ANALYSIS AND IMPROVEMENT OF STACK EFFECT FOR THE STAIRCASE OF APARTMENTS IN FIRE ACCIDENTS IN TAIWAN

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ABSTRACT

Fires in buildings account for 60% of fires in Taiwan. Since establishment of the National Fire Agency in 1995, many fire codes have been promulgated resulting in a gradual decline in the number of casualties of fire. However, for old apartments in urban areas, although regulations aimed at improving fire-prevention refuge facilities and fire-fighting equipment of existing building have been announced, they cannot be implemented efficiently due to the lack of public acceptance. This investigation has found that hundreds of thousands people live in such buildings. However, the structure of many buildings is poor in terms of smoke control theorem. This investigation adopts smoke control theorem to examine the Stack Effect in apartment staircases, and seeks improvement. Such an approach is expected to benefit fire safety of the apartments.

KEYWORDS

fire, apartment, stack effect, arson.

INTRODUCTION

The Efforts of the Government

Residential Fire accidents are considered as a serious issue abroad. In 2000, 31,980 fire accidents occurred in Japan. Among them, 17,309 incidents (57%) were residential fire. 1,418 people were killed by fire in 2002, as shown in Fig. 1.(Japan Fire and Disaster Management Agency, 2006)

Many employment and commercial opportunities have been created in Taiwan by the economic boom of the 1970. The population has rapidly moved to urban areas and surrounding satellite cities, thus increasing apartment density and consumption. The use of buildings has become varied and complex.

The National Fire Agency in Taiwan strongly advocates fire prevention measures and has announced many Fire Codes. It has introduced a system for inspection of fire control, overhaul declaration, flame prevention and fire prevention in public buildings. These measures have led to a gradual decline in the number of fire incidents, as shown in Fig. 2. (National Fire Agency of Taiwan, 2005)

However, the regulation does not cover existing apartments, particularly those for old residential communities. To comply with Article 77 point 1, "Regulations on improvement on fire- prevention refuge facilities and fire-fighting equipments of existing building" of the Construction Act, amended in Feb. 2003, the National Fire Agency has sought to enhance the refuge facilities and fire fighting equipments of the old buildings. (National Fire Agency of Taiwan, 2003) However, the scope of the regulation only includes public buildings, such as cinema, restaurants and large shopping malls.

The regulation does not cover buildings with fewer than five floors in city planning areas, or fewer than four floors outside city planning area with residential area not over 1000 square meters,. Responses in Consideration politics from citizens reveal that the regulations for improvement is difficult to implement, meaning that the fire control safety of these buildings cannot be enhanced efficiently.

Current Problem

The lack in understanding of fire control among citizens, and the management problem in fire control mean that the proportion of residential fires remains high. Residential fires are the most frequently occurring building fires. Figure 2 illustrates the statistics of building classification of the fire accidents from the Ministry of Interior, which indicate that although the numbers of times of fire accidents drop gradually, residential fires (independent residence, group of residence) still accounts for 60% of all fires. (Ministry of the Interior, Taiwan, Dec. 2006)

Since residential apartments are not restricted by fire control regulations in Taiwan, landlords and homeowners are not required to install fire control equipment. (National Fire Agency of Taiwan, 1998) Hence, the residents are not protected effectively against fires. Fire control equipment includes alert equipment to detects fires, fire extinguishers to puts fires out, and escape equipment to help the citizens to escape a burning building. Therefore, access to the buildings cannot be controlled, nor observed once fire accidents occur. Thus, residents living in such buildings should have suffering consciousness need to be aware of fire prevention. (C.H. Su, 2006)

For the apartments near the cities, especially for the group of residence constructed in 60s and 70s, most of them include arcade. According to the habits of the citizens, the alleys around the buildings and under the arcade are full of motorcycles and miscellaneous objects. In some of the first floor, there are shops. For the reason of commercial behavior, the parking of motorcycles is restricted. The residents of those buildings have to park the motorcycle in front of the gate as shown in Figure 3.

