Numerical Calculations and Computer Graphic Analysis of Window-to-Window Propagation of Building Fires

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ABSTRACT

Building fires such as the "Andraus Building Fire" in Sao Paulo, the "Hotel New Japan Fire" in Tokyo and the "First Interstate Bank Building Fire" in Los Angeles have aroused great interest in the upward propagation of building fires. However, there have been little studies about the propagation of high-rise building fires via windows after the study of Yokoi, more than 30 years ago, who studied the behavior of hot gas flowing out of a window and the needed spandrel height to prevent fire spread upstairs.

The behavior of fire flows at openings such as doorways and windows have been numerically investigated by the authors. Here is attempted numerical simulations of the window-to-window fire propagation and in particular of the behavior of fires invading into the upstairs room via windows. And we made computer graphic animation video movies from the initiation in a lower room to the full development into the upstairs room. In addition, experiments using a 1/5 scale model showed that the flow patterns calculated are reasonable.

1. INTRODUCTION

In the world, high-rise buildings with many wide glass windows are increasingly constructed every year and so fires in them, too. In particular, fires of the "Andraus Building" [1] in 1972 in Sao Paulo, Brazil, the "Hotel New Japan" [2] in 1982 in Tokyo, Japan and the "First Interstate Bank Building" [3] in 1988 in Los Angeles, USA have aroused great interest in the upward extending building fires like in the movie "Towering Inferno". Although some might have been caused directly by the fire spread through the void space between slabs and walls, the fire spread via windows has clearly [2] been observed.

More than 30 years ago, Yokoi [4 5] has studied the behavior of hot gas spurting out of a window of burning building and the needed spandrel height to prevent the fire spread upstairs. After that there have been some, but very little, studies about the fire propagation upwards via building outer surfaces. For example, Oguni et al. [6] and others [7] studied the fire propagation via combustible materials on verandas of disused aparment houses. (Verandas are horizontal projections and can deflect the upward flame. In Japan, they are also the places to dry washed clothes, blankets and mattresses in the sunshine, and at the same time in winters plastic containers of kerosene oil are stored there.) However, more basic phenomena of the via window fire spread over the

building surfaces without any combustible materials are not fully clarified yet due to the difficulty of the large real scale experiments, and the fire accidents mentioned above are just the cases.

The behavior of fire flows, particularly of the mass flow rate, at openings such as doorway and window have numerically been studied by the authors[8, 11]. Recently, Satoh [12] has numerically investigated the characteristics of fires flowing out of enclosures with an opening, either window-type or doorway-type. Periodic generation and decay of vortices around the opening were examined. Figure 1 shows the calculated isothermal patterns of flows in both types of enclosures. Immediately above the opening, some portion of the upward hot flow turns the flow direction downwards and the circulating flow generates a vortex.

