Fire safety in high-rise buildings under elderly housing

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Abstract. As China has entered the aging society, most of the buildings are concern to the use of elderly. When fire occurs in crowded places, the elderly casualties will take up larger proportion. However, current residential design code did not made special targeted requirements of this kind of buildings in construction standards and building design for there is a lack of elderly building security legal documents and data support. To solve this problem, it is considered the provisions of the building height restrictions from the perspective of construction safety in the revision process of Code for design of residential building for the aged. The purpose is from the angle of architecture and improves the elderly living safety to reduce fire evacuation process in risk. Furthermore, the building plane complexity and other internal factors will also become an important factor affecting the evacuation. This study focus on the tall residential buildings, several different numerical simulations are carried out to clarify the main influence factors of evacuation in elderly concentrated buildings and to provide data support for the architectural design and standard formulation.

1. Introduction
Fire is a disaster caused by the loss of control combustion in time and space. Among all kinds of disasters, fire is one of the most frequent and widespread threats to public safety and social development [1].

Building fire in China is more serious which is related to the Building structure form, production and living characteristic. When a fire occurs in a building with a lot of smoke released and spread rapidly, personnel in the building cannot evacuate is smoked dizzy even suffocation poisoning death. At the same time, smoke spreading around greatly affects the personnel evacuation and escape and increase the property damage and casualties. Therefore, smoke is the most harmful factor in the fire. Statistics at home and abroad show that the personnel death in fire is 75% ~ 85% due to the hazards of smoke. Poisonous and harmful gases are the main causes of fire casualties. Not only the great toxicity of hot
smoke, but also the reduced visibility of internal space gives more difficulty to evacuation and firefighting works. With the rapid flow of hot smoke spreading, the fire further expands and takes a turn for the worse \([2,3]\). For example, Dongdu shopping mall, Luoyang, Henan Province in 2000, the fire led to 309 deaths caused by workers’ illegal use of welding in the basement. All deaths were due to gas poisoning. In February 2003 Daegu subway fire, casualties of more than 200 people, most of which are caused by smoke. In 1975, the Japanese thousands of department store fire caused 118 death and 93 among because of smoke. Therefore, it is important to understand the mechanism of the generation and movement of fire smoke, and to prevent and control the disasters.

Nowadays, fire is a common problem faced by people all over the world. And all sorts of fire cases and data show that there is close relation with the evacuation. In order to ensure the safety of personnel, evacuation strategy and plan not only need consider the environmental and emergencies factors but also take into account the psychological and behavioral characteristics \([4-7]\).

Such psychological and behavioral characteristics related to the personnel features, the structure of buildings, safety evacuation routes or facilities. It also influenced by fire development and fire products, individual characteristics, and staff's cognitive level, social characteristics, different dangerous situation and other factors. However, there is little study on the characteristics and rules of how these factors affect psychology and behavior of people in fire evacuation in China. Study on this issue not only have the important practical significance in building fire in the psychological and behavioral characteristics, enrich personnel evacuation psychology and behavior reaction database, as the performance of fire protection design and draw up the fire emergency evacuation plan provides the scientific reference basis, but also has theoretical significance to build and enrich our country’s psychology of fire, fire psychology, social psychology, architecture and other.

In recent years, with the increasing number of old people in China, the State encourages all kinds of social forces to participate in the construction and operation of various types of facilities for the elderly. However, with the increasing number of facilities for the elderly, number of fire accidents also increased, and resulting in casualties of the fire accidents have occurred from time to time. Such as 26 July 2013, Hailun, Heilongjiang Province, A fire occurred in combined nursing home and 11 people were burned to death, 2 people lightly smoked hurt. On the morning of December 7, Harbin, Heilongjiang Province, Antai nursing home took place the fire accident which caused 2 old men was killed and three others were injured. The general factors impact of personnel evacuation include the age, gender, physical health status and other personal factors, and also covers the characteristics of the occupation and other social relations.

