Fire safety design on the performance-based for skyscraper – a case in Japan

Naohiro Takeichi, Yoshikazu Minegishi

Abstract

Performance-based design of evacuation safety for high-rise complex and its verification are presented in this paper. In the design process, three points of view were mainly considered; prevention to/from city fire, control of fire and smoke spread and egress plans under bad scenarios. To prevent fire spread to/from neighborhood, buffers were installed at the connections to other facilities. In addition, in the high-rise complex, some buffers are installed to prevent fire spread across the occupancies, and limit number of evacuees who have to escape. Other buffers named safe waiting area were prepared for queuing evacuees. On the verification, all rooms in the whole building were verified on performance-based. Mainly ASETs were estimated by smoke spread from αt2 design fire. The atrium was verified by two-layer zone model simulations. Pressurizing system of staircases was verified by smoke movement simulation with network zone model.

Keywords

Performance-based design, pressurizing system, evacuation, fire compartment

1 Introduction

In Japan, many high-rise buildings have been designed under the performance-based solution. Prior to 2000, many atriums, sports stadiums, other new structures/ spaces which do not meet the prescriptive code were built by alternative solutions. Following the amendments of the building regulations at 2000[1], alternative solutions came to be widely used in order to realize flexible architectural design and reduce the building cost.

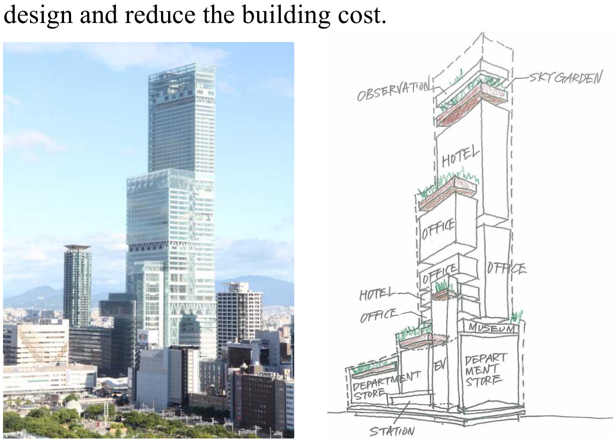

Fig. 1 Appearance of Abeno Harukas and its occupancies

To realize the Abeno Harukas which is the highest high-rise building in Japan (Fig.1), in flexible design, high efficiency, and cost effectively, performance-based fire safety design was adopted.

2 Strategy of Fire Safety Design and its Verification for Abeno Harukas

The Abeno Harukas is a project of renovation and reconstruction for the biggest department store located in Osaka which was built before WWII. The store has included a railway station and had been connected to other buildings and also another subway station.

In this redevelopment, one part of the structure was reconstructed to a tower and the other part were kept and renovated. The new facility became more complex with a railway station, the biggest department store, restaurants, museum, office, observatory, etc.

Concentration of the different uses contributes for efficiency of the land and energy in daily uses, however, there is also the side that, in an emergency, for instance when a fire occurred, the fire would influence to all occupants and make a large number of evacuees.

