BUILDING FIRE ZONE MODEL SIMULATION WITH SYMBOLIC MATHEMATICS

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ABSTRACT

There are many good reasons for using symbolic mathematics in computer models instead of traditional program such as FORTRAN. Fire environments including upper layer temperature and interface height of smoke layer in different buildings were simulated with a one room fire model compiled by symbolic mathematics. Three heat release rates and two opening conditions were used in the simulations. Values of the three heat release rates were estimated based on the minimum heat release rates required for flashover.

All the rooms with a higher heat release rate would get a higher upper layer temperature and a lower interface height within a shorter time. It might be dangerous in a room even under a 500 kW fire with doors closed. Only some big rooms can endure a longer time under a 500 MW fire with doors opened. Even under a 100 kW fire, the smoke layer might develop to a lower stage within a short time in a small room. The opening size is the key point to onset flashover. Floor area or room size affect the time to flashover for the same net heat release rates in different rooms.

KEYWORDS: Building fire, Fire model, Symbolic mathematics

INTRODUCTION

Fire environment should be estimated in engineering performance-based design[1-5] for building safety assessment. ‘Computer fire model’[6,7] is not necessarily synonymous to ‘performance-based design’ as pointed out by Sheppard and Meacham[8]. It is regarded as a key element in scenario analysis for studying the consequences of a fire, though there are other methods for predicting the indoor fire environment. Satisfactory approximate models with simpler structure would be useful for practical use[9.] The two-layer zone model[6,7] is very suitable for use in hazard assessment. It is relatively simple and calculations can be performed rapidly in a personal computer.

There are difficulties in promoting computer models written in old program such as FORTRAN in fire safety engineering design[10.] The program structure itself is complicated and the source codes are usually not available. It is difficult to read the program and change the parameters concerned.

With the rapid development of symbolic mathematics, application to fire modelling with this approach would be worthwhile to consider. Programming is relatively simpler than using traditional high-level languages such as FORTRAN and BASIC. It will be much more flexible to change the equations and parameters concerned describing the physics involved.

MAPLE[11,12] is a symbolic computation system. It is ideal for formulating, solving, and exploring mathematical models. Therefore, a fire model was developed by applying MAPLE[11-15] to compile equations extracted from the two-layer zone model FIRM[7]. Results predicted by solving the two key ordinary differential equations on smoke layer temperature and interface height in MAPLE are basically the same as those computed from the model FIRM compiled by high-level programming languages. But it is very easy to change the equations concerned in the fire model. Further, in the updated version of the symbolic mathematical package, more interactive environment is allowed. Input file can be a word processing document with mathematical expression typed in by following the instruction manual[12].

In this study, fire environments including temperature[16] and interface height of smoke layer in different buildings will be simulated using the fire model with symbolic mathematics. Zone model CFAST will be used to compare the results.

FIRE ENVIRONMENT SIMULATION

The two key equations on upper layer temperature and smoke layer interface height will be solved numerically by the model with symbolic mathematics. Other relevant equations and commands were also compiled with MAPLE program. As it is a one-room fire model, different rooms in the building should be simulated separately.

Simulations will be carried out to predict the fire environment in the following different rooms:

- 10 rooms (P1…P10) in a university building
- 5 rooms (C1…C5) in a commercial building
- 4 rooms (R1…R4) in a residential building

The position and size (L×W×H) of the rooms selected are shown in Figs. 1 to 3 and Tables 1 to 3 respectively.