METHOD

The apartment staircase is the only route for the residents to escape when the apartment is on fire. Unfortunately, it is also the channel to spread the smoke. In general, the biggest danger is from the heat and smoke, not the directly from the flames. The stack effect is most significant in an airtight building.

A common situation of the serious apartment fire is as follows. The lower floor is on fire at midnight, waking the residents. Since they are blocked by barred windows, they rush out from the doors. However, the smoke and fire spread rapidly to the stairs. Miscellaneous objects, such as bicycles, in the stairs incease the speed of burning. The frightened residents in the upper floor escape downwards, and are trapped and maybe killed in the staircase.

This study adopts the numerical method to analyze and improve the stack effect of the staircase in the apartments. The building fire simulation is now divided into "Zone Model" and "Field Model". In terms of calculation, the Zone Model is easier and quicker than the Field Model. (Yang, K. H. 2001)

This study has adopted FDS application that mainly uses LES as the model for calculation to describe the air flowing phenomenon driven by fire floating force. It is the fourth edition that has been announced on September of 2005. This software has been developed by Building and Fire Research Laboratory of National Institute of Standards and Technology. It is a very good tool to assist the fire simulation. (Chung, K. C. 1999)

FDS 4.0 has for a while been adopted abroad as an tool for assessment of smoke control, the possibility and type of fire spread, living factors for escape and the efficiency of active fire protection systems. The structure of FDS software can be divided into the following three parts:

- Pre-processor: the pre-processor requires a text-only format. The simulated model dimensions, specification of items, distribution of grid points and boundary conditions, which form the basis of simulation and calculation, are entered on the command line.
- Data solution: this component is the algorithmic nucleus of FDS; it reads the parameters such as geometric dimensions in pre-processing and solves for them numerically, and outputs the required calculation results.
- Post-processor: the post-processing of FDS is combined with the graphical software "Smokeview" of Open GL, which can indicate properties of the flow field from two-dimensional and three-dimensional imaging and animation by rendering the software calculated results.

The FDS divides temperature, density and pressure into spatially averaged quantity and perturbation; the spatial coordinates are differentiated by the two-step central difference method, and the time is differentiated by the dominant two-step Runge-Kutta Method. The governing equation is expressed as follows. (Kevin B. McGrattan, 2002.)

(1) Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \bar{u} = 0 \quad (1)$$

(2) Momentum Equation

$$\rho\left(\frac{\partial \bar{u}}{\partial t} + \frac{1}{2}\nabla|\bar{u}|^2 - \bar{u} \times \varpi\right) + \nabla p - \rho g = \nabla \cdot \sigma \quad (2)$$

(3) Energy Equation

$$\rho c_p \left(\frac{\partial T}{\partial t} + \bar{u} \cdot \nabla T\right) - \frac{dp_0}{dt} = q + \nabla \cdot k \nabla T \quad (3)$$

(4) Ideal Gas Equation

$$p_0(t) = \rho R T \quad (4)$$

Herein

$$T = T_0(t)(1 + \tilde{T}) \quad (5)$$

$$\rho = \rho_0(t)(1 + \tilde{\rho}) \quad (6)$$

$$p(\bar{r}, t) = p_0(t) - \rho_0(t) g z + \tilde{p}(\bar{r}, t) \quad (7)$$

In which, p, u, T respectively represent pressure, flow speed, and temperature, cp is heat capacity, k is the coefficient of heat conduction.

SmokeView is a post-processing software application to combine the data of FDS programs, which can express the results calculated by FDS as 2D or 3D images or animation through graphical manipulation.

The first problem encountered by computer simulation is calculating the predictions of grid point dimensions. First, this study compares the various results of simulation to Heskestad's Correlation (Heskestad G., 1986), to conduct testing of grid points. The four types of grid points have the following dimensions as shown in Table 2, which fully attests to the fact that the size of grid points 0.25 m selected for simulation are appropriate.