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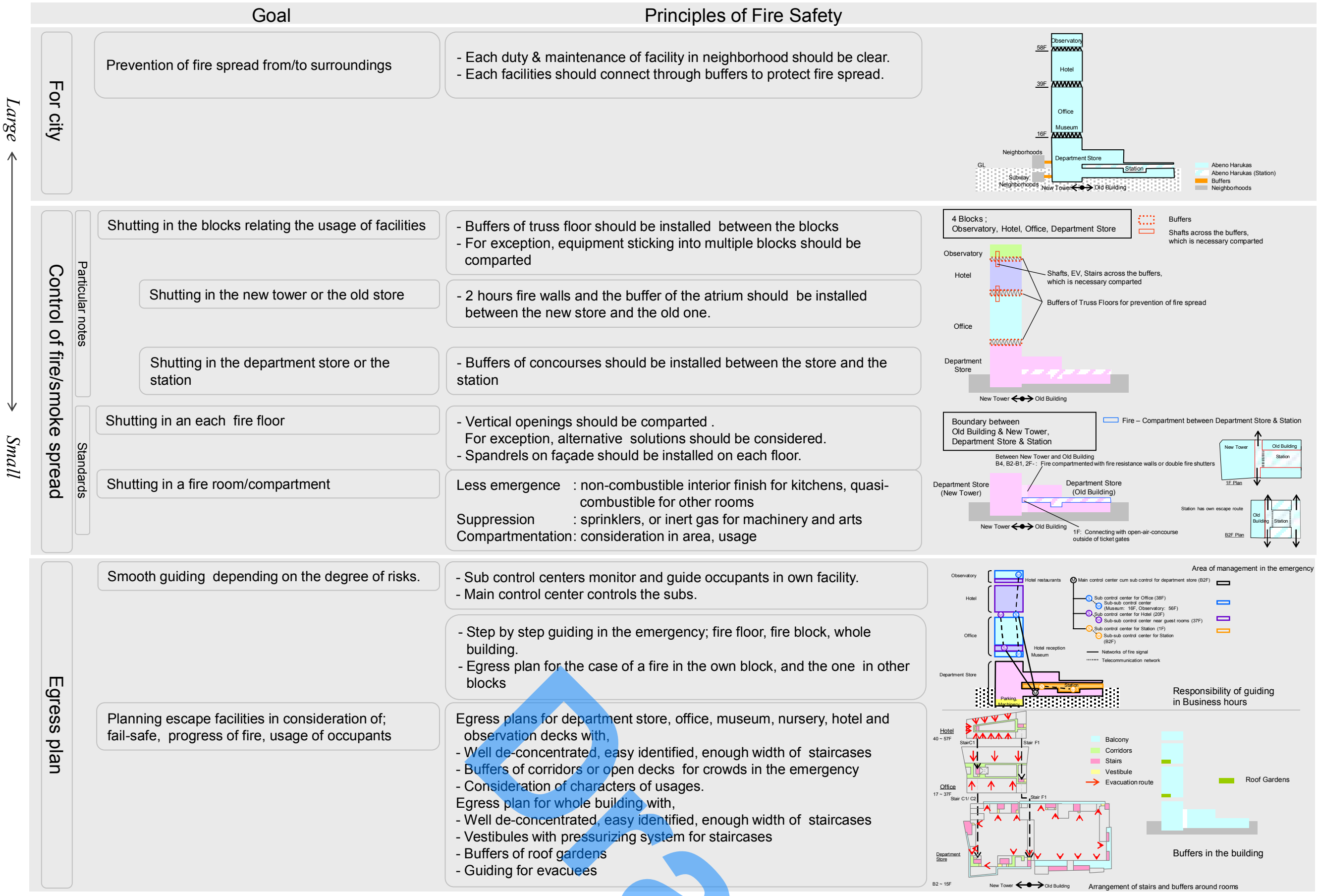

Fig. 2 Principles of fire safety

In the process of fire safety design, we considered the following three points of view;
1) Prevention of fire spread from/to surroundings
2) Control of fire and smoke spread
3) Egress plans under bad scenarios

Fig 2 shows the total principles of the fire safety design. Under the principles, facilities and equipment were designed. Also those were verified by performance-based methods.

The fire safety design in details and some verification methods are described below.

3 Limitation of Hazards

3.1 Protection of Fire Spread to Outside of the Building

The building is like a hub in the city, which connects to another subway and other buildings.

To protect a fire spreading to each other, buffers area set between the building and surroundings. The buffers are not only fire-compartded by walls and shutters, but also they are open the air or having smoke exhaust system to avoid fire spreading to other buildings.

The buffers are set at the every connection to the surroundings as shown in Fig 3.

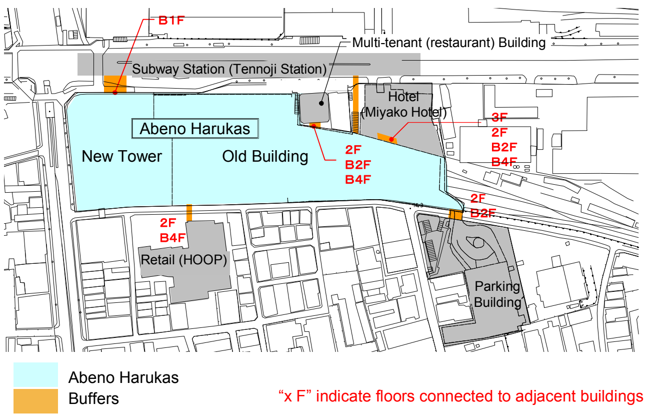

Fig. 3 Buffers between the Abeno Harukas and neighborhoods

3.2 Protection of Fire Spread over the Usage

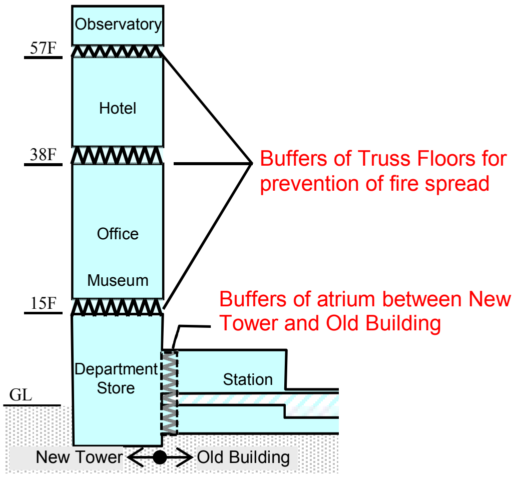

Fig. 4 Buffers of truss

To avoid fire spreading over the usage, this building is divided into 4 blocks relating to the occupants, and buffers are located between the blocks, as shown in Fig.4.

