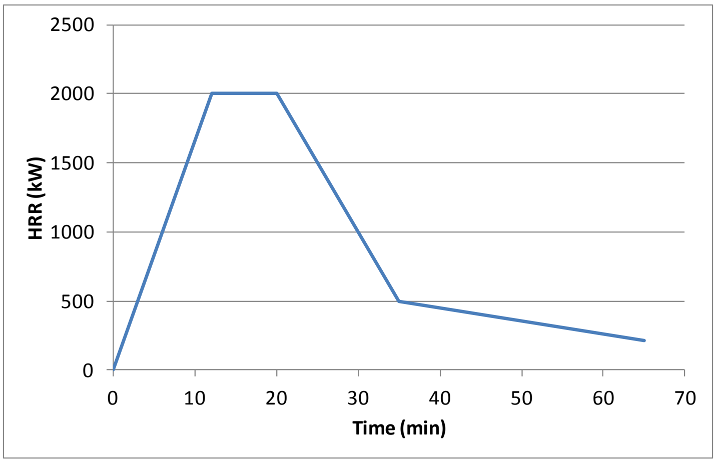
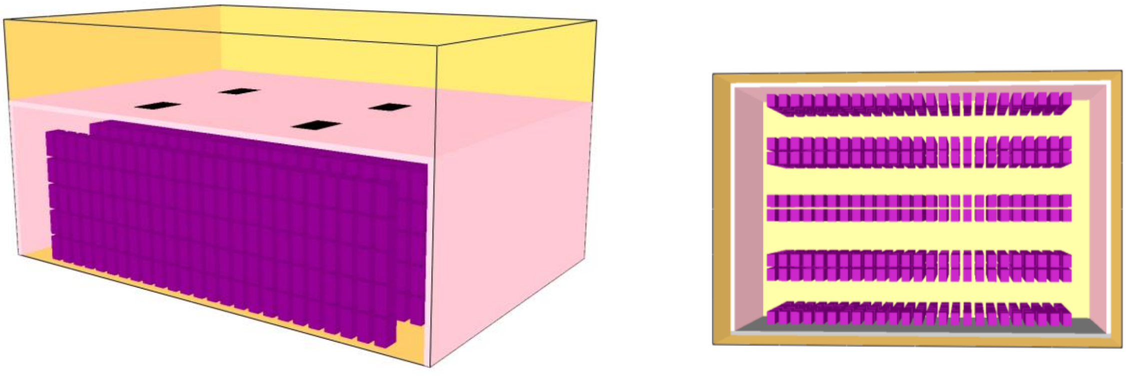


Figure 5: Heat release rate of a commodity composed of wood

In FDS, fire propagation among the commodities is controlled by an ignition temperature parameter. Three different values have been tested in the present work: 150 °C, 200 °C and 250 °C. The roof is supposed to break down bit by bit at a temperature of 400 °C. This is also a challenging parameter to implement, thus it remains uncertain and also needs further investigation. The 3D warehouse configuration is presented in Figure 6.