Age difference is the main factor that affects the walking speed and the fire reaction of the safety evacuation. General sense, the walking speed of young people is faster than the elderly and children and sensitive response is relatively stronger. All kinds of statistical data show that the most died in fires are elderly and children for they cannot make a timely response to the fire, and also cannot quickly leave the fire.

2. Building fire simulation

This study aims to evaluate the safety of evacuation in buildings with elderly focus living by the analysis of simulation results. In this study, we study the mixed population of 60 years old people with different proportion.

This study will focus on the residential buildings in Beijing to carry out the numerical simulation of fire and evacuation.
Table 1. Simulation objects and conditions

| Objective                  | Fire development                                                                 | evacuation situation                                                                 |
|----------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Old residential building   | Numerical simulation results of different fire scenarios include smoke spreading,| Simulation results of evacuation scenarios include evacuation time, congestion,        |
| (Unit apartment)           | smoke layer height, temperature in the corridor and the staircase, and the law  | evacuation effect, and then put forward reasonable suggestions for evacuation.          |
|                            | of the smoke spreading.                                                           |                                                                                        |

The details of the building shows as follow:

Unit corridor residential building: the gross area of 12150 m², 18 floors, building height 54m, floor height of 3m. The whole building is new-style symmetrical layout. Each floor has 10 rooms, The residential building model and a standard floor plan is shown in Figure 1.

![Building south scenograph](image1) ![Building west scenograph](image2) ![Building standard floor plan](image3)

(a)Building south scenograph   (b)Building west scenograph   (c)Building standard floor plan

Figure 1. The anisotropic view of unit apartment

3. Fire conditions

The simulation modeling is completed by Pyrosim software, and the fire and evacuation simulation is completed by FDS software [8].

Assuming that the initial state of the flow field is static, the initial temperature is 20 °C, and the pressure is 1 atm for there is no difference in the temperature and pressure between the interior and exterior. In the process of fire simulation, all exits and exits are kept clear.

Thermal boundary conditions of all solid surfaces are set to the characteristics of the relevant materials FDS in order to reduce the interference of other factors and to simplify the calculation. In this study, we assume that all walls, ceiling and flooring materials of the buildings are concrete.

The temperature of the flow field is measured by thermocouples, and the measurement of the height of the smoke layer is measured by the layer device at a certain place. At the same time, the arrangement of slices can be used to display the temperature and other parameters of a section.

3.1. Thermocouple arrangement

Taking into account the average height of the human eye in about 1.6m and when the smoke descend to 1.6m will directly affect the evacuation of personnel, the horizontal direction of the thermocouples
are arranged at the height of 1.6m (from the floor). Thermocouples are mainly arranged in three places: corridor, staircase, fire room and the adjacent room which are key places affecting evacuation.

3.2. Layer height arrangement
5 points are arranged evenly on the middle axis of the first floor corridor.

3.3. Slices arrangement
Slices are set in the stairs, and through the corridors to analyze the temperature change of the staircase, fire and corridor.

![Figure 2. Fire and measuring points in first floor plan of unit apartment](image)

4. Results analysis

4.1. Fire development
Power of fire source in the simulation was set of two different respectively to consider the smoke development and temperature change in the corridor under the conditions of fire with windows open and completely closed.

| Table 2. Fire simulation of unit apartment |
|------------------------------------------|
| **2MW fire** | **5MW fire** |
| Temperature in corridor | |
| ![Graph](image) | ![Graph](image) |


Smoke layer height in corridor

*Note: maximum heat release rate of the fire reference for the Shanghai Civil building smoke control code DGJ 08-88-2000 the civil anti smoke technical specification of section 4.2 "fire model identified and smoke discharge". It gives the fire model in various places. When residential buildings are not equipped with sprinkler system, maximum heat release rate refer to the without sprinkler office / guest room of 5MW fire. Same as following.