The buffers between the blocks are “truss floors” with machinery rooms so that there are less combustible. In addition, the height of the truss floor is expected to protect vertical fire spread. By limiting the fire spread inside the fire block, necessity of urgent evacuation of non-fire block is reduced and this contributes to less confusion in the egress and overflow of staircases.

Meanwhile, at the bottom of the tower there is a biggest department store. Because of different floor heights of the part in new tower and the other part in the old building, they are connected through an atrium. To avoid fire spreading to each other, we designed the atrium as another buffer. When a fire occurs, fire and smoke will be stopped spreading at the boundary. Both areas are provided own escape ways, for not passing over the atrium in the egress.

4 Egress

4.1 Egress Control

The Abeno Harukas has a variety of occupancies and each of the occupancy has each different opening hours, own managers and staffs. In an emergency, they have to be united, informed and controlled in a one system.

It should be reminded that Harukas is a huge facility and it will take much time to travel. For example, when a fire detector alerts, it will take longer time than usual building to determine that the alert is real or not.

We designed some equipment and their network for earlier determination and guiding system for occupants.

4.1.1 Network of Control Centers

Managers and staffs of each occupancy are familiar with their own facility, however if they act based on their own judgments in an emergency, the situation would be very confusable or a panic would occur at worst case.

To avoid the confusion in an emergency, occupants are divided into 4 groups: Hotel, Offices, Department store and the station. Division is made by considering their daily management, quantities of occupants and distance. The groups are related to the fire blocks as described before.

Each group except the department store has own sub control center. A main control center organizes sub control centers and directs the department store, as shown in Fig.5. In an emergency, by distributing sub control center hazards can be recognized quickly and the officers in where the emergency occurs focus to inform and help their occupants at first. Other sub centers are informed by the main control center.

4.1.2 Step-by-step Guiding

To consider the risk of the occupants, guidance for escape

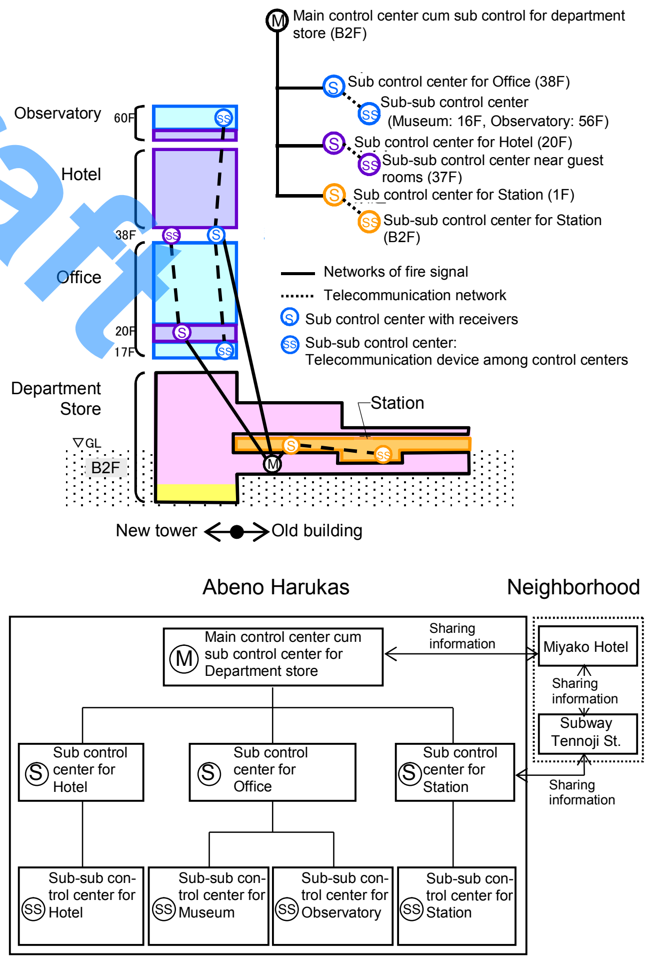

Fig. 5 Network of control centers

is planned by step by step to avoid overcrowd and confusion that would induce unexpected accidents.

Right after a fire detector detects the hazard, the fire alarm alerts only in the fire floor and the above fire floor immediately. Secondly after a while, it alerts to the fire group. Finally, it alerts in the whole building.

The occupants facing to the imminent danger can escape at first before the exits or staircases are crowded. The other safer occupants wait during this earlier stage. They will be guided if the fire will be spread and as needed.

4.2 For Uncontrolled Crowd

To protect occupants during this escape period, we designed not only usual fire compartment of rooms and floors, but also set some buffers as described before. Those fire buffers can prevent fire spread even if a fire cannot be limited within usual fire compartment. These can limit the number of evacuee who has to evacuate. However, there is still a possibility that evacuation of whole building is necessary, evacuation facilities are carefully planned as follows.

4.2.1 Arrangement of Exits and Safe Waiting Area

Exits are dispersedly arranged in order to shorten traveling distance and not to be over crowded. Those numbers and sum of width were given under performance-based design.

