FIRE GROWTH AND FIRE DETECTION IN AIR-CONDITIONED ROOMS

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ABSTRACT

The air-conditioning flow highly affects the flow pattern of fire gases. However, the combustion and fire detection in the air-conditioned rooms have not fully been investigated, except for the special cases such as in LSI clean rooms (where no false alarms are existent). In the air-conditioned ordinally rooms such as offices or hotels, there may be caused some worst cases; both the delayed detection and accelerated fire combustion happen simultaneously. And recently the number of buildings which are air-conditioned in all seasons is increasing.

This study describes the analysis of behavior of accelerated combustion of fires and early fire detection in air-conditioned rooms, experimentally and numerically. It has been found that in some cases the combustion speed of polyurethane sheet is twice or 3 times accelerated by the cool downward air-conditional flow. At the same time, the smoke and fire gases are highly diluted by the air-conditioning flow, where the conventional fire detectors are less effective.

The multi-element fire detector including carbon monoxide sensor can detect fires early and reliably, in corporation with the fuzzy expert logic.

1. INTRODUCTION

The buildings, which are air-conditioned daily and in all seasons, are recently increasing due to the improvement of office amenity as well as office automation based on computer network.

As generally known that fire detectors must be placed at least some distance apart from the exit of air-conditioning, the air-conditioning highly affects the flows of fire gases and therefore detection of fires.

Some studies[1)] have already dealt with the fire detection in air-conditioned rooms. However, they were all related to the use of extremely "high-sensitive fire detectors" in LSI clean rooms. It is very easy to detect fires in such clean rooms, since there essentially exist no dust and no false alarm sources. In addition, if the air-conditioner is always operated such as in computer center building, the problem becomes easy. Because the false alarm sources are extremely few in those rooms, although they are not always as clean as in LSI clean rooms. Namely if there is no or less false alarms, the problem is simply solved by increasing the sensitivity of fire detectors.

On the contrary, the ordinary rooms, forming a large majority, including offices and hotel rooms, are not clean, but rather dirty in the view point of fire detectors due to human activities.

The air-conditioners installed in those ordinary rooms are seasonally and daily switched on and off. This leads to the difficulty of detection of fires, because the air-conditioning causes the dilution of fire gases whereas high-sensitive fire detectors may cause frequent false alarms when the air-conditioner is switched off. The early and reliable fire detection requires the high sensitivity plus reduction of false alarms. Therefore a new type of fire detector is strongly needed, since the ability of conventional smoke and heat detectors is limited.

However in real buildings the conventional simple smoke or heat detectors have been installed and they are waiting for fires in spite of their poor ability in the air-conditioned rooms such as offices and hotels.

Due to this reason the author[2,3] has investigated the fire gases reaching a multi-sensor fire detector (mainly for smoldering fires in an air-conditioned room in his previous studies). It has been found that smoldering fire gases diluted by the air-conditioning cause the long delay of fire detection[2].

Another problem in the air-conditioned rooms is that the combustion of fires may be highly accelerated. The flaming fires in air-conditioned rooms must be detected as soon as possible since in some worst cases there may be caused both the delayed fire detection and the accelerated fire combustion simultaneously. No previous fire detection studies in air-conditioned rooms have investigated the accelerated combustion of fires in relation to the dilution of fire gases due to air-conditional flows.

Therefore, it is urgent and important to investigate the early and reliable fire detection in air-conditioned ordinary rooms where quite high possibility of fire hazard is predicted. This study describes the behavior of accelerated flaming fires, the dilution of fire gases and early and reliable fire detection in air-conditioned rooms, experimentally and numerically.

2. EXPERIMENTS

2.1 EXPERIMENTAL SETUP

Experiments were conducted in an air-conditioned room, as shown in **Figure 1**, with dimensions of 4.45 x 4.45 x 2.45 m (H). The cool (or warm) air-conditioner of recirculation type was installed in one corner of the room (see **Figure 1**). The combustion of the fuel placed at each location ① to ⑨ on the floor was investigated. And the dilution of fire gases near the ceiling was measured in the cool air flow.

Used combustion fuels were the soft type polyurethane sheet and wood stick, since they are typical in the ordinary rooms and also employed in the International Standard Fire Test (ISO-TF) as flaming fire materials. The dimensions of each material and the total weight used in the experiments were as follows:

(1) Soft type polyurethane sheet (the same as in ISO TF 4)

CASE I 50 x 50 x 2 cm, total weight = 80 grams.

100 x 100 x 2 cm, total weight = 320 grams.

(2) Wood stick

CASE II 25 x 1 x 2 cm (the same as in ISO TF 1),

total weight = 870 grams for 4 x 6 layers.

CASE III 5 x 0.2 x 0.2 cm, total weight = 200 grams.