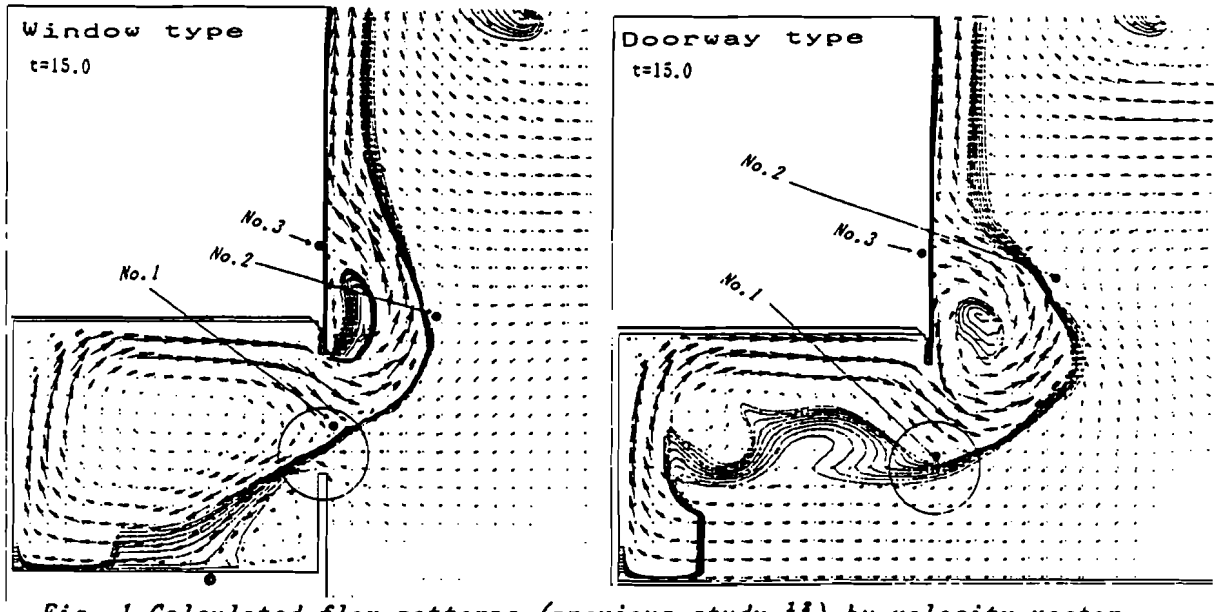


Fig. 1 Calculated flow patterns (previous study [12]) by velocity vector distributions and isothermal lines (isotherms are displayed only in the vicinity of the boundary of hot gas and cool air.)

However, neither this study nor Yokoi has examined the behavior of invasion of the fire into the upper room from the original room. It is uncertain how the upward flow is split into two directions, i.e. upward and into the upper room.

Here is attempted a numerical simulation of the window-to-window fire propagation, assuming the window glasses are open or already broken down in both the original fire room and the upstarirs room. Computer graphics (CG) supply large amount of information about the flows of fires. Hence we made CG animation video movies from the initiation of fire in a room to the full development of the fire in the room upstairs. Further 1/5 scale model fire experiments using liquid fuel were conducted.

2. NUMERICAL SCHEME

Numerical calculations were carried out using the almost same computer code

as in the previous study [12] . The numerical scheme, the formulation of the finite difference equations and the other details of calculations are already shown in the references [13 17] and so no more are presented here. The calculations conducted here correspond to 1/5 scale model fire experiments. The flow domain was two-dimensional, similarly to the previous [12], and the total area was 1.98 (horizontal) × 2.02 m(vertical). The basic cell was 2 cm square each. The fire room was 0.7 × 0.5 m(height) and the upstairs room had the same dimensions as the original fire room. The height of window was 0.38 m. Thus the outside area was 1.28(horizontal) × 1.52 m(vertical). Although the burning of n-heptane was estimated to release 150-220 kW/m of heat, it is difficult to simulate quantatively the combustion phenomena of liquid fuel at present. Hence, in the calculations 70 kW/m volumetric heat release rate contributing to the convective buoyant energy was employed.

3. NUMERICAL RESULTS

Figure 2 shows the calculated flow patterns of the window-to-window fire propagation, which were chosen from the CG (computer graphics) animation movie (color in original).The original fire in the lower room was initiated at the place, on the floor, shown in the figure at 1.0 sec in Fig.2.

It can be seen from Fig.2 that a first block of the fire flow, due to the 70 kW/m of heat release in the two-dimensional enclosure with dimensions of 0.7 × 0.5 m (height), disappeared within 3 seconds from the top of numerical free boundary, abruptly just like a flash-over in a room. After the first block of the fire flow disappears at the upper free boundary, the boundary layer between the hot and cool air in the upper room are waving and slowly come down close to the floor, accompanying the oscillatory motion of the upward flow along the outer wall.

In Fig.1, vortices were created around the wall immeadiately above the window or doorway opening. In the case in Fig.2, too, a vortex was created almost at the same location as in Fig.1. This vortex moves upwards and so the hot flow along the outer wall or the window opening was pushed and bent left to right. Thus the hot fire flow invades into the room of upper floor.

Diffrently from Fig.2, Fig.3 shows the flow patterns of hot gas flow from a window opening in the case there is no rooms of upper floor with broken window glasses. Hence the upward flow from the window of the lower room moved along the vertical surface of the outer wall.

The flow patterns over the outer wall surfaces between Figs. 2 and 3 are quite similar on the whole. In particular the common flow behavior is seen at 9.5 and 11.5 sec in both Figs.2 and 3. In the four figures at the time, the hot flows are pushed ahead and inflated immediately above the top of the window of the fire room. In this way, the hot flow over the outer wall becomes fluctuating. This means that the glasses of upper room windows are heated up and cooled down repeatedly. This must be more severe exposures than constant heating to the glass surfaces to reach the break down of windows.