In addition, there are buffers called safe waiting areas which are fire-comparted corridors with smoke protection system or open balconies.

To consider the situation that evacuees have to queue in the safe waiting area when the staircases are fully occupied. The area of safe waiting area was given by numbers of occupants in each floor.

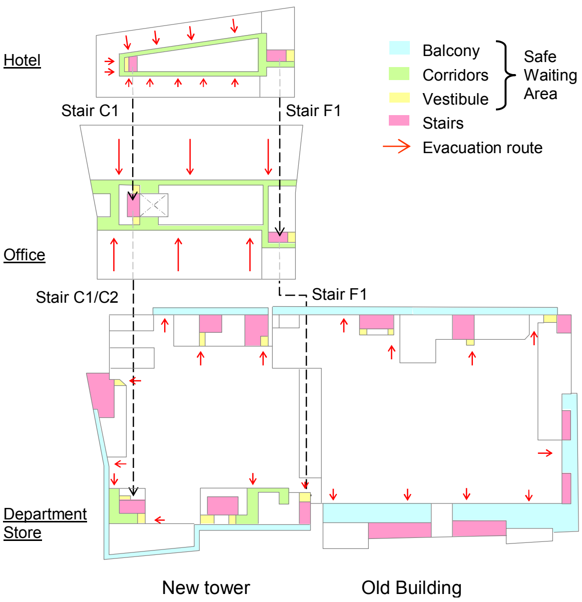

Fig. 6 Arrangement of stairs and buffers around rooms

There are two stairs in the observatory and hotel, three ones in the offices, and ones of 40cm width per 100m^2 of the floor area in department stores, as shown in Fig 6.

4.2.2 Installation and use of Roof Gardens

There are roof gardens on the truss floors between the blocks as shown in Fig 7. At worst case of fire, there is a possibility of leaking smoke into staircases or the situation of evacuee staying long time in the crowded staircases.

The roof gardens were planned as temporary waiting area for evacuees. Evacuees can escape from the occupied staircases to the roof gardens, stay safe in less crowded gardens, and transfer to another less crowded staircase at the floor.

The roof gardens are monitored by the main control center and evacuees will be guided by the sign and provided information from the main control center.

4.2.3 Pressurized Vestibule for Staircases

All staircases are enclosed by fire resistant walls or open to outside. Especially in the offices, hotel and observatory which are in the upper floors of the tower, the staircases have the vestibule with pressurizing system.

The pressurized vestibules are rational for a skyscraper because it is able to compete to stack effects of staircases.

5 Fire Safety Plan to Each Occupancy

5.1 Department Store

The old department store on the site had amazing fire safety design; perimeter balconies for escape and transferring roof terrace which can connect the stairs above railway platforms to the ground.

At this reconstruction into high-rise tower, we kept the fire safety principles; the balcony is extended to the new tower area. Evacuee can escape to the balconies or fire comparted corridors and they can queue temporary for safe.

The new tower area and the old area have different floor heights and those areas are connected with a narrow atrium as mentioned before. In a case of fire, evacuation through the atrium may be a risk to the evacuees in the connected upper floors as shown in Fig 8.

To avoid the risk, new and old areas are divided at the atrium by the measures described at **Sec. 3.2**, and each area has sufficient own means of egress.