The initial flow pattern of cool air in the room is shown in **Figure 1-B**, where the blowing speed at the exit was 3.0 to 4.0 m/s and the temperature decrease $\triangle T_0$ was -6K. The speeds of cool air near the floor were 0.1 to 0.5 m/s.

The speeds of warm air-flow ($\triangle T_0$=7K) near the floor were almost uniform (0.1 to 0.2 m/s) independent to the locations ① to ⑨. The effect of warm air-conditioning upon the combustion was far less than that by cool air-conditining. Therefore hereafter described is onlv the cool air-conditining effect upon combustion.

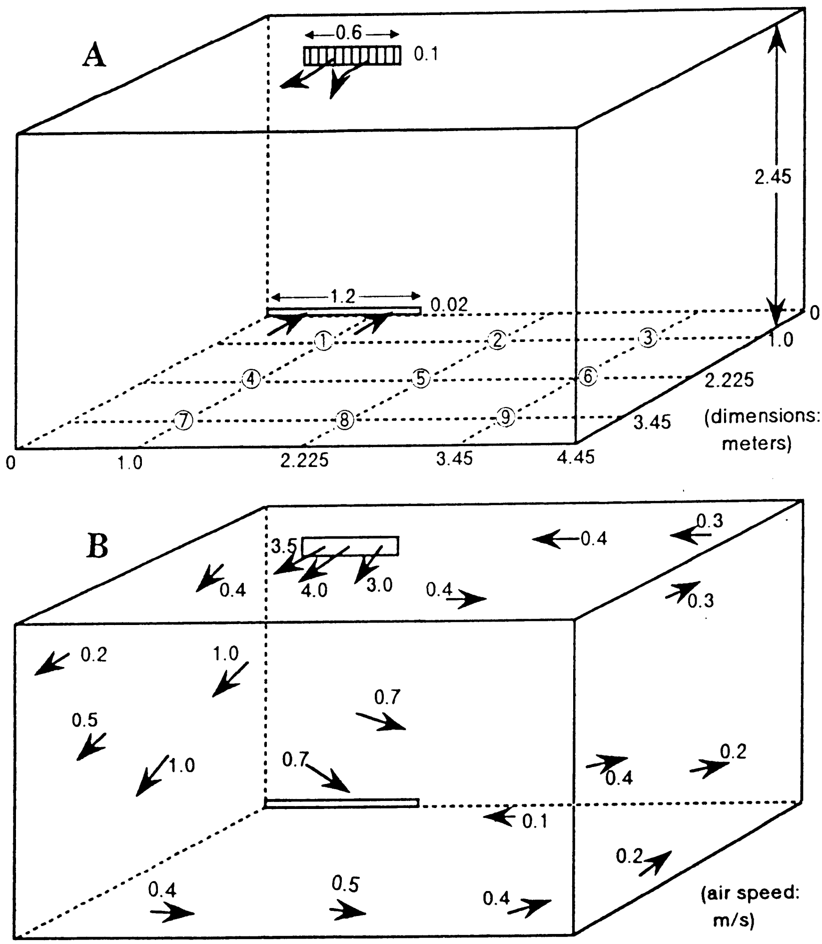

FIGURE 1 Experimental setup for fire detection and initial flow pattern in the cool air-conditioned room.

2.2 EXPERIMENTAL RESULTS

2.2.1 Combustion of polyurethane

The flame on the surface of polyurethane sheet spreads rapidly, producing black smoke. Since the combustion at the locations ⑦, ⑧ and ⑨ shown in **Figure 1-A** was greatly accelerated by the cool air-conditioning flow. Therefore a larger polyurethane sheet (100 x 100 x 2 cm) was used in order to avoid the effect of fringe. But in other cases a smaller sheet (50 x 50 x 2 cm) was used for the fuels placed at locations ① to ⑤.

The combustion profiles at each location ① to ⑨ in the cool air-conditioned room are shown in **Figure 2.** The photos shown in **Figure 2** are however not at the same clock, but to indicate the typical profile. Particularly, at the locations ⑦ and ⑧ the flame spread over the polyurethane sheet was extremely rapid, although the spreading pattern differed slightly at each experiment due to the effect of varying air-conditioning.

