Computer Simulation of Fire Dynamics in Industrial Hall

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Abstract. In this paper, computer simulation of smoke spread dynamics in industrial hall is investigated. A set of simulations of fire in three industrial halls with the same geometry varying in the height of ceiling is realized using the FDS fire simulator, version 6. The obtained simulation results are described focusing on the impact of the ceiling height and fire barriers on the fire course and smoke spread dynamics.

1. Introduction

Advances in Computational Fluid Dynamics (CFD) stimulate the development of fire models capable to describe fire in environments with complex geometry incorporating a wide variety of physical phenomena related to fire. Several fire simulators based on CFD fire models are now available for instance the CFX, SMARTFIRE and FDS systems. The aim of this paper is to demonstrate the use of FDS (Fire Dynamics Simulator) [5] for analysis of smoke dynamics in industrial halls in the case of fire. FDS models fire-driven fluid flows. It solves numerically a form of Navier-Stokes equations appropriate for low-speed ($Ma < 0.3$), thermally-driven flow with an emphasis on smoke and heat transport from fire. The core algorithm is an explicit predictor-corrector scheme, second order accurate in space and time. Turbulence is treated by means of Large Eddy Simulation (for larger spaces) or Direct Numerical Simulation (for very fine mesh resolution). FDS comprises models for main relevant physical and chemical processes related to fire such as combustion, pyrolysis, radiation transport, suppression, etc. In December 2013, the 6th version of FDS was released. For multi-mesh calculations and multi-processor computer systems, parallel versions of FDS are also available. FDS has been used for simulation of fires in various structures such as theatre, supermarket, office building, airport boarding passage and nuclear power plant. However, there are no papers in the literature studying the impact of the height of ceiling of industrial halls on the smoke spread dynamics in case of fire. In this paper, we utilize our actual experience with FDS [1, 2, 3, 6] and use the system for such analysis.

2. Computer simulation of fire in industrial hall using FDS

We consider three industrial halls with the same geometry that differ from each other by the ceiling height (figure 1). *The first hall* is 3 m high. It is compartmented into two rooms by separating wall of the 2.2 m height and 10 cm thickness in which a closed 2 m high alloy door is located. The vertical smoke barrier mounted on the ceiling above the separating wall is 30 cm high and 10 cm thick. The

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distance between the barrier and separating wall is 0.5 m. All walls, ceiling and barrier are composed from concrete. The floor is made from inert material. There are not any vents providing interaction between fire and external environment. Two 2.2 m high alloy doors in the hall are closed. Symmetrically arranged manufacturing desks composed from inert material are 0.9 m high. *The second hall* is 6 m high. The distance between the fire barrier and separating wall is 3.5 m. *The third hall* is 9 m high. The distance between the barrier and separating wall is 6.5 m. Other parameters of the halls are the same. The floor, walls and ceiling are represented by computational domain borders with the corresponding boundary conditions. The manufacturing desks, separating wall, doors and fire barrier are represented by obstructions (table 1). A form of technological accident leading to ignition of flammable technical material which fell down from manufacturing desk is considered. We assume that smoke will enter the next room and that the vertical barrier and separating wall will slow down the fire. The fire source is represented by a 0.5 x 1 x 0.2 m burning block with 4 burning faces of total fire area of 1 m^2 and 650 kW/m^2 HRRPUA boundary condition. In all scenarios, the same fire source located at the same place is considered.