Table 2 Four size of grid points in analysis of grid points

Test cases	Grid Size (m)
# 1	1.0 × 1.0 × 1.0
# 2	0.5 × 0.5 × 0.5
# 3	0.25 × 0.25 × 0.25
# 4	0.125 × 0.125 × 0.125

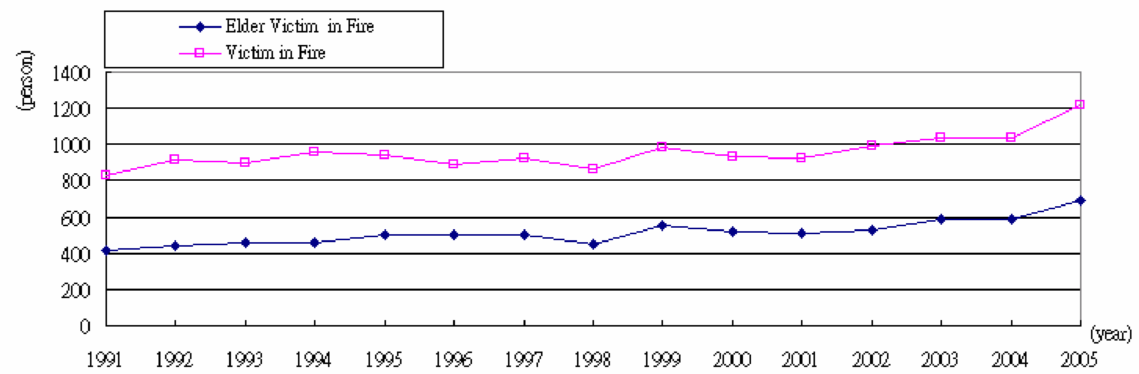

Figure 1 Number of victims in the fire accident in Japan

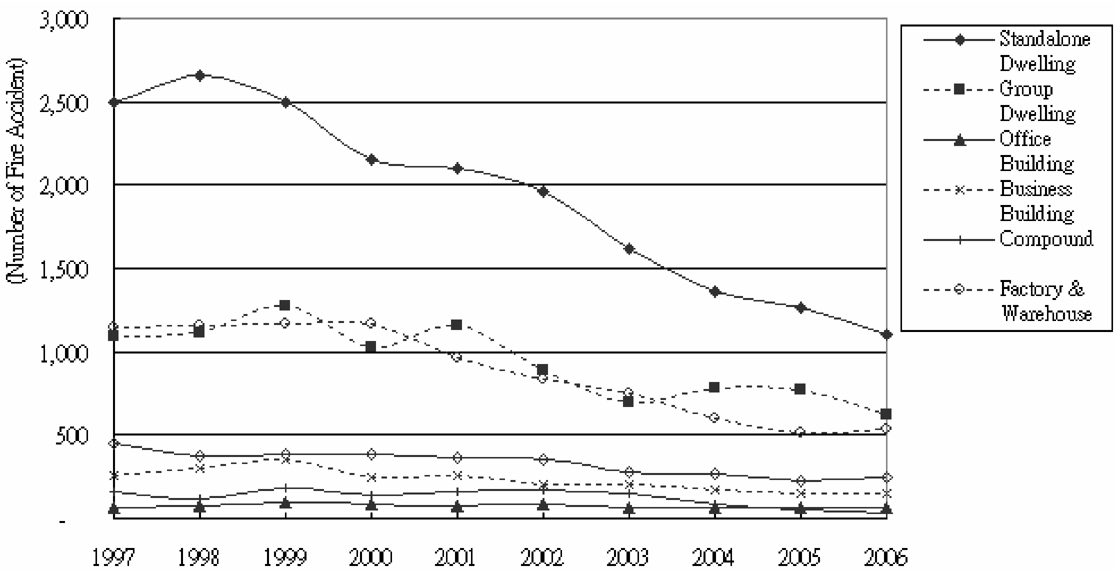

Figure 2 Number of times of the fire accident in Taiwan

Figure 3 Example 2 Motorcycles under arcade are parked near the gate

EXPLANATION OF SIMULATION CONDITIONS AND RESULTS

The simulation assumes a pair of apartment buildings that are double five floors, with a stairwell in the center with geometric measurements of 10m (length) × 9m (width) × 20m (height). To simplify, first assume that only one motorcycle is present under the arcade, with dimensions of 0.5m (width) × 1.5m (length) × 1.25m (height). There are approximately 1,160,000 grid points, which differ based on different conditions. Figure 4 shows a diagram of the appearance of simulation model, and the red block on the first floor represents the location of the fire origin.

To simulate the main door conditions of existing apartment buildings, assume that there is a ventilation opening above the main door of Case 1, with dimensions of 2m (width) x 0.6m (height), similar to actual dimensions. There is a window in the staircase of each floor, with dimensions of 0.5m (width) x 1.25m (height). For another contrast, assume that there is a ventilation opening of the same size under the main door of Case 2. Assume that under actual conditions in a fire, the ventilation opening on the roof opens after 90 seconds, the right side of the main door opens after 120 seconds, and that the left and right sides of the main door are both 1.0m (width) x3.0m (height).

The ventilation opening of the door is observed to understand the way in which smoke enters apartment buildings, the purpose of which is to understand the smoke distribution in the stairwell. Assume that burning of motorcycles is ultra fast for the purpose of description and analysis. This paper refers to the report of actual burning tests for strength of fires, use 2.0 MW, and 180 seconds is required before reaching maximum heat release rate, the fuel chemical reaction is propane, established internally by the FDS program.

This study establishes three cases for analysis, as shown in Table 3:

Table 3 Explanation of each simulated case

Case	Explanation
Case 1	Stairwell door opening at the top
Case 2	Stairwell door opening at the bottom
Case 3	Stairwell door opening at the bottom, with motorcycle moved away from the main door

In observing the simulation results of the two cases, it can be known that there is danger for openings above doors (Case 1); even though usually this helps with lighting and ventilation, once there is a fire, according to Figures 5 (A) and (B), it can be known that approximately 90 seconds after the fire starts, thick smoke has rushed into the stairwell of the apartment buildings. Conversely, it shows that main doors with opening at the bottom do not have so much smoke within the stairwells, which are beneficial for protecting residents from the harm of smoke.

In comparing the conditions of higher buildings in apartment buildings, at the same time, Figures 6 (A) and (B) show the smoke distribution on the fourth floor in Case 1 and Case 2, which can accentuate the different distributions of smoke caused by different locations of openings on the main doors, which further shows the considerable impact caused by the stack effect in the stairwell.

In Case 1 with a main door with an opening on the top, the smoke distribution of the building's second and third floor indicates a very serious distribution of smoke, meaning that people cannot easily evacuate. These simulation results can explain the difficulties faced by residents from rapidly spreading fires in apartment buildings due to accidents such as motorcycle arson in the arcade. Regrettably, residents tend to return to their homes when they discover that the escape route has become filled with smoke, but these spaces are blocked by iron windows, often without escape equipment such as escape slings. This also explains why, enormous losses in human life and property can occur only minutes after fires begin.

Figure 7 (A) displays the temperature distribution on the floors at a height of 1.8m, and shows thick smoke of high temperatures rush into the building because of air flow after fires occur, increasing the temperatures of the floors. The temperature after 300 seconds can be as high as 300°C on the second floor, and 150–280°C on other floors. Thus, residents of apartment buildings face emergency situations when fires occur.

