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FIFTEENTH MEETING OF THE UJNR PANEL ON FIRE RESEARCH AND SAFETY MARCH 1-7, 2000

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Systematic Experiments of Room and Corridor Smoke Filling for use in Calibration of Zone and CFD Fire Models

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1. INTRODUCTION

In the smoke control designs, smoke layer height and temperatures are calculated for safety checking. Quite often, the design Heat Release Rate (HRR) is described by t^2-fires [1, 2],

$$Q_f = \alpha t^2 \tag{1}$$

where Q_f [kW] is design HRR, α [kW/s^2] is the fire growth rate, and t [sec.] is the time from ignition. Putting the design fires in the building to be designed, the smoke propagation is calculated typically by zone models [3-6] such as BRI2 and CFAST. To be certain with the calculated results, the models will have to be validated against design fire scenarios.

Both BRI2 and CFAST has been verified against many experimental data. However most of the experiments were carried out using steady HRR, mainly because of the simplicity of experimental procedures. Thus question may arise if those models are still valid for t^2-fires.

In this study, a series of full scale experiments were carried out using t^2-fires. Fire room and corridor smoke filling process was measured. The size of the corridors and arrangement of smoke curtains were varied in several patterns. Comparisons were made between experimental results and the results by two zone models, BRI2 and CFAST.

2. EXPERIMENTAL PROCEDURE

2.1 Fire Source

Figure 1 shows the schematics of the fire source. A triangular shaped polyurethane mattress was used as a fire source. Base width is 600 [mm], while the height of the triangle is 900 [mm]. The thickness was 160 [mm]. Using three load cells, the mass loss rate was measured continuously. The HRR was calculated by multiplying its heat of combustion 36 [kJ/g].

2.2 Room and Corridor Arrangement

The experiments were carried out on third floor of Full-Scale Fire Laboratory at the Building Research Institute. Figure 2 shows the arrangement of room and corridors. The dimension of the room of fire origin is W 7,900 x D3,300 x H 2,700 [mm]. Doorway size between fire room and corridor was W1,000 x H2,000 [mm]. Corridor ceiling height was 2,700 [mm].