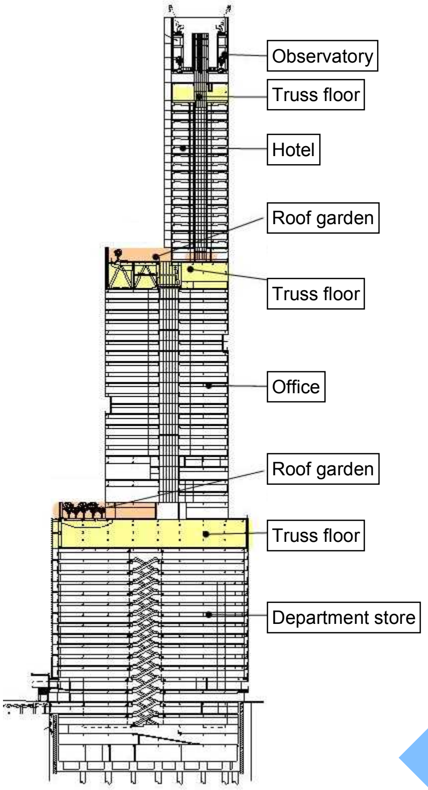

Fig.7 Buffers of truss and roof gardens

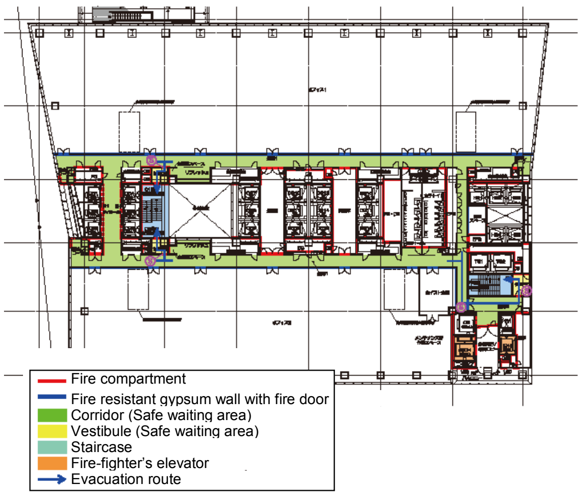

Fig. 9 Plan of Office

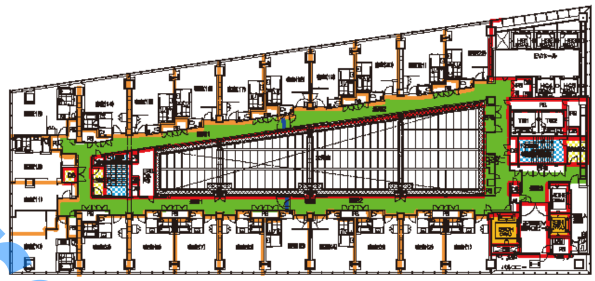

Fig. 10 Plan of Hotel

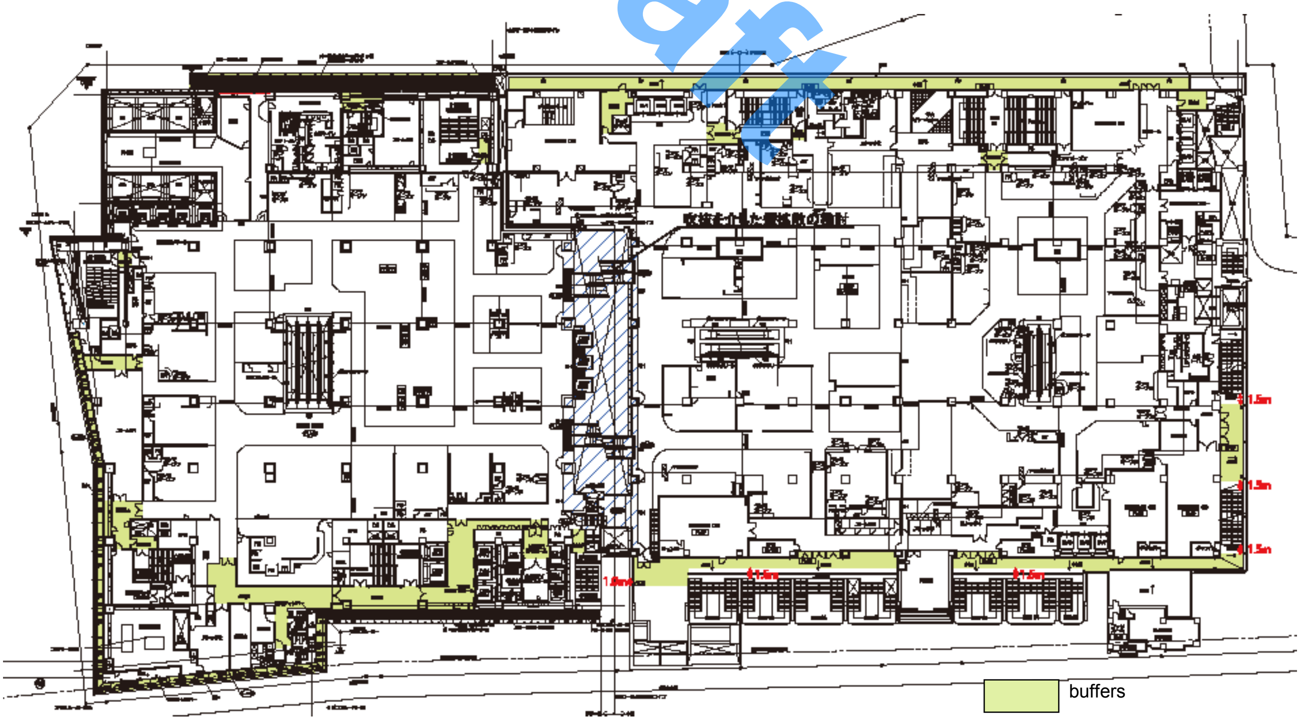

Fig. 8 Plan of Department store

5.2 Office

The office floors are designed as center core style. Corridors in the core and also the vestibules of staircases are designed as safe waiting area. Just following the prescriptive code, only two stairs are required from just view point of travelling distance, however for performance-based design three stairs are provided for reducing egress time. Two of them are provided as scissors stairs.

The vestibules have pressurizing system, reversely corridors and office areas have smoke exhaust system. The volume of pressuring and exhaust was designed to acquire enough pressure to protect vestibules from smoke.

5.3 Hotel

Generally in a hotel use, providing a balcony on the guest room for emergency route is recommended by authorities [2]. But the hotel in this building is located in the high-rise section. Thus because of strong wind and fear for falling, balconies is not effective.