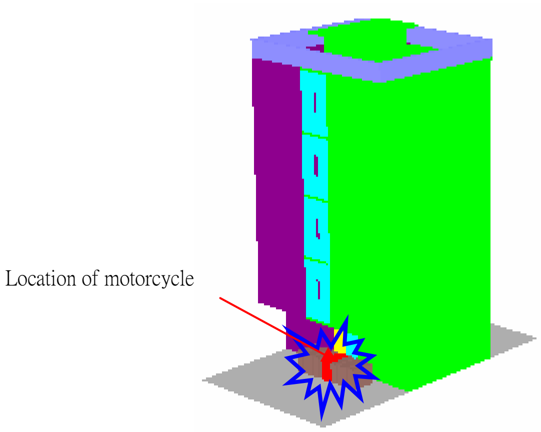

Figure 4 Diagram of the model

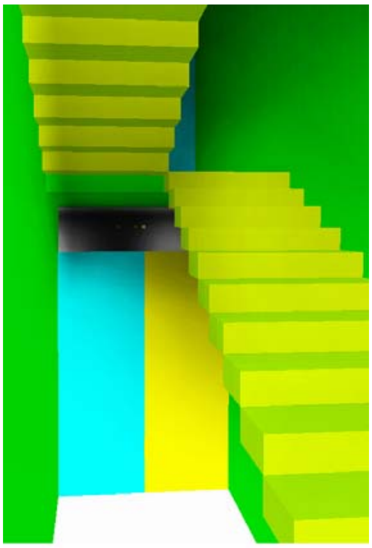

Figure 5 (A) conditions of stairwell on the first floor (opening at the top at 75 seconds)

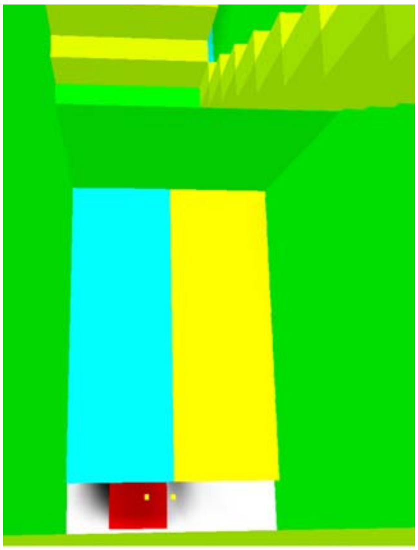

Figure 5 (B) conditions of stairwell on the first floor (opening at the bottom at 75 seconds)

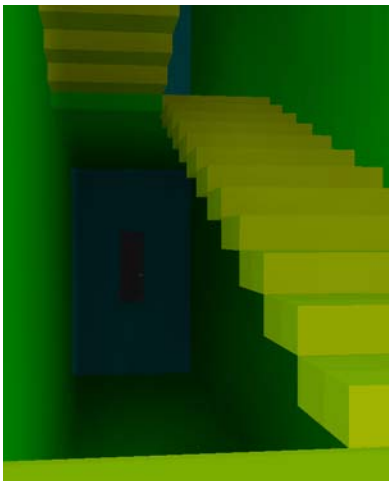

Figure 6 (A) conditions of stairwell on the fourth floor (opening at the top at 75 seconds)

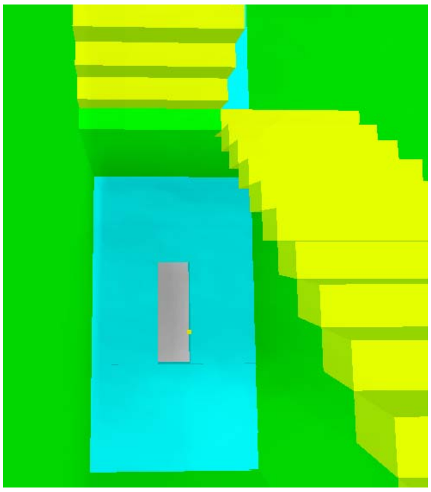

Figure 6 (B) conditions of stairwell on the fourth floor (opening at the bottom at 75 seconds)

