Computer Simulation of A Severe Basement Fire

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Abstract

In the past twenty years, many severe basement fires occurred and caused huge losses of human lives and damages to property in Taiwan. During a basement fire, smoke at high temperatures and poisonous gases (such as CO) may easily spread through corridors and ventilation systems in the entire building. Therefore, protecting against the basement fires in commercial buildings is of important concern for Taiwan's fire protection authority. This paper utilizes FDS (Fire Dynamic Simulator) to construct a simulation model for investigating the Kardeng basement fire that occurred in Taipei (1993). The fire accident unfortunately caused tremendous property losses and heavy casualties (22 died and 7 were injured). The major important parameters of the flow field - such as speed to the spread of fire, smoke movement, upper layer temperature, and CO concentration are obtained to analyze and understand the fire dynamic characteristics. The computed results reasonably agree with post-accident reports. The simulation results obtained may be utilized to improve the better and safer designs for basement building fire protection capability in the future.

Keywords：Flashover, Field Model, Computer Simulation, Fire Dynamics

1. Introduction

It is common practice that most underground basements of buildings are utilized and developed for commercial establishment in Taiwan[1]. However, the fire protection capabilities of these commercial basements and buildings are often underestimated and poorly designed. Hence, many basement fires have occurred; and as a result, have caused considerable casualties in the past twenty years. During a basement fire, air flow at high temperature along with some poisonous gases (such as CO) can quickly spread through corridors and ventilation systems into the entire building due to the well-known stack effect. To improve the understanding of the hazards associated with building fires in Taiwan, several studies have investigated fire development using simulation software[2-5]. To reestablish fire scenes,[6] Carbon monoxide (CO) is the most important cause of asphyxia and the principal cause of fire death. [7] investigated fire exposed time using the FDS fire model to predict CO and carboxyhemoglobin (COHb) concentrations in three deceased Pittsburgh firefighters in 1995. Incapacitation time is approximately 2.9 and 7.7 minutes for CO concentrations of 2000ppm and 5000ppm when COHb and Respiration Minute Volume (RMV) are 47% and 70L/min, respectively.

This study employed FDS fire model developed by the National Institute of Standards and Technology (NIST)[8-10] to reestablish the Kardeng barbershop fire in Taipei. The accident resulted in heavy losses of human lives as illustrated in Table 1. The fire model uses Large Eddy Simulation (LES) techniques[11] and a mixture fraction combustion model[12] to predict thermal conditions in building fires. Several parameters affecting fire spread are calculated during fire simulation and compared with those at the fire scene. Fire and smoke movement are discussed exhaustively to predict fire dynamic behavior and possible reasons for fire deaths.

2. Fire Incident Description[13-15]

The Kardeng barbershop (Fig 1) occupies the basement, first floor, and second floor of a 12-story building. The fire occurred at 6:00 p.m. and was extinguished at 7:40 p.m. on May 12,

1993. The Kardeng barbershop was located at No. 39-1 Sec.2 Sin-Sheng North Road, Taipei City. An arsonist set himself on fire in the basement floor hall. He tumbled around in pain and subsequently lied down in Room 115.Figures 2-3 show fire spread direction and consequence.

The following are the possible reason for death and injury:

(1) The basement floor had only one stairway up to the first floor, therefore restricting access.
(2) The fire originated in the basement floor hall near the exit and there were also secondary fire sources.
(3) Fire and smoke filled the escape route.
(4) Large numbers of combustible objects and materials were ignited.
(5) Heavy smoke accumulated as the basement floor was enclosed.
(6) Persons on the second floor could not escape from windows as they were covered with advertising boards.
(7) The barbershop did not have a broadcast system to help people in escaping the fire.
(8) The fire-protection equipment available was inadequate for extinguishing the fire.