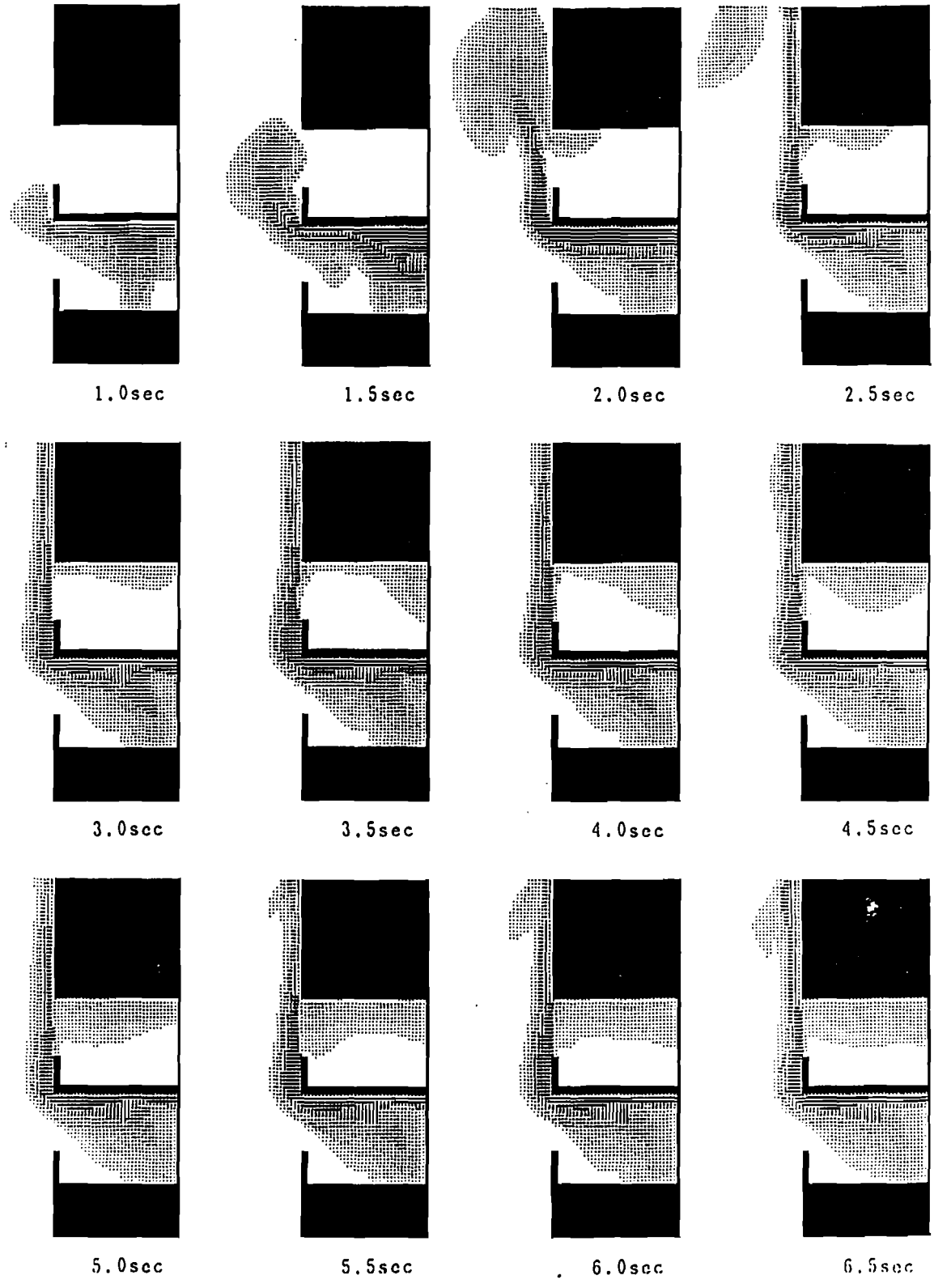