Consider now the moving the opening of the main door to the bottom. Figure 7 (B) indicates that this action delays the escalation of temperature, while causing the thick smoke to collect in the arcade. For the second floor, it can be delayed until 390 seconds later. However, since the fire continues to grow, the smoke gradually accumulates downwards. The smoke smoke enters the building once it reaches the location of the opening, bringing with it air at a high temperature. Since the origin of fire is under the floor, the temperature of the second floor, gradually increases to slightly higher than that of Case 1, close to 400°C. Other floors, reach temperatures of 200–250°C.

These findings indicate that having an opening at the bottom of the main door can indeed slow the entry of smoke, which can lengthen the time that people have to escape, representing a strong benefit.

Contributions of this study can be seen in Case 3 which indicates that less smoke flowed into the building when the source of fire (motorcycle) was moved away from the main door, and when the opening of the main door was moved to the bottom. Similarly, temperatures at the location of 1.8m above the floors were also much lower, as indicated in Fig. 7 (C): the temperature was reduced to 50°C, which is significantly lower than those in Cases 1 and 2. Two reasons were found for this observation. The first reason is that the motorcycles were parked away from each other due to the buffers between motorcycles, and were parked far from the doorway, thus preventing the fire from becoming too big. The second reason is that smoke could not easily accumulate after the motorcycle caught fire fire, because the opening was moved to bottom of the door; thus the ten minutes of simulation produced no accumulation and descent of smoke into the apartment buildings as in Case 2.

CONCLUSION

Due to Taiwan's increasing prosperity, its population is rapidly congregating in urban areas and nearby satellite villages, resulting in continuous rises in collective residential population densities; this results in frequent fires, and hence casualties and serious loss of property. Although the National Fire Agency has promulgated many fire prevention regulations, and reduced the number of casualties from fires, these do not fully cover existing residences such as apartments, or the tens of thousands of old buildings with residents of lower socioeconomic status.

Since these buildings are not required to have fire prevention facilities, their residents are adequately protected from fires. Additionally, because these buildings generally do not have gatekeepers, the identities of people who enter are not regulated, and people cannot be alerted in advance if fires occur. Residents in such buildings thus need a greater sense of awareness of fire prevention measures.

This study has observed the planning and arrangement of existing tens of thousands of apartment buildings, and found that they have very poor smoke control. The only considerations for the openings above the doors of most buildings are ventilation and lighting. These openings tend to become the avenue for smoke to rapidly enter the building once fires occur; moreover , due to the stack effect, stairways, which are the only routes to safety, become filled with smoke in very short periods of time.

To prevent this problem, while still allowing ventilation in stairwells, simulation Cases 1 and 2 compare the opening at the top of the door to that at the bottom. These cases indicate that moving the opening to the bottom significantly reduces the dangers. Accordingly, this study recommends making this change in order to achieve a safe living environment.

The data indicates that fires in these buildings usually burn for a short time of only 30–60 minutes. The appropriate analysis of smoke control theories is very beneficial if it can give people a few more minutes to escape, it would be highly. Regrettably, fire prevention equipment in apartment buildings generally only comprises a few simple fire extinguishers. This may be due to the lack of promotion, or the preoccupation of residents with their jobs, or the failure of fire prevention authorities to examine the buildings.