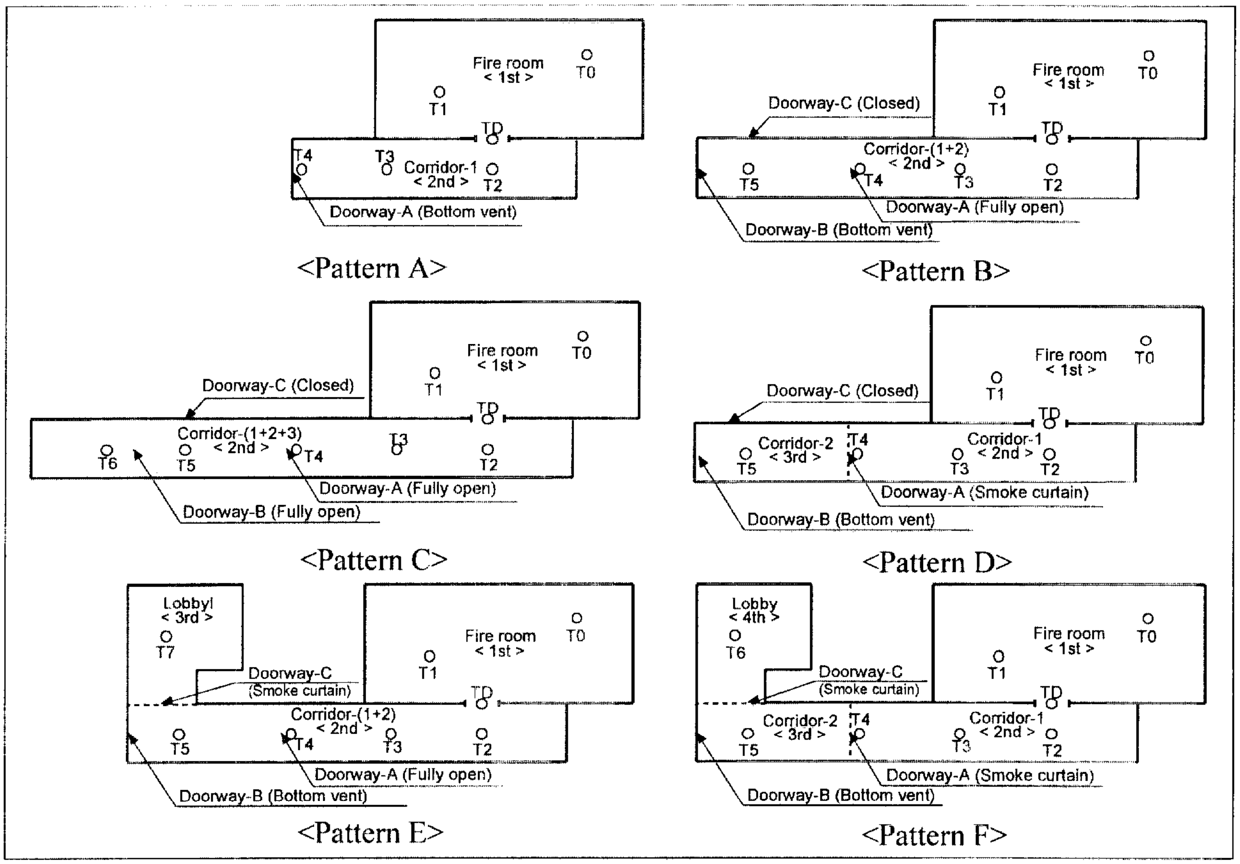


Figure 3 The arrangement of each experimental pattern

Table 3 summarizes the opening condition of the doorways between corridor spaces. As shown in Figure 4, doorway height was changed in three ways. It was either fully open, smoke curtain at the top, or small vent at the bottom.

Table 3 The opening condition of the doorway

	Pattern A	Pattern B	Pattern C	Pattern D	Pattern E	Pattern F
Doorway-A	Bottom vent	Fully open	Fully open	Smoke curtain	Fully open	Smoke curtain
Doorway-B	• • • •	Bottom vent	Fully open	Bottom vent	Bottom vent	Bottom vent
Doorway-C	• • • •	• • • •	Closed	Closed	Smoke curtain	Smoke curtain

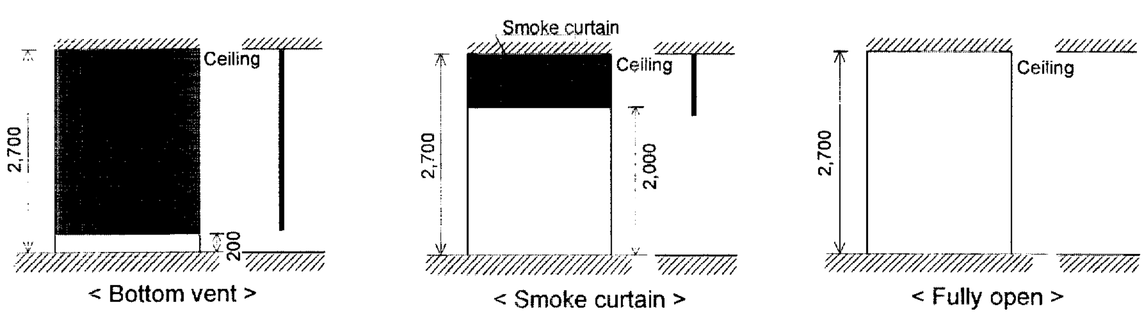
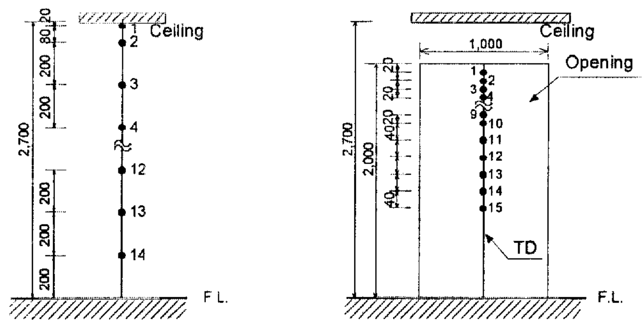


