Study on Mechanical Smoke Prevention and Exhaust in Fire Escape Routes of the High-Rise Building

W WANG
Sichuan Fire Research Institute
Ministry of Public Security of P.R.China
Dujiangyan, Sichuan 611830, China

ABSTRACT

Safe escaping of occupants is the most important matter in the event of fire in the high-rise buildings. Hence, how to assure the safety and reliability of escape routes is a major subject in the field of structural fire prevention research.

The paper gives a brief introduction and conclusions on a research subject with a title "Study on Smoke Exhaust Technology of Positive Pressure Supply Air Mechanisms in Staircases of the High-Rise Buildings", a key technical research project of the nation during its 8th fire-year plan, undertaken by the building fire prevention research division of Sichuan Fire Research Institute. A feature of this project is that all the tests were conducted in a full-scale building, i.e. an experimental fire tower for high-rise building, which is the highest and largest substantial building specially used for fire tests in the world today. There tests on initiation, development and read laws of substantial fires in guest rooms of a hotel were performed and at the same time, many kinds of test on automatic fire alarm, positive pressure supply air, operation of negative pressure smoke exhaust blowers and emergency evacuation of hotel guests were also conducted. during these systematical fire tests, a series of scientific conclusions and safety pressure values were obtained by analyzing and investigating the tested data on the temperature, pressure, air velocity and the chemical compositions of the smoke and so on at the site.

KEY WORDS:

Experimental Fire Tower, Smoke Prevention and Exhaust, Escape Routes, Temperature, Pressure, Air velocity, Chemical Compositions of smoke, Smoke Test, Simulation Fire Test, Full-Scale Fire Test.

1. INTRODUCTION

One of the Characteristics of a high-rise building fire is difficult to evacuate crowd. you can imagine how difficult it will be for the crowd to escape from a very high building at fire, with dozens or even hundred of stories under a conditions of electrical power cutdown usually. Building fire examples in existence show that a lot of people's lives are lost on their way for escaping or in the front of the elevator entrance. Practice demonstrates that solving the suddenly separate movement of endangered crowd is extremely important. At the beginning of 80's, Code on Fire Protection Design for Residential High-Rise Building was prepared and issued in China, in which, there was a very clear regulation that a staircase for safety evacuation shall be set up. If a fire occurs in a high-rise building, people inside will be safe is they move into a evacuation staircase in the floor they occupy and then they will have enough time to escape outside from the building at fire or move to other safety areas. Generally speaking this is a method to overcome the difficulty in a long and dangerous escape route. For creating such a short and safe escape route, a range of technical measures and related equipment are needed, especially for those evacuation staircases which are in the middle of a building or in the buildings without natural light and smoke purging conditions. As for the construction and structure of the staircase, fire-resistant performance of the construction materials was proved early in 70's, and fire door in the evacuation passage also met requirements on fire prevention. Today, one of key problems needed further to study is, how do we enable smoke and high-temperature air-flow caused by fire move in a direction opposite to that of escaping crowd movement, i.e., escaping crowd move from their rooms to the evacuation staircase, while smoke and high temperature air-flow accumulated in the corridor outside the door of front room of smoke proof staircase move to origin of fir and other direction opposite to people evacuation. Apparently, if we can find such a method through out tests, we can, without doubt, assure the life safety of the crowd on their escaping.

2. CONTESTS OF STUDY

To make the smoke and hot air-flow move in direction opposite to that of crowd movement in a escape routes, the critical factor is that the pressure difference must be produced among corridor, from room of staircase and staircase in a escape route. The relationship of the pressure should be: the pressure inside the corridor is lower than that in the front room, and that in the front room is lower that that in the staircase. If such a relationship is established, it can be guaranteed that the smoke and the hot air-flow shall not move into the front room, and still, at the time when the fire door of the front door is opened by occupants, the pressure inside the front room shall be decreased, and the velocity of the fresh air-flow due to the decreased pressure shall be higher than that of the smoke and the hot air-flow. That will force the smoke and the hot air-flow moving backward.

3. TEST PRINCIPLES

3.1 To find out the maximum pressure of the smoke and the hot air-flow produced in actual fire inside the corridor through simulation test inside the full-scale construction model.