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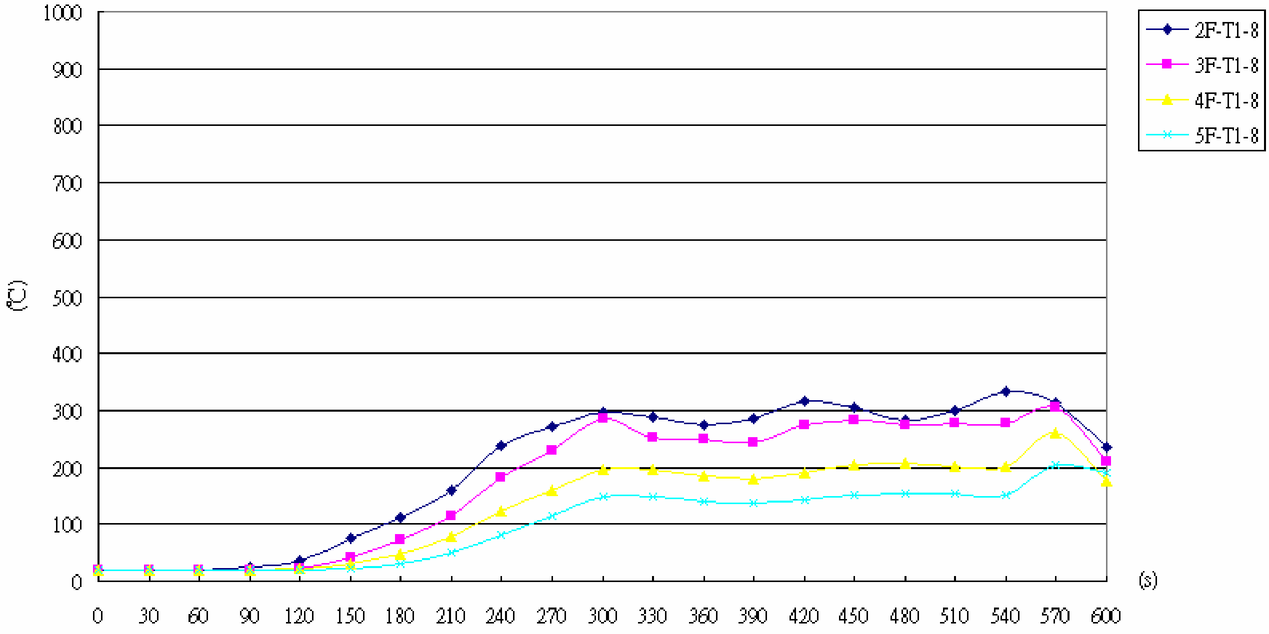

Figure 7 (A) Distribution of temperatures in stairwells of various floors (Case 1)

