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Full-scale smoke tests in a three-storey residential building

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ABSTRACT

This work presents summarized results based on three real-scale tests carried out on a three-story building. The main purpose of these tests is to get some information on how the smoke flows in a building with floors connected with a staircase in order to assess the ability of numerical codes to simulate the smoke flow in complex geometries with multiple rooms.

During these tests, a well-controlled source fire was used and measurements of temperatures and velocities were made all over the different stairs and rooms into the building. The heat release rate in the fire room was deduced from the measured mass loss rate and gas analysis. A comparison between numerical results using the two zones model CFAST [5] and the experimental results was also made.

The current work will provide a large database to evaluate software programs used in fire safety engineering.

KEYWORDS:

Full-scale tests; building fire; fire smoke; stratification; smoke propagation; zone model.



INTRODUCTION

An experimental campaign was carried out, in July 2016, on a 3 storey building in order to study the smoke flow in the case of a fire starting at the ground floor. This campaign was carried out at La Chataigneraie (Vendée, France) in collaboration with the P'PRIME Institute of Poitiers, LEMTA of Nancy and SDIS 85.

One main purpose of this work was to investigate how the smoke is traveling through the whole building, flowing between rooms and different storeys. Indeed, very few experimental campaigns that deal with such configuration exist in the literature, among them, we can cite the work by [6]. In this context, this article presents different measurements of temperatures, heat release rate and other physical quantities made during the smoke tests in the residential building in order to characterize the thermal conditions and stratification.

One of the main goals of this work was to build a database to evaluate the ability of software programs used in fire safety engineering to simulate smoke propagation in large and real domains. In the present study, the two zones model CFAST [5] was used and the numerical results were compared to experimental ones.

EXPERIMENTAL CONDITIONS

Presentation of the building

The experiments concern three apartments located on the ground, 2nd and 3rd floors of the building (the apartment on the 1st floor was kept closed and was not instrumented). These apartments are identical. Three rooms with opened doors are accessible: two bedrooms numbered 1 and 2 and a dining room/living room. The apartments are connected by a staircase. Access doors to the kitchen, sanitary facilities and a third bedroom are closed. The entrance to bedroom 1 of the 3rd floor apartment is also closed. The building configuration is shown in Fig 1.

The fire and air supply are located in bedroom 1 on the ground floor. The window of bedroom 2 on the third floor is kept open to ensure the natural smoke extraction.

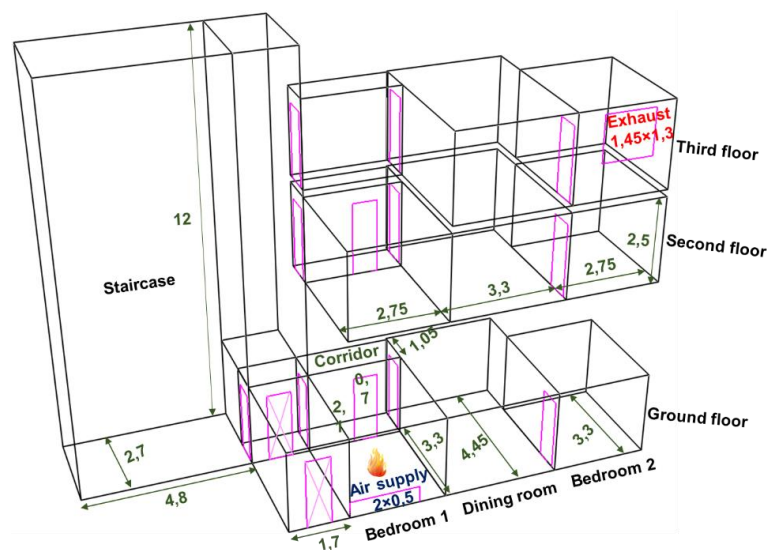


Fig 1 Test configuration (*dimensions in meters*)

Fire source

Inside the bedroom 1 on the ground level a calibrated wood crib is used as a fire source. It has been dimensioned using equations from the SPFE Handbook [1], in order to obtain a maximum value of heat release rate (HRR) of about 927 kW if the combustion is controlled by pyrolysis and 1.16 MW if the combustion is controlled by the ventilation. Note that the size of the doors of the rooms and the size of the vent area on the wall (0.5 x 2 m²) have been taken into account to calculate this later.

A preliminary test, performed at CSTB in the same conditions, suggested that the average HRR in the steady phase is 610-635 kW and that the collapse of the wood crib occurs 76 min 20 s after ignition. During the experiments the mass loss of the wood crib has been measured continuously.

