Simulation of floor to floor fire spread

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Abstract: This paper studies floor to floor fire spread. CFD simulations are compared with experiments in literature for gas temperature and incident heat flux. The influence of the aspect ratio of the opening, a downstand, a balcony, the heat release rate, and an atrium is examined.

Keywords: fire spread, façade, atrium, CFD

I. INTRODUCTION

In a building each floor is normally a fire compartment. The fire rated walls, ceiling and floors contain the fire and prevent it to spread. The façade is an exception: the windows do not have any fire resistance. As a consequence the fire may spread to the outside through the openings. The flames will rise and may break the glass of the windows above. If so, the fire will spread to the floor above.

The phenomenon of floor to floor fire spread is still today a serious threat in high-rise building, as is shown by recent catastrophic fires. As façades becomes more complex (e.g. double skin façade) and as architecture becomes more complex (inclined façades, sky gardens, …) rules of thumb do no longer suffices. Therefore, the study of floor to floor fire spread is highly relevant and required.

II. LITERATURE STUDY

A. Experiments of floor to floor fire spread

Experiments on floor to floor fire spread are rather scarce. The first well documented work was done by Yokoi [1]. Other interesting work has been done by Law [2], Suzuki [3] and Oleszkiewics [4].

The experiments of Suzuki and Oleszkiewics have been used here for the validation of CFD simulations.

B. Modelling of floor to floor fire spread

There exist analytical formulas (hand calculations) for the modelling of window flames. The application domain of these formulas is limited. CFD calculations are more appropriate to study certain influence on the fire spread. CFD simulations has been used by Mammoser and Battaglia [5] to study the influence of a balcony.

C. Glazing in fire

The behaviour of glass in a fire is crucial. Before breaking, it will contain the fire and prevent the supply of air. After breaking, the fire will spread through the opening and the opening will provide air to let the fire grow.

The criteria to predict the cracking and breaking of glass, that are derived from experiments are diverse. The incident heat flux, the gas temperature, the surface temperature of the glass, the temperature difference between exposed and shaded glass, … are some of the criteria that are found in literature.

The cracking and breaking criteria can be quiet different dependent on the study quoted. Sometimes a detailed description of the glass examined, lacks in the studies.

The following criteria can be used to assess glass breaking in fire: single glazing breaks at an incident heat flux of 10kW/m², double glazing at 10,5kW/m² and tempered glass at an incident heat flux higher than 43kw/m²

III. VALITDATION

Floor to floor fire spread has been modelled with CFD. Two CFD codes have been used: FDS which uses a LES model, and Smartfire which uses a RANS model for turbulence. Before simulating new configurations, the models have been validated by comparing them with the experiments of Suzuki and Oleszkiewics

A. Gas temperature

The option Baroclinic vorticity in FDS was necessary to perform good simulations. In the simulations it was necessary to incorporate a part of the environment. One floor above the fire floor may be sufficient but it is advised to use two floors. The width perpendicular to the façade must be minimum 1,5 x height of the window. For the width to the side of the window 1,75m is sufficient.

When a fine grid is used, the simulations seemed to differ more from the experiments. This is probably due to the averaging method used in the post-processing of the simulations. As the FDS results are transient, the results were averaged in time.

In the simulations of the experiment of Suzuki, the influence of the radiation factor in FDS was limited.

The influence of the boundary conditions of the walls in the fire compartment on the results is important. Realistic boundary conditions should be applied.

Simulations with FDS and Smartfire were compared with the experiments. FDS gave good prediction of the flame and plume temperature, although temperatures were over predicted. In the simulations with Smartfire the plume sticks to the façade. The thickness of the window flames and plume are predicted too small.

B. Total heat flux

The experiments of Oleszkiewics were simulated with FDS. Three different openings were simulated: 0,94m x 2,70m, 2,60m x 2,70m, and 2,60m x 1,34m. For each window size a heat release rate of 6,9MW and 10,3MW was applied.

For the low heat release rate FDS gave good trends of the incident heat flux above the window. For the high heat release rate the prediction of the trend was less good. The values of the incident heat flux were sometimes over predicted and sometimes under predicted.

For the simulation 2,60m x 1,34m, 10,3MW the incident heat flux was strongly under predicted. Increasing the radiation factor in FDS showed only a slight improvement. The disagreement should be examined further.

III. Simulations

In these simulations the influence of the aspect ratio of the opening, a downstand, a balcony, the heat release rate, and an atrium is examined.

The wide window with limited height (4mx2m) was most critical to floor to floor fire spread. For the other window sizes (4mx3m and 1mx3m) there was not a clear distinction.

The height of the location of the balcony and the width of the balcony was examined. The best location of a balcony to minimise the danger of floor to floor fire spread, is just at the top of the opening. Although higher locations still seems effective. In the simulations a balcony of 0,5m was sufficient tot avoid floor to floor fire spread when single glazing would be used. In the case of double glazing no balcony would be required. The type of glass used in the façade is of course crucial in evaluating the possibility of floor to floor fire spread.

A downstand in the fire room did have an influence on the results: the window flames were shorter and the temperatures lower.

When doing blind simulations the design fire chosen, seemed determining in the evaluation of fire spread. A high heat release rate gave much higher incident heat fluxes.

The location of the fire influences the windows flames olny if it is located close to the window. If located near the wall opposite of the window, only minor differences were noted.

The influence of an atrium on floor to floor fire spread was examined in 4 cases.

For a natural smoke and heat venting system openings were chosen at locations that are most probable to influence the flames. There was indeed noticed an influence. The incident heat fluxes in the simulation were 36% higher than in the free case (no atrium).

When a mechanical smoke and heat venting system with low extraction rate (100'000m³/h) was used, the influence was lower than for the natural case. The incident heat flux was increased by 25%. When the extraction rate was increased to 300'000m³/h, there was no longer a smoke layer in the atrium. The window flames and plume were pushed to the façade by the induced flow of the extraction system. The incident heat flux was increased by 45%.

For an atrium with the mechanical extraction rate of 100'000m³/h the width of the atrium was decreased from 8m to 6m. The smaller atrium did not influence the flow pattern nor the incident heat flux.

V. Conclusion

CFD can be used in the analysis of floor to floor fire spread. Simulations have been done with FDS The predictions of gas temperatures are reliable, the predictions of the incident heat flux on the façade is for fires with high heat release rate not reliable.

CFD is capable of analysing new, complex configurations.

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