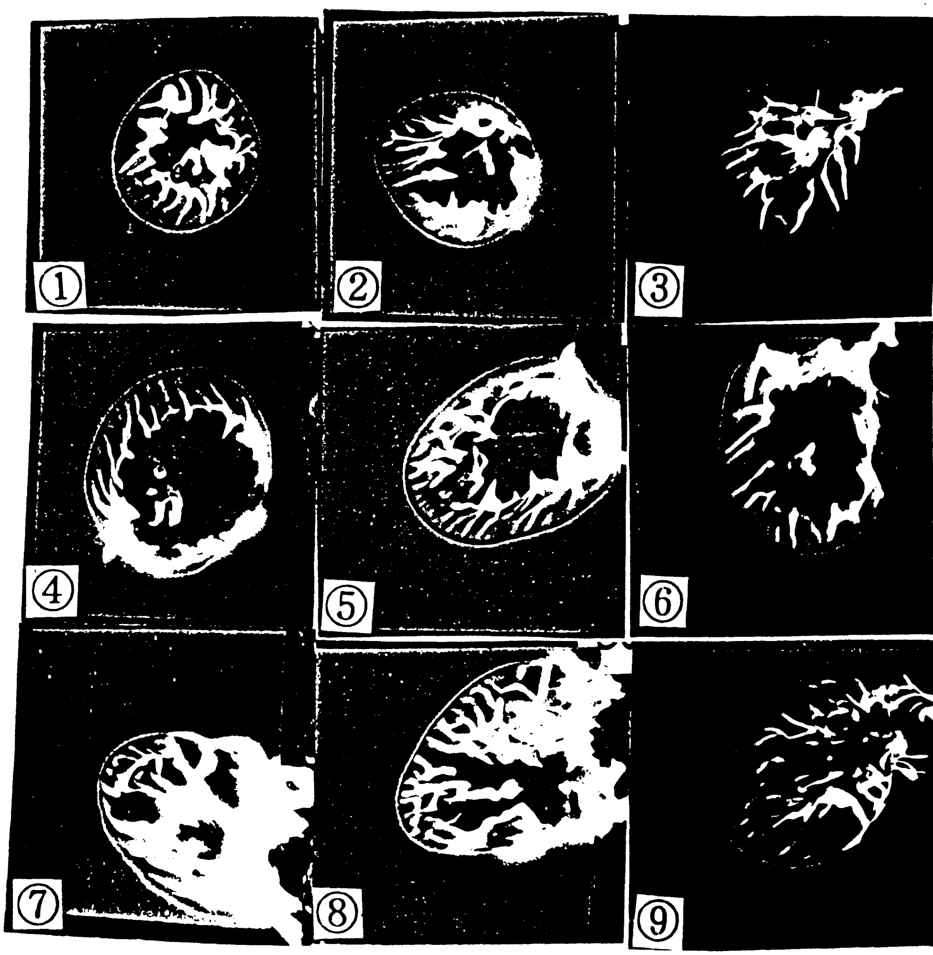

FIGURE 2 Combustion profile of polyurethane sheet placed at each location in the cool air-conditioned room.

Figure 3 shows the mass loss profile of the polyurethane sheet as a function of time with variation of the fuel location and effect of cool air-conditining. The left and right figures indicate the profiles for one and two sheets of polyurethane, respectively. The mass loss rates increased up to two to three times, independently to the number of polyurethane sheet.

Figure 4 shows the time variation of combustion of polyurethane located at ⑧ in either with or without cool air-conditioning. **Figure 5** shows the time variation of combustion profile for locations 2 and 7 in cool air-conditioning.

It is found that even the very low air speed of cool air-conditioning with about 0.2 m/s at the floor level could produce 10 to 20 % acceleration of the combustion of polyurethane as seen in the comparisons of **Figures 3-A1, 3-A2, 3-B1, 3-B2, 4** and 5.

Figures 3-A1, 3-A3, 3-B1 and **3-B3** indicate that the cool air flow with the speed of 0.4 to 0.5 m/s greatly affects the combustion of polyurethane, namely the increase of up to twice to three times.

