ANALYSIS OF FIRE CHARACTERISTICS IN APARTMENT BUILDING THROUGH FULL SCALE EXPERIMENT AND ZONE MODEL SIMULATION

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ABSTRACT

Fire characteristics of a typical apartment building in Korea was studied through full scale experiment and zone model simulation. The fire was ignited at the living room and allowed to spread to other parts of a single unit in a five storied apartment building. Various data including temperatures, species concentrations, and images were collected in the experiment. A zone model(CFAST) was used to analyze the same apartment building that represents the average households in Korea. The results were compared with a full scale experiments. While CFAST allows one compartment involved with fire, the experiment allowed the fire to spread to other compartments. Therefore, the comparison between experimental data and Zone-Model data is valid until the living-room fire spread to other parts of the apartment. Flashover occurred at approximately 380 seconds in a fire experiment, and at approximately 420 seconds in Zone-Model. Based on all of data between experimental data and Zone-Model data, it is concluded that the safe escape time is about 250 seconds.

INTRODUCTION.

A fire is affected by complicated mechanisms such as mass transfer, heat transfer, and chemical reaction. Therefore it is very tedious and costly to perform experiments to analyze heat and mass transfer, and fluid flow of a building fire for various conditions. Therefore, in fire dynamics numerical analysis is introduced[1]. There are two types of fire models: zone model and field model[2]. There have been many zone models developed for simulating office fire and compartment fires, etc. Most of them have been validated as reported in the literature[3,4,5]. Also, as reported by Duong[4], zone models can be applied to simulate fire in a large aircraft, provided the plume equation is selected properly. Law[6] established the effective source of the plumes and the range of the validity of the correlation developed. Thomas[7] presented conventional formulae for flows of hot gases from opening in a compartment fire in a way which may well simplify the correlation data. Very detailed models like the HAVARD code[8] or FIRST code[9] predict the burning behavior of multiple items in a room, along with the time-dependent conditions therein. Full-scale experimental studies on a residential building reported by P.C.R Collier illustrated that zone model can be used to simulate a fire in a typical New Zealand dwelling[10]. The zone model usually divides each room into two spaces or zones: an upper zone that contains the hot gases produced by the fire and a lower zone that contains a space beneath upper zone that is the source of the air for combustion. Zone sizes change during the course of the fire. The upper zone can expand to occupy virtually all the space in the room. It is computationally fast but yield no information on the internal structure.

Field model avoids the simplification inherent in zone models. The interested space is descritized into numerous computational cells, and the temperatures, velocities, and concentrations are calculated from governing equations for each cells. W. K. Chow[11] illustrates the simulation of the smoke filling process using field model for the three types of atrium in Hong Kong. Some of researchers[12,13,14] modeled the fire growth and smoke spread using field models or commercial software packages such as UNDSAFE and PHOENIC etc. To date, field model has not yet progressed to the point where they can handle the wide range of physical/chemical phenomena and complex shapes of real buildings.

The aim of this research is to compare the results of a full-scale fire experiment of a typical Korean apartment with those predicted by a fire and smoke-transport computer model using construction methods, materials, and furnishings common to Korean housing stock. It was also intended to develop valuable understanding of fire development and behavior in those types of buildings.

THE MODEL

In order to compare the results of experiment with model, a CFAST[15,16] that is a commercial package to allow one to predict the evolution of a fire in a room and the subsequent transport of the smoke and toxic gases which evolve from the fire is used. It is a member of a class of models referred to as zone or finite element models. This means that each room is divided into a small number of volumes (called layers), each of which is assumed to be internally uniform. That is, the temperature, smoke and gas concentrations within each layer are assumed to be exactly the exactly the same at every point in the layer. In CFAST, each room is divided into two layers. Since these layers represent the upper and lower parts of the room, conditions within a room can only vary from floor to ceiling, and not horizontally. This assumption is based on experimental observations that in a fire, room conditions do stratify into two distinct layers. While we can measure variations in conditions within a layer, these are generally small compared to differences between the layers. It is based on solving a set of equations that predict state variables (pressure, temperature and so on) based on the enthalpy and mass flux over small increments of time. These equations are derived from the conservation equations for mass, momentum, and energy, and the ideal gas equation of state. It calculates the time evolving distribution of smoke and fire gases and temperature throughout a building during a user-specified fire. But, It has some restrictions;

a. The fire specification inputs (heat release rate, area of the base of the tire, height of the base of the fire, etc) are limited to 20 steps.
b. Items to be burned are confined to maximum five items.
c. The number of component of fire origin is confined to only one.