Alternative solutions are considered as below.

- Each room is comparted by fire resistant wall
- The corridor is the only evacuation route for all occupants in the floor. Thus, the corridor is divided into two fire compartments to limit smoke spreading. If smoke leaks in one compartment, the other one is kept free from smoke at least.

In addition, the vestibules are pressurized in the hotel.

6. Verification

In the assessment in Japan, initial settings in the regulation [3] or well-established methods [4] are commonly used.

Against Abeno Harukas, for more precise prediction of ASET and RSET, some formulas were adjusted and added from initial settings. For example formulas for smoke descent time in the regulation is abbreviated conservatively, thus we modified it into time historical calculation. Some particular simulations were also used.

Some examples of design fires are shown in Fig 11.

According to the regulation, all room evacuation safeties and all floor evacuation safeties should be verified. Also whole building evacuations should be verified. Some examples will be described in details below.

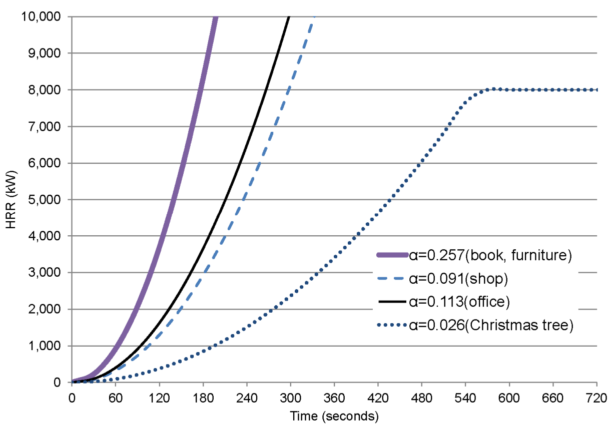

Fig. 11 Design fires

6.1 For Atrium in the Department Store

There are some goods and decorations at the atrium from B3F to 14F in the department store. Expected maximum combustible material was a 5m-high Christmas tree.

The smoke spread through vertical openings would create a significant hazard, thus that we assumed two severe scenarios shown in Table 2. At the both scenarios, smoke of the fire enters into the shop area in the upper floor.

Smoke spread was simulated by two layer zone model "BRI", and the egress time was calculated by the regulation's default formulas except the starting time of evacuation. The starting time was estimated on the each scenario.

The result of #1 scenario is shown in the Fig 13, which shows smoke layer doesn't drop to critical height in the stores, which connect to the atrium

Table 2 Scenarios of fire at the atrium

#	parameters	pre-condition
1	*Fire*	αt^2 fire of the Christmas tree at the atrium. α: 0.0265; Max: 8MW limited by the fuel
	Compartment	A shutter on 11th or 14th floor won't be active.
	Evacuee	Customers on the 11th and 14th floor. They assumed to start when the smoke filled till 10% of the ceiling height.
2	*Fire*	αt^2 fire in the shop at the B2nd floor, which connect to the atrium. α: 0.257; Max: 70MW limited by ventilation
	Compartment	A shutter on 11th or 14th floor and one on the shop on the B2nd floor won't be active.
	Evacuee	Customers on the 11th and 14th floor. They assumed to start when the smoke filled till 10% of the ceiling height.

Effects of sprinklers were not expected in all cases.

6.2 For Pressurizing System for Smoke Control

All evacuation stairs in high-rise floors are designed as the "special evacuation stairs" which means having vestibules to protect stairs from smoke spread as set in Building Standard Law. In this building, all vestibules of stairs on the office and hotel floors are installed with pressurizing smoke control system. Performance of the pressurization

