

Contribution to the study by numerical simulation of a fire plume coming out through a window on façade “Application to the comprehension of the wind influence on an eventually stack effect”

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INTRODUCTION

The fire that occurred in a social housing in Dijon (France) in November 2010 has raised questions about a possible stack effect due to the frontage of façade and its influence on the vertical extension of the fire by the outside. In this study, we handle this problem using the numerical simulation of fluids mechanics CFD and the LES numerical approach of the turbulence. Admittedly, the simulation allows us to have access to variables and physical phenomena, but still now, the analytical models are limited to deal with certain multi physics problems. Strong assumptions need to be done in order to model a problem as the one considered here “*façade supposed inert*”, although formed by various coated with a coating of insulation. Thus, this study does not take into account (and not solves) the coupled phenomena of the pyrolysis of the organic reinforced coating and expanded polystyrene (insulation from the outside) and the dynamics of a fire plume emerging through an open window and the influence of a fluctuating wind (the wind is considered to be a constant speed).

In order to simplify, we decided to build the studied configuration as two superposed rooms with a front façade having windows in the ground and first floor levels (the first floor window is supposed always closed, the broken of its glass is not studied either) with a back façade without windows (cf. Fig. 1). The outer walls are forming an inside corner of the 90° (90° dihedral configuration) and other second dihedral configuration forming an inside corner of the 135°. This study aims to:

- Simulate a fire plume, which emerges from the window of the room on the ground floor. The fire plume has a nominal power of 2 MW;
- Analyze the fire plume dynamics under the influence of two wind speeds: 60 km h^{-1} and 30 km h^{-1} ;
- Analyze the influence of the angle of the dihedral configuration (by modeling two dihedral opening angles: 90° and 135°);
- Analyze the influence of the position of the window from which the fire plume emerges (changing the window’s position to the walls dihedral side), while keeping the same wind direction (parallel to the plane bisecting the dihedral configuration).

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➤ **Simulation S1:** DOA = 90°; WV = 0 ms⁻¹

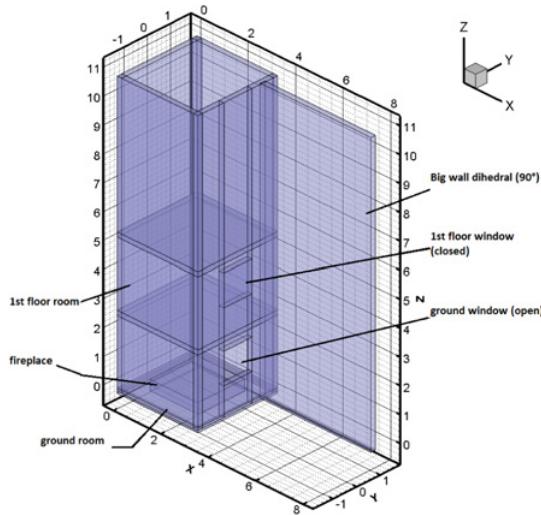


Figure 1. Numerical domain of S1 simulation.

THE CFD CODE FDS, THE HARDWARE DEVICES

The software used in this work was the code “*Fire Dynamics Simulator V5*” (FDS V5.5.3) developed by the National Institute of Standards and Technology (USA). FDS is a computational fluid dynamics (CFD) model of fire-driven fluid flow. FDS solves numerically a form of the Navier-Stokes equations for low-speed (low Mach number), non-compressible thermally-driven flow, with an emphasis on soot mass fraction (smoke) and heat transport from fires. The calculus was performed in a DELL work station (8 processors and 4 MB RAM memory), in parallel using the OpenMP (Open Multiprocessing) application programming interface (API) that supports multi-platform shared memory multiprocessing programming. Using OpenMP we save the time to cutting the numerical grid and the post treatment of data results.

THE NUMERICAL MODEL

The numerical model has the following characteristics:

- Numerical grid (a Cartesian grid with rectangular cells):
 - total volume = 700 m³ (10 m × 10 m × 7 m);
 - unitary grid volume = 0,7 m³;
 - total grid number = 7 E + 05;
 - total physical time of simulation = 900 s.
- Rooms:
 - walls thickness = 0,10 m;
 - ceiling thickness = 0,18 m;
 - dihedral opening angles = 90° and 135°;
 - inside superposed rooms dimensions = 3 m × 3 m × 2,5 m;
 - windows dimensions = 1,2 m × 1,2 m.