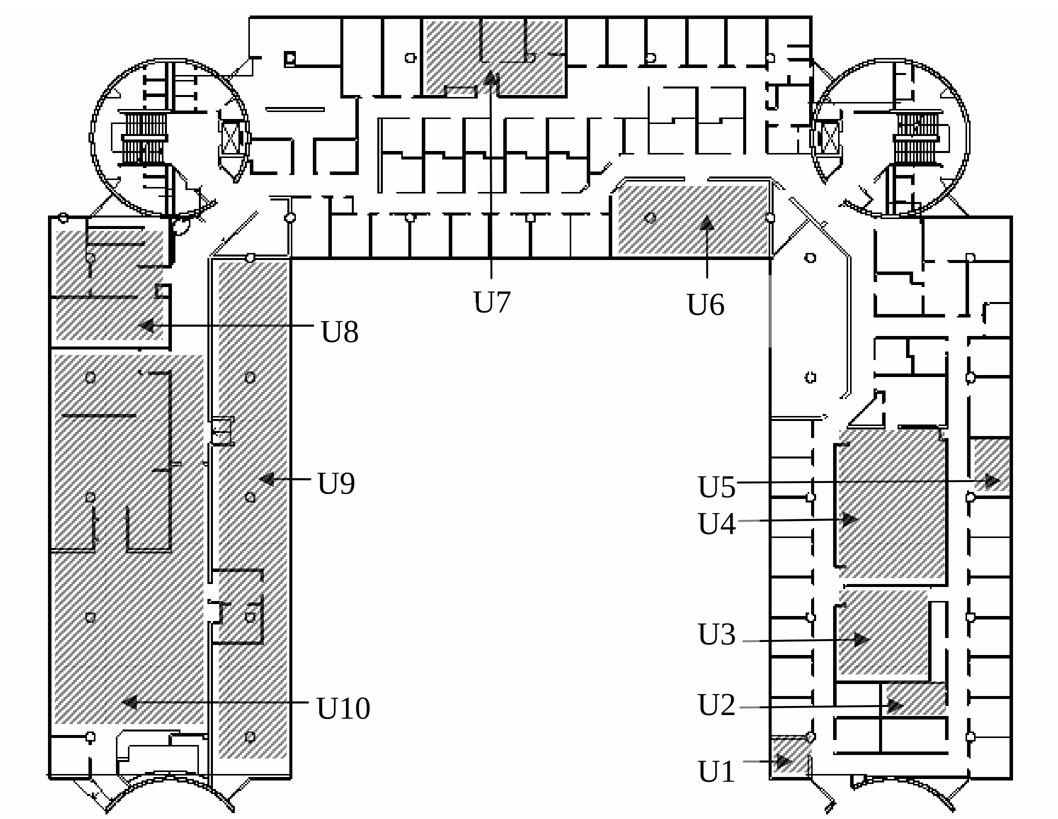


FIGURE 1. Layout of the rooms considered in a university building

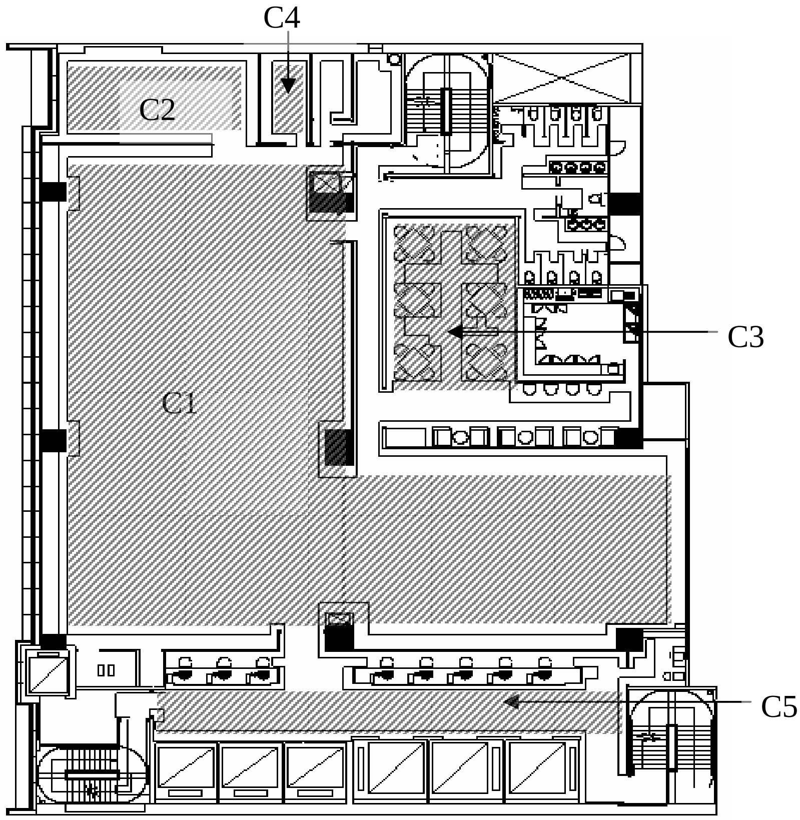


FIGURE 2. Layout of the rooms considered in a commercial building

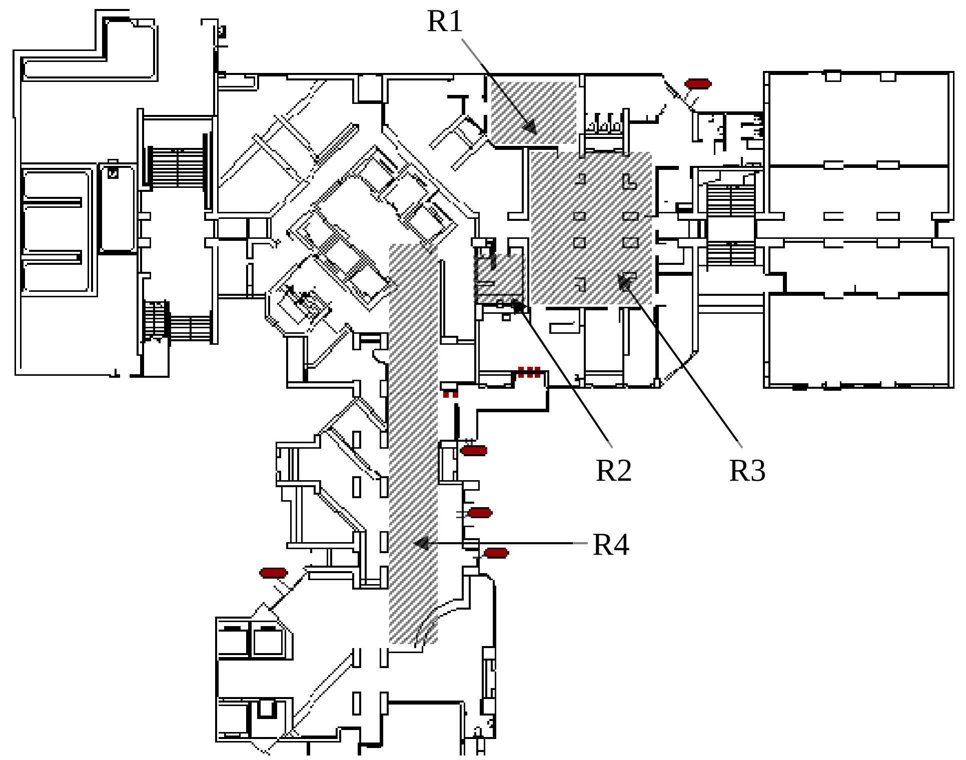


FIGURE 3. Layout of the rooms considered in a residential building

As the windows are commonly closed, only the doors are taken as openings of the rooms. The height of doors H_V is taken as 2 m. Two scenarios for openings are considered:

- Openings are fully opened
- Openings are closed with a leakage area of 2 m × 0.2 m

The minimum heat release rate $\dot{Q}_{\min}$ (kW) required for flashover in a room[16] can be estimated by the height H_V (m) and width W_V (m) of the opening as:

$$\dot{Q}_{\min} = 750 H_V^{\ 1.5} W_V \qquad [1]$$

The sizes of the openings are assumed to be 2 m × 0.8 m and 2 m × 0.2 m for doors are open and closed respectively. Putting these values into equation [1], the values of the minimum heat release rate $\dot{Q}$ are 1697 kW and 424 kW. Therefore, values of 2 MW, 0.5 MW and 0.1 MW will be taken as the design fire $\dot{Q}$ for simulating the fire environment.