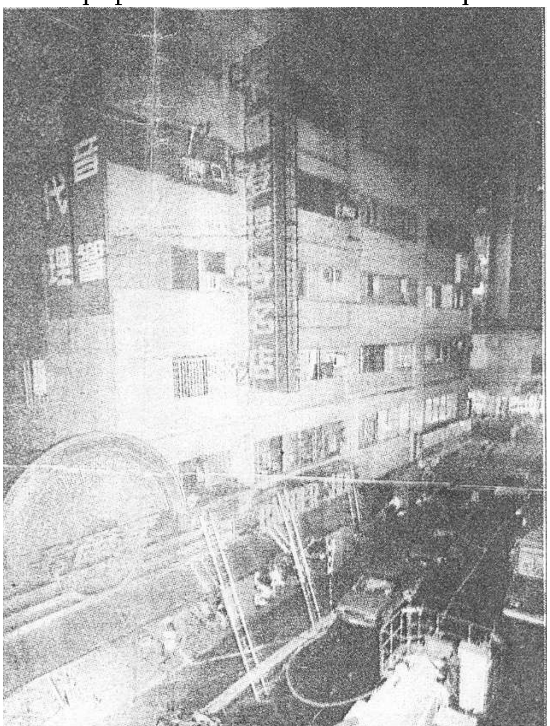


Fig. 1. Top view of the fire building.[13]

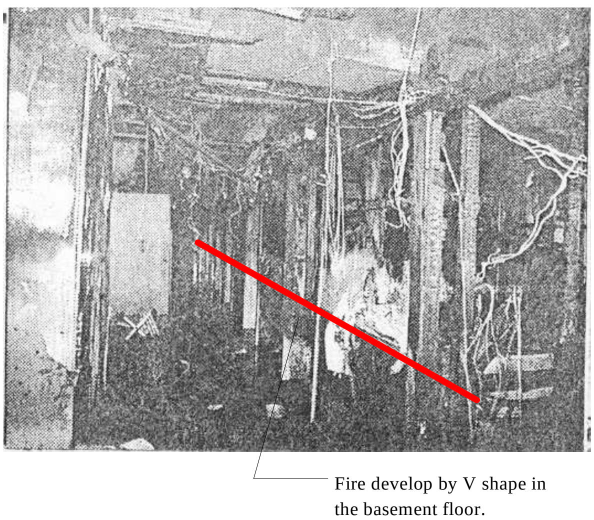


Fig. 2. Fire scenario in the basement

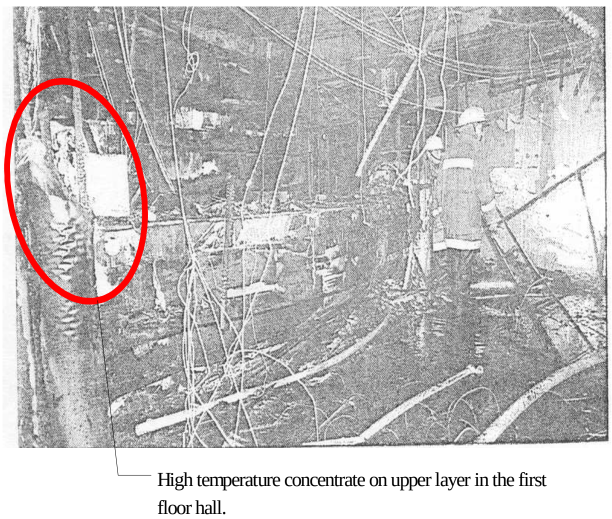
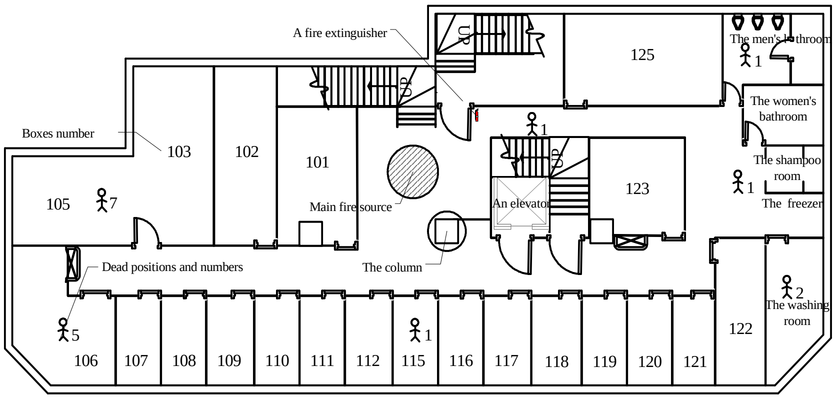
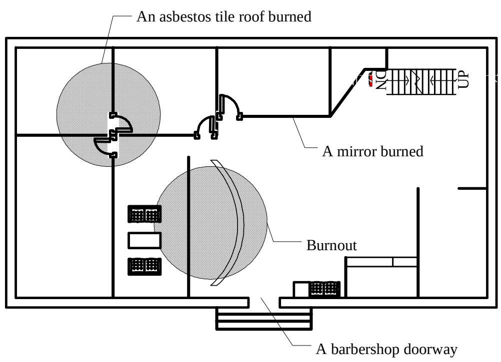