Figure 4 The schematic of doorway condition (unit: mm)

2.3 Smoke Temperature Measurements

To measure the smoke layer height and temperature, thermocouple trees were put in the locations shown in Figure 2. The tree has type-K thermocouples (0.3 [mm]-diam.). As shoen in Figure 5 vertical temperature distribution was measured at by installing 14 thermocouples on earch tree. Doorway smoke temperature profile was measured by 15 thermocouples (tree TD). The total number of thermocouples was 127.



a) trees T0-T7 b) tree TD

Figure 5 The schematic of the thermocouple trees (unit: mm)

3. RESULTS

3.1 Fire Growth Rate

As an example, measured HRR curve for exp. pattern A is shown in Figure 6. The HRR could be well approximated by t^2-growth. The fire growth rate for this experiment was 0.0065 [kW/s^2]. Also in the other experiments, the HRR is almost t-squared. The fire growth rates are summarized in Table 4. The range of scatter was 0.0079 to 0.0045 [kW/s^2].

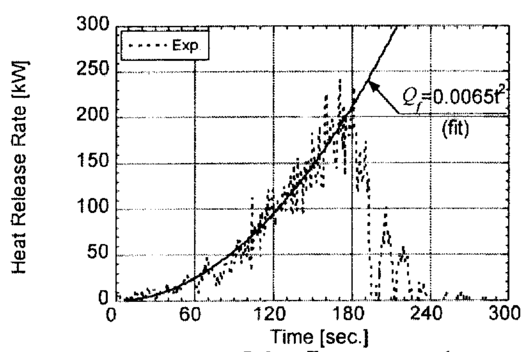


Figure 6 HRR of the fire source (pattern A)

Table 4 Results of fire growth rate

Experimental pattern	A	B	C
Fire Growth Rate • •[kW/s^2]	0.0065	0.0071	0.0056
Experimental pattern	D	E	F
Fire Growth Rate • •[kW/s^2]	0.0045	0.0079	0.0049

3.2 Smoke Layer Height and Average Smoke Temperature

Using the N-percent method [7] (N=10%) smoke layer height and average temperature were calculated for all the experimental results. Figures 7 to 12 shows the results. In each set of figures, series (a) denotes the smoke layer height, (b) denotes the average temperatures.

(1) Fire Room

The smoke layer development in the room of fire origin is about 60 seconds after ignition (T0 and T1). After that the layer descends almost uniformly. After 120 seconds, the layer height close to the doorway (T1) is kept higher than that close to fire source (T0). This is because of the air inflow from corridor. After decay (180 seconds), smoke layer descends almost close to the floor (about 200mm above floor at T0, 600mm at T1). The above tendency is common to all the experimental patterns, which means that it is almost independent on the corridor size and arrangement.

(2) Corridor

Corridor smoke layer begins to develop at about 120 seconds. The rate of smoke layer development differs slightly depending on the size of corridor. In case of small corridor (pattern A), smoke layer decended quickly after 120 seconds. While, in case of large corridor (typically in patterns C and D) the development is relatively slow. It should be noted that there is a special distribution difference in smoke layer height in the corridor, especially in cases of large corridor. In case of pattern E, the difference in smoke layer development is about 30 seconds between the locations (T2 and T5).

The effect of smoke curtain is observed to delay the smoke propagate time to downstream corridors. This is obvious through the comparison between patterns E and F. In the pattern E, the lobby smoke developed at 150 seconds. While in the pattern F, the lobby smoke developed at 220 seconds. The difference is attributed to the smoke curtain at the doorway-A.

As a general tendency, the smoke layer decends right after the fire source has decayed. In all of the experiments, corridor smoke layer has declined to lower than 1 meter above floor. It means that the corridor is unsafe after combustion of three minutes unless some smoke management system is provided.