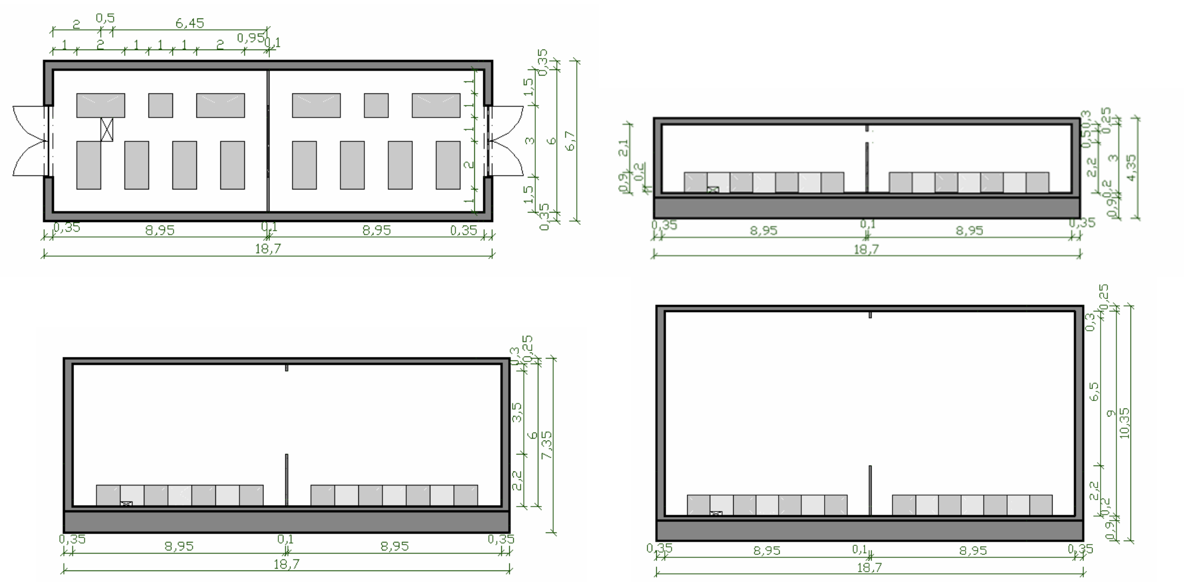

Figure 1. Scheme of 3 industrial halls considered: ground plan and side view.

Table 1. Simulations parameters: N_O, N_V and N is the total number of OBSTs (obstructions), VENTs and computational mesh cells, respectively; N_C is the number of cells per CPU core; N_x, N_y and N_z is the number of cells in x-, y- and z-direction, respectively; T is the total computational time.

Scenario	N_O	N_V	N	N_C	N_x	N_y	N_z	T
Hall 1	22	6	2592000	432000	60	120	60	12 hrs 15 min 15 s
Hall 2	22	6	5184000	864000	60	120	120	24 hrs 9 min 15 s
Hall 3	22	6	7776000	1296000	60	120	180	37 hrs 18 min 49 s

Table 2. Smoke spread: T_C, T_{LW}, T_{BW}, T_{FW}, T_{SW} and T_{FB} is the time of reaching the ceiling, left-, back-, front-, and separating walls, and the fire barrier, respectively.

Scenario	T_C	T_{LW}	T_{BW}	T_{FW}	T_{SW}	T_{FB}
Hall 1	1.9 s	2.9 s	3.1 s	4.0 s	6.7 s	6.7 s
Hall 2	3.3 s	4.1 s	4.0 s	5.1 s	35.5 s	7.4 s
Hall 3	5.1 s	4.0 s	4.5 s	6.6 s	40.5 s	8.8 s