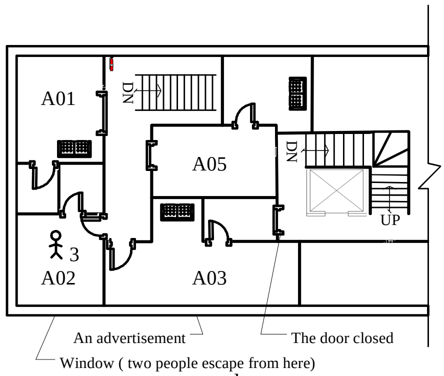
Fig. 3. Fire scenario in the 1st floor hall.[14]

floor corridor.[13]



The B1 floor plan (a)





The 1st floor plan (b) The 2nd floor plan (c)

Fig. 4. Building floor plans [15].

3.The numerical model developed

Figures 4-5 present the FDS field model for reestablishing the full-scale geometric configuration of the Kardeng barbershop fire. The arsonist burned himself with five liters of gasoline. Persons near the fire source were aware of the fire and escaped immediately. Consequently, room doors 101, 111, 112, 115, 116, 117, A03, and all doors on the first floor were opened during the fire simulation, and other doors also had a rift 0.02m height from the floor. Because two people escaped through room window A02, we suppose that the window was opened 90 seconds after the fire started. Table 1 presents the other boundary conditions.

Table 1 Input and boundary conditions for the FDS model.

Boundary Conditions	Parameters Description
Geometry	31.5m×12.74m×9.9m
Grid numbers	135×50×45
Simulation time	300 seconds
Fire source	The fire source was a 2m×2m×0.0014m rectangle gasoline material. (vaporization heat is 837kJ/kg)
Fire point	The place where arsonist layed down was a 2m×2m×0.0014m rectangle gasoline material. (vaporization heat is 837kJ/kg, and ignite time is 20 seconds)
Burning object	The burning objects were 0.7m×1.3m×0.4m rectangle OAK* material. (vaporization heat is 2000kJ/kg)
Room partitions	The room partitions were wood material. (vaporization heat is 1900kJ/kg)
Ceilings	The room partitions were COMBUSTIBLE CEILING TILE materials. (vaporization heat is 2500kJ/kg)
Carpets	The carpets were CARPET* material. (vaporization heat is 2000kJ/kg)
Doors	The doors were STEEL* material.
Beams, columns, and walls	The building was constructed by CONCRETE* material.