TABLE 1. Results for a university building

Room	Size (L×W×H) / m^3	Q / MW	Opening Area/ m^2	T_U / °C	Z_i / m	Room	Size (L×W×H) / m^3	Q / MW	Opening Area / m^2	T_U / °C	Z_i / m
U1	3×2.5×3	0.1	2×0.8	114	1.3	U6	10×5×3	0.1	2×1.5	96	1.4
			2×0.2	211	0.8				2×0.2	172	0.7
		0.5	2×0.8	328	1.1			0.5	2×1.5	256	1.4
			2×0.2	601 (43s)	0.5				2×0.2	601(286s)	0.5
		2.0	2×0.8	638 (11s)	0.8			2.0	2×1.5	605(58s)	1.1
			2×0.2	601 (16s)	0.5				2×0.2	600(71s)	0.6
U2	4×3×3	0.1	2×0.8	114	1.3	U7	10×5×3	0.1	2×3	85	1.6
			2×0.2	211	0.8				2×0.2	172	0.7
		0.5	2×0.8	328	1.1			0.5	2×3	212	1.5
			2×0.2	603 (18s)	0.6				2×0.2	601(286s)	0.5
		2.0	2×0.8	615 (13s)	0.8			2.0	2×3	564	1.4
			2×0.2	603 (18s)	0.6				2×0.2	600(71s)	0.6
U3	6×6×3	0.1	2×0.8	114	1.3	U8	9×7×3	0.1	2×0.8	110	1.2
			2×0.2	196	0.8				2×0.2	152	0.7
		0.5	2×0.8	328	1.1			0.5	2×0.8	328	1.1
			2×0.2	601(206s)	0.5				2×0.2	601 (90s)	0.6
		2.0	2×0.8	611 (38s)	0.8			2.0	2×0.8	601 (65s)	0.8
			2×0.2	603 (52s)	0.6				2×0.2	601 (90s)	0.6
U4	10×7×3	0.1	2×2.4	87	1.5	U9	35×5×3	0.1	2×4	74	1.6
			2×0.2	142	0.7				2×0.2	84	0.9
		0.5	2×2.4	223	1.5			0.5	2×4	196	1.6
			2×0.2	601(400s)	0.5				2×0.2	366	0.5
		2.0	2×2.4	600(133s)	1.3			2.0	2×4	517	1.5
			2×0.2	602(100s)	0.6				2×0.2	601(248s)	0.6
U5	5×2.5×3	0.1	2×0.8	96	1.4	U10	25×10×3	0.1	2×4	69	1.6
			2×0.2	211	0.8				2×0.2	72	1.1
		0.5	2×0.8	256	1.4			0.5	2×4	189	1.6
			2×0.2	605(72s)	0.5				2×0.2	266	0.6
		2.0	2×0.8	614(15s)	1.1			2.0	2×4	516	1.5
			2×0.2	607(19s)	0.6				2×0.2	600(353s)	0.6

TABLE 2. Results for a commercial building

Room	Size(L ×W×H) / m^3	Q / MW	Opening Area/ m^2	T_U / °C	Z_i / m
C1	25×22 ×4	0.1	2×5.0	46	2.2
			2×0.2	46	2.2
		0.5	2×5.0	111	1.6
			2×0.2	112	1.3
		2.0	2×5.0	365	1.5
			2×0.2	379	0.6
C2	7.5×3.3 ×4	0.1	2×1.2	101	1.4
			2×0.2	195	0.8
		0.5	2×1.2	277	1.3
			2×0.2	601(217s)	0.5
		2.0	2×1.2	604 (43s)	1.0
			2×0.2	601(93s)	0.5
C3	7.5×5 ×4	0.1	2×5.0	79	1.7
			2×0.2	165	0.7
		0.5	2×5.0	192	1.6
			2×0.2	600(325s)	0.5
		2.0	2×5.0	488	1.5
			2×0.2	601(139s)	0.5
C4	3.3×1.5 ×4	0.1	2×0.8	135	1.1
			2×0.2	211	0.8
		0.5	2×0.8	421	1.0
			2×0.2	602(44s)	0.5
		2.0	2×0.8	-	-
			2×0.2	-	-
C5	20×2×4	0.1	2×0.8	81	1.6
			2×0.2	160	0.7
		0.5	2×0.8	199	1.6
			2×0.2	601(347s)	0.5
		2.0	2×0.8	517	1.5
			2×0.2	600(148s)	0.5