Due to these restrictions, comparisons between experimental results and Zone-Model predictions are conducted only to a fire in the living room.

THE EXPERIMENT

The building was a modern, three-bedroom, five-story apartment building with a floor area of 80 m^2. The layout of the house comprised a hallway connecting the three bedrooms, toilet, two balconies and combination living room / kitchen. (Figure 1.) In the experiment, household items' total weight was 890kgs.

The opening conditions were:
(a). The amount of starting openings.
@ window of front balcony : 2 of 11 are open
@ window of living room : a quarter is open.
@ room 1's window : a quarter is open
@ room 1's door : 1 of 3 is open
@ room 2's door : a quarter is open
@ room 2's window : completely sealed
@ sliding door of kitchen : The door to the back-balcony is all open.
@ back-balcony : a quarter is open
(b). The change of openings.
After the flashover (at 380 seconds), the opening conditions were changed.
@ window of the front-balcony : 2 of 11 are open 6 of 11 are open
(c) Measurement.

The location of measurement is shown in Figure 2. Temperatures were measured in each room at four different heights. Concentrations of oxygen and carbon mono-oxide were measured at 2.2 m high in the living room. The smoke produced in a fire includes toxic gases and reduce the optical density restricting the vision of people needed to escape from the hazard. So, it is essential for the resident's safe escape to analyze the smoke flow. To measure the smoke flow from living room to room 3, smoke instrument was installed in the room 3 at 2.2m above the floor.

(d) Ignition.

The fire was ignited using wood crib at the center of the living room.

ZONE-MODEL APPLICATION

Fire load determines the fire severity. A fire load is expressed as the combustible weight of the room divided by the floor area of the room[17]. In the fire experiment, the fire load of the living room was about 64kg/m^2. Zone-Model limits the number of items burnt to maximum five items. Items were separated each other in Zone-Model, the area occupied by combustibles in Zone-Model was one-third of a fire experiment's. 67kg/m^2 fire loads were used to predict a living-room fire in Zone-Model. The data related to between a fire load and fire duration indicated 64kg/m^2-fire load kept on burning until 100 minutes[17]. Regarding unburned combustibles after flashover, the fire load that was used in Zone-Model seemed reasonable.

The apartment was divided into total 10 compartments. (Figure 1.) (No.10 compartment is considered as the outside.)

As CFAST has no fire growth model, two factors-heat release rate (Kw/m^2) and ignition distance (m)-are used to predict a fire scenario[16,18]. The input heat release data for the fire source was developed from the database in CFAST and involved sofa, books, ward closet, and pine. The time to ignition of the second item is the time at which the mass loss rate of the burning object first reaches the value necessary to produce the required flux at the distance between the objects. In order to predict the time to ignition of the second item, MLTFUEL which is included in HAZARD I is used[15,16].

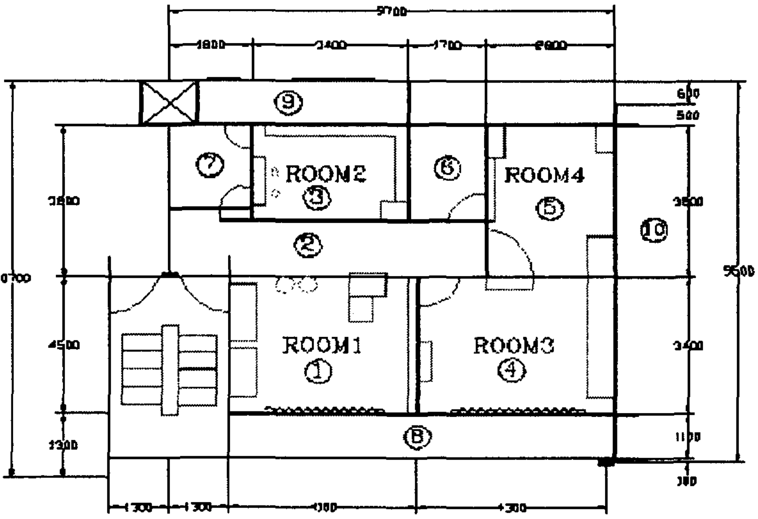

Figure1. Floor plan and zone model numbering of the apartment.

Table 1. Relationship among mass loss rate, ignition distance, and ignition time of second item in Zone -Model.