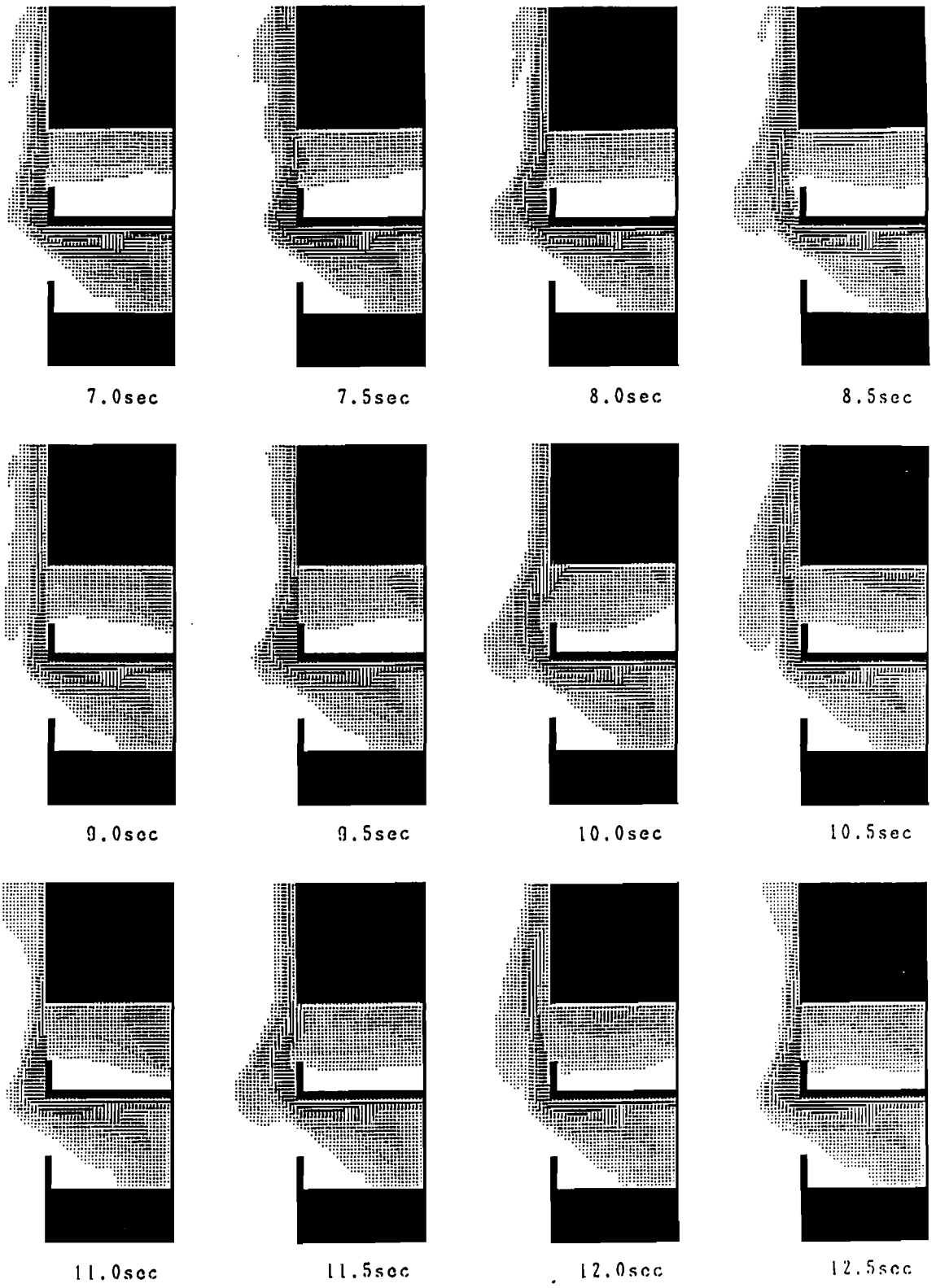