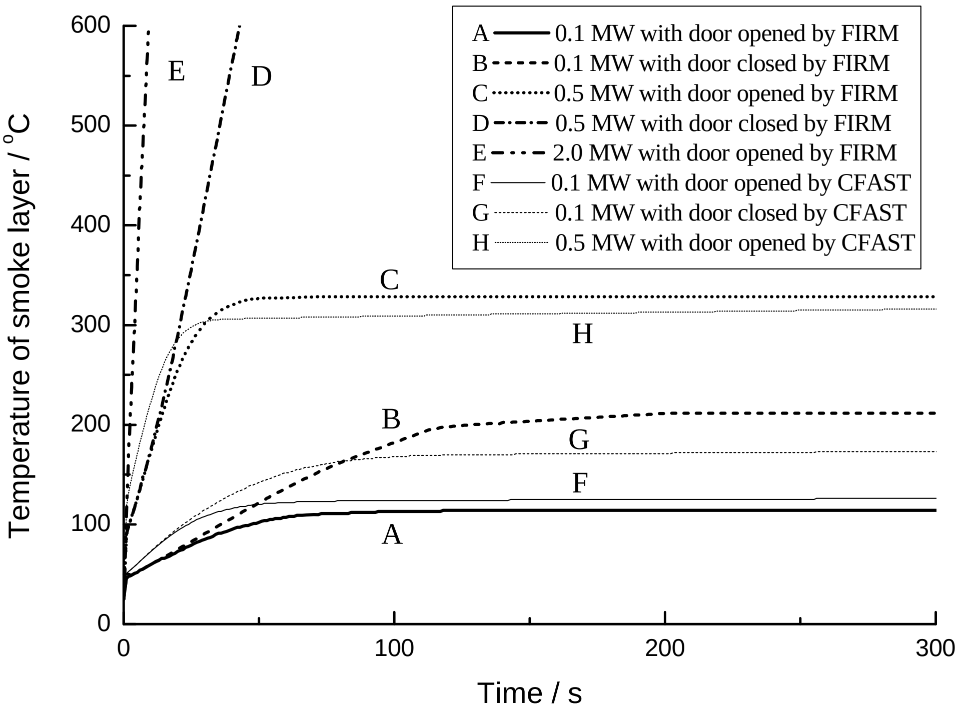
TABLE 3. Results for a residential building

Room	Size(L ×W×H) / m^3	Q / MW	Opening Area / m^2	T_U / °C	Z_i / m
R1	6×4.5 ×3	0.1	2×2.0	91	1.5
			2×0.2	207	0.8
		0.5	2×2.0	235	1.4
			2×0.2	603(155s)	0.5
		2.0	2×2.0	601 (37s)	1.3
			2×0.2	602 (39s)	0.6
R2	3×3×3	0.1	2×0.8	114	1.3
			2×0.2	211	0.8
		0.5	2×0.8	328	1.1
			2×0.2	606 (52s)	0.5
		2.0	2×0.8	612 (10s)	0.8
			2×0.2	609 (15s)	0.5
R3	16×12 ×3	0.1	2×3.0	74	1.6
			2×0.2	81	1.0
		0.5	2×3.0	205	1.5
			2×0.2	336	0.5
		2.0	2×3.0	564	1.4
			2×0.2	600(271s)	0.6
R4	30×6 ×3	0.1	2×10	71	1.8
			2×0.2	83	0.9
		0.5	2×10	173	1.6
			2×0.2	357	0.5
		2.0	2×10	425	1.7
			2×0.2	601(255s)	0.6