➤ Fireplace:

- fuel = wood;
- C fraction = 3, 40;
- H fraction = 6, 20;
- O fraction = 2, 50;
- heat of combustion = 14706, 0 [kJ kg⁻¹];
- fireplace surface = 4 m²;
- HRRPUA = 800 [kW m⁻²]
- Soot yield = 0, 05;
- CO yield = 0, 08.

➤ Speed conditions of wind:

- Speed conditions = 0 ms⁻¹, 8, 3 ms⁻¹ and 16, 6 ms⁻¹.

The resulting numerical model created with this data is shown on Figure 1 and Figure 7.

THE SIMULATIONS CONDITIONS

A total of 8 different conditions were simulated in this work. Table 1 shows the summary of simulations parameters. The 1st simulation (S1) is used to estimate the height of the fire plume in a quiet atmosphere (without the wind influence).The 2nd and 3rd simulations (S2 and S3) are used to determinate the wind influence on the fire plume dynamics with the direction of wind perpendicular to the windows from which the fire plume emerges (condition of the frontal wind).The 4th to 6th simulations (S4, S5 and S6) are used to evaluate the wind speed influence and the dihedral opening angle on the fire plume dynamics and the last two simulations (S7 and S8) to evaluate the influence of the window position.

Table 1. Summary of simulations parameters.

Simulation	Dihedral opening angle (DOA)	Window position	Parameters	
			Wind conditions	
			Direction	velocity [ms ⁻¹]
S1 (1st numerical grid was used; cf. Figure 1)	90°		nothing	0
S2	90°		parallel to the little wall of dihedral configuration	8,3
S3 (2nd Numerical Grid was used; cf. Figure 7)	90°	On the little wall of dihedral configuration	nothing	0
S4	90°		parallel to the the plane bisecting the dihedral configuration	8,3
S5	90°			16,6
S6	135°			8,3
S7	90°		nothing	0
S8	90°	On the big wall of dihedral configuration	parallel to the the plane bisecting the dihedral configuration	8,3

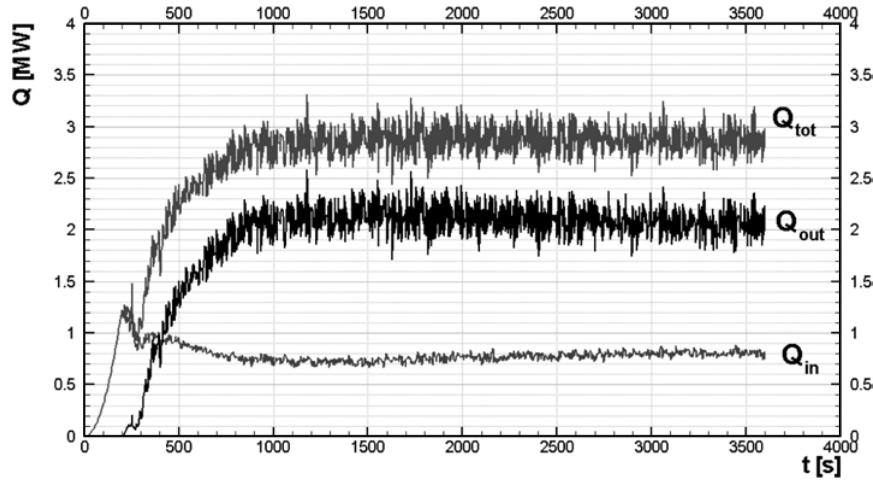


Figure 2. Curve of the power fire development in the time function.

RESULTS AND DISCUSSION

In this part we detail the work done and give the simulation's features. In order to evaluate the wind influence on the emerging fire plume dynamics, and the comprehension of an eventually stack effect we analyse the output quantities: flow speed field [ms^{-1}], temperature flow field [$^{\circ}\text{C}$] and the heat rate released by the fireplace [kWm^{-3}]. All these output variables were recorded each 10 s of physical time. An average calculus on the total simulation time was performed for each variable, in this way we obtained the average behaviour for each variable.