3.2 By means of mechanical supply air, based on the pressure level of the smoke and the hot air-flow inside the corridor, to increase the air pressure inside the front room, to keep the supply air flow pressure inside the front room remain higher than that of the smoke and the hot air-flow inside the corridor.

3.3 By means of mechanical supply air, based on the pressure level inside the front room, to increase the air pressure inside the staircase, to keep the pressure remain higher than that inside the front room.

4. TEST SCHEDULE

4.1 A full-scale high-rise fire testing tower building is to be constructed for our test research. Following are some brief descriptions of this tower:

(1): General Description of the main tower

A. Total building area: S_z=5998.93 sq.m
B. Height above ground: H_z=39.6 m
C. Height of underground story: H_d=4.5 m
D. Floor number of the tower: 12 stories above the ground and 1 story under ground.

Inside the tower, there are every kind of full-scale room for test, such as the hotel guest room, office and accommodation rooms, meeting room, video and movies hall, KARAOKE and dancing hall, underground garage and dual purpose open and blocked refuge floor, etc. (see fig.1, 2).

(2): Test Equipment inside the tower
A. Mechanical pressurization supply air system inside the staircase.
B. Various structure and layout of mechanical pressurization supply air system inside the front room.
C. Two-way mechanical smoke exhaust system inside bed room.
D. Mechanical smoke exhaust system on the wall, suspended ceiling inside the

corridors.

E. Various layout mechanical smoke exhaust system on the wall, suspended ceiling inside the front room.

F. Water pool, tower top water tank, outdoor fire hydrant, automatic sprinkler, network water supply and fire extinguishing system.

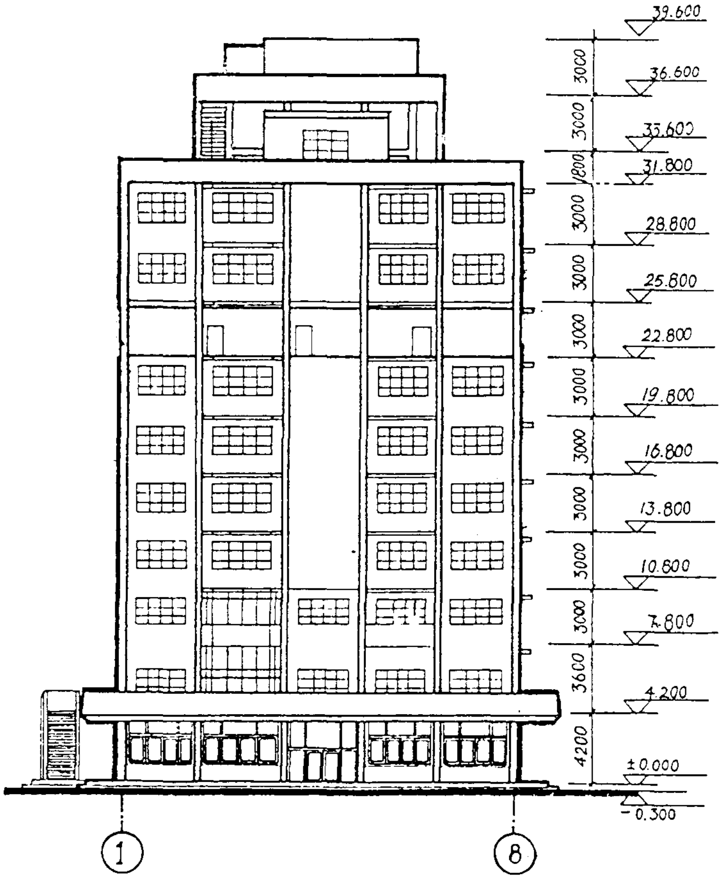

fig. 1 Vertical view of the tower

G. Multi-points air pressure and smoke pressure measuring network system.

H. Temperature measuring system

I. Synthetic testing and data processing computer system.

J. Automatic fire-alarm system.

K. Movable TV, video-recording and microwave transmission system for test site.

Besides, we have also some special meters and appliances such as movable smoke generator, high-temperature anemograph, smoke chemical compositions site analyzer, portable micro-barometer, etc..

In December, 1994, an Special Appraisal Committee, sponsored by Ministry of

Public Security, had an examination on this tower, which was certificated to be the first class of the same kind construction in the world.