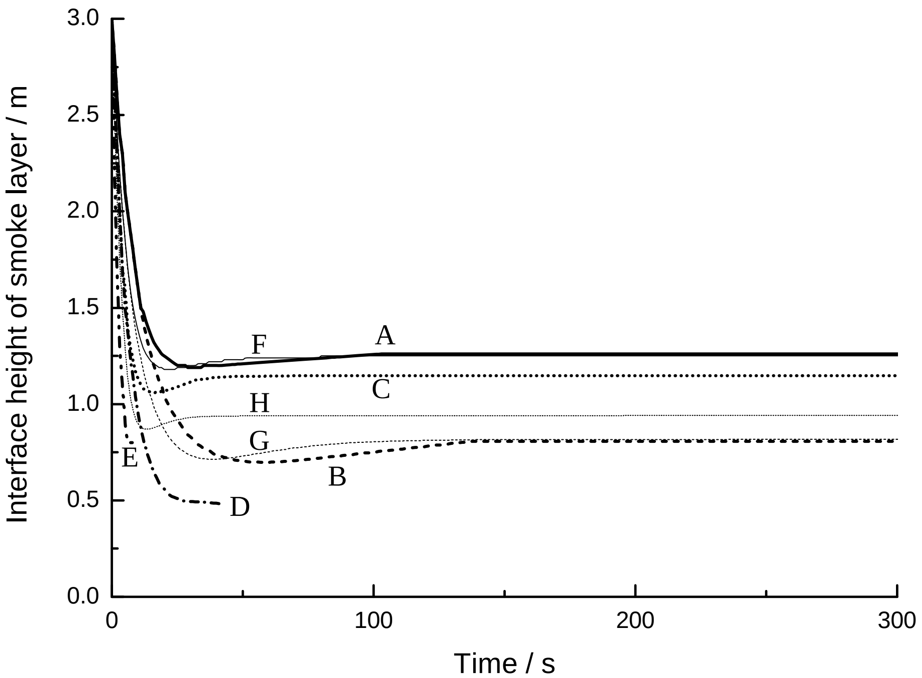
SIMULATION RESULTS

600 °C was taken as the criterion of flashover in the model. The simulation will stop when the upper layer air temperature is about 600 °C (the time to flashover is shown in brackets in the Tables) or the running time is 600 s.

Results predicted on interface height of smoke layer Z_i (m) and upper layer temperature T_U (°C) for different buildings are shown in Tables 1 to 3. Transient values Z_i and T_U for a sample in the university building are shown in Fig. 4a and 4b. For comparison, three scenarios on 0.1 MW and 0.5 MW with door opened were simulated again by CFAST with results shown in Fig. 4. The relations between room floor area with T_U and Z_i respectively are shown in Fig. 5a and 5b.