Simulation S1

Firstly, in order to control the fire plume parameters, the nominal power fire was measured into the total numerical volume. Figures 2 and 3 show power fire curve development in function of the time. We observed that the total power fire Q_{tot} is near of 3 MW, the fire plume power Q_{out} (emerging through the room's window) is near of 2 MW, as desired, and the fire into the room Q_{in} is near of 1 MW.

Analyzing the power curve (cf. Figure 2), we identify the main states of the fire development:

the first into the room and the second when the fire plume emerges from the room through the window. In this way we observed the instant when the fire activity goes from the fire regime named “controlled by the rate of pyrolysis fuel gas production”, to the fire regime named “controlled by the ventilation”. In this second fire regime, the oxygen O_2 necessary to the combustion process comes from the outdoor and enters through the open window into the room's volume. In our case the fire phenomena, controlled by the ventilation, arrives at 195 seconds after the fire starting. At this instant (195 s), the amount of oxygen O_2 into the volume's room was consumed. The upper area window being blocked by the hot combustion gases coming out, these gases are at pressure bigger than the outdoor pressure. The gases coming out, burn and form the fire plume. At this time the oxygen O_2 necessary to the combustion process, enters through the bottom middle area of the open window. The interphase (imaginary line) defining the border between the upper and bottom window's zones is characterized by a gradient of pressure $dp/dy = 0$. The height of the fire plume in a quiet atmosphere was calculated being about 7, 5 m.

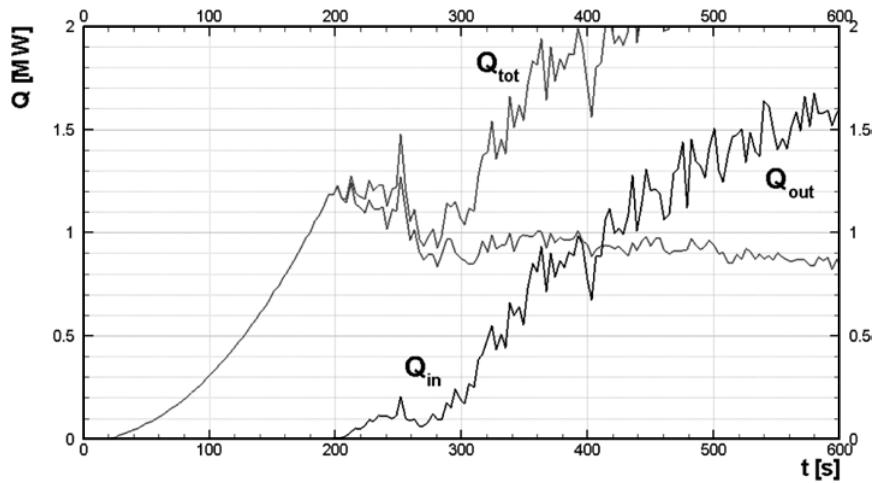


Figure 3. Curve of power fire plume development: time of the fire regimes separation.