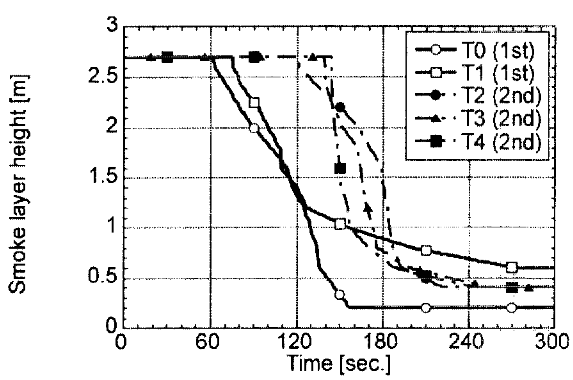


Figure 7(a) Smoke layer height (pattern A)

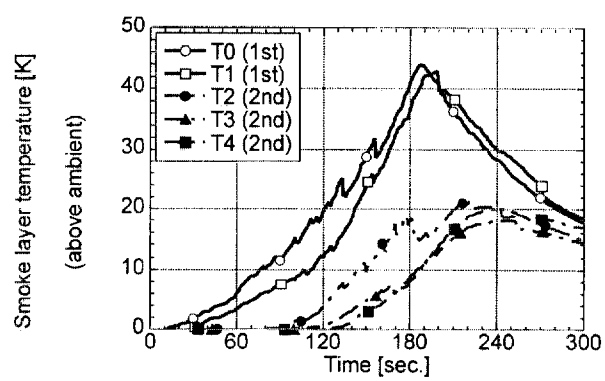


Figure 7(b) Smoke layer temp. (pattern A)

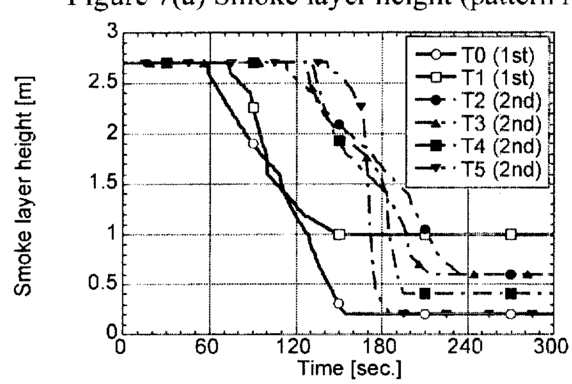


Figure 8(a) Smoke layer height (pattern B)

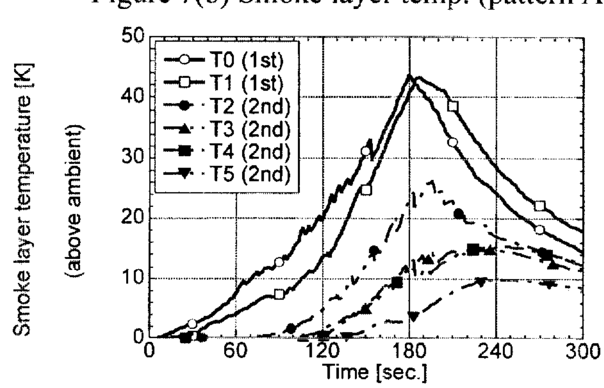


Figure 8(b) Smoke layer temp. (pattern B)

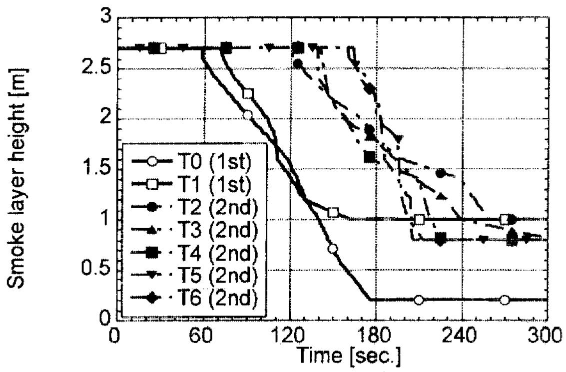


Figure 9(a) Smoke layer height (pattern C)