Fig. 2 Calculated flow patterns displayed by isotherms (multi-storied building)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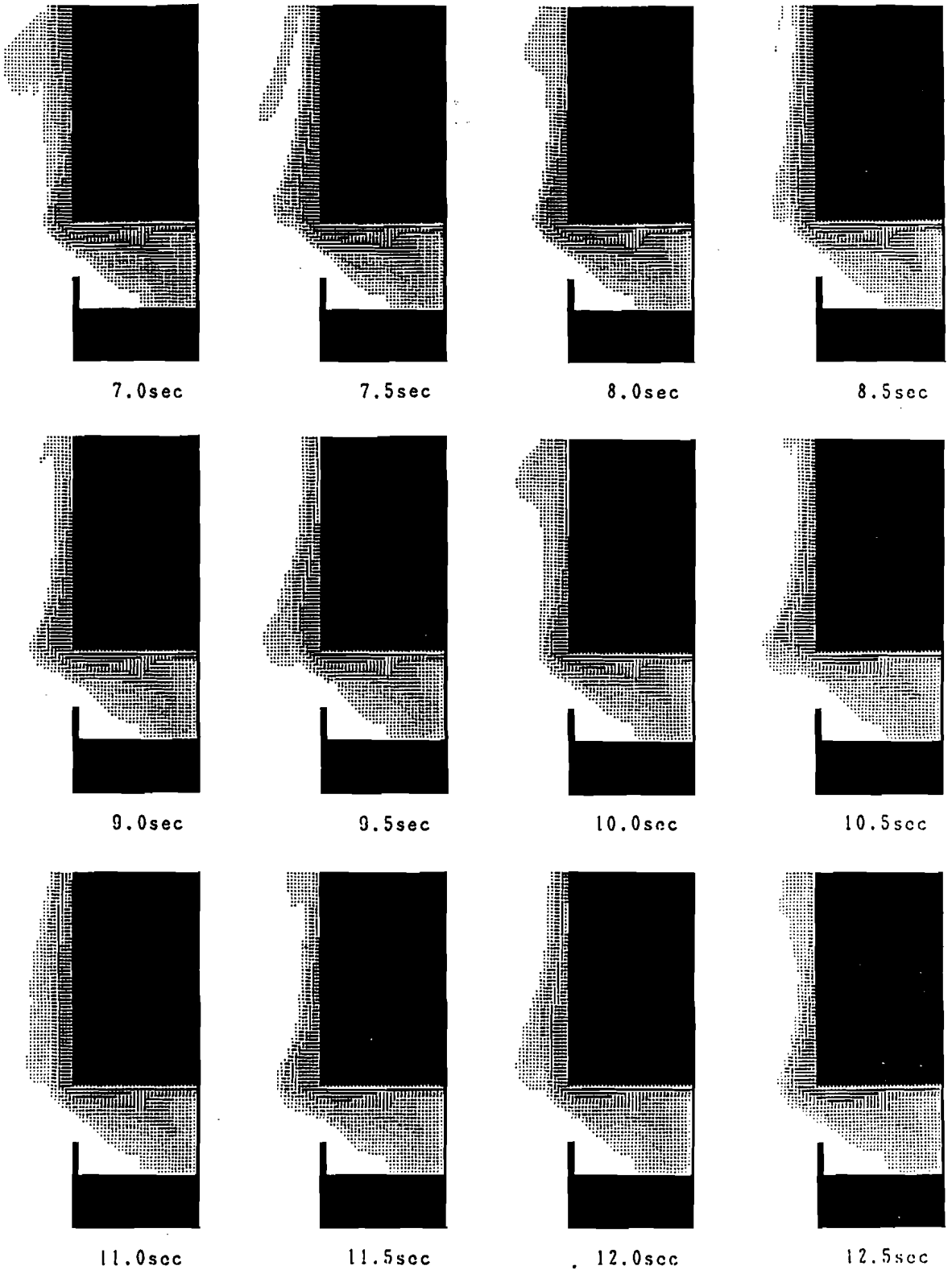
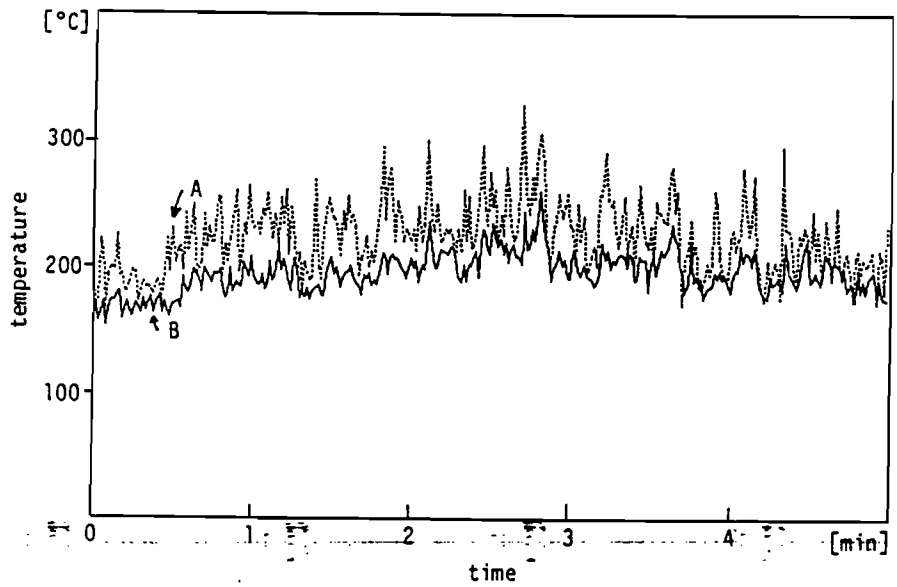