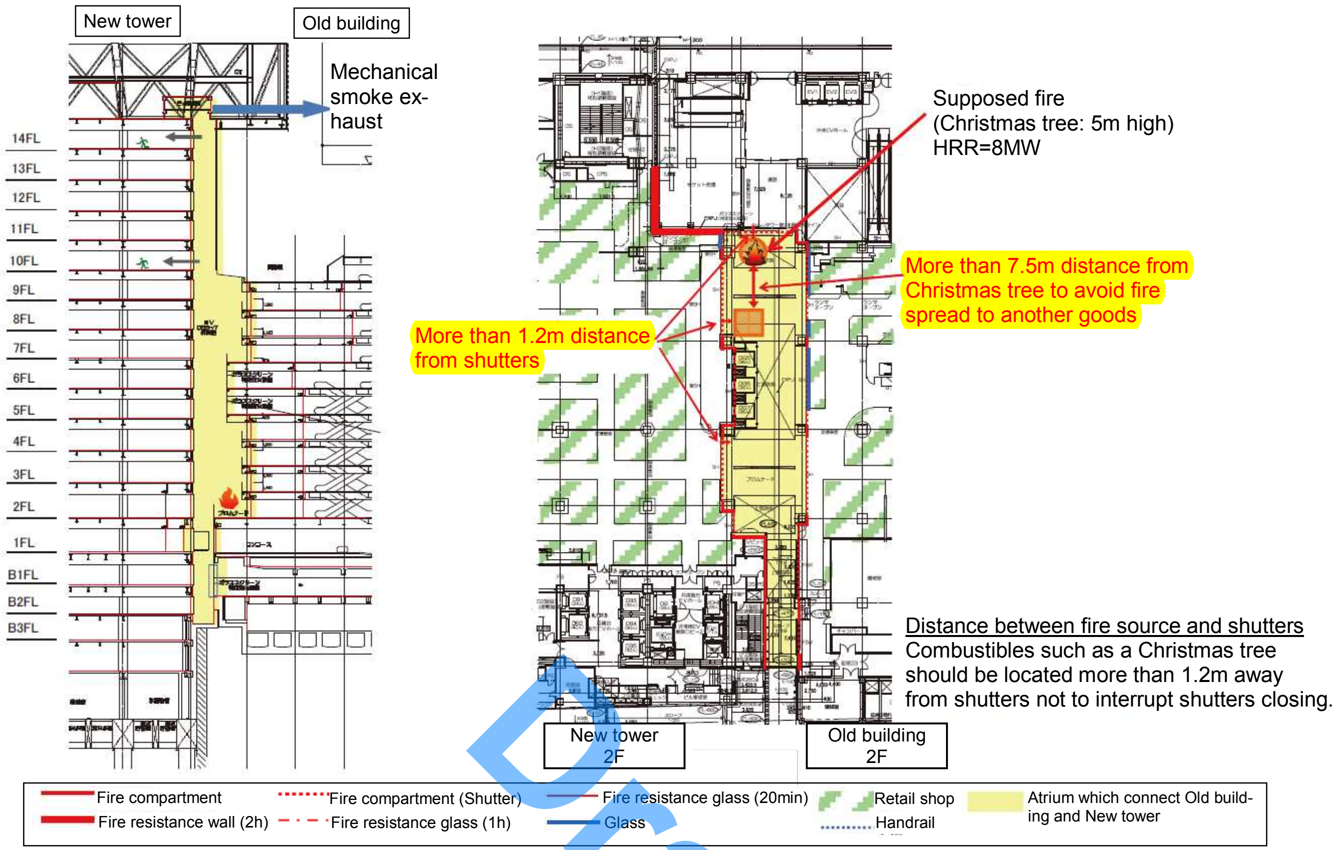

Fig. 17 Fire safety design of the atrium

system was designed through smoke movement simulation with network zone model.

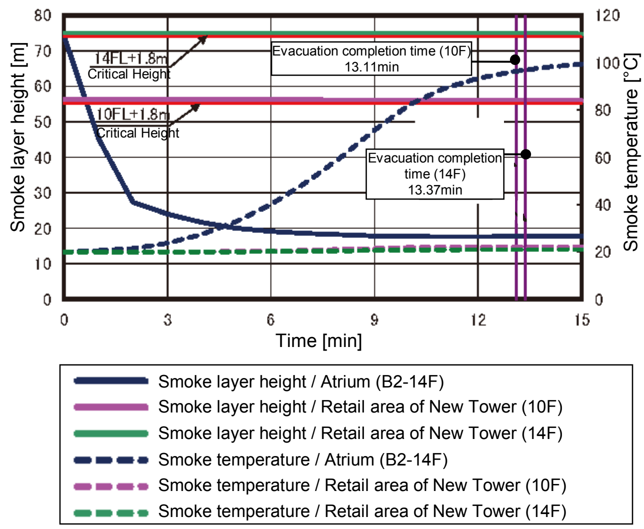

Fig. 13 Smoke layers assumed in a case of a tree-fire in the atrium

Conditions for the pressurization design are as follows;

1) Fully developed fire in office area was assumed (the temperature in the fire room was assumed to be 800°C) and smoke propagate from fire room to corridor through gaps on fire doors which were caused by some pinched obstacles. The temperature in corridors was assumed to be about 200°C by the leakage.
2) To ensure robustness of pressurization, condition of fire doors was given conservatively. Fire doors between vestibules and corridors were assumed to be open 50% for passing of evacuees or fire-fighters, those between vestibules and staircases were assumed to be 10% open for pinching of obstacles, such as fire-fighter's hoses or evacuee's shoes, and those between staircase and outside on ground level were assumed to be 100% open in consideration of the long egress time to the ground.
3) Pressure relief openings are installed to decrease pressure in fire room and/or corridor to consider for running down of mechanical smoke exhaust because of temperature rise on exhaust fans. Those openings of pressure relief are interlocked with pressurization fans.
4) Conversely to 2), if all fire doors could be closed successfully, pressure in the vestibules became excessively high, and exit doors could not be open. To prevent over pressure, pressure relief dumpers are installed between the vestibules and corridors, or the vestibules and outside. By this pressure control, door opening force under the pressure is maintained smaller than 10kgf.