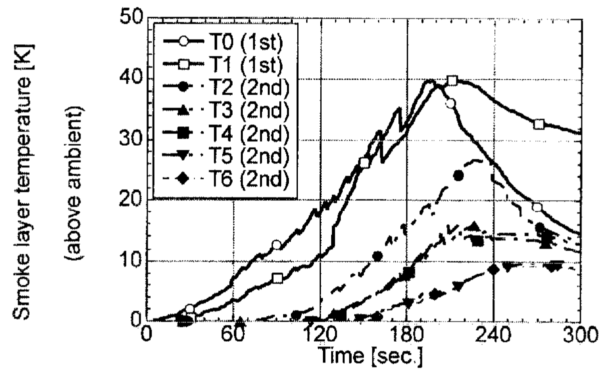


Figure 9(b) Smoke layer temp. (pattern C)

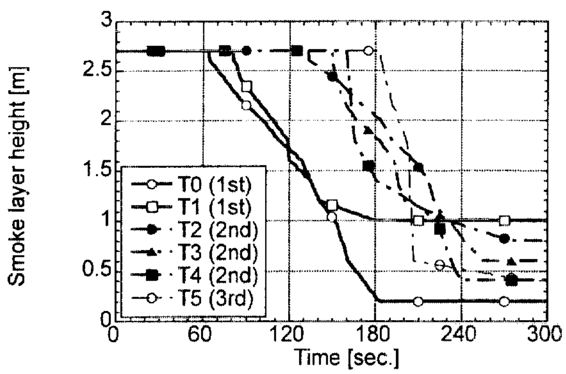


Figure 10(a) Smoke layer height (pattern D)

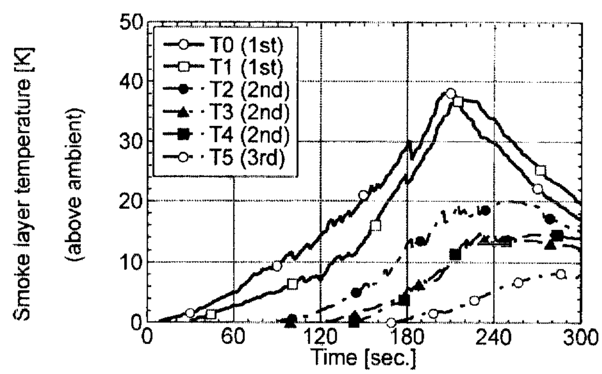


Figure 10(b) Smoke layer temp. (pattern D)

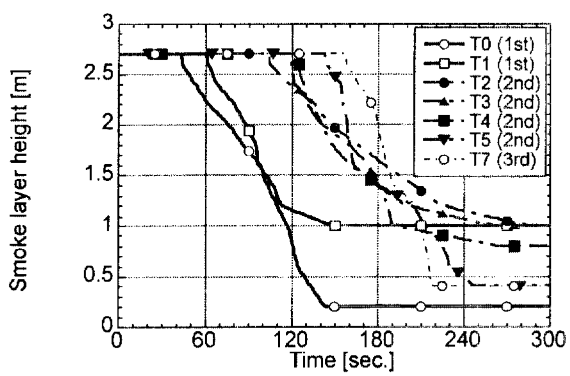


Figure 11(a) Smoke layer height (pattern E)

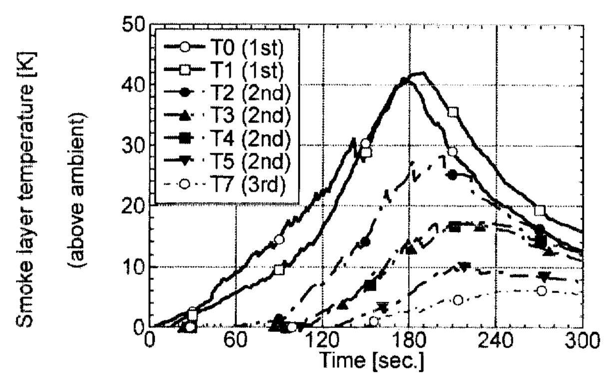


Figure 11(b) Smoke layer temp. (pattern E)