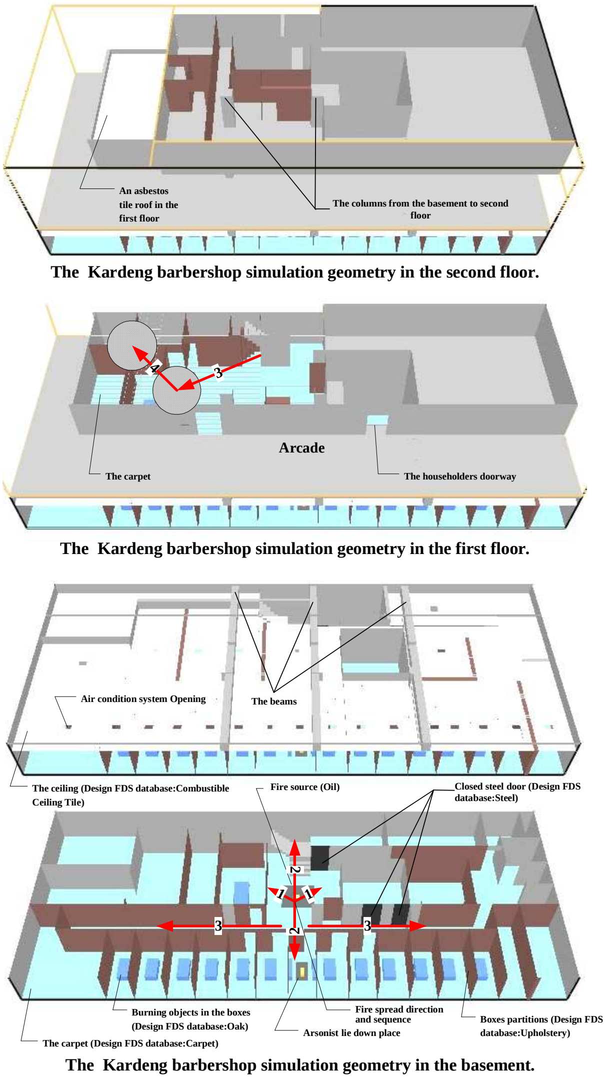


Fig. 5. Building full-scale plans

4.Results and Discussion

4.1 Computational cells and parameters test

To acquire an accurate simulation and to reduce the computing time, seven test grid numbers (1) 180×72×54, (2) 192×80×60, (3) 200×81×64, and (4) 216×90×72 (5) 125×50×40, (6) 135×50×45 and (7) 150×60×45 are tested. Figs 6-7 shows the total HRR for the various grid numbers. Although all curves exist a similar trend, according to the post accident report and analysis, it was concluded that grid(6) best described the physical phenomena and actual fire behavior. Its total HRR reached the maximum (40MW) at 40 seconds. As a result the fire was extinguished on the closed basement floor due to insufficult oxygen. After t>200 seconds, the 1st floor fire and smoke emerged continuously from an opening.

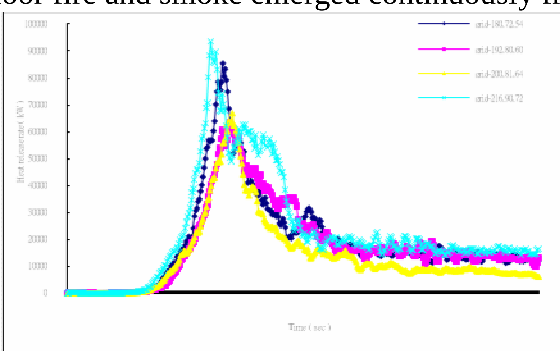


Fig. 6. Total HRR of grids 180, 192, 200, and 216 in X-dir.

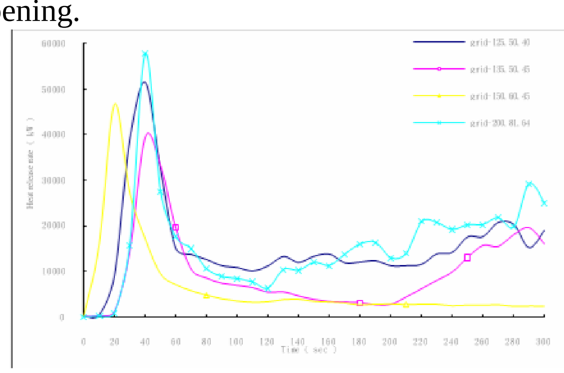


Fig. 7. Total HRR of grids 125, 135, 150, and 200 in X-dir.

4.2 Fire and smoke spread

The temperature in the basement floor hall and corridors rose rapidly after 20 seconds (Fig. 8). The hall temperature was >600°C during the 30-60 seconds. The basement floor fire gradually died down due to limited available oxygen and the stratified temperatures. The corridor CO concentration was >3500ppm after 60 seconds (Fig. 9). Although some people escaped to the other rooms and moved away from the fire source, smoke continued to expand through door rifts and air conditioning pipes. A hole burned through room ceilings on the first floor at 60 seconds, and fire as well as smoke continuously spread out from this hole. The temperature was >420° C after 36 seconds and rose again after 245 seconds (Fig. 10). The first floor CO concentration curves showed oscillations above 2500ppm due to fire continuously mixing with clear air (Fig. 11). The temperature of the basement floor stairway was >400°C during the 30–60 seconds, and the stairway filled with smoke at high temperatures. The temperature at basement floor stairway was higher than that on the first floor stairway and both were >130°C during fire calculation.

The room window A02 on the second floor opened at 90 seconds, allowing outside smoke to flow into the room A02. Although temperature and CO concentration were both lower during the fire simulations, people were still unable to escape through the window as they were impeded by smoke and soot. The V fire shape spread (similar to Fig. 2) in the basement floor and rooms, moved to the first floor hall at about 40 seconds (Fig. 12). The escape route through basement corridors and stairways was filled with high-temperature smoke (Fig.13 and 14). At this point, those who stayed in basement or second floors could not escape. The fire plume and air flow at high temperature concentrated on the first floor rooms and the hall ceiling (Figs.15 and 16). These developments were in reasonable agreement with Fig. 3. The rooms of dead persons were continuously filled with smoke (see Fig. 17).