EXPERIMENTAL AND NUMERICAL RESULTS

Three tests were made. The weather conditions were bad during the first with wind strength and direction preventing and stopping the smoke extraction. Moreover, during this test, the ceiling of the room fire collapsed on the fire source, so this test is not considered. The test results of the two other tests are similar and are presented in the following paragraphs.

Heat Release Rate

HRR is plotted in fig. 2. It is estimated from Thornton's rule and the measured mass loss rate. The averaged HRR during the steady phase is 790 to 935 kW. It is relatively close to the theoretical value of 927 kW. It is higher than the values of 610-635 kW measured during the preliminary test probably because of the room confinement. Thus, we obtain a burning time of 48 to 52-minutes which is less than the 76-minutes obtained in the pre-test.

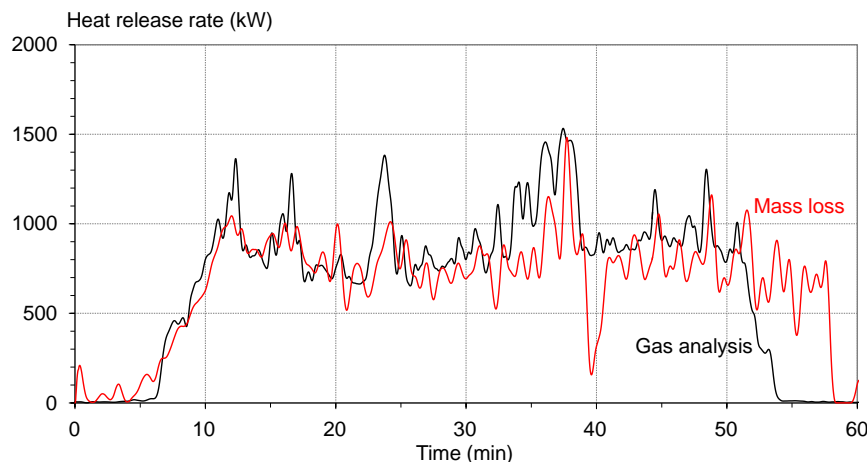


Fig. 2. Temporal evolution of the HRR

Temperature

We will mainly focus on the temperature measurements in the different rooms for every floor. The well-known Janssens and Tran [2] model was used to evaluate the temporal evolution of the smoke layer height and the lower and upper layers mean temperature in each room. The stratification criterion S proposed by Newman ([3]) is also calculated for every room. All the results are presented in fig 3, Fig 4 and Fig 5.

On the ground floor, the smoke interface stands at about 1 m from the floor in the fire room, 1.5 m in the dining room and 0.5 to 0.75 m in the bedroom 2. Newman's parameter S is above a value of 1.7 (considered by the author as a stratification threshold value) in bedroom 1 and dining room of the ground floor, suggesting that the flow is stable and stratified in these two rooms. The thermal stratification in bedroom 2 fulfills the threshold value criterion during the first 20 minutes. In the rooms on the 2nd and 3rd floors, the S parameter is less than 1.7, which shows an unstratified flow while the height of the smoke interface between the upper and lower layers varies between 0.4 and 0.75 m according to Janssens model.

Thresholds values usually used in fire safety engineering ([4]) are defined to evaluate the practicability of escape walkways in case of fire: air temperature, extinction coefficient, smoke layer height and radiative flux below respectively 40 °C, 0.4 m⁻¹, 1.8 m and 2 kW/m². The temperature is lower than the critical value of 40 °C near the floor (0.5 to 0.75 m) in bedroom 2 on the ground floor and in the hallway, and in the bedroom 1 and the dining room on the 2nd floor (see fig 4). The temperature levels in the other rooms do not allow evacuation of the building under acceptable conditions. It is also observed that the radiative fluxes measured on the ground floor, in the fire room and in the corridor quickly exceed the threshold value of 2 kW/m². Though, the radiative flux remains insufficient to spread the fire in the other premises.

Simulations were performed using the CFAST version 6.2 two-zone model. The HRR given in figure 2 (based on mass loss) is prescribed in the code. The radiative fraction is set at 0.33 (default value). The walls and ceilings are made of concrete for the fire room and gypsum in the other rooms. Fig. 4 shows that the temperature levels of the upper and lower layers are estimated by the model with acceptable accuracy. With the exception of the lower layer in the fire room, the difference between the temperatures, evaluated by the

CFAST code and the measurements, does not exceed 22%. We shall note that the temperature signals include the radiation on the thermocouples since they were not protected from radiations. The smoke layer height calculated with the zone model is significantly underestimated in the dining room on the ground floor. It is null in the bedroom 2 on the ground floor and the rooms of the 2nd and 3rd floors during the steady phase of the HRR. Note that in those rooms, Newman’s parameter is lower than 1.7 (unstratified flow).