Side view Top view

Figure 6: General overview of the calculation geometry

3.2. Results and Discussion

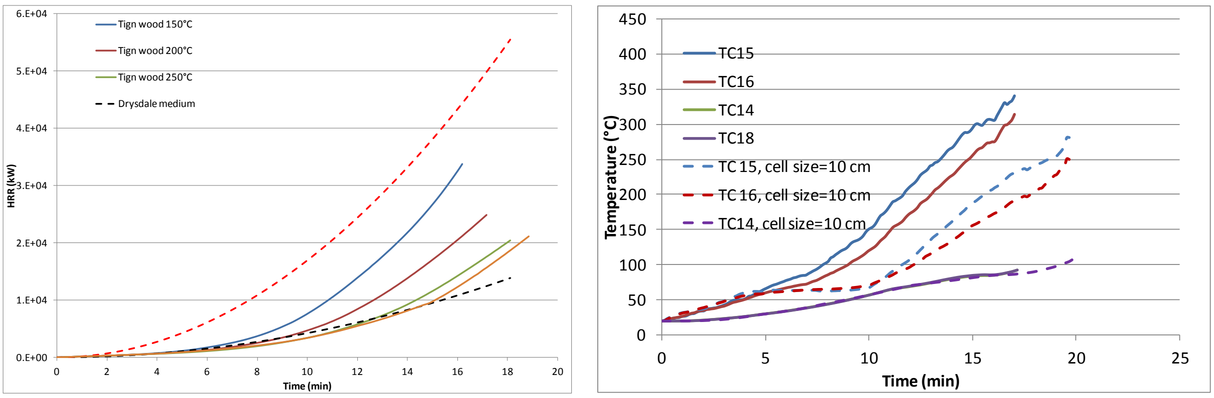
The time before smoke exhaust opening and roof collapsing is presented in Table 1.

	Time before first smoke exhaust opening	Time before roof collapsing
Tign. = 150 °C	9.3 min	12.4 min
Tign. = 200 °C	10.7 min	13.9 min
Tign. = 250 °C	11.9 min	15.6 min
Tign. = 250 °C, cell size = 10 cm	14.8 min	16.7 min

Table 1: Time before smoke exhaust opening and roof collapsing for the different calculations

As expected, the lower the ignition temperature of wood, the quicker the propagation and hence the earlier the opening of first smoke exhaust and roof collapse. The finer grid, however, shows significant lag in the opening of smoke exhaust as compared to the coarse grid. Such discrepancy is related to temperature calculation differences for both mesh sizes. Those times are to be compared with the experimental times for first exhaust opening and roof collapsing, namely, 11 min and 18 min.

The overall HRR during the fire and temperature evolution for thermocouples number 15, 16, 14 and 18 are presented in Figure 7. In all figures, not mentioning the cell size means that it is equal to 20 cm.



HRR Temperatures

Figure 7: Calculation output – HRR and temperatures

Heat release rate are compared to those corresponding to Medium and Fast fire growth curves of Drysdale[2]. All the HRR evolutions are between those curves, with faster HRR curves for lower ignition temperatures. There is a slight discrepancy in HRR between fine and coarse grid manifesting after 13 min. The temperature discrepancy between those two cases for thermocouples 15 and 16 is yet striking. Whereas smoke exhaust opening event is not visible for the coarse grid, the temperatures for the finer grid show a plateau followed by a sudden increase right after smoke exhaust opening. Thus, oxygen deprivation happens only by changing mesh size. Even though HRR remain very similar between fine and coarse grid before 10 minutes, temperatures are significantly different. It should also be mentioned that for all the simulations performed, temperatures are significantly lower than those obtained during the FLUMILOG experimental campaign. This is mainly due to the prescribed heat release rate shown in Figure 5 for a commodity of wood pallets, which is too slow as compared to the actual burning of wood within the warehouse during the full-scale testing.

Finally, Figure 9 shows temperature evolution with time for fine and coarse grid for a side view at a longitudinal plane cutting through the fire starting point. Temperature scale ranges from 20 °C to 250 °C as presented in Figure 8. Blue zones are regions of 20°C temperature or below, and red zones are regions of 250 °C temperature and above.