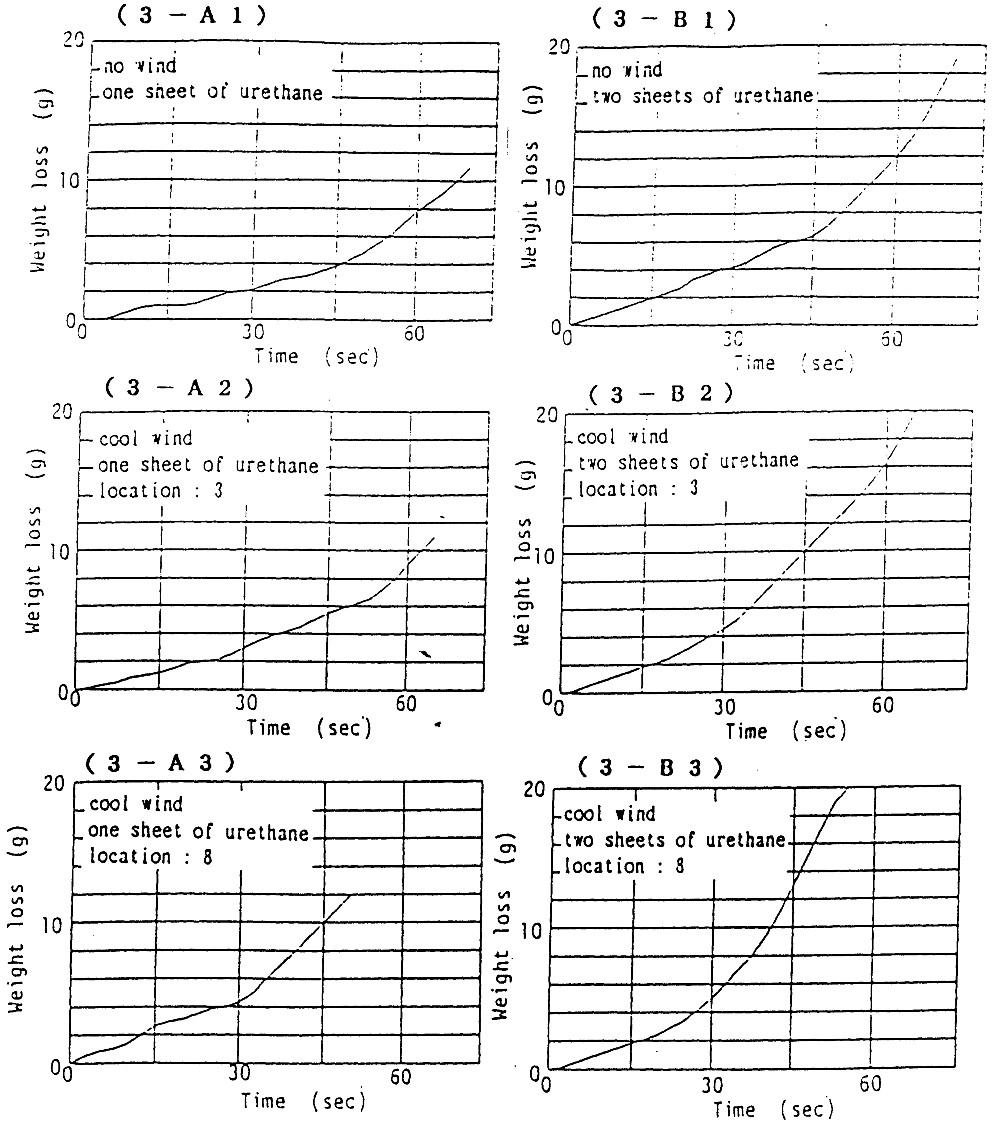

FIGURE 3 Relationship between weight loss of polyurethane and time.
(Location for no wind : room center, locations for cool wind : 3 or 8)