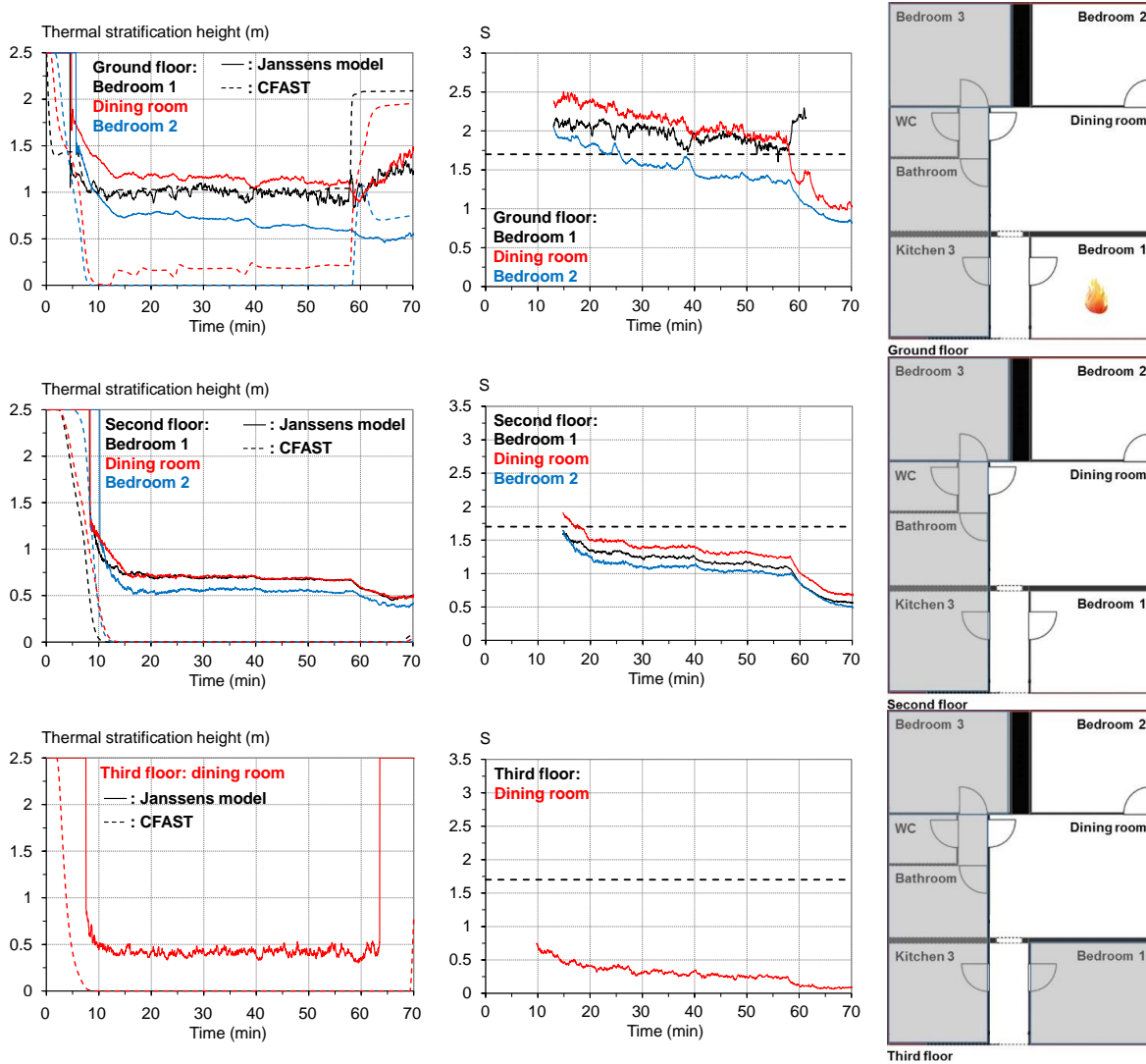
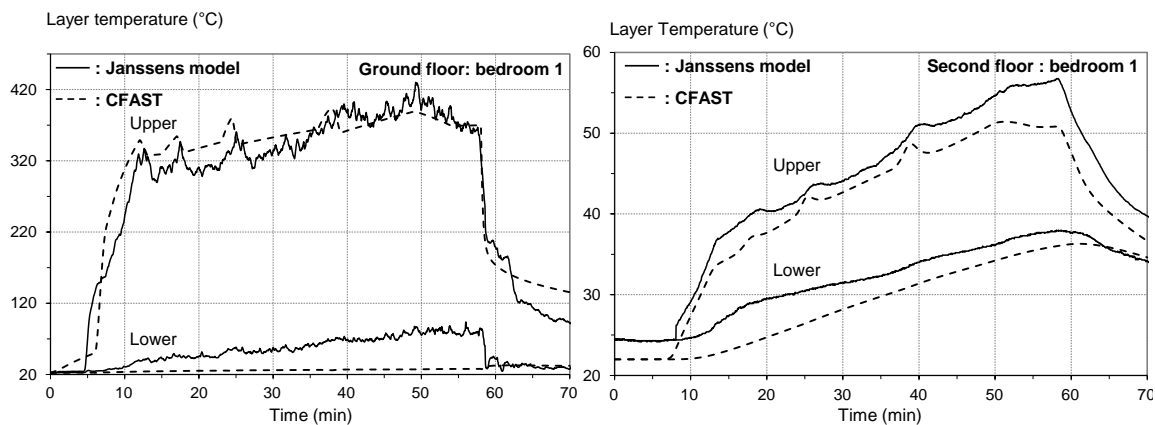