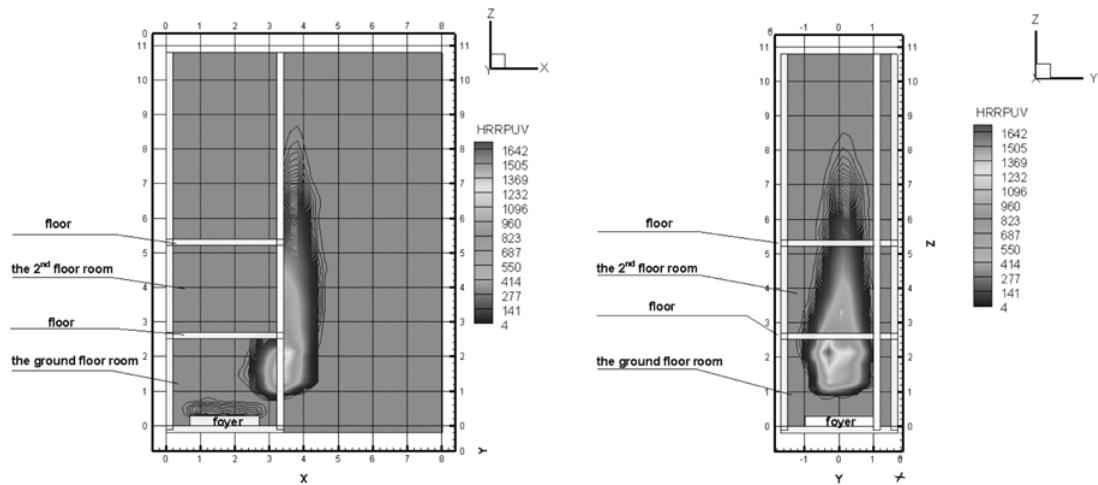


Figure 4. Field of heat release rate per unit of volume kW^{-3} : plane XZ in the left and YZ in the right.

Simulations S2 and S3

In S2 (condition of the frontal wind with a wind velocity equals to $8,3 \text{ ms}^{-1}$). The results shows (Fig. 6) that the fire plume is pushed and deformed against the big wall under the wind influence. This can be explained by the pressure gradient caused by the wind. In opposite way S3 (wind velocity equals to 0 ms^{-1}) shows that the fire plume is symmetrical respect to the central window axis. It is not influenced by the wind.

Simulations S4, S5 and S6

For S4 (frontal wind with a wind velocity equals to $8,3 \text{ ms}^{-1}$), the results (Fig. 9) shows the strong wind influence on the fire plume emerging throw the window. Figure 9 shows on the left figure the temperature field and on the right figure the velocity field. The left figure shows that the average position of the fire

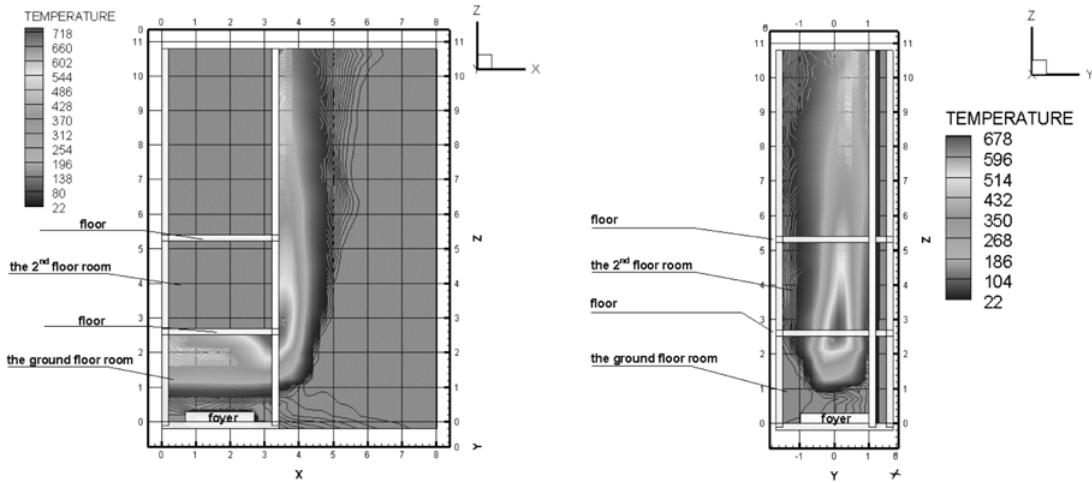


Figure 5. Field of temperature °C: plane XZ in the left, plane YZ in the right.