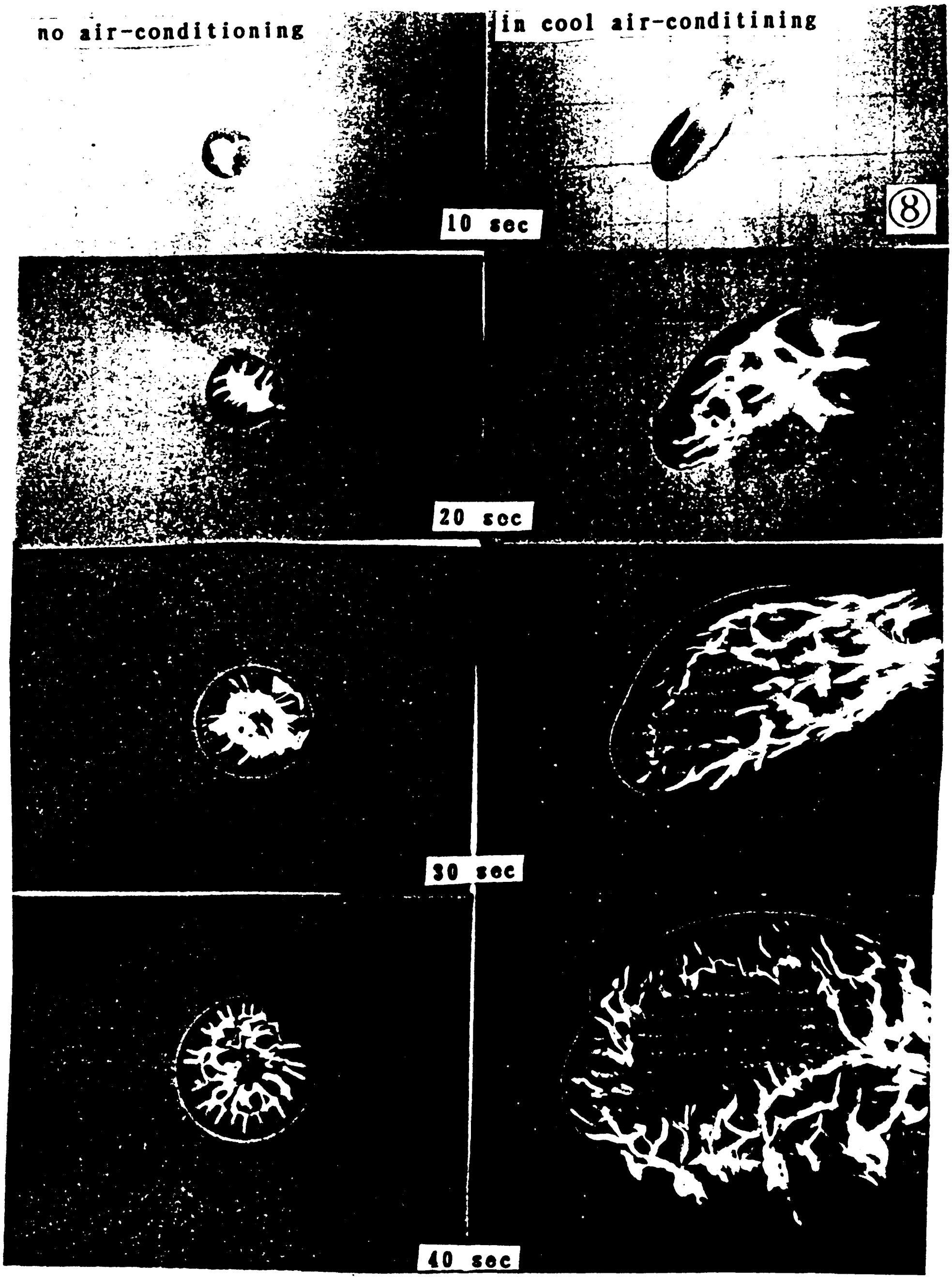

FIGURE 4 Combustion profiles as a function of time with and without air-conditioning.