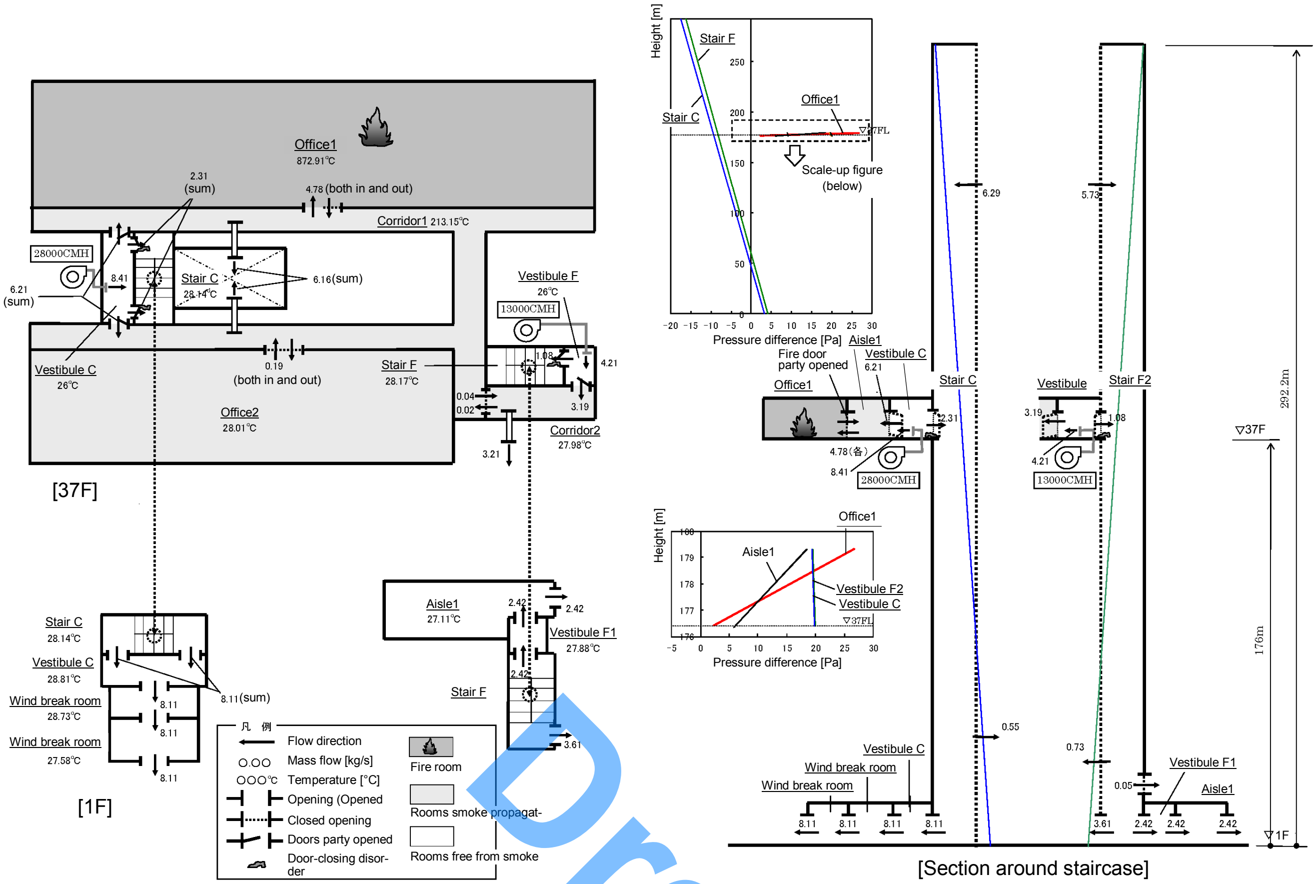

Fig. 14 Network zone model simulation of pressurizing system for staircase

Fig 14 is one of the results of network smoke movement simulation. About 300m high staircases cause strong stack effect, thus to counteract this pressure, the amount of air supply for vestibule pressurization tend to be large. Pressurization system is only installed for the vestibules on higher floors; office, hotel, and observatory floors. The stack effect in summer season is the most adverse condition for pressurization of smoke control.

9 Conclusion

In the assessment of high-rise buildings, well-established methods and conservative judgments are commonly used.

In the performance-based design, all rooms and escape routes were designed to have evacuation safety and verified by engineering methods.

To limit the hazards, not only ordinal fire compartments and sprinklers were installed but some varieties of buffers are also set at connections among neighborhood, among blocks of occupants, between the new tower and the old building. Also for evacuees, quantities of means of egress and safe waiting areas are designed based on evacuation and smoke movement prediction. Networks of control centers are structured for quick response and guiding of evacuees in an emergency.

For those calculations, time historical smoke prediction method which is adjusted from formulas in regulation is used. In addition, two layer zone models is used for the atrium, and network zone model for pressurizing system of staircases.

References

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