➤ **Simulation S2:** DOA = 90°; WV = 8,3 ms⁻¹

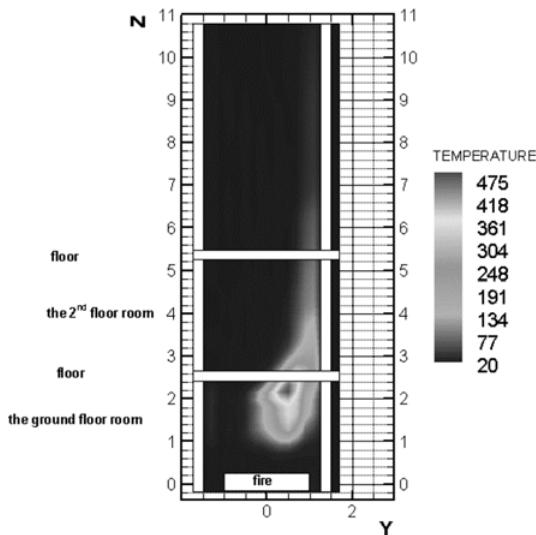


Figure 6. Field of temperature °C: plane YZ.

plume is near from the exterior corner of dihedral configuration (angle of 270°). The velocity field shows an acceleration of the plume flame near from the exterior corner of dihedral configuration (angle of 270°), also we noticed that he fluid lines are deformed under the walls influence, this have as result, the elevation of static pressure nears from the walls, so is observed that this effect only caused by the wind and not by the stack effect. So the dynamics behaviour of the fire flame is only drive by the pressure gradient caused by the wind. In S5 (frontal wind, wind velocity equals to 16,6 ms⁻¹), the wind influence on the fire flume is more important than in S4 case. The fire plume is strongly perturbed and deformed by the wind. The fire plume is pushed against the exterior walls of the dihedral configuration near the corner forming an angle of 270°. This confirms that flame dynamics is only drive by the pressure gradient caused by the wind and not by the supposed stack effect. S6 (frontal wind, wind velocity

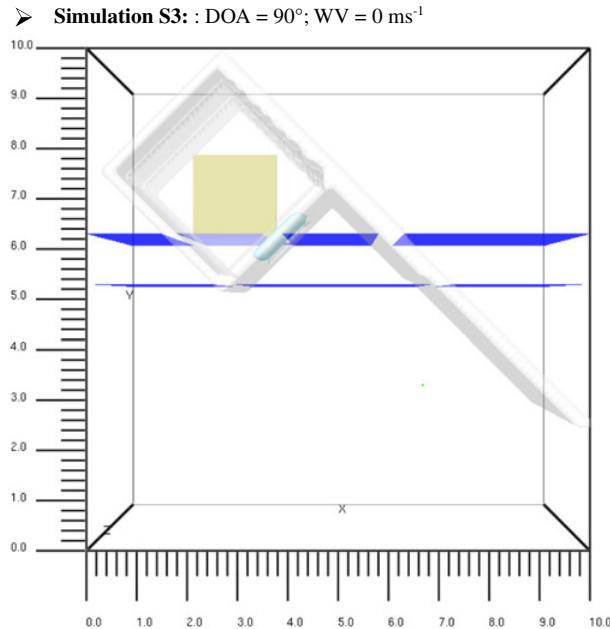


Figure 7. Numerical domain of simulations S3 to S6.

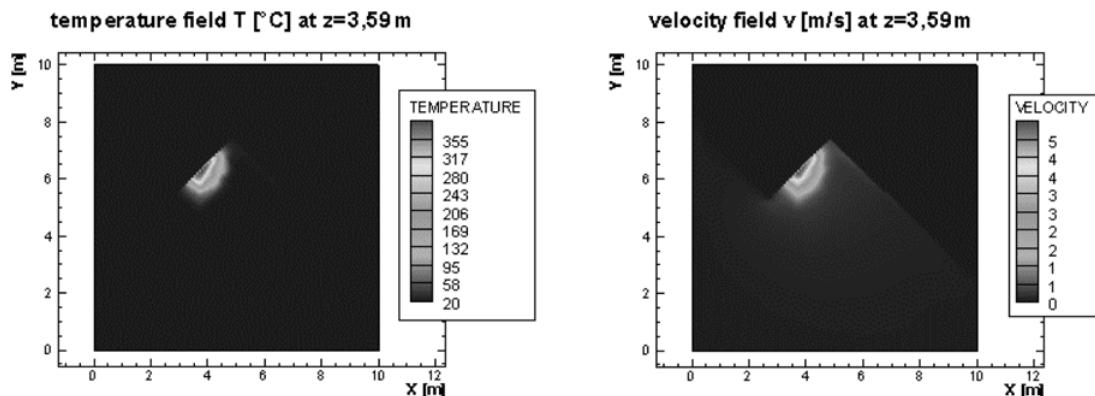


Figure 8. Fields of temperature (left) and velocity (right); fields takes on the plane XY at $Z = 3,59$ m (near the second floor window), from the floor ($Z = 0$).