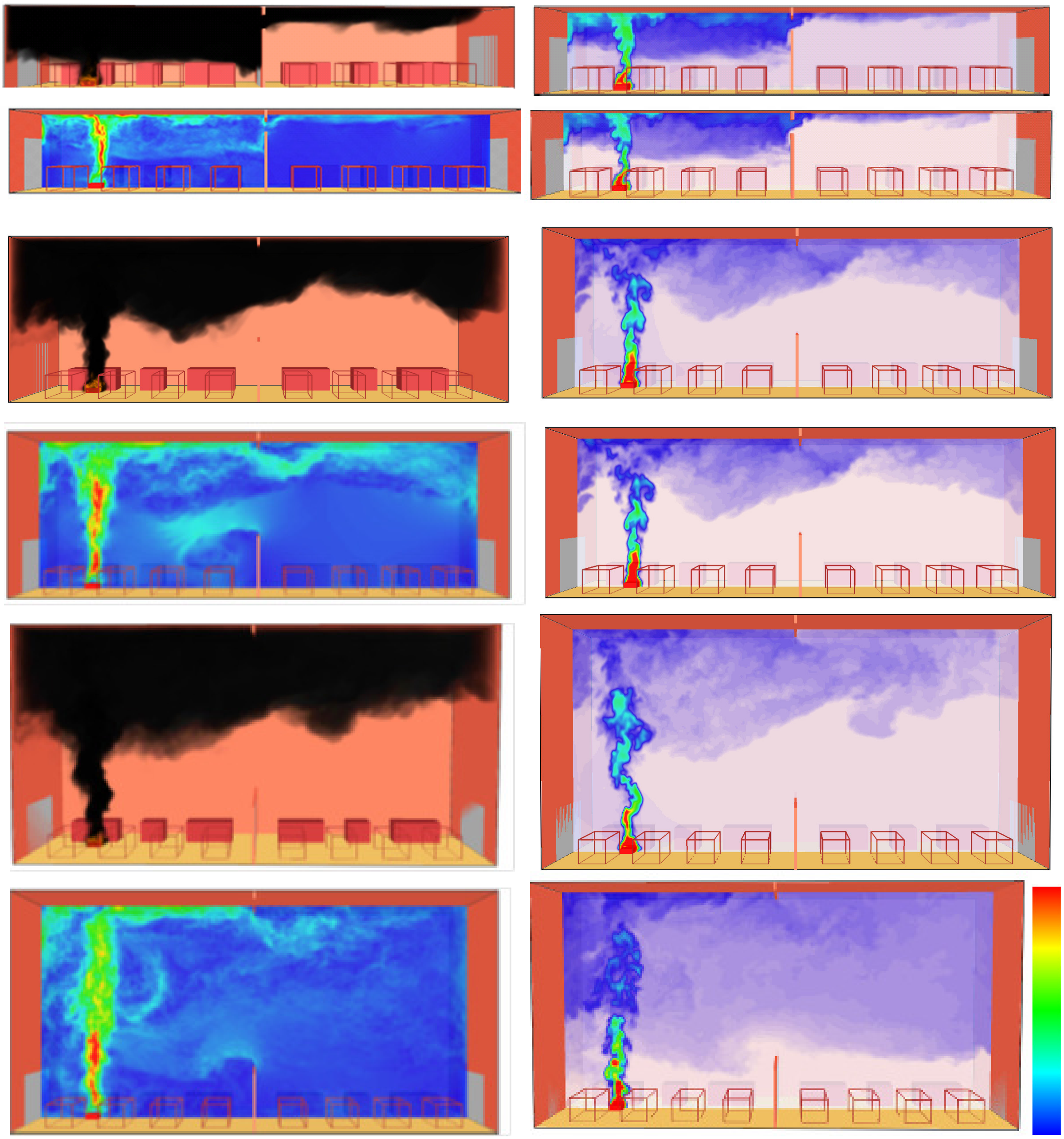

Figure 2. Fire simulation at the 23rd s: smoke spread dynamics and slices of gas temperature, velocity and soot concentration for 3 halls considered; the same colour scheme is used for temperature, velocity and concentration varying between 20 and 820°C, 0 and 5 m/s, and 0 and 0.015 mol/mol, respectively.

The calculations were realized in parallel on a 6-core personal computer (Intel i7-990x, 3.46 GHz CPU, 24 GB RAM) using all 6 CPU cores. In all 3 scenarios, the 18 m long and 6 m wide computational domain was divided into 6 computational meshes of 5 cm resolution (see table 1); all meshes were fine in the sense of mesh sensitivity study [4, 5]. The course of fire is illustrated in figure 2 and table 2. At first, smoke propagated upwards and then stratified under the ceiling. After reaching vertical barriers (the back, left and front walls, and fire barrier), turbulent clouds of smoke started to form spreading along the barriers downwards. The clouds size depended on velocity of gases movement. Later, a smoke layer height equalizing was observed which formed a new layer propagating backwards under the original layer. Main tendencies of spread of different smoke layers are illustrated in figure 2. In the *1st hall*, the fire barrier slowed entering smoke into the 2nd room. Moreover, only smaller part of smoke entered through the vent between the fire barrier and separating wall and began to stratify under the ceiling in the 2nd room. The best part of smoke moved downwards along the separating wall in the 1st room and formed a turbulent cloud of smoke (at the 12th s it reached the 1.6 m depth). Later, an equalizing of smoke layer height was observed. At the end of the 1st min, the 1st room was completely filled by smoke and a smoke stratification comprised of 3 relatively laminar layers under the ceiling was observed in the 2nd room. In this case, the fire barrier markedly decelerated the smoke spread from the 1st to the 2nd room. Since the distance between the fire barrier and separating wall was small, overall circulation between the 1st and 2nd rooms was limited. We observed a weak flow coming from the 2nd room moving downwards along the separating wall in the 1st room which started to rise and stabilized in a roughly horizontal direction. The main tendencies of fire course in the *2nd and 3rd halls* were similar; however, the vent between the fire barrier and separating wall was substantially bigger and significantly affected the smoke dynamics. Higher volume of cold air in halls with higher ceiling decreases the temperature of hot gases released from fire by phased hot/cold air mixing. Higher volume of oxygen supported combustion and caused that the temperature in proximity to fire source was markedly higher. The simulation results indicate that the ceiling height has a marked impact on the fire spread and fire safety in industrial halls. In both cases, the distance between the fire barrier and separating wall was big enough to enable circulation between the 1st and 2nd rooms. Because of small height of the fire barrier, smoke released form the fire source passed beneath the fire barrier with very limited delay only. The separating wall was too small to markedly decelerate the circulation between the 1st and 2nd room and inlet of fresh air to the fire source, and affected the smoke spread only a little. To provide sufficient decrease of smoke spread from the 1st to the 2nd room in the 2nd and 3rd halls, it would be necessary to reduce the size of vent between the fire barrier and separating wall, increasing the fire barrier depth or separating wall height.

3. Conclusions

In this paper, the impact of the ceiling height and fire barriers on the smoke dynamics in industrial halls in case of fire is illustrated using the FDS fire simulator. A great potential of the CFD-based fire model for analysis of fire-induced thermal flows is demonstrated. The simulation results indicate that FDS is able to capture main tendencies of smoke dynamics in the case of industrial hall fire and describe specific physical phenomena related to the type of fire; therefore, FDS has potential for the use for analysis of safety risks and suggestion of fire safety measures.

4. Acknowledgment

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5. References

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