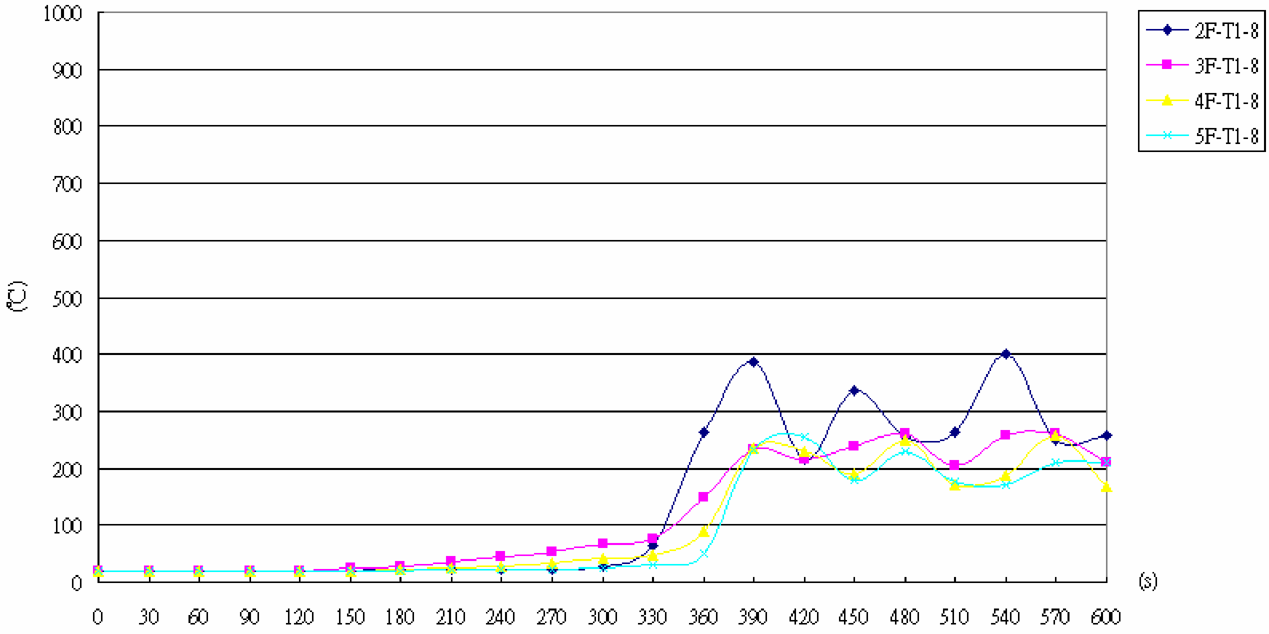

Figure 7 (B) Distribution of temperatures in stairwells of various floors (Case 2)

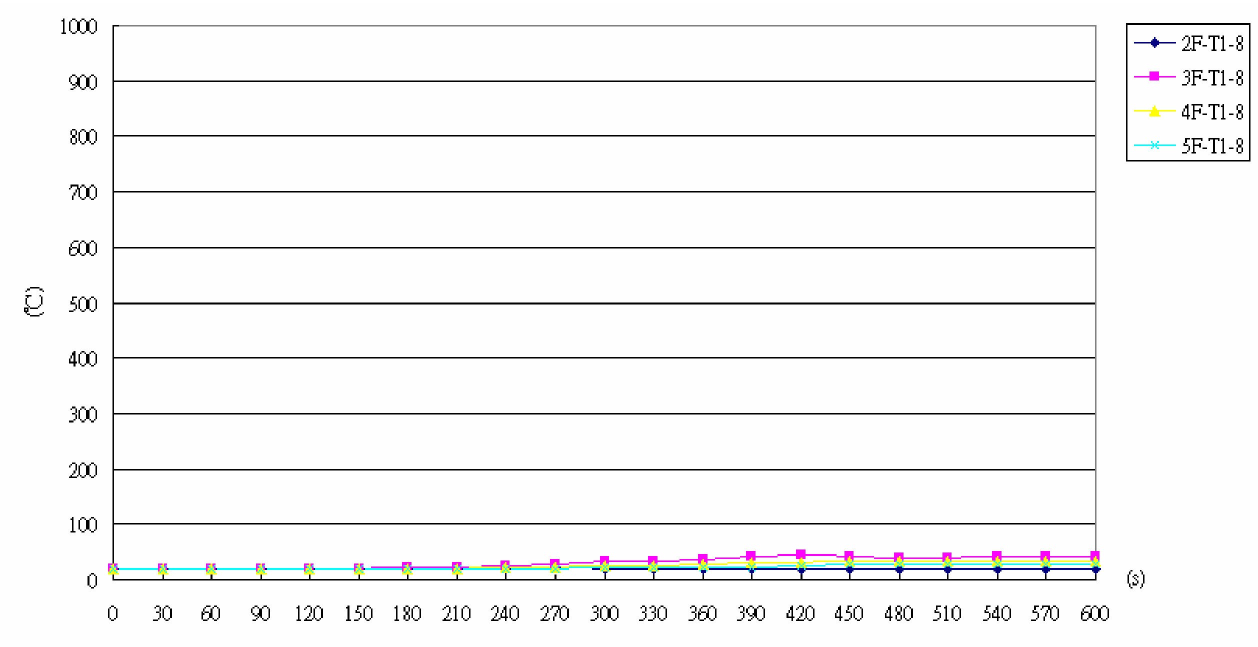

Figure 7 (C) Distribution of temperatures in stairwells of various floors (Case 3)