$8,3\text{ ms}^{-1}$, opening dihedral angle 135°) shows also the wind influence on the fire plume dynamics and confirms again that the fire plume dynamic is only derived by the pressure gradient caused by the wind. The opening dihedral angle of 135° contributes to lowering the level of the pressure gradient and thereby the value of the escape velocity of the fire plume at each side of the dihedral configuration.

Simulations S7 and S8

In this simulation we notice also the wind influence on the fire plume behaviour. The different windows position (on the big wall forming the dihedral) does not add significant changes.

➤ **Simulation S4:** DOA = 90°; WV = 8,3 ms⁻¹

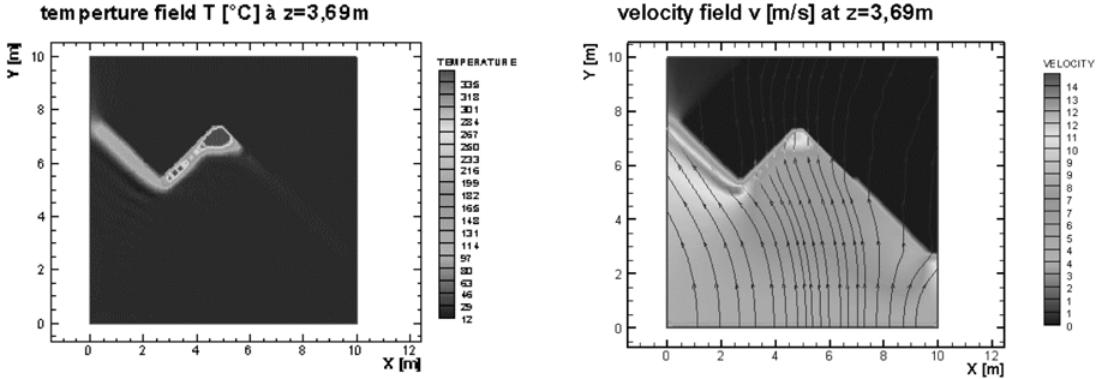


Figure 9. Fields of temperature (left) and velocity (right); fields takes on the plane XY at $Z = 3,69\text{ m}$ (near the second floor window) from the floor ($Z = 0$).

➤ **Simulation S5:** DOA = 90°; WV = 16,6 ms⁻¹

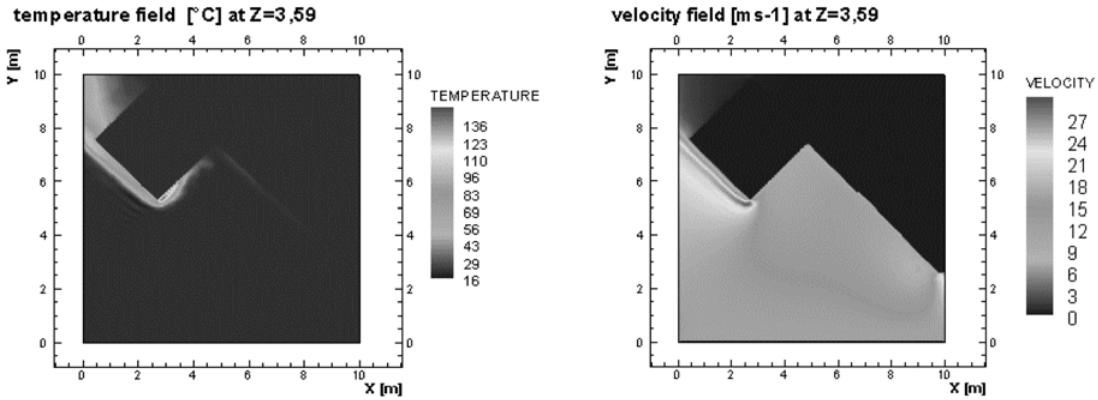


Figure 10. Fields of temperature (left) and velocity (right); fields takes on the plane XY at $Z = 3,59\text{ m}$ (near the second floor window) from the floor ($Z = 0$).

