IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Study on Distribution Characteristics of Key Target Personnel Density and Earthquake Rescue Strategy

To cite this article: Rushan Liu *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **562** 012055

IOP Conf. Series: Materials Science and Engineering **562** (2019) 012055 doi:10.1088/1757-899X/562/1/012055

Study on Distribution Characteristics of Key Target Personnel Density and Earthquake Rescue Strategy

Rushan Liu, Lupeng Yan and Dongqi Yan

Institute of Engineering Mechanics, Key Laboratory for Earthquake Engineering and Engineering Vibration, China Earthquake Administration, Harbin, Heilongjiang, 150080

Email: liurushan@sina.com

Abstract. The first priority after a catastrophic earthquake is to carry out emergency rescue for people buried in collapsed buildings. Some large public buildings often have a high concentration of personnel and are the key targets for emergency rescue during earthquakes. This paper summarized four survey methods for the indoor personnel density of key buildings, carried out a sampling survey on indoor personnel density in different time periods in some schools, hospitals, shopping malls, and cinemas in Yanjiao District of Sanhe City in China using these methods, investigated the changing raw of the personnel density in these key target buildings within a period of one day and the changing characteristics of the personnel density in working days and holidays, compared the differences in the time distribution of the personnel density among different types of key targets, and initially explored the strategies and attention points of rescue for indoor personnel in different key targets at different original times of earthquake, thus providing reference for rescue decision-making of indoor personnel in key buildings in the event of a sudden disaster.

1. Introduction

The first priority of the emergency work after the earthquake is to carry out emergency search and rescue of the personnel buried in the collapsed houses, so as to minimize the loss of human life. The spatial distribution of earthquake-buried personnel determines the spatial deployment of rescue forces [1]. There are many factors affecting the number of casualties in earthquakes, which are not only related to the number of collapsed buildings, but also related to the personnel density in buildings, the occurrence time of the earthquake and the effectiveness of rescue measures [2]. Some key targets such as shopping malls, supermarkets, primary and secondary schools, hospitals and cinemas are often the places where the personnel are most highly concentrated, and the indoor personnel density varies greatly with time. Once these key targets collapse due to the earthquake during the period of personnel concentration, a large number of buried personnel will be generated, who will become the top priority of rescue. If these personnel are not rescued in time, the number of casualties will inevitably increase. On the other hand, if an earthquake collapse occurs at a time when there is no personnel concentration, but a team is sent out to the scene for rescue at this time, which will form a waste of rescue forces and affect the efficiency of earthquake rescue. Therefore, it is of great significance to study the changing law of personnel density in key target buildings over time for timely deployment, scientific decision-making and command efficiency improvement of emergency rescue teams after the occurrence of severe earthquakes.

In the past ten years, some scholars have conducted surveys and simulation studies on personnel density for certain public facilities [3]-[5], especially for large supermarkets and department stores, stations etc. However, these studies are mainly aimed at the evacuation, prevention and control of fire and accident risks, the allocation of engineering energy and power indicators and the management and control of social unrest and violence risks, their study focuses and contents are different from the needs of earthquake rescue. Some domestic scholars have studied and explored the effect of indoor personnel density on the assessment of the number of casualties after earthquakes or the calculation model by means of the whole society or the classification of the overall building use types in individual areas [2], [6], [7] . However, it is rare to investigate and study the changing raw of specific indoor personnel density over time for different key targets. However, the reality is that the indoor personnel density in different key targets varies greatly with time and often has distinct characteristics.

In this study, we conducted a sampling survey on the key targets such as supermarkets and department stores, primary and secondary schools, hospitals and cinemas in Yanjiao District of