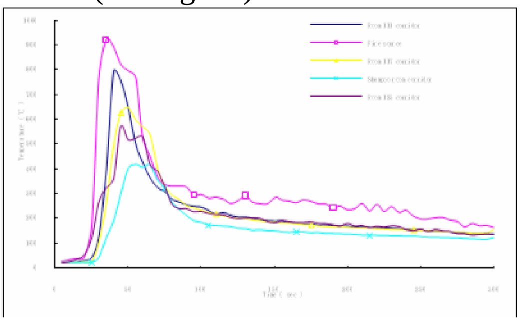


Fig. 8. Upper layer temperature. of the basement corridor

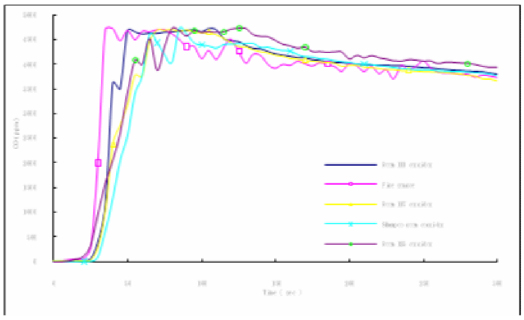


Fig. 9. CO concentration of the basement corridor.

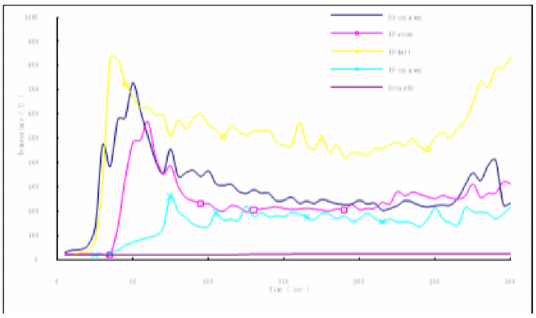


Fig.10. Upper layer temperature of the first floor, second floor, and stairways.

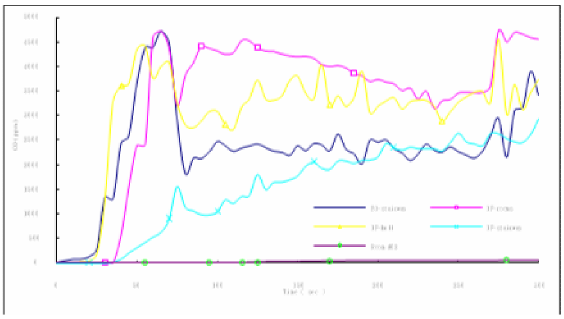


Fig. 11. CO concentration for the first floor, second floor, and stairways.

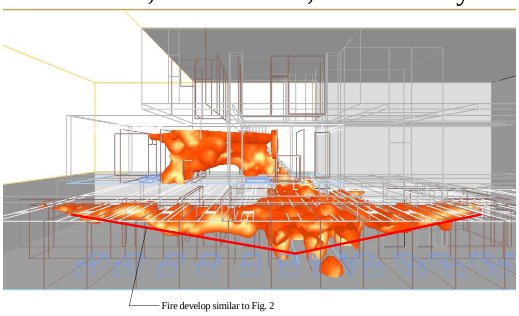


Fig. 12. Fire spread at 40s.

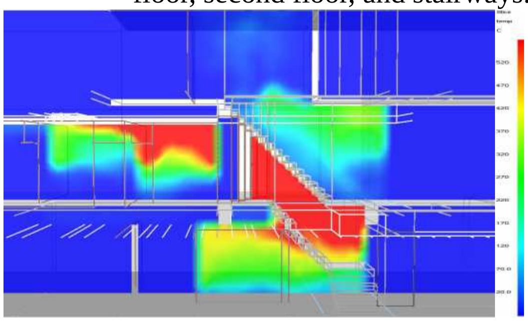


Fig. 13. Temperature field at 40s.

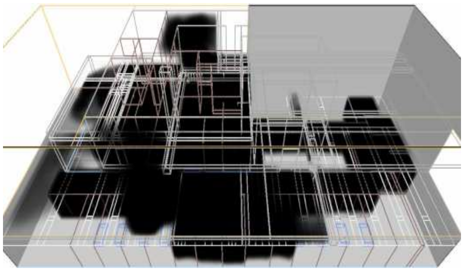


Fig. 14. Smoke movement at 40s.