The first item	The second item	Mass loss rate of the first item	Distance between the first item and second item	The ignition time of second item
Pine	Sofa + Books	0.0370 kg/sec	0.8m	150 seconds
Pine	Wardrobe Closet + Books	0.0470 kg/sec	0.5m	210 seconds
Sofa + books	Books(1)	0.6361 kg/sec	2.0m	420 seconds
Wardrobe Closet + Books	Books(2)	0.5400 kg/sec	2.0m	480 seconds

According to the MLTFUEL's results, the mass loss rates change 0.037kgs, 0.047kgs, 0.6361kgs, and 0.54kgs at 150, 210, 420, and 480seconds. Table 1 shows relationship among mass loss rate, ignition distance, and ignition time of each item. The time for the flame to spread to the book(1) and book(2) are predicted at 420 seconds and 480 seconds respectively. A fire scenario is assumed as the pine first, sofa and books, closet and books, books(1) and finally books(2). The sofa and books started to burn 150 seconds after the pine were ignited. The time to ignition of the second items (sofa, wardrobe closet, and books) is determined by radiation from the first item.

RESULTS AND DISCUSSIONS

Fig. 3 shows a comparison between the experimental result and the prediction of Zone-Model about the CO concentration in the upper layer of living room where the fire is occurred. Until 380

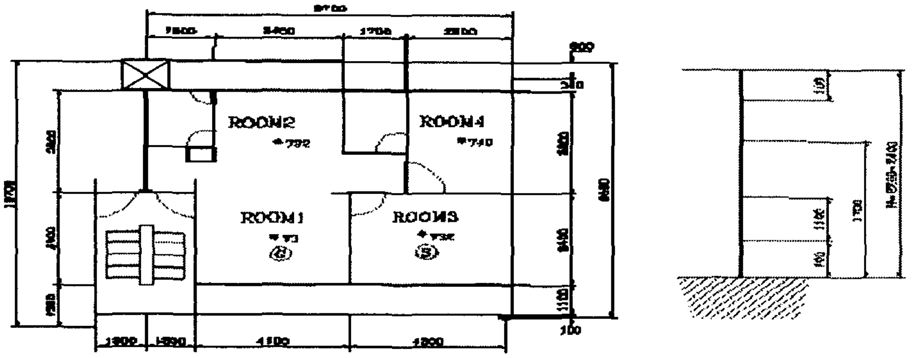

Figure 2. The location of measurement probes.
(S: Smoke density, G: Gas concentration, T: Thermocouples)

seconds, the CO concentration was gradually increased in an experiment. After the flashover that broke out about 380 seconds, the CO concentration rose to 4%.

The CO concentration rose to 1.4% at 210 seconds in Zone-Model. The effect of the CO concentration rising to 1.4% is significant because 1 minute exposure at this level would be lethal.

Fig. 4 shows a comparison between the experimental result and the prediction of Zone-Model result on O_2 concentration in the upper layer of the living room. Starting with 21% oxygen content, the O_2 content fell to 0% in a fire experiment at 400 seconds. As windows began shattering and falling out by flashover in the front-balcony and in the living room, the O_2 content was increased at 440 seconds. A similar trend with the O_2 content was observed in the Zone-Model prediction, although the time when O_2 content fell to 0% was predicted about 20 seconds faster than a fire experimental result.

Fig.5 shows the smoke density comparison of the prediction of Zone-Model with a fire experimental result. In the experiment result, there was no variation upto 200 seconds. The smoke density rose to 1.65(m^{-1}) at 350 seconds. In the model result, the smoke density rose to 1.75(1/m) at 300 seconds. The visibility needed for a person not familiar with the building to escape is 20-30 m while that for a person familiar with the building is 3-5 m. According to the results, the escape limit time in this case is 250 seconds at most.

Fig. 6 illustrates the temperature compared between the model prediction and experimental result in the upper layer of the living room. In the experiment, the temperature of upper layer arose to 160°C at 300 seconds, thereafter, flashover occurred at 380 seconds. In the model, flashover took place at 420 seconds. Because there was no instrument to measure the interface in a fire experiment, Fig. 7 shows only the result predicted in the model. Interface descended to a level of about 1m above the floor at 190 seconds, and temperature in the upper level were underpredicted but followed the general trend.

Fig. 8 shows temperature comparison between the model prediction and experimental result in the front-balcony. There was no change of temperature until 340 seconds. Due to the flashover of the living room fire at 380 second, the flame spread to the front-balcony. The temperature rose to maximum of 900°C at 400 seconds. Eighteen minutes later, the flame spread to the upper floor in

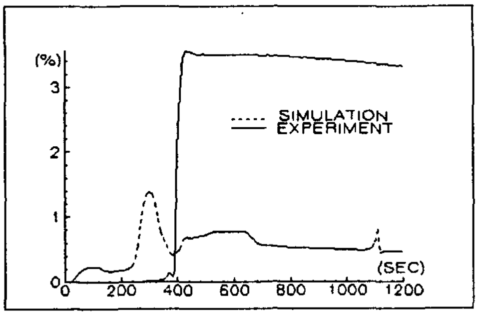

Figure 3. CO concentration in the upper layer of the living room.