4.2. Evacuation situation

The 6 evacuation cases are designed for the simulation of the evacuation of the unit department as shown in Table 3 [9].

| No. | Initial personnel (per/floor) | Reaction time (s) | Personnel diameter (m) | Average evacuation speed (m/s) | Remarks |
|-----|-------------------------------|-------------------|------------------------|-------------------------------|---------|
| DE1 | 25                            | 20                | 0.4-0.5                | 1.2                           |         |
| DE2 | 25                            | 50                | 0.5-1.0                | 0.8                           |         |
|    |                               |                   |                        |                               | All necessary evacuation routes (including doors, stairs, doors, etc.) are open to 20% |
| DE3 | 25                            | 50                | 0.5-1.0                | 0.8                           |         |
| DE4 | 50                            | 50                | 0.4-0.5                | 0.8                           |         |
| DE5 | 50                            | 50                | 0.5-1.0                | 0.6                           |         |
| DE6 | 50                            | 50                | 0.5-1.0                | 0.6                           | All necessary evacuation routes (including doors, stairs, doors, etc.) are open to 20% |

As shown in the table, DE1 stand for the normal situation of personnel distribution, that is, 80% cases of adults. DE2, DE4 and DE5 are more representative of the elderly, in which the difference between the characteristics of adults and the elderly is different from the reaction time and the speed of evacuation.

**DE2**: the number of evacuation of the case is not much, the proportion of the elderly is 50%. The case mainly considered the evacuation process in the case of medical equipment. Personnel diameter is 0.5-1.0 m. But because there are more elderly people, their response time for the fire will be relatively long, so the reaction time will increase, set to 50 s.

**DE4**: the number of evacuation doubled stand for more people, the proportion of elderly people 50%. There is no medical device in this case. The personnel diameter is 0.4-0.5 m.
DE5: the number of personnel evacuation under the program is more, and there are medical facilities, and other settings are the same as the DE2.

DE3 and DE6: there are additional tests. The case considered all the necessary evacuation routes (including entrance doors, stairs and unit door, etc.) are widening 20%, in order to consider in more personnel evacuation difficulty test the need to broaden the evacuation routes.

By the above, we can see that in accordance with the normal design, that is, building evacuation routes not broaden, when evacuees set for general situation, namely more than 80% for adults, fire evacuation completed successfully. However, in the elderly more and with stretchers or other medical equipment, part of the staff did not evacuate successfully in simulation time. It is shown that if the proportion of people with weak ability of evacuation in the building increased, it is difficult to complete all the escape when the smoke and temperature are allowed to escape.

5. Conclusion
This study focus on one type of high residential building and fires and smoke flow spreading simulation were carried out. Combined with the results of the numerical fire and evacuation simulation, the main conclusions can be summarized as follows:

5.1. The law of smoke spreading
(1) Smoke was easy to gather at the end of the corridor, and the people in both sides of the corridor will be seriously affected.
(2) The distribution of smoke in the staircase was influenced by the position of the fire source, the ventilation and the floor height. In general, the temperature of the staircase decreased with the increase of the building height.
(3) Smoke spreading in the fire floor was different from the others. Smoke layer accumulation effect was more obvious at the end of corridor. Compared with the central corridor, smoke in end corridor is high temperature and layer height is low. In the middle and top floor, end corridor accumulation effect was not obvious and the temperature of the central corridor was higher than the temperature at the end of the corridor.

5.2. Fire hazards of different fire scenarios
(1) The larger the area of ventilation, the more difficult of smoke gathered in room, the higher the smoke layer height is. And with the increase of the ventilation area, convective heat transfer effect was enhanced. Temperature in corridors and staircases was relative lower, and then it left more time for people to escape.
(2) With the increase of the fire power, the smoke temperature of the corridor and the staircase was high and increased rapidly, and the height of the smoke layer is decreased significantly. Furthermore, the fluctuation range of the upper and the lower is larger, which would threaten to the safety evacuation of personnel.

5.3. Different fire scenarios of evacuation
Unit department buildings under normal condition can meet the requirements of the safety evacuation. But once the fire happens when old people is more and with medical facilities, it will be unable to meet the safety evacuation requirements.

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