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Full-scale experimental and numerical studies on compartment fire under low ambient temperature

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ABSTRACT

A fire experiment with wood crib was conducted in a concrete building under low ambient temperature of −10 °C to explore fire development and temperature distribution. The concrete building consists of a two-storey compartment with the size of 9.0 m by 5.0 m by 4.8 m high and a four-storey stairwell with the size of 5.0 m by 2.4 m by 10.0 m high. The fuel mass loss rate and temperatures at different positions were measured. Two fire cases, with different assumed ambient temperatures of −10 °C and 20 °C respectively, were then simulated by using FDS software to investigate the effect of ambient temperature and compare with the experimental results. The numerical results show that the calculated heat release rate is in reasonably good agreement with the measured full-scale result before water suppression. The calculated temperatures in the hot combustion gas layer at different positions agree also very well with the measured values. However, the measured fresh air temperature at the floor level near the fire source is higher than the calculated value. This discrepancy may partly depend on measuring errors as analyzed in the paper.

1. Introduction

A good understanding of the development in compartment fires is necessary for fire researchers and firefighters for predicting and estimating temperature and smoke production. Experimental measurements and numerical simulations are the two main methods used to investigate the dynamics of compartment fires. Increasingly fire protection concerns are being addressed using fire modeling software tools, including two-zone models and computational fluid dynamics (CFD) models. As computer processing power becomes more available at lower costs, CFD programs are increasingly being used in all aspects of engineering. However, due to the insufficient knowledge of material properties and incomplete models on the pyrolysis and burning behavior of materials, there is still a need for improvement of numerical simulation techniques. Full-scale fire experiments are necessary for examining the accuracy of numerical results to improve the precision of the applications.

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Of the available numerical simulation software, Fire dynamics simulator (FDS), developed by National Institute of Standards and Technology (NIST), is frequently used for simulating building fires. FDS solves numerically a form of the Navier–Stokes equation appropriate for low-speed, thermally-driven flow with an emphasis on the transport of heat and smoke from fires [1]. It has been used for a lot of studies and applications in recent years, such as room fire simulation [2–4], liquid fire simulation [5,6], smoke characteristics in fire scenario [7–9], fire investigation [10,11], and water suppression in fire scenario [12,13]. Gutierrez-Montes and Rein [2] conducted three fire experiments in a 20 m cubic enclosure using pools under different ventilation conditions, and the experimental results were compared with those predicted by FDS. The comparisons show good agreement in the far field of the plume, but the accuracy is poor at the lower plume region and near the flame. The work of Wen [5] has demonstrated the capability of FDS to deliver reliable predictions on most important parameters of pool fires. Hadjisophocleous [7] carried out fire tests in an experimental 10-storey tower to generate realistic smoke movement data, and a full size FDS model of the tower was developed to predict smoke movement, which demonstrated that FDS is capable of modeling fire development and smoke movement in a high rise building. Full-scale experiment and numerical simulations were carried out by Yang [11] on a shelf fire in a storehouse to study the ignition manner, fire spread and combustion characteristics. The experimental results of temperatures and the fire growth and spread process were compared with the results of numerical simulations, which showed that the numerical results were in good agreement with the experimental results.

The main purpose in this study is to show the results of full-scale compartment fire experiment under low ambient temperature and compare with FDS simulation. A fire experiment was conducted in a two-story concrete building connected with a high stairwell under low ambient temperature in Luleå, Sweden. A wood crib, made up of 72 wooden boards, was used as fuel and some jet fuel was used for ignition. Four thermocouple trees were designed to measure the gas temperatures in the compartment. The mass loss of fuel was also recorded by a scale under the fuel during the fire experiment. FDS simulations of this fire scenario under different ambient temperatures were completed to compare with the experimental results and demonstrate the well known effect of different ambient temperatures on fire development. The alternative of specifying the heat release rate (HRR) curve was not used as HRR was always an unknown parameter in a real case analysis. The HRR, in this study, was calculated by the FDS model based on the fuel mass, fuel properties, fuel arrangement, compartment dimensions and ambient temperature, which are possible parameters even though the fire test was not carried out. HRR, gas temperature and mass loss rate were obtained from the numerical simulation. The comparisons between the fire experiment results and the FDS simulation results were carried out.