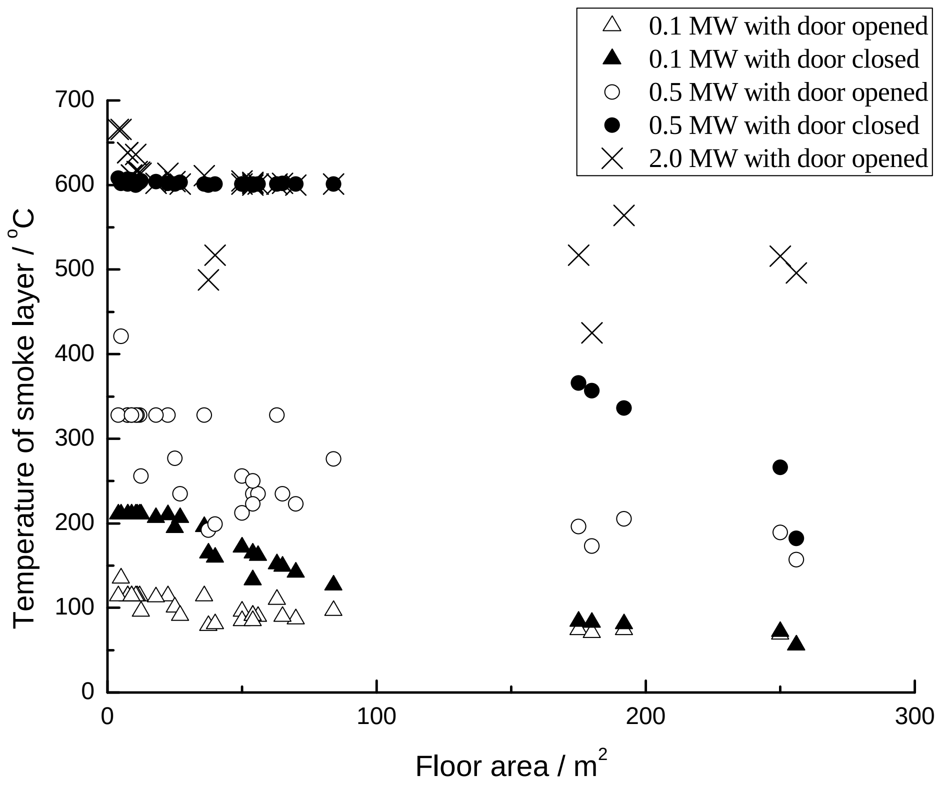


(a) Temperature

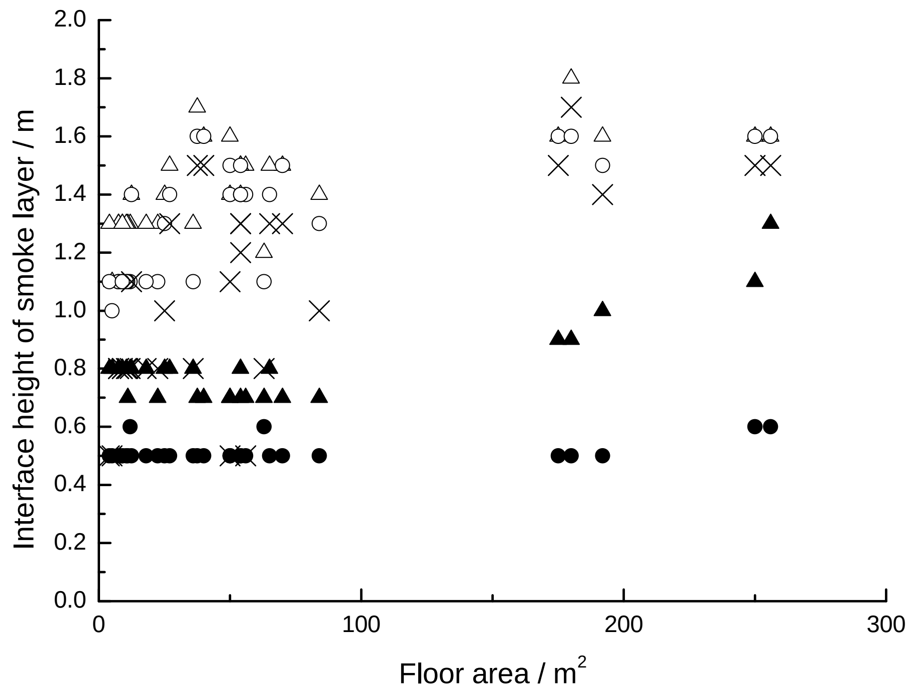


(b) Interface height

FIGURE 4. Temperature and interface height of smoke layer for room U1 in a university building



(a) Temperature



(b) Interface height

FIGURE 5. Temperature and interface height of smoke layer against the floor area

From the above results, there was no flashover happened for a small fire such as 0.1 MW or 0.5 MW with door opened. But the temperature might be up to a dangerous stage in a small room such as 421 ^{o}C at 600 s for C4.

For a 2 MW fire with doors closed, flashover happened in almost all the rooms within a short time, except 379 ^{o}C for room C1 at time 600 s.

Results on temperature for small floor areas were similar for 0.5 MW with door closed between 2 MW with door opened. But the temperature in bigger rooms was much lower for 0.5 MW with door closed than that of 2 MW with door opened. There was similar trend for 0.1 MW with door closed between 0.5 MW with door opened.

However, interface height of smoke layer in the rooms with door closed was found much lower than that in the rooms with door opened.

For the example U1 in a university building as in Fig. 4, results simulated were agreeable between the model by FIRM with symbolic mathematics and CFAST. The difference between those results due to different physical models used in FIRM and CFAST is acceptable.

CONCLUSION

It is obvious that fire models are essential tools for fire hazard assessment. The program is more transparent with symbolic mathematics. Values of all parameters can be identified easily, in comparing with traditional high-level computer programs.

Both temperature and interface height of smoke layer in different rooms of three buildings were simulated successfully using the zone model compiled with symbolic mathematics. This is a good demonstration on the potential application of symbolic mathematics for modelling the building fire environment.

From the results, all the rooms are dangerous under a 2 MW fire and 500 kW fire with doors closed. Only some big rooms can endure a longer time under a 500 MW fire with doors opened. Even under a 100 kW fire, the smoke layer might develop to a lower stage within a short time in a small room.

All the rooms would achieve a higher smoke temperature with higher heat release rate. The interface height of smoke layer might be much lower within a shorter time when the opening is smaller. Results indicate that fire started in a room with higher fire load density might be easier to develop to a danger stage even flashover. Floor area and opening condition are two key points for fire hazard assessment.

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