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Numerical simulation of fire and smoke transport for an old-style apartment fire

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Abstract: Most old apartments in Taiwan lack fire prevention equipment, making fire awareness and escape difficult, as well as timely fire fighting, which leads to increased death tolls from fire incidents. This research utilizes Fire Dynamics Simulator (FDS) software to analyze and simulate the fire accident that occurred in a single old-style five-story apartment on Siu-Lang Road, Chung-Ho City. In this event, many occupant vehicles were parked at the front door of the apartment building or in nearby parking lanes. The fire engine can only drive in after vehicles were cleared from the fire area, a situation that delayed emergency fire rescue and resulted in the casualty (1 dead and 7 injured). The computer simulation calculates the distribution of temperature field and smoke field at the fire scene, and is in reasonable agreement with the post report provided by the fire department and media. This study also reestablishes the original fire scenario for fire identification, analyzing the room temperature changes and Carbon Monoxide (CO) concentration field of the primitive fire scene. The simulation results provide parameters that influence personal escape, and suggestions to avoid future unfortunate events.

Keywords: Fire spread, Smoke Transport, Computer simulation, Apartment Fire

1 Introduction

In Taiwan, new-style buildings are quite different from old-style buildings in outward appearance, construction materials, interior decoration, and strict fire prevention laws and regulations. On the other hand, residents of older buildings often make extra/unsafe compartment and roof renovations, greatly increasing fire potential risk factors. Many fire accidents occurred and caused huge casualties in the past twenty years. This study investigates how to eliminate fire risk factors, and reduce the possibility of disaster. Therefore, this work finds that reinforcing fire protection equipment in older buildings is imperative to fire prevention.

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Due to well-developed computer technology and fire-related simulation software, using a computational method to assess building safety has become the most economical and simplest method for fire researches. Fire simulation software programs have been used in building fire analysis[1−4]. By calculating the data of precise smoke flow field and temperature changes, the program can not only predict a safe time frame to escape, but also recommend safer fire equipment design.

2 Description of the Fire Incident

The simulated case happened in an old five-story apartment of Chung-Ho City, Taipei County. The fire occurred in the early morning, shortly after 5 am, on March 3, 2007. The first floor was used for a laundry shop and resident consisting of families lived on the second to fifth floors. Figure 1 shows the fire stack effect, with smoke engulfing the five-story apartment. More than fifty residents were able to escape in a panic and traumatized situation, many with smoke blackened clothing. Sixteen inhabitants were besieged in the fire scene. Figure 2 shows firefighters at the waterline, with everyone working courageously during the rescue work[5].

Figure 1: The fire stack effect

Figure 2: Firefighters performed the rescue work

The fire resulted in the death of a twenty-five year old woman, the daughter of the laundry shop owner, as well as smoke inhalation of seven apartment inhabitants, transported to the Yung-Ho Branch of Cardinal Sin-Tan Hospital and Taipei Tzu-Chi General Hospital. Among them, the store owner received endotracheal intubation as first aid due to laryngeal edema, yet the other injured were not serious. The fire department inspection revealed a wooden table in the first floor laundry shop as the initial fire point. Due to a light stand and candle on the table for worship and burning incense, either a wire short-circuiting or a candle fire were suspected as the cause of the fire. The case is still needed for further investigation.

3 Computer model

The Fire Dynamics Simulator (FDS) software is derived from Computational Fluid Dynamics (CFD), developed by the National Bureau of Standards of the United States. The version 1 of the FDS software was launched in February 2000. The team continues to enhance and improve software features, publishing version 4.0.7 in March 2006[6], and recently promoting version 5.0 in 2007.

The FDS provides a lot of fire research information, such as flame expansion, smoke movement, fuel or wall surface heat transfer, sprinkler influence, as well as a smoke control system, and a sprinkler / sensor system of fire safety design. Researchers mainly use the FDS for calculating the smoke flow field and heat transfer in building fires by the Navier-Stokes Equations.