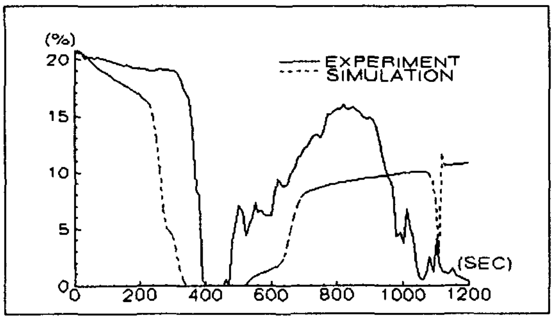

Figure 4. O_2 concentration in the upper layer of the living room.

the experiment. The model predicted that the temperature of upper layer rose to maximum of 950°C at 400 seconds. When a 40kg weighting sofa is burned, heat fluxes produced were maximum 2.89MW[19]. Heat fluxes 2.8MW in the model prediction in the front balcony was enough to spread the flame to the upper floor, if there existed combustibles in the front-balcony.

CONCLUSIONS

The following findings from this study may be used as a guide for analyzing fire hazards and calculating the safe escape time for an apartment building fire in Korea.

(1) Flashover time was predicted at 420 seconds while it occurred at 380 seconds in the experiment..

(2) The upper layer temperature of the living room rose to 970°C in a fire experiment, Zone-Model predicted temperature about 840°C.

(3) The model predicted that interface descends to a level of about 1m above the floor at 190 seconds in the living room

(4) The model predicted that the CO density of the living room rose to 1.4% while CO density rose to 3.5% in the experiment.

(5) The model predicted that O_2 concentration of the living room fell to 0% at 360 seconds while the experimental results show that it fell to 0% at 400 seconds

(6) The model prediction shows that the smoke density of the room three rose to 1.75(m^{-1}) while the experimental result shows the smoke density of the room three rose to 1.65(m^{-1}).

(7) Zone-Model prediction and a fire experimental result show that if there exist combustibles in the front balcony, the flame would spread to the upper floor.

Based on all of results between the model prediction and the experimental results, it is concluded that the safe escape time is at most 250 seconds and the zone-model reasonably well predicted the fire phenomena of a typical Korean apartment fire.

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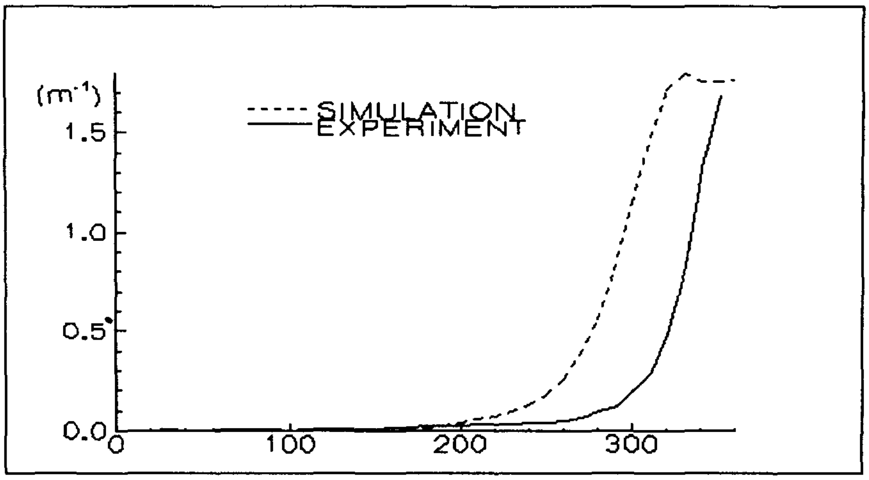