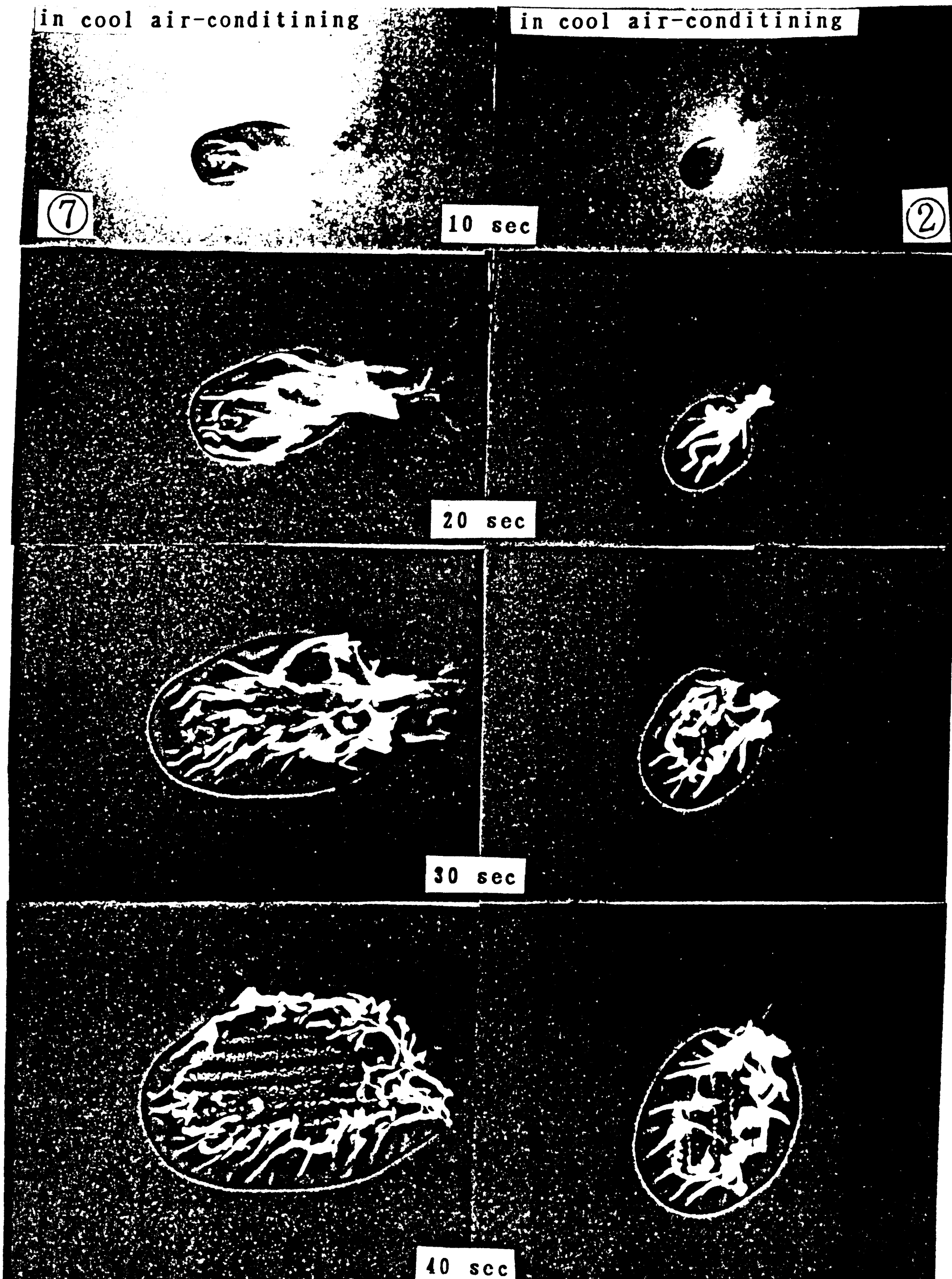

FIGURE 5 Combustion profiles as a function of time with variation of fuel location.

Figure 6 shows the signals of multi-element sensors of heat, smoke and carbon monoxide placed at the center of the ceiling in either with or without cool air-conditional flow. Two sheets of polyurethane were placed at the location ⑨. The air-conditional flows affect greatly the sensor signals. So it is found that the fire detection by conventional heat or smoke detectors must considerably be in delay .

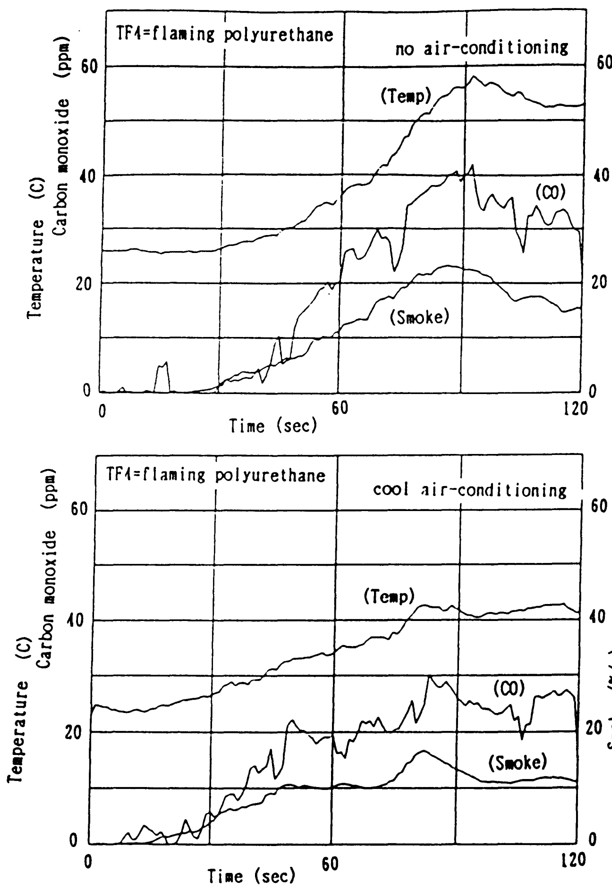

FIGURE 6 Variations of temperature, CO gas concentration and smoke density as a function of time for flaming polyureyhane

On the other hand it has been found that the multi-element fire detector including CO gas sensor can detect fires much earlier than by conventional ones.

2.2.2 Combustion of wood stick

Case II is relevant to the ISO Fire Test 1 for flaming fires where dried beechwood sticks (1 x 2 x 25 cm each) are arranged in parallel crosses. The surface of each stick is polished smoothly, since the reproducibility of the combustion of this type wood stick is not always well.The original fire test requires 70 sticks consisting of 10 sticks by 7 layers in a testing room (H= about 4 m). However due to the difference of room dimensions between the present experiments (H=2.45 m) and ISO, the number of sticks was reduced to 24 (4 sticks by 6 layer).

The flaming combustion in this case produces only little amount of smoke, so the fire detection must be based on the heat sensor among the conventional fire detectors. However it should be pointed out that the combustion of this type produces considerable CO, too. **Figure** 7 shows the sensor signals of three-element fire detector placed at the center of the ceiling in either no or cool air-conditioning flow. The wood sticks in parallel crosses were placed at the location ⑤ where the effect of acceleration of combustion was about several %. At the location ⑧ the acceleration of combustion was about 10 to 20 %, differently from the polyurethane. It is however found from **Figure 7** that the dilution of fire gases is considerable. Therefore neither the conventional heat detector nor smoke detectors must uselessly wait the accelerated flaming fires in cool air-conditioned rooms.