(1) Mass conservation equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho^{\mathbf{u}} = \dot{m}''' \tag{1}$$

(2) Conservation of momentum equation

$$\frac{\partial}{\partial t}\rho\mathbf{u} + \nabla \cdot \rho\mathbf{u}\mathbf{u} + \nabla p = \rho g + f_b + \nabla \cdot \tau_{ij} \tag{2}$$

(3) Energy conservation equation

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot \rho h\mathbf{u} = \frac{Dp}{Dt} + \dot{q}''' - \dot{q}_b''' - \nabla \dot{q}'' + \varepsilon \tag{3}$$

(4) Ideal gas equation

$$p = \frac{\rho R T}{\bar{W}} \tag{4}$$

Table 1: Nomenclature

ρ	Density	h	Enthalpy; heat transfer coefficient
g	gravity vector, normally (0,0,−g)	T	Temperature
$\mathbf{u}$ =(u,v,w)	Velocity vector	$\dot{q}'''$	Heat release rate per unit volume
f_b	External force vector (excluding gravity)	$\bar{W}$	Molecular weight of the gas mixture
$\dot{m}'''$	Mass flow rate of per unit volume	$\dot{q}''$	Heat flux vector
τ_{ij}	Viscous stress tensor	p	Pressure
ε	Dissipation rate	R	Universal gas constant

Figure 3 shows an internal geometric space model according to the fire scene layout investigation and fire scene measurement, provided by the Taipei County Fire

Department. The first floor is divided into a total of fourteen rooms, with fire igniting from the wooden table in room 2. This research analyzes and discusses the upper layer temperature (ULT) and CO concentration at the fire scene. The second floor (Room 15, 16), third floor (Room 17, 18), fourth floor (Room 19, 20), and fifth floor (Room 21, 22), each floor divided into two rooms respectively. For the purposes of simulation analysis and discussion, this work divides the five floors into twenty-two rooms.

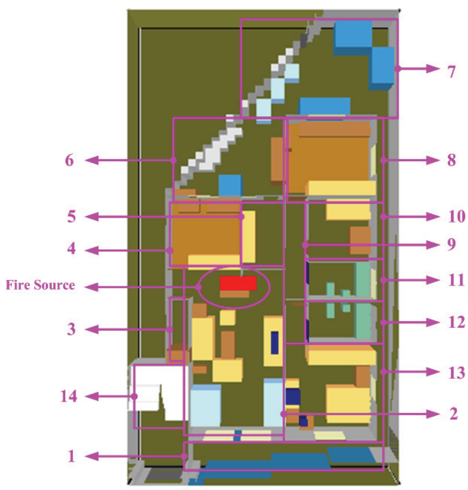

Figure 3: 1F The fire simulated room numbers

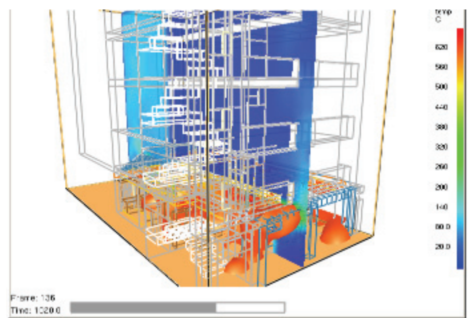

Figure 4: Fire intensity in room 2 (1020s)