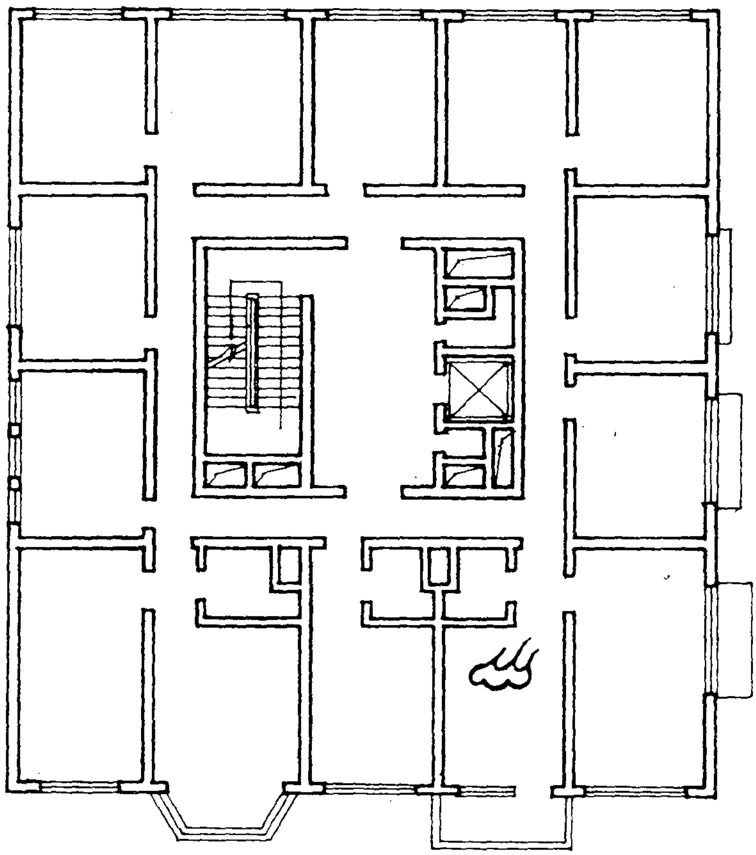

Fig.2 Scheme of the Tower

4.2 Choice of Test Type

(1): Smoke Generating Test

To find out the resisting capability of different pressure values against the smoke and the hot air-flow, tests shall be repeated many times. If all the tests were carried out with real simulated fire, it will cost too much. To be more economic, a special smoke generating appliance, movable smoke generator, is used as the smoke generating source. This kind of smoke generator is able to generate smoke continuously for 60 minutes, with smoke generating capacity of 0.4~0.5 cu.m per minute, and the smoke temperature at the outlet is specified between 150 and 200 degree centigrade.

Under constant smoke-generating condition, the pressure change of the smoke is observed and recorded from the igniting-room to the corridor. At the same time, comparison tests are carried with smoke exhaust and no smoke exhaust in the corridor. With the pressure increased inside the staircase and inside the front room and the simulating the situation of door opened or closed, we can obtain the optimal pressure values to keep the smoke from entering the front room and/or the staircase. Visual and chemical compositions analysis are used to determine if the smoke has entered the front room and/or the staircase or not.

(2). Simulation Test of guest room

Based on the smoke generating test results, a preliminary optimal safety pressure values are obtained. Then a stimulation fire test of real fire is carried to examine the preliminary pressure values. According to the fire load density in a standard guest room of a real hotel, we use equivalent volume of wooden and textile materials in place of real furniture and furnishings inside standard guest room.

To make the density and layout of flammable materials more close to the real situation in hotel, based on our observation and investigation a five-star graded hotel with 63 stories, "Guandong International Hotel", which is the highest building, is chosen as the model in our tests. To make the layout of flammable materials more reasonable, the density value of each kind of materials is calculated as follows:

A. Density value of wooden materials, $L_{d1}=20\ kg/m^2$.

B. Density value of textile materials, $L_{d2}=3.6\ kg/m^2$.

C. Density value of leather and plastic materials, $L_{d3}=0.2\ kg/m^2$.

Out concept is that the fire is caused by a guest, who smokes while lying on bed, and the ignites the flammable coverings. So, we choose the middle of the bed as the original point of the fire.