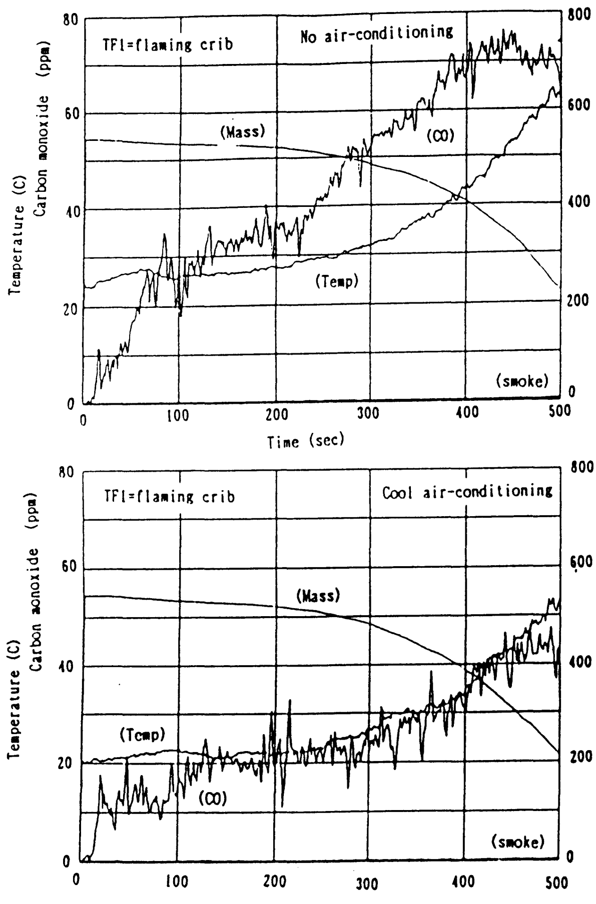

FIGURE 7 Variations of temperature, CO gas concentration and smoke density as a function of time for flaming wood stick.

Figure 8 shows the combustion of wood sticks (CASE II) placed at the location ⑤ in a room either with or without cool air-conditioning flows. The flame in no air-conditioned room was very laminar, but was turbulent in the cool-air-conditioned room. This also indicated that even the mild cool air-conditioning flows disturb and encourage the flame burning of wood sticks.

FIGURE 8 Combustion profile of wood sticks in pararelle crosses (4 x 6 layers).

Next investigated was the combustion of one pile of thin sticks (CASE III) used for match (0.2 x 0.2 x 5 cm each). Total weight of one pile of thin sticks was 200 grams. The combustion profile was almost reproducible. The smoke was produced only little, as in the CASE II. The measurement showed that the mass loss rate of a pile of thin sticks placed at the location ⑧ in a cool air-conditioned room increased 20 to 30 % compared with that in no air-conditioned rooms, differently from the CASE I. **Figure 9** shows the combustion profiles of thin wood sticks placed at the location ⑧ in either no or cool air-conditioning flows. It also indicated that the cool air-conditioning flow greatly disturbed and accelerated the flame burning of wood stick.

FIGURE 9 Combustion profile of a pile of wood sticks.

3. COMPUTER SIMULATIONS

In the experiments the detailed flow behavior was not visble well. So computer simulations were conducted.

Experiments showed that the smoke and fire gases in the air-conditioned room were not always uniformly mixed in the room, namely the temperature near the ceiling increased due to the fire gases, but the temperature near the floor was cool. In addition there exists no clear boundary between hot and cool layer. And even when the air-conditioning is not operated, the inside of hot air layer due to the fire source is not uniform, but the layer itself consists of multi-thermo layers. Therefore so-called two-layer zonal analysis and the simple ventilation method are useless to analyze the present problem of fire gas flows in air-conditioned flows.

Therefore here a field model code, UNDFRI developed by the author et al. [6,7], was used. (The details are known in the References.) The room was divided into 28 x 28 x 28 uniform grids, including the adiabatic wall boundary.

When there is no air-conditioning in a room, the iso-smoke and iso-thermal lines become similar because the governing equations of energy and gas species are similar in the calculations. But if there exists cool or warm air-conditioning, the smoke and heat flows give different patterns due to the double heating sources; air-conditioning (cool source) and fire (hot source).

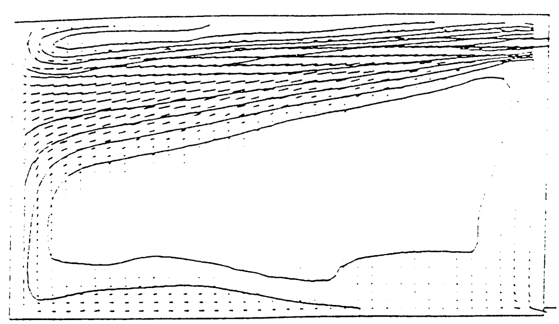

FIGURE 10 Numerical results of cool air-conditional flows. (Vertical cross-sectional view including the exit of air-conditioning)

First, only air-conditioning flows (without any fire source) were calculated. **Figure 10** shows the vertical cross sectional view of the flow pattern (isotherms and velocity vectors) of cool air-conditioning. The blowing out speed of cool air-conditioning ($\triangle T$=-5 K) is 3 m/s.