2. Full-scale experimental setup

The fire experiment was carried out at the Luleå Emergency Training Center, Sweden, in a concrete building containing a two-storey compartment and a four-storey stairwell, as shown in Fig. 1. The building is a typical local building, which is used for the daily training of the local firefighters. The dimensions of the two-storey compartment are 9.0 m by 5.0 m and 4.8 m high. The dimensions of four-storey stairwell are 5.0 m by 2.4 m and 10.0 m high. The thickness of the concrete walls and floors is about 0.2 m. There is an inside door with the size of 0.8 m by 2.0 m between the compartment and the stairwell on the ground floor, which was always open during the fire test. However, the same inside door on the upper floor was always closed, so no smoke would flow into the compartment on the upper floor. Two more outside doors of the compartment and the stairwell, naming as Door-1 and Door-2, are located on the ground floor with the size of 1.6 m by 2.0 m and 0.8 m by 2.0 m, respectively, as shown in Fig. 2. Door-1 and the windows were all closed during the whole fire experiment to prevent heat loss as the environment temperature was very low. Door-2 was closed in the beginning of the fire experiment and then opened after 22 min, as the firefighters need to enter into the compartment through Door-2 to rescue the fictitious trapped occupant and extinguish the fire. There are still some gaps, although the doors and windows are closed. Besides these doors, there are two more holes with the approximate size of 40 cm by 15 cm on the ground level and a small opening with the size of 60 cm by 30 cm on the roof of stairwell. Fresh air was supplied into the concrete building through the gaps and holes, and the generated smoke mainly flowed out through the opening on the roof. There are two 2.5 m long walls which divide the compartment into three small compartments due to its origin design, as shown in Fig. 2.

The fuel in the fire experiment was wood crib, which was placed in a steel tank, in the left small compartment on the ground floor. The wood crib, as shown in Fig. 3, was 0.8 m high and made up of 72 boards. The distance between two adjacent boards was about 0.1 m, and the total mass of the crib was about 120 kg. Six wooden boards were randomly selected for detailed measurements. The following parameters were controlled: dimensions, mass, density and moisture content as shown in Table 1.

In order to ignite the wood crib, about 5 kg jet fuel was sprinkled on the wood crib, and about 15 kg jet fuel was put in the steel tank below the wood crib. Eight wood boards were positioned on every two layers of the wood crib crosswise as shown in Fig. 3. The horizontal area covered by the wood crib was about 0.70 m^2. The steel tank was placed on a scale to monitor the mass loss rate of the fuel. The scale was insulated, and the bottom of the wood crib was located approximately at a height of 0.3 m from the floor.

During the fire test, the fresh air would be supplied into the compartment mainly through gap of Door-1, and therefore one

Fig. 1. Exterior of the concrete building.

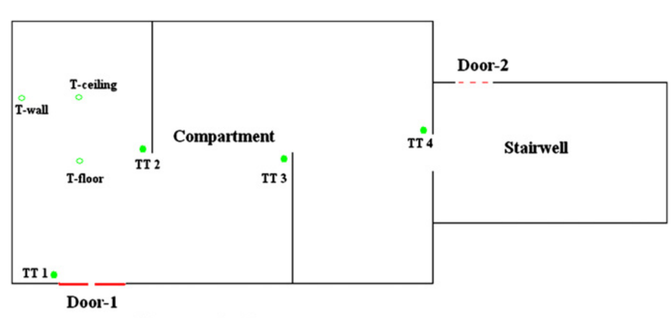

Fig. 2. Plane layout of the building and the positions of thermocouples.