Figure 5: Actual flame in room 2

4 Verification and Results

The fire observation record given by the NanShi branch fire department in Taipei County,[7] reports that when the fire brigade arrived at the five-story building (approximately 17 minutes after the fire occurred), fire engulfed the living room of the first floor. A large quantity of smoke and flames dispersed without explosion, and ET-TODAY also reported the fire scene on national television. In figure 4, the transient fire intensity in Room 2 was at 1020 seconds. The fire intensity resulted in temperature reaching 500 ° as the fire continued burning. Figure 5 shows the first floor fall into flames as the fire brigade arrived, very close to the simulation results obtained.[8] Figure 6 shows that the upper temperature curve of Room 2 sustained high temperatures above 400 ° during simulation untill the end of 1500 seconds. i.e. (maintaining illustration in this condition for more than 860 seconds.) The fire intensity of Room 2 is at 660 seconds (Figure 7), burning strongly to a high-temperature of 547°. Figure 8 shows that the wood table and furniture in Room 2 completely destroyed, consistent with the simulation condition.[9] The concrete would crack with a temperature higher than 500 °. Figure 6 shows the Room 2 became upper temperature distribution, the highest temperature appearing at 682 ° in 683 seconds, and maintaining the high temperature around 450 °. The fire intensity not only burned the ceiling decoration in Room 2, but also cracked the concrete walls. Due to long exposure under high temperatures, the concrete wall easily flaked off with jetting water during the fire rescue. A large area of flaked wall in Figure 8 and 9 might confirm this phenomenon.

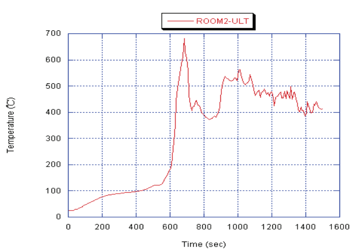

Figure 6: Upper temperature in Room 2 (1020s)

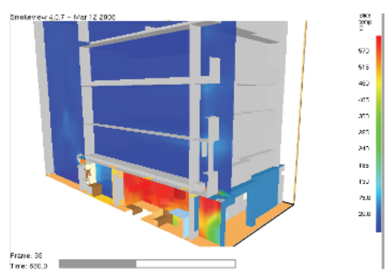

Figure 7: Fire intensity in Room 2 (660s)

The main source at the fire was the wooden table in the living room (Room 2) of the first floor. Initially, a small fire developed. A gentle curve in temperature at the initial ignition stage was due to the large air space of Room 2, along a corridor and doors to adjacent rooms. The indoor temperature did not easily rise up, only achieving to 97 ° at 400 seconds. The wooden table ignited after 481 seconds, and

Figure 8: Interior furniture after accident

Figure 9: Room2 after accident burning of the fire

indoor temperatures started rising sharply. Inhabitants escaped from Room 1 and opened the rolling iron-gate, to cause massive air to fill into the first floor. Room 2 was immediately engulfed in a sea of fire, and the temperature quickly increased to 682 ° due to the flashover phenomenon. Subsequent fires produced enormous heat to quickly spread to adjacent Rooms (13), (5), and (10). Rooms (6) and (8), which are further away from Room 2 were less affected by the fire flow, and the maximum temperature of room (6) reached to 242 ° at 833 seconds, therefore fire damage to the building was not serious, as displayed in Figure 10. Regarding Room (16) - (22) from the 2nd to the 5th floor, the staircase entrance did not present a fire hazard, as it was separated from the fire scene by walls. Therefore Rooms 16 - 22 were not directly impacted by the fire. The average temperatures only rose a little bit to around 31 - 37 °, causing residents in this environment to feel sick, but without serious or fatal results. Simulation results showed that a large open room near the fire source was sufficiently combustible, and seriously damaged. Rooms (2), (13), (5), and (10) were in serious burning situation. Rooms (6) and (8) are the reverse because the stairway served as an independent path from the 2nd to the 5th floor; which is separated by a wall from the fire scene, the highest temperature only reached 75 °. As a result, no fatalities occurred for persons in this environment, and all residents successfully escaped from the fire scene without any burn or injury.