Fig. 3 Calculated flow patterns displayed by isotherms (single-storied building)

4. EXPERIMENTS

In the 1/5 reduced scale multi-storied building (0.7×0.5(height)×0.6 m) with an open window, either methanol or n-heptane was burned in a steel tray (0.14×0.03(liquid depth)×0.6 m). The fire flame of n-heptane was ejected long upwards from the window, but the methanol fire flame was comparatively weak in buoyancy and the flame height was short.

In the upper room with an open (broken) window, the temperatures near the the ceiling was measured, using methanol fuel. Figure 4 shows the temperature variation at two locations (one is near the window and the other is near the inner wall). The temperatures were highly oscillating, in particular at the location near the window, but the difference between the both was about 50℃.



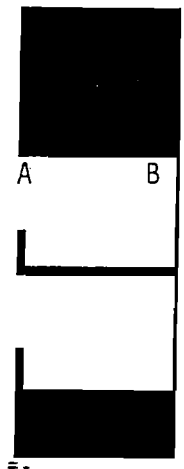


Fig. 4 Temperature variation at two locations (A and B) in the upper room measured experimentally. (fuel : methanol in the steel tray)

Figure 5 shows the photoes of the n-heptane flames burning in the steel tray mentioned above. In the experiments, the ejected n-heptane flames were highly oscillatory in the cases of both broken glass windows (case A) and non-broken windows (case B) of the room of the upper floor. The ejected upward flame was vertically pushed to the wall and window, and moved vertically. The side views of the upward flames between the cases (A) and (B) show that the flame shape and the height are almost the same as seen in photoes A and B of Fig.5. However, the oscillatory motion in the case (A) was affected by the open (broken) window compared with that in case (B).

The n-heptane flame in the original fire room covered all the floor area due to the high evaporation rate. In addition, the photo D in Fig.5,which was taken at the shutter speed of 1/125 sec, shows the detailed structure of the flame and vortices.