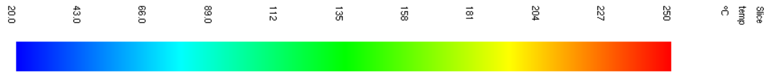


Figure 8: Temperature scale

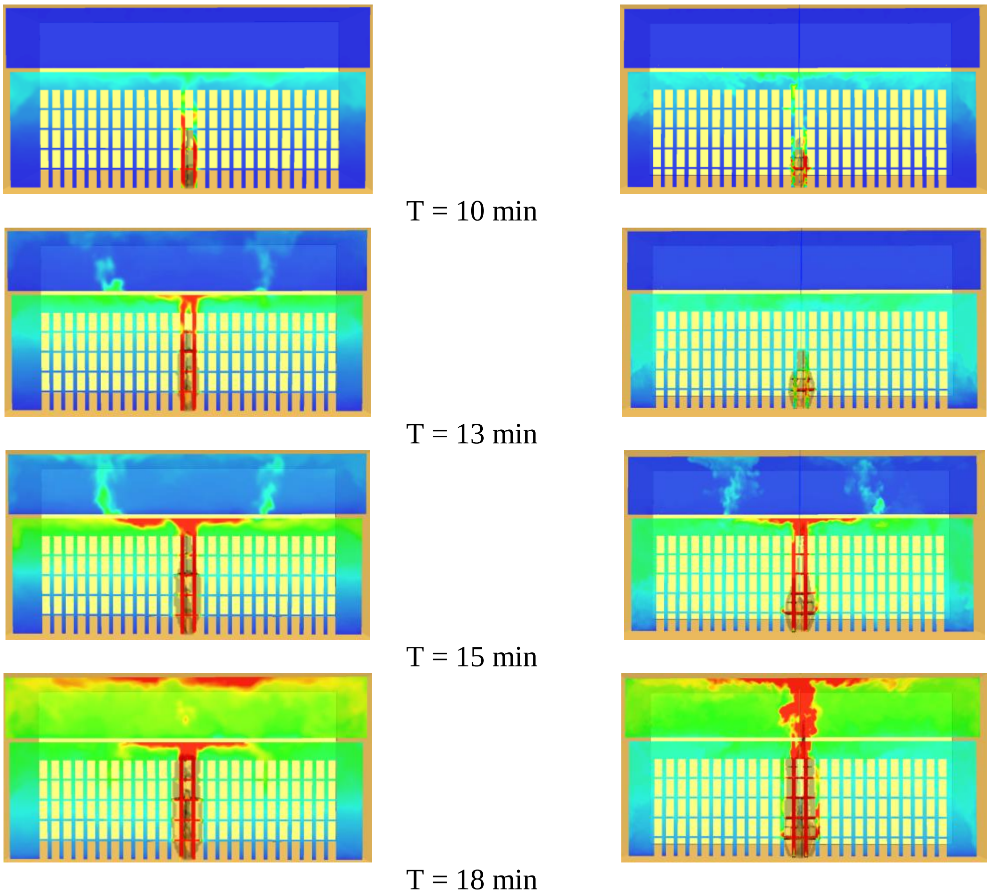


Figure 9: Temperature evolution with time; left : coarse grid (20 cm cell size), right : fine grid (10 cm cell size)

It can be deduced from Figure 9 that the fine grid calculation leads to lower values of temperature even before smoke exhaust opening and is more sensitive to exhaust opening than the coarse grid calculation.

4. CONCLUSION AND PROSPECTIVE WORK

A 3D numerical calculation of the FLUMILOG warehouse experiment has been performed with FDS6. It has been show that several calculation parameters need further investigation such as wood pallet heat release rate and roof collapsing temperature in order to obtain more realistic temperatures within the fire. Mesh size must be of particular attention when simulating this fire: a finer mesh results in an earlier opening of smoke exhaust and leads to calculations which are more sensitive to exhaust opening. Further investigation will be led regarding mesh size and wood pallet HRR. Radiative heat flux propagation criterion will also be investigated as compared to wood ignition temperature heat flux propagation criterion.

5. REFERENCES

[1] McGrattan, K., Hostikka, S., McDermott, R., Floyd, J., Weinschenk, C. and Overholt, K., Fire Dynamics Simulator – Technical reference Guide, NIST Special Publication 1018 – Sixth edition
[2] Drysdale, D., An Introduction to Fire Dynamics – Wiley, Third Edition, 2011