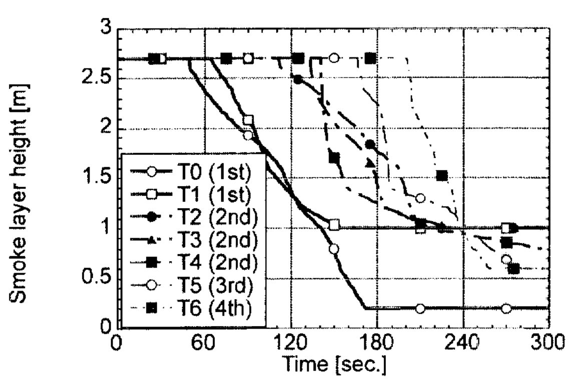


Figure 12(a) Smoke layer height (pattern F)

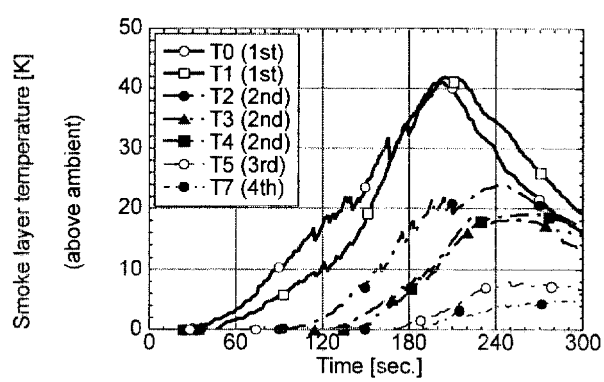


Figure 12(b) Smoke layer temp. (pattern F)

4. VALIDATION OF ZONE MODELS (BRI2 and CFAST) FOR t^2-FIRES

4.1 Calculation

Two zone models, BRI2 and CFAST was selected to simulate the experimental realization. Among the experimental data, the condition for patterns A was selected and simulated by BRI2 and CFAST, respectively. The input HRR curve is shown in Figure 13.

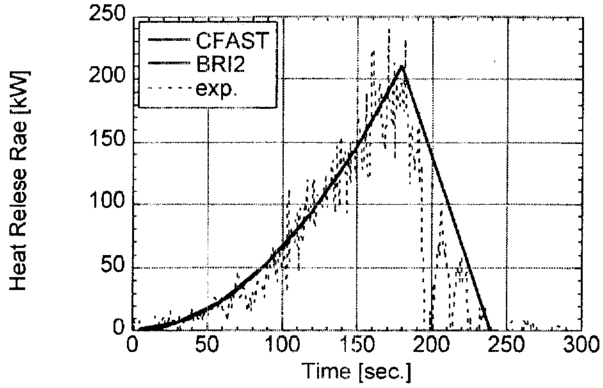


Figure 13 The input HRR curve (pattern A)

4.2 Comparison Results

The calculated results are shown in Figures 14, 15 (pattern A) in comparison with experimental data. Both of the two models predict faster smoke development in case of pattern A. As to the temperature, model predictions are slightly higher than the maximum temperature of the smoke layer. In this sense, the models are valid to use in engineering design purpose.