The smoke accumulated in Room 2 after the wooden table ignited, reached the room ceiling and quickly spread to other rooms in a short period of time. From the beginning of the simulation until the end in 1500 seconds (Figure 11), the average CO concentration in Room 2 was about 2000 ppm, a great threat to human life, and resulted in a fatality in Room 4 due to lack of escape time. A wall from the fire scene separating Rooms 16 - 22 isolated the other first floor rooms and kept them from direct fire intensity. When the stairwell was opened, the smoke immediately occupied the emergency exit and caused the so-called stack effect. The CO concentration increased similarly to the parabola trend. As the emergency exit opened up untill 1500 seconds at the end of the simulation, the average CO concentration was between 500∼1000 ppm. Despite individuals escaping at that time, some residents suffered serious CO smoke inhalation, including an eighty-five year-old woman among them. The other wounded were not seriously injured. Hence, the CO concentration has great impact to personal escape in a fire, and the degree of the impact probably related to person's age as well as physique of body.

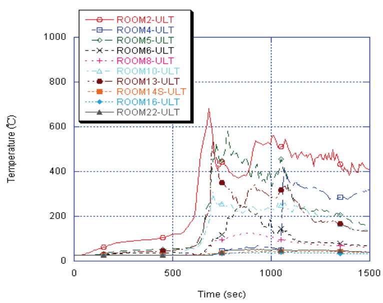

Figure 10: Upper temperature distribution

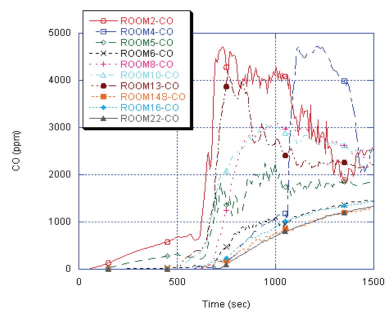

Figure 11: CO concentration distribution

5 Conclusion

The following conclusions are obtained from this study:

- The wooden table was the fire source, and no fire extinguishers were available for putting out the initial fire. Some inhabitants escaped by opening the rolling iron gate, causing a large amount of air flow into the fire room that induced the flashover phenomenon and blocked the internal exit.
- The fire occurred in the early morning (about 5am); when residents were sound asleep, and their reaction abilities low. Simulation results showed a fatality because of excessive carbon monoxide and thick smoke inhalation.
- A fire alley was located next to the victim's bedroom and another behind the kitchen at the back-end to the outdoors, but a fixed window grate unfortunately prevented escape.
- Inhabitants escaped from the upper floor downstairs to the open staircase door on the first floor which induced the stack effect, and caused smoke inhalation for certain persons.

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References

Lin, C. S.; Wang, S. C.; Hung, C. B. ; Hsu, J. H.(2006): Ventilation Effect on Fire Smoke Transport in a Townhouse Building, *Heat Transfer-Asian Research*, Vol. 35(6), pp. 387-401.

Lin, C. S.; Wang, S. C.; Chou, K. D. (2008): Fire Damage Investigation Using FDS in a Basement Building, *The 3rd International Symposium on Energetic Materials and their Applications*.

Wang, S. C.; Lin, C. S.; Yu, C. C. (2008): Dynamic Simulation of Backdraft Phenomena in a Townhouse Building Fire, *Heat Transfer-Asian Research*, Vol. 37(3), pp. 153-164.

Mammoser III, J. H.; Battaglia, F. (2004): A computational study on the use of balconies to reduce flame spread in high-rise apartment fires, *Fire Safety Journal*, pp.277-296.

McGrattan, K. B. and Forney, G. P. (2006): Fire Dynamics Simulator (Version 4) User's Guide, *NIST Special Publication 1019, National Institute of Standards and Technology*, Gaithersburg, Maryland.

Taiwan news media ET-Today, TVBS, CAN, the United Evening News, 2007.

Fire dispatched observation records, The fire department Nan Shi branch in Taipei County, 2007.

Babrauskas, V. (2001): Ignition of Wood: A Review of the State of the Art, pp. 71-88 in *Interflam 2001*, Interscience Communications Ltd., London.

Hsu, J. H,; Lin, C. S. (2006): Residual Bearing Capabilities of Fire-Exposed Reinforced Concrete Beams, *International Journal of Applied Science and Engineering*, Vol.4(2), pp.151-163.