The times of each door opened and closed are determined according to the escape routes when fire occurs, and the total time needed for escaping. The escape routes are specified as follows:

When warned by fire alarm, the guests open the room door (door No.1), then => enter corridor => open the front room door (door No.2) and enter the front room => open the staircase door (door No.3) and enter the staircase => down to the base floor along the stairway, open the door to the reception hall (door No.4) and enter the hall => open the door to outside (door No.5) and get out of the building at fire.

The time of doors opened and closed are shown in tab.1.

tab.1

Total test time	Test time of period	Controlled test conditions
30'	0~5'	(1). ignite according to test requirements
		(2). automatic alarm light is on (red) and buzzer begins to buzz
		(3). after alarm, pressurization begin according to locations and values specified in tests
		(4). escape along the specified route
		(5). all the doors are opened during escaping
	5~10'	fire doors along the escape route are opened and closed 6 times per min.
	10~30'	All the fire doors are closed except the fire door to the staircase at the first floor, which is opened and closed 1 time every 3 min.

(3). Fire test of full-scale guest room

The main purpose of the test is to check once more the accuracy and reliability of the results and conclusions obtained in two kinds of above-mentioned tests, to make sure that no problems will occur in the application of these values and conclusions.

A feature of this test is that the layout of the guest room, furniture and furnishings inside the guest room are similar to that in a real guest room of a hotel. Thus, the test results is strong. Other test conditions and procedures are identical to those in (2) Simulated fire a guest room.

5. TEST RESULTS AND DISCUSSION

5.1. Smoke generating test

26 times of such a test have been done. Following are the general description of these tests:

(1). Air pressure was increased only in the staircase and not in the front room.

Air pressure at 10 Pa, 20Pa, 30Pa, 40Pa, 50Pa and 60Pa were adopted for the tests. The results show that the air pressures over 40 Pa in the staircase are safety air pressure values, and the 40 Pa is the optimal safety pressure value. When the air pressure in the staircase increase to 40 Pa, the smoke shall not enter the staircase when the people open the doors No.1~5 on their escape way. At 40 Pa of air pressure, all the door can be opened easily and conveniently by the people on their escape way. When the door to the staircase (door No.3) is closed, as the people open the front room door, there is a little smoke entering the front room from the upper of the door, and soon after, when the door No.3 is opened, a little smoke in the front room moves back. Both the direct observation and the analysis results of the chemical composition show that this amount of smoke can not do any danger to the people. and as the door No.2 and No.3 is opened, the smoke in the corridor moves back to the room where smoke is generated.

(2). Pressurization to the smoke proof staircase without front room

Before the test begun, open the fire door between the front room and the staircase. In this way, the front room and the staircase are communicated as a enlarged staircase. When the test begins, close the door No.2 between the corridor and the front room, and supply air to the enlarged staircase until the air pressure reaches to 40 Pa. Now, open the door No.2, it is found that the smoke does not enter the front room, but moves backward. this shows an obvious smoke proof effect.

(3). Pressurization to the staircase and the front room at the same time

Two groups of such test have been done. Each group test is repeated 3 times. the test results are shown as in tab.2

tab.2

Group No.	Pressurization values (Pa) in		When door opened, the smoke description in	
	staircase	front room	staricase	front room
1	30	20	no smoke entering	a little smoke enters the room when door No.2 is opened, and few seconds later, moves backward.
2	40	30	no smoke entering	no smoke entering and the smoke in the corridor is forced back into the room where smoke is generated

These results show that the optimal air pressures are 40 Pa in the staircase and 30 Pa in the front room.

(4). Pressurization to the staircase and the front room at the same time, and smoke exhausted by blower on suspended ceiling in corridor.

Two groups of such test have been done. Each group test is repeated. The test are shown as in tab.3.

tab.3

Group No.	Pressurization values (Pa) in		When door opened, the smoke description in	
	staircase	front room	staricase	front room
1	20	10	no smoke entering	a little smoke enters the room when door No.2 is opened, and moves backward when door No.3 is opened
2	30	20	no smoke entering	no smoke enters when door No.2 is opened

The test show that the smoke exhaust system on suspended ceiling do reduce the smoke amount in the corridor, but when the fan turns at the Max. speed of 1100 revolutions, only half of the smoke amount is reduced. It is impossible to purge all the smoke in the corridor. In our test, the vent of the smoke exhaust is multi-foils of 1000x800 mm size, about 5 m from the smoke generating room, the corridor is 1.15 m in net wide, and the thickness of the smoke layer increases progressively in a range of 200~500 mm, moves at a speed of about 0.3 m per sec. In such a test condition, the smoke near the opening of vent is purged obviously, but the smoke layer of 500~300 mm away from below of the opening is not influenced, and still moves forward at its original speed. This means that the smoke exhaust opening has a certain negative pressure smoke exhaust effect when its negative pressure drawing arrange is within 300 mm from the opening.