Summary of the results

Here DOA means Dihedral Opening Angle and WV means wind velocity):

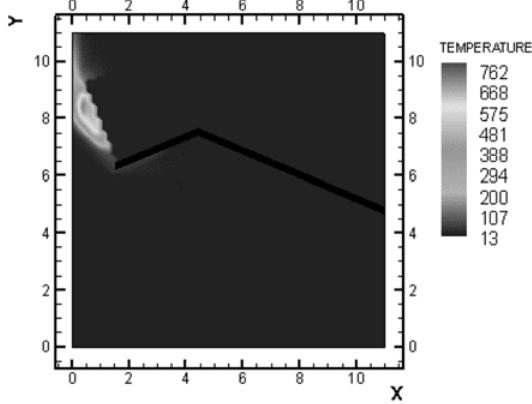
Simulation 1 (S1: DOA = 90°; WV = 0 ms⁻¹): In the absence of wind the stack effect is near none existing if the wall forming the angle 90° is at 0,6 m from the window in a frontage of façade. In this case the fire plume coming out through the window is almost symmetrical to the vertical axis of the window.

Simulation 2 (S2: DOA = 90°; WV = 8,3 ms⁻¹): If a wind of 30 km h⁻¹ is present and it is parallel to the window plane (parallel to the little wall of dihedral configuration), the fire plume coming out through the window is pushed against the wall forming the angle 90°.

Simulation 3 (S3: DOA = 90°; WV= 0 ms⁻¹): The conclusion is similar to the conclusion for S1.

Simulation 4 (S4: DOA = 90°; WV=8,3 ms⁻¹): If a wind of 30 km h⁻¹ is present and is parallel to the plane bisecting the dihedral configuration, a little fire plume deformation is observed near the dihedral origin. This “stack effect” is not strong and less important as the dynamics system. The dynamics of fluid of fire plume is driven by the pressure gradient. The fire plume coming out through the window is pushed against the big wall forming the angle 90° a little more than in S1 and S3.

- **Simulation S6: DOA = 135°; WV = 8,3 ms⁻¹**
temperature field [°C] at Z=3,69



- velocity field [m s⁻¹] at Z=3,69**

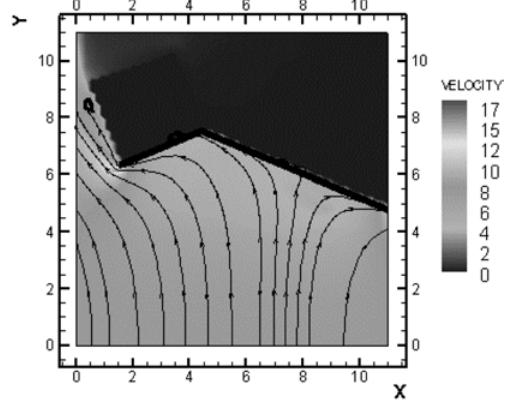
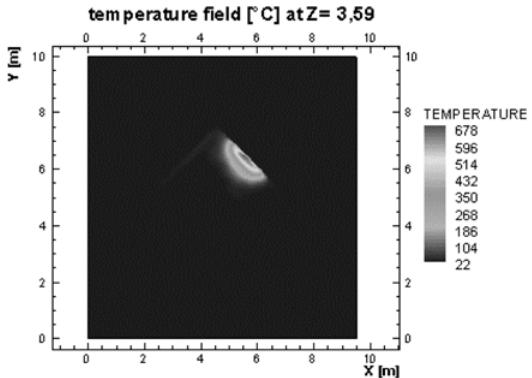


Figure 11. Fields of temperature (left) and velocity (right); fields takes on the plane XY at $Z = 3,69$ m (near the second floor window) from the floor ($Z = 0$).