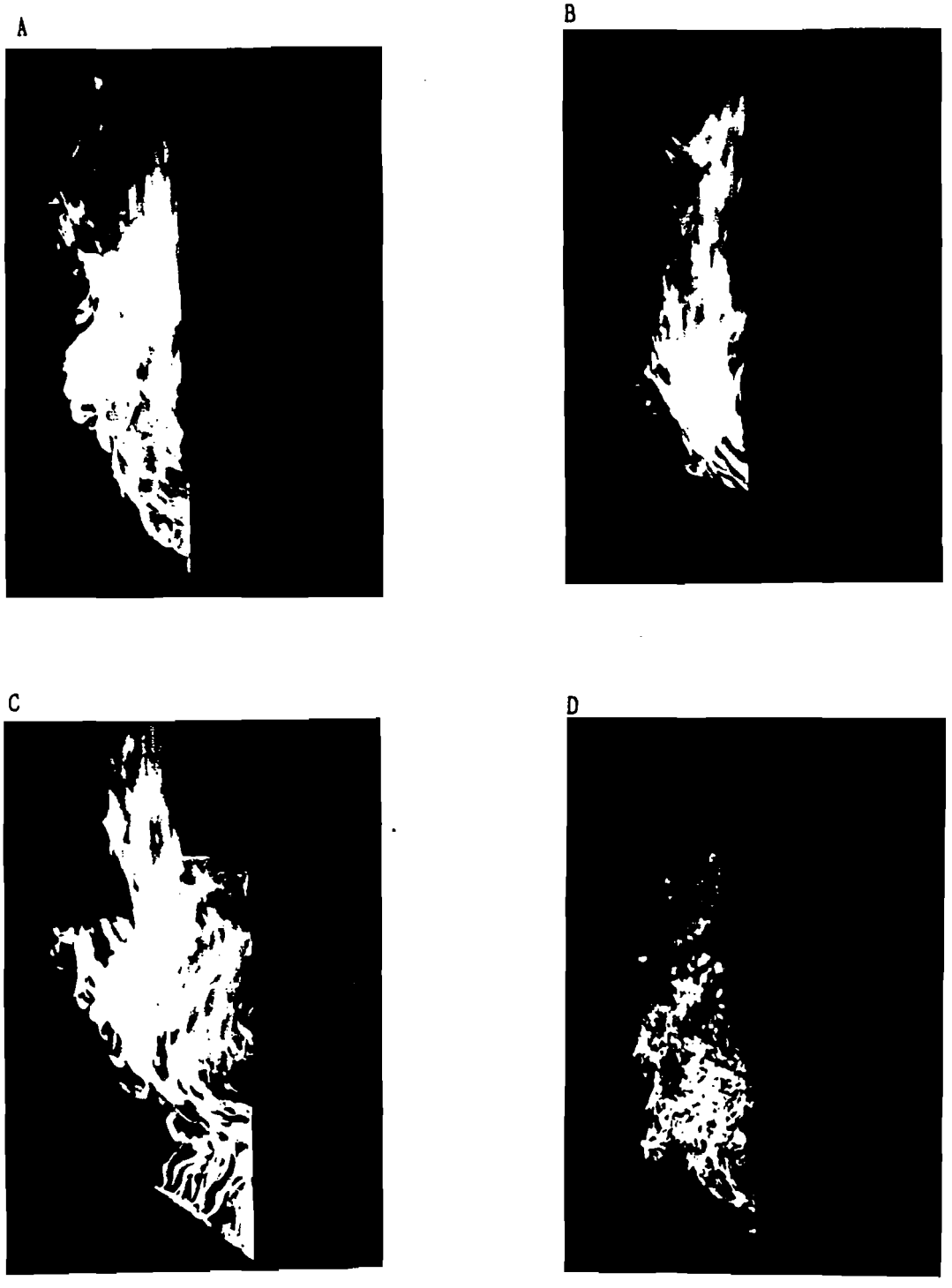


Fig.5 Burning flames of n-heptane ejected from a window and moving upwards.
photo A : closed window (case (B)), photoes B-D : open window (case(A))
photoes A-C : shutter speed=1/30 sec, ptoto D : 1/125 sec
Photo C shows the flame which covers the whole area of the floor
of original fire room and invades into the upper room.

5. DISCUSSIONS

The ejected flame of n-heptane became so long above the window of the original fire room as seen in Fig.5 in this experiment. Although the liquid fuel may not always be appropriate for the building fire simulations and the scale effect may be considerable in the reduced scale model, the aspects of the burning fire on the outer walls are very similar to the photos in journals and news papers reporting such large fire accidents as mentioned above indicating long ejected flames and reaching the windows of upper floor, even when the outer walls of the building were non-combustible.

Recently Oleszkiewicz [18] studied to provide data for the evaluation of hazard of fire spread along the building facade, using the test facility of the ASTM Standard Burn Room, in which propane gas burners were installed to produce fire plume. The shape of the plume, shown in the report, above the window is very similar to those shown in Figs.2 to 4 of this study.

The ejected n-heptane flames in the experiments were highly oscillatory in the cases of both broken glass windows (case A) and non-broken windows (case B) of the room ofthe upper floor. The ejected upward flame was vertically pushed to the wall and window in the experiments. This phenomena are very similar to the motion in the animation movie of computer graphics based on the numerical calculation.

It is considered that the oscillatory motion of the upward flame over the wall could affect the break down of window glasses repeating to heat and cool down. Window-to-window fires are accelerated by the existence of combustible materials near the window and the ceiling in the upper room.

Since recently high-rise buildings in the world are increasing year by year, the possibility of via window fire spread is still existent and may increase. Due to the difficulty of the large scale building fire experiments, numerical simulations are effective to analyse the flame behavior invading into the upper room and the spread of fire upstairs, and could be more significant.

6. CONCLUSIONS

It was found from the numerical calculations and the 1/5 reduced scale model experiments that the ejected fire flame from the original fire room is strongly pushed towards the building walls. The upward flow shows oscillatory behavior. The upward flames are almost similar in shape and length in both cases of the broken window and closed window. However, the oscillatory motion was affected by the existence of the window opening.

Numerical calculations showed that the generation of vortices around the area immediately above the window of the original fire room. In addition, the photo taken at the fast shutter speed showed the existence of vortices in the flame.

Numerical calculations are effective to analyse the flame behavior invading into the upper room and the spread of fire upstairs.

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