Figure 5. Smoke density comparison in the upper layer of the bed room

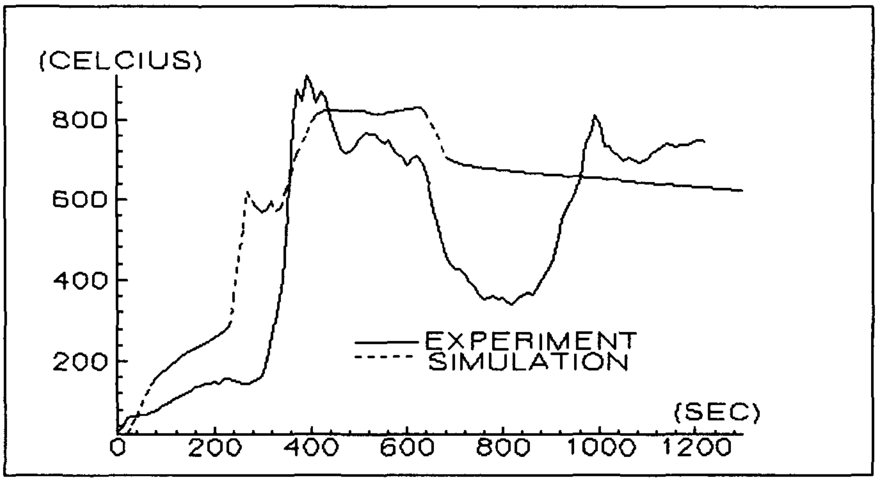

Figure 6. Temperature comparison in the upper layer of the living room

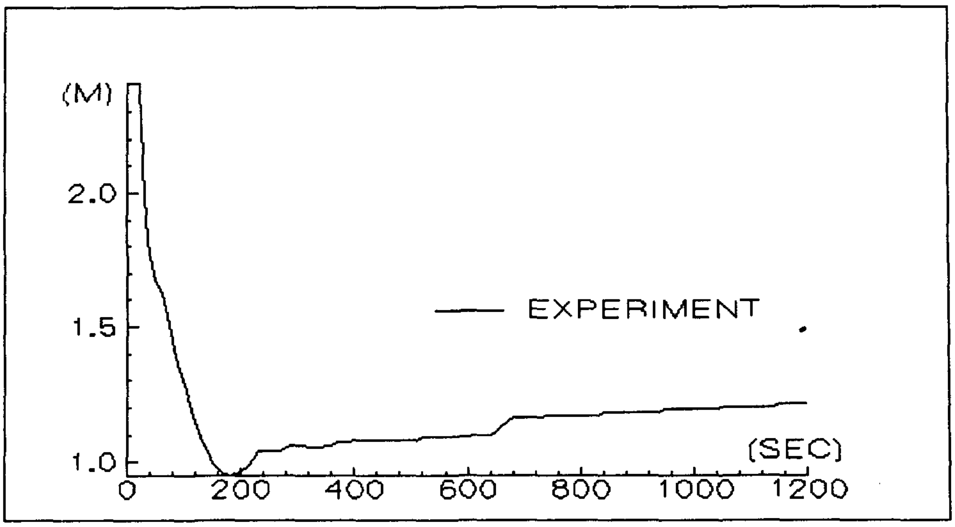

Figure 7. Upper layer interface in the living room.

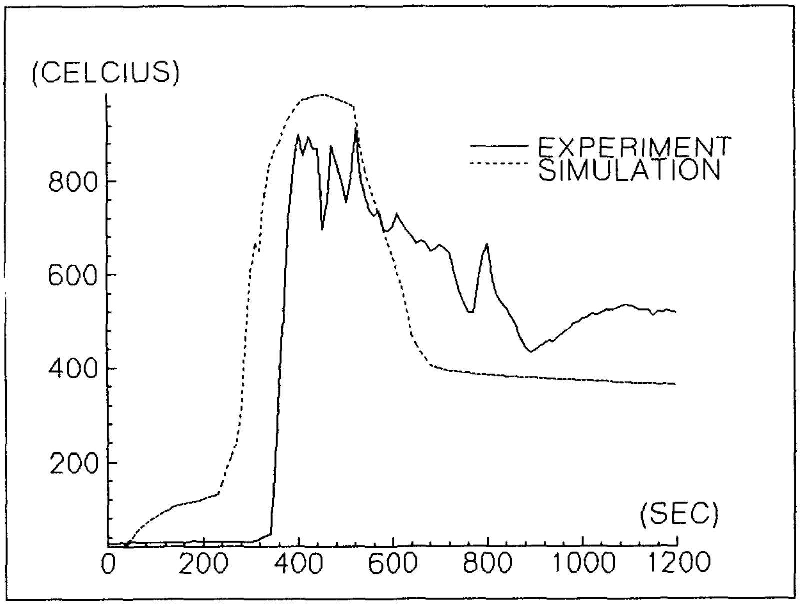

Figure 8. Temperature profile at the front balcony.