- **Simulation S7: DOA = 90°; WV = 0 ms⁻¹**



- velocity field m s⁻¹ at Z=3,59**

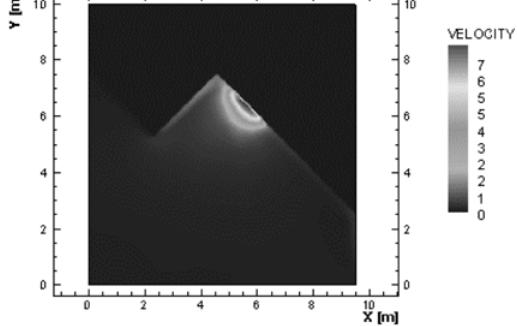


Figure 12. Fields of temperature (left) and velocity (right); fields takes on the plane XY at $Z = 3,59$ m (near the second floor window) from the floor ($Z = 0$).

Simulation 5 (S5: DOA = 90°; WV = 16,6 ms⁻¹): If a wind of 60 km h⁻¹ is present and is parallel to the the plane bisecting the dihedral configuration, the fire plume coming out through the window is strongly perturbed and pushed towards the exterior of the small wall forming the angle 90° (absence of stack effect).

Simulation 6 (S6: DOA = 135°; WV = 8,3 ms⁻¹): With an angle of dihedral of 135° and a win of 30 km h⁻¹, the fire plume coming out through the window is strongly perturbed and pushed towards the exterior of the small wall forming the angle 135° (absence of stack effect).

Simulation 7 (S7: DOA = 90°; WV = 0 ms⁻¹): Conclusion is similar to S1 and S3 (weak stack effect).

Simulation 8 (S8 DOA = 90°; WV = 8,3 ms⁻¹): In this case the fire plume coming out through the window is strongly pushed against the big wall forming the angle 90°, it is explained by the deflection of the wind on the solid area of the big wall.

➤ **Simulation S8:** DOA = 90°; WV = 8,3 ms⁻¹

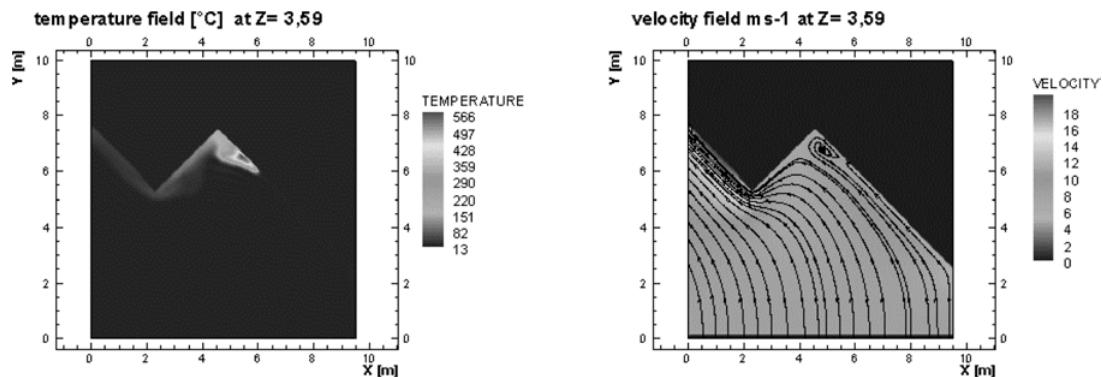


Figure 13. Fields of temperature (left) and velocity (right); fields takes on the plane XY at $Z = 3,59$ m (near the second floor window) from the floor ($Z = 0$).

CONCLUSION

The work was performed to study whether the dramatic fire that occurred in Dijon (France) in 2010 was influenced by the stack effect. The study showed that this is not the case. The wind influence is preponderant at the supposed stack effect.

In this study we did not take into account the pyrolysis of the walls (formed by the organic reinforced coating and expanded polystyrene) and we did not evaluate his influence on the vertical extension of the fire by the outside. In order to include the pyrolysis phenomena of the walls, the development of the pyrolysis models is a desirable and interesting subject for futures researches.

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