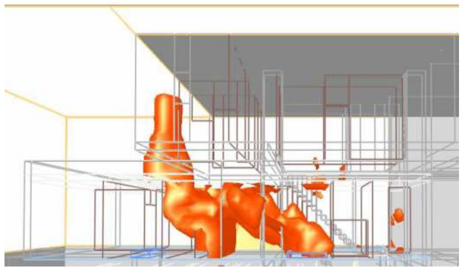


Fig. 15. Fire spread at 300s.

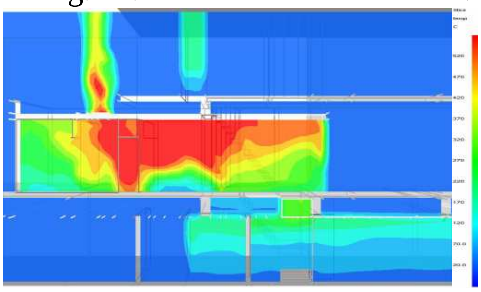


Fig. 16. Temperature fields at 300 s.

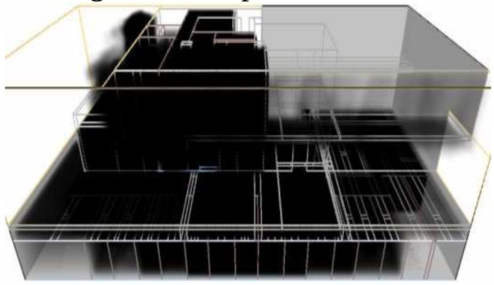


Fig. 17. Smoke movement at 300 s.

Because the fire source was highly volatile gasoline, the escape route filled rapidly with high-temperature smoke; consequently, only 35 people near the fire source followed the stairway and escaped in time, while the others couldn't escape and died eventually. The central air conditioning system outlets were assumed open in the rooms ceiling. If forced ventilation was operated during the fire, smoke spreading to the rooms containing the fire would result in quicker death. A man hid in the men's basement bathroom (Fig. 18), blocked the door rift with clothing, and then covered his mouth and nose with wet clothing. He was rescued by firefighters 40 minutes later. This rescue was rare during the building fire. Although the bathroom door rift was opened, the smoke had difficulty spreading into the bathroom according to numerical results. If smoke prevention was reinforced, more people could be saved from the fire.

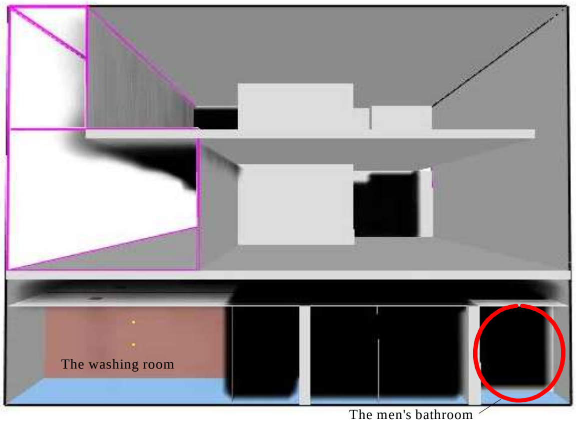


Fig.18. Inability of smoke spreading into the men's bathroom where 1 man survived.

5. Conclusions

The FDS fire model, as it applies to fire behavior and toxicology, is still a relatively uesful and novel tool. The fire case demonstrates the potential for fire experts and engineers to work together when attempting to identify the details of basement fires in Taiwan. This study demonstrates the use of a numerical fire model reconstruction using FDS simulation with quantitative data. In this fire calculation the escape routes were filled with smoke at 40 seconds in the numerical model. Therefore, the escape time was <1 minute. The actual escape scenario was more serious than that in the numerical simulation as people opened the room doors to escape from the fire. Moreover, this condition of fire would be worse if the central air conditioning system were in full operation. The simulation results showed reasonable agreement with post accident reports. Future fire-modeling techniques and simulation programs are expected to have increased accuracy when predicting and assessing fire dynamics.

6. References

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7. Acknowledgement

The authors would like to give thanks to the National Science Council of the Republic of China, Taiwan, for financially supporting this research under contract No.NSC98-2221-E-155-068.