Fig. 3. Smoke layer height and stratification criterion compared to CFAST for the three floors.



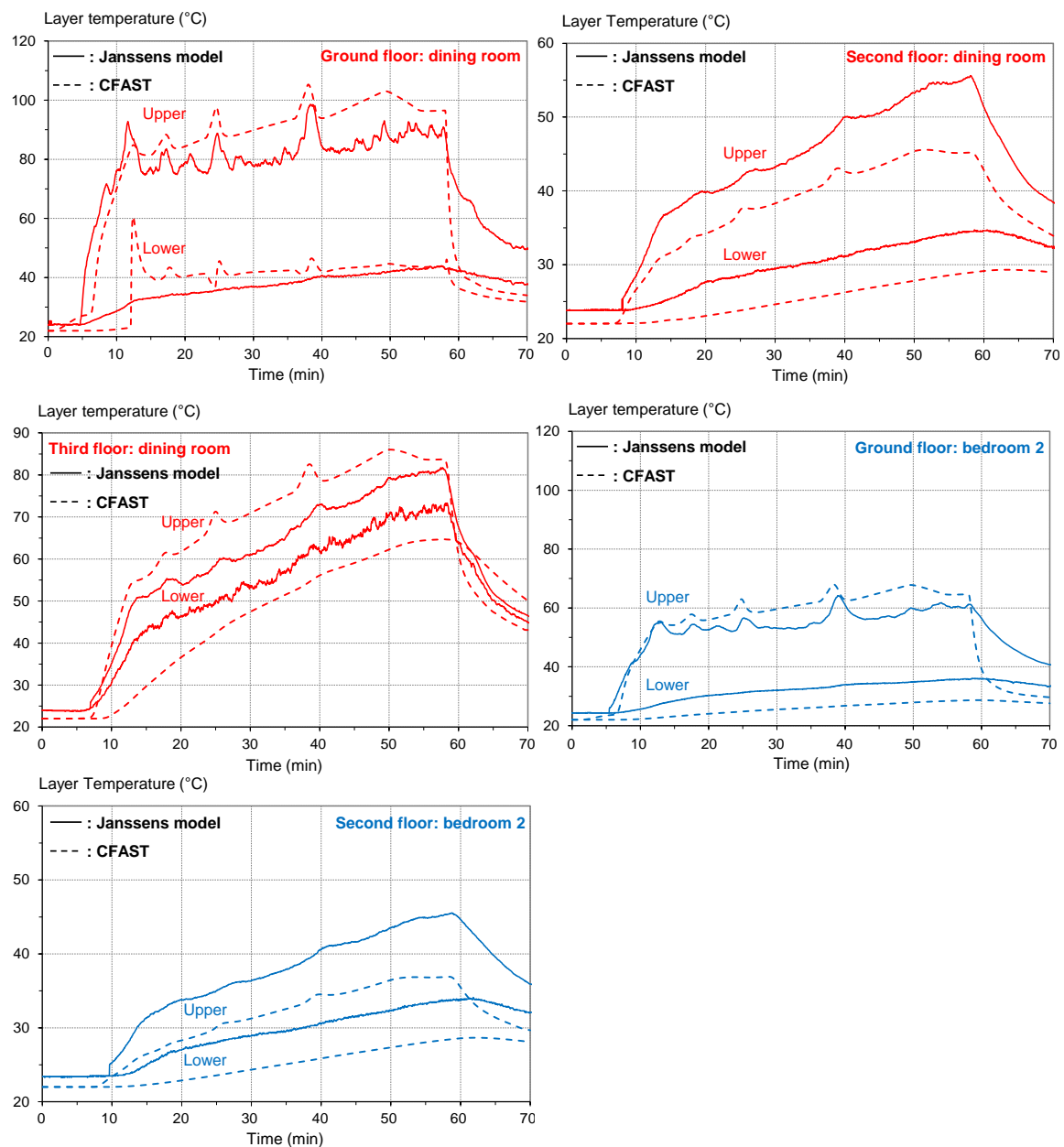


Fig. 4. Temperature measurements compared CFAST in different rooms.

The results are significantly identical between the two entrainment models proposed by the code (McCaffrey and Heskestad) and relatively insensitive to the soot and carbon monoxide production values generated by the combustion reaction. Using the version 7.2.4 of CFAST seems to improve the predictions of the smoke layer height when adding several assumptions: conductivity of the walls, considering leaks through the doors of the kitchen and sanitary area (using CFAST 7.2.4 with the real initial conditions gives an unreal physical behavior). However, the predictions of layer temperatures in 2nd floor rooms are less accurate than those obtained with version 6.2.

Smoke flow through the building

The velocities were measured at every door using propeller anemometers or McCaffrey probes linked differential pressure sensors. The mass flow rate flowing from the ground floor to the third floor is 2.6-2.7 kg/s during the steady phase of the HRR (see figure 5). The measurements suggest that the smoke fills all the open rooms of the building very fast. This requires less than 2 min 45 s.

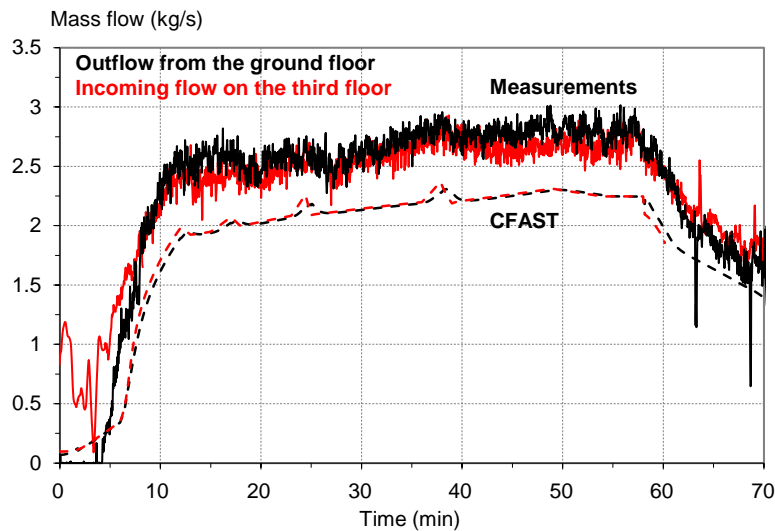


Fig. 5. Mass flow flowing from the ground floor to the 3rd floor

CONCLUSION

Smoke tests were carried out in a three-storey residential building. The tests involved three identical apartments located on the ground, 2nd and 3rd floors of the building, with a communication through a staircase. A wood crib was used as a fire source in the bedroom near the entrance gate to the ground-floor apartment. The measured HRR was about 790 to 935 kW.

The different measurements showed that the smoke filling time of all the premises was very fast and lasted less than 2 min 45 s. The mass flow rate from the ground floor to the top floor was evaluated at 2.6-2.7 kg/s during the steady phase of the HRR. The smoke layer height was found to be 1 m in the fire room, 1.5 m in the dining room on the ground floor and 0.4 to 0.75 m in the other rooms according to Janssens model [2]. According to Newman's criterion [3], the flow was stratified on the ground floor. The temperature was below the acceptability threshold value of 40 °C near the ground (0.5 to 0.75 m) in the bedrooms on the ground floor, the hallway and the dining room of the apartment located on the 2nd floor.

Upper and lower layer temperature levels were predicted by the CFAST version 6.2 [5] two-zone model with acceptable accuracy (a difference from experimental data less than 22%). The code underestimates the stratification smoke layer height in the dining room on the ground floor where it reaches its maximum according to the measurements.

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