In out test, we observed a phenomenon. When the door No.2 and No.3 is opened, due to the pressure change, most smoke in the corridor is forced back into the room where smoke is generated, but the smoke near the suspended ceiling is reluctant to move back, and is still gathered around the opening due to the influence of negative pressure. Because out smoke purging opening is near suspended ceiling outside the front room door, the smoke brings some threats to the people. It seems that it is not good to set the opening near the front room door. Due to the same reason, in our traditional design, we usually set the smoke purging opening in the front room. It seems that this is not good, but harmful.

(5). Pressurization to staircase, and smoke exhaust blower on the wall in the corridor

The main purpose is to compare the effects of smoke exhaust on suspended ceiling with that of smoke exhaust on wall.

By two tests, it was found that at the same fan speed, the effect of wall smoke exhaust system is not so good as that of suspended ceiling system. Obviously, due to the position, smoke exhaust system on suspended ceiling has a larger area contacting with the smoke flow, and is much more effective that wall system.

5.2. Simulated fire test of guest room.

This test is more realistically than smoke generating test, and also more strict in test conditions. This test is necessary to examine the preliminary conclusions we obtained in smoke generating test.

(1). Pressurization of 40 Pa in staircase, and 30 Pa in the front room

Two times of such test were done. The fire in the guest room developed normally, with the highest temperature about 950 degree centigrade. No smoke entered the front room in our two tests. what is more, as the people opened the door No.2 and No.3, within about 1 minute, the smoke in corridor moved back to the guest room where it burnt fiercely, and soon after, the smoke and the hot air in the room rushed outside into the sky through burnt doors and windows, while in the corridor, there was no smoke.

(2). Pressurization of 40 Pa in the staircase, and no pressurization in the front room

Two times of such test were done. The fire in the guest room developed almost in the same way as it in the above-mentioned tests. The smoke in the corridor is densely, with visual distance of less than 1 meter.

Test began. During the first 5 minutes, when the crowd was escaping, no smoke entered the front room; during 5~10 minutes after the test, when the doors were kept opened and closed, every time when door No.2 is opened, a little smoke enters the front room due to the negative pressure caused by the opening of the door. The smoke is little, so the alarm system does not sound. When the door No.3 was opened, due to the pressure change, the smoke in the front room slowly moved back to the corridor, and then, back to the igniting room.

5.3. Full-scale Fire test of guest room

(1). The type and amount of furniture and decorative materials in the guest room are shown in tab.4.

tab.4

Serial No.	Type	Weight (kg)
1	single bed	27.50
2	single bed	29.50
3	bed head cabinet	4.50
4	reading desk	15.50
5	TV-rack	11.50
6	luggage shelf	5.50
7	bed cushion	18.50
8	bed cushion	19.00
9	cotton fibers	2.50
10	cotton fibers	3.00
11	cotton fibers	3.00
12	cotton fibers	4.00
13	pillow	0.75
14	pillow	0.75
15	bed sheet	0.50
16	bed sheet	0.50
17	tea table	6.50
18	turnable chair	7.50
19	turnable chair	8.50
20	room door	65.00
21	W.C. door	44.00
22	Carpet	37.40
23	Pelmet	2.80
24	All the others	117.00
comprehensive weight: 434.7 kg		
comprehensive flammable materials density: 23.8 kg/m^2		

Note: No.24 refers to some small wooden adornment, such as wooden mirror frame, pelmet box, etc.. The weight should be understood as the total weight.

(2). The layout in the fire test room is shown in fig.3 and photo No.1.