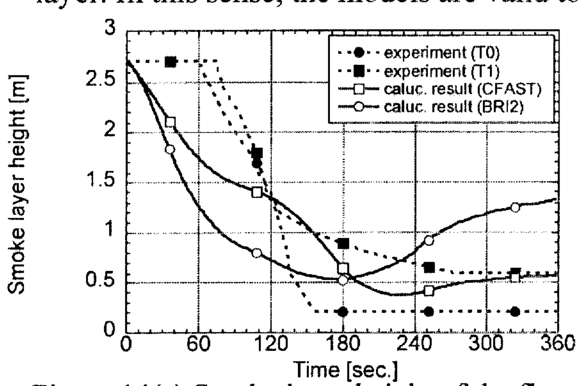


Figure 14(a) Smoke layer height of the fire room

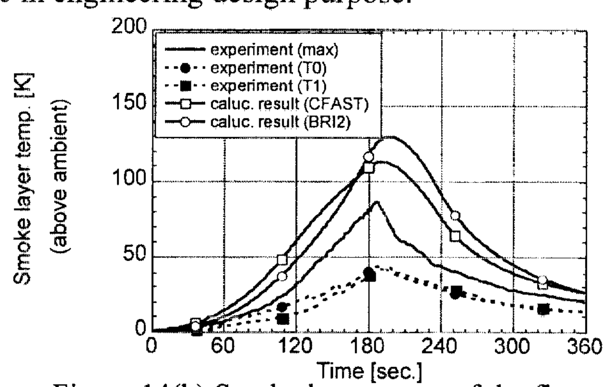


Figure 14(b) Smoke layer temp. of the fire room

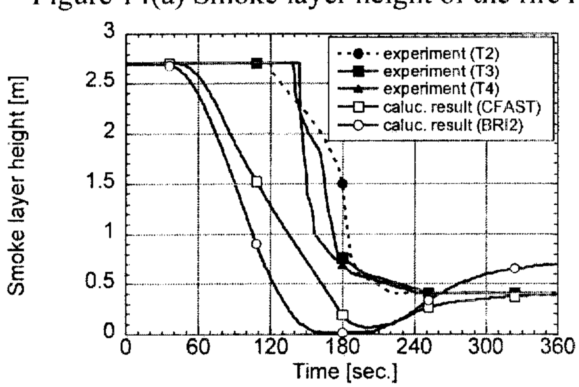


Figure 15(a) Smoke layer height of the corridor-1

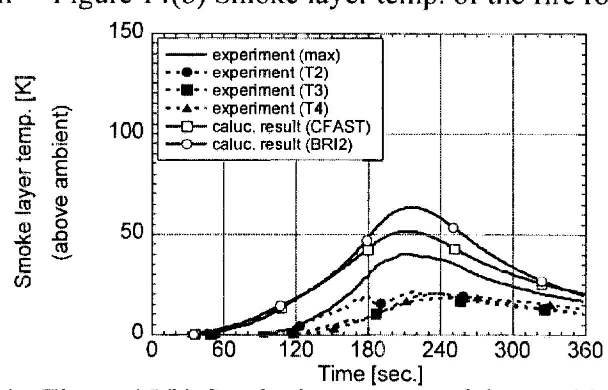


Figure 15(b) Smoke layer temp. of the corridor-1

However, the post decay behavior is not well predicted by zone models. After decay, the model prediction gives the decrease of smoke layer temperature. At the same time, the thermal shrinkage of smoke layer seems to be predicted. As a result, smoke layer height is increased after decay. This difference is clear in case of BRI2 predictions. In experiment, there is a considerable "mixture" between smoke layer and air layer during decay period. Thus the smoke layer quickly descend to floor level. In an engineering viewpoint, this difference might mislead fire engineers. Thus there is a need to revise zone model codes to include mixing of less buoyant smoke with lower air layer.

5. CONCLUSION

A series of full scale experiments were carried out to investigate the smoke propagation behavior for t^2-fires. The effect of corridor arrangement (size and smoke curtains) were analyzed. The corridor size and smoke curtains have beneficial effect to delay the smoke propagation to downstream corridors. In the experiments, quick mixing of smoke after the decay of fire was observed. In the prediction of smoke layer by using zone models, this effect is not taken into account. Thus there is a need to revise zone type equations to include smoke-air mixing during post decay period.

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NOMENCLATURE

Q_f : design Heat Release Rate [kW]
t : time from ignition [sec.]
α : fire growth rate [kW/s^2]

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