Next one fire source (heat release rate Q was varied 10 to 50 kW) was placed at the locations ⑦ or ⑧ in the cool flow. And the flow patterns were examined. **Figure 11** shows the cross-sectional view of flow vector distributions and isotherms due to a heat source (Q=20 kW) in the horizontal layer at 10 cm above the floor. The plan views of flow patterns shown in **Figure 11** are almost similar to the patterns shown in **Figure 2** by experiments.

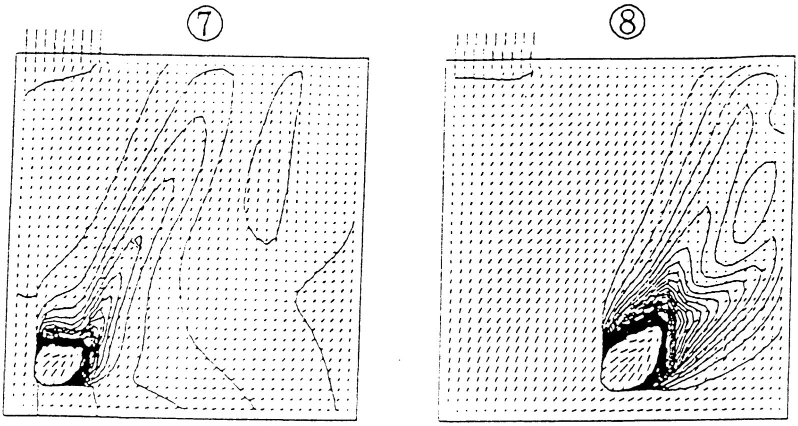

FIGURE 11 Numerical results of fire gas flows in cool air-conditional flows. (Horizontal cross-sectional view in the layer at 10 cm anove the floor)

4. DISCUSSION

The experiments showed that flaming fires are highly accelerated by cool downward flows. Particularly the polyurethane sheet burns twice to 3 times faster in the cool downward air flow than in no air-conditioned room. Therefore for example if the soft synthetic bedclothes in shopping stores were ignited within downwawd blowing air-conditioning, it would be very dangerous because the combustion is extremely fast.

However, the combustion of wood sticks is less affected by the air-conditioning, depending on the total surface area touching with the air.

This study also indicated that the smoke and fire gases are greatly diluted by the air-conditional flow. Therefore there should exist the worst case for the soft synthetic bedclothes mentioned above, where the detection of fires is in delay by the use of conventional detectors.

It is generally known that a fast burning, namely flaming fire would produce large amount of oxigen rich compounds such as CO_2 and H_2O. On the other hand, a slow burning, namely smoldering fire with low heat output would produce relatively large amounts of oxygen deficient compounds such as CO and H_2[8]. The author's previous study[3,4] reproduced this tendency and also indicated all the ISO Test Fire flaming marerials (wood sticks, polyurethane and n-heptane) produced considerable amount of carbon monoxide enough to detect by the CO sensor developed by the author et al., excluding ethanol (but pure ethanol fire in ordinally rooms is not predicted in real).

Therefore although fire smoke and gases are diluted and become difficult to detect them early in air-conditioned rooms, a carbon monoxide sensor together with heat and smoke sensors can play a great role to detect fires early and reliably, using the fuzzy expert system[4,5].

The flow patterns of fire gases in the experiments are not visible well, but numerical results can give visible flow patterns, which are almost similar to the flow in experiments and useful information.

5. CONCLUSIONS

This study investigated the behavior of accelerated combustion of fires and early fire detection in air-conditioned rooms, experimentally and numerically.

The air-conditioning flow highly affects the flows of fire gases and dilute them, resulting the delay of fire detection. And the flaming fires are highly accelerated by cool downward flows. Particularly, the combustion of polyurethane in cool air flow with the speed of 0.4 to 0.5 m/s at the floor were twice to three times accelerated. However, the combustion of wood sticks is less affected by the air-conditioning, depending on the total surface area touching with the air.

There should be a worst case where the fire detection by conventional sensors are in delay, whereas the fire combustion is highly accelerated in a cool air-conditioned room.

A carbon monoxide sensor together with heat and smoke sensors can play a great role to detect fires early and reliably, using the fuzzy expert system·

The numerical results of flow patterns of fire gases are almost similar to those in experiments and give useful information.

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