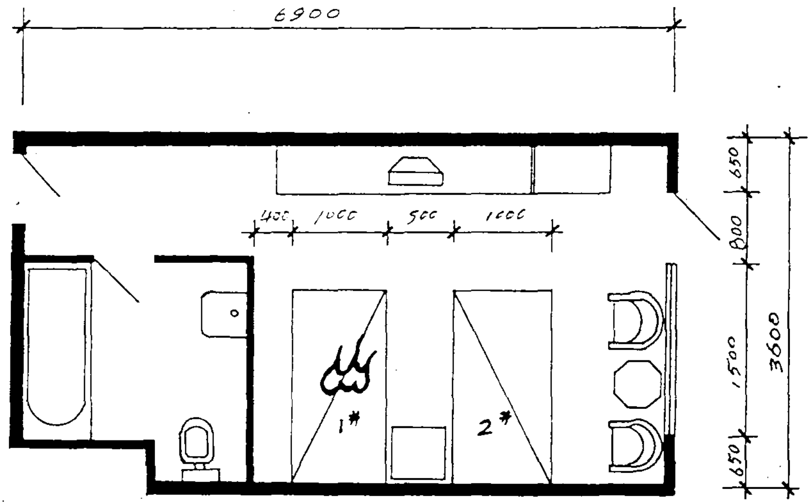

Fig.3 The layout in the fire test room

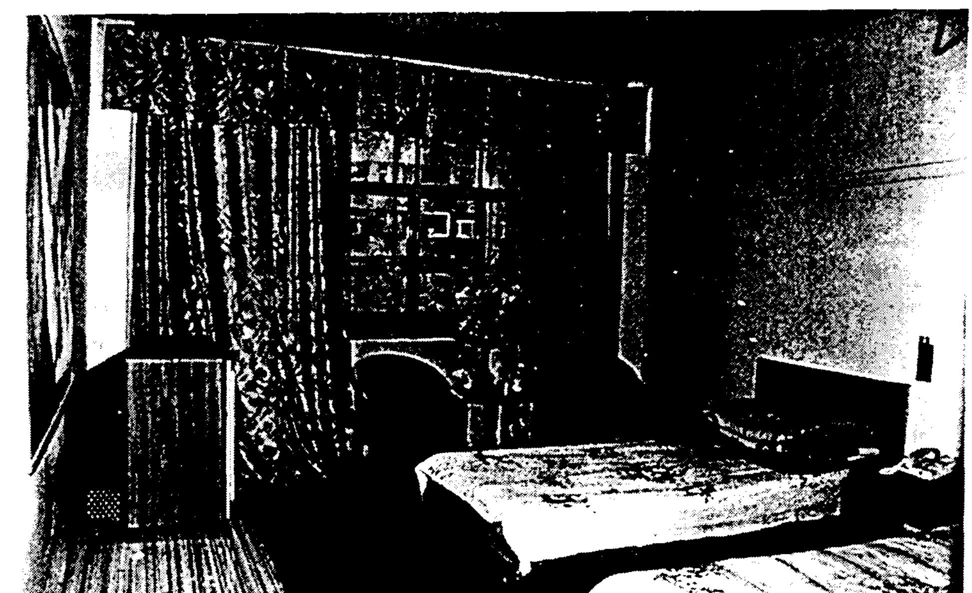

Photo No.1 The layout in the fire test room

(3). Approval test with pressurization of 40 Pa in the staircase.

The test details are descripted in tab.5.

tab.5

test and time:	15:30, June 21, 1995
location:	2nd floor of the tower
climate:	cloud, 24 degree centigrade
pressure:	40 Pa in the staircase
time	Description
0'00"	test began. Suppose a smoker was smoking lying on the bed (photo No.2)
0'20"	Sensor No.1 in the room alarmed, and supply air fan in the staircase operated.
1'40"	pressure in staircase increased to 40 Pa, and people in guest room began to escape along the specified route.
4'30"	bed in the room burnt fiercely, smoke in the room became dense; soon after, smoke entered the corridor, but not the opened door No.2
5'00"	close the fire doors No.2,3,4. The fire door is kept opened and closed 6 times per minute (see photo No.3)
7'20"	a little smoke entered the front room
10'00"	close the door No.2 and No.3 on the fire test floor. the door No.4 on the first floor was kept opened and closed 1 time every 3 minutes.
12'53"	the bed No.1 was burnt very fiercely, with the flame height of 80 cm. the telephone was burned fiercely too. smoke was very dense in corridor, with the visible distance less than 1 meter. smoke in front room disappeared.
20'30"	the two beds in the fire test room burnt fiercely with very dense smoke. temperature in the room is as high as 950 degree centigrade (see photo No.4)
28'30"	some smoke entered the front room when door No.2 was opened, soon after, the sensor in the front room alarmed, about 30" later, smoke moved backward out of the front room
30'00"	fire-extinguishing work began. almost all flammable materials in the room were burned (see photo No.5)

The whole test shows that the staircase is safe at pressurization of 40 Pa. Because of no pressurization in the front room, when door No.2, which is between the front room and the corridor, is opened, a little smoke will enter into the front room. Visual observation, or chemical composition analysis, or alarm of the smoke sensor shows that. When the door No.3, which is between the front room and staircase, is opened, the smoke moves back out of the front room.

(4). Approval test with pressurization of 40 Pa in the staircase and 30 Pa in the front room test time: 15:30, June 23, 1995

climate: cloud, air temperature is 24 degree centigrade

test condition and procedures are the same as these in the above-mentioned approval test.

Similar to the above-mentioned approval test, in this test, the test room was burnt fiercely, smoke was very dense in the corridor with visible distance less than 1 meter, temperature was as high as 200 degree centigrade, and the smoke pressure was very close to that of the above-mention tests, with the maximum of 10 Pa. But no smoke entered into the front room no matter the doors were opened or closed. When the door was opened suddenly, a little smoke entered, but moved out of the room and back into the corridor very soon, while in the above test where no pressurization in the front room, the smoke stayed in the front room for a while.

Photo No.2 Test begins, ignite the bed No.1 in the room

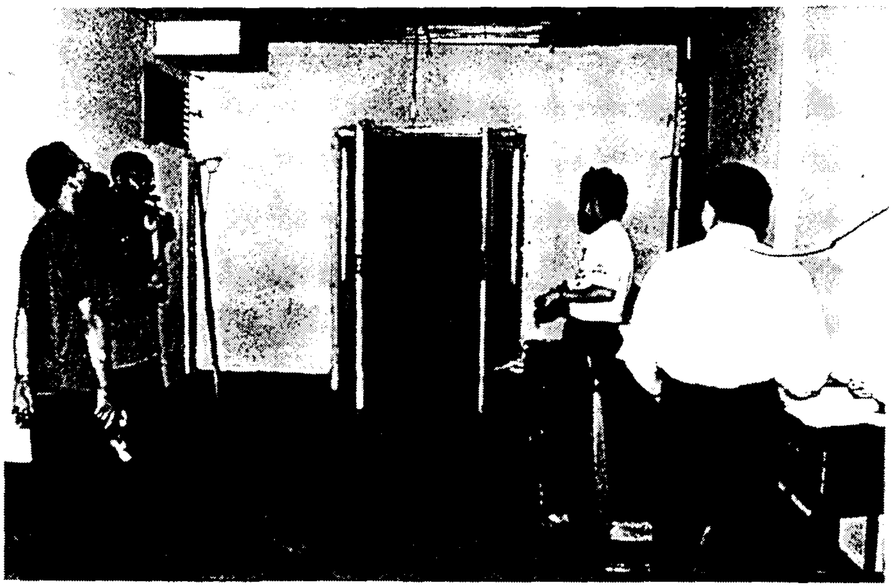

Photo No.3: Simulate the series of behaviors of the occupants to open the door No.2 to the front room

Photo No.4: all materials in the test room were on fire

Photo No.5: 30 minutes later, fire-extinguishing works began

6. CONCLUSIONS

(1). For high-rise buildings, the optimal safety supply air pressurization is 40 Pa in the staircase and 30 Pa in the front room;

(2). For the smoke proof staircase with no front room, the optimal safety supply air pressurization is 40 Pa;

(3). smoke exhaust system should not be located inside the front room of the smoke proof staircase;

(4). smoke exhaust opening should be far from the front door for evacuation;

(5). The best location of smoke exhaust opening in corridor is on suspended ceiling.

REFERENCE

Wang Weiyun, December, 1994, "Study on smoke prevention and exhaust in staircase of high-rise buildings", Science and Technology Reports, the Ministry of Public Security, P.R.china

Wang Weiyun, august, 1995, "Study on smoke exhaust technology by positive pressure supply air mechanisms system in staircase of high-rise buildings", Science and Technology Reports of the State Science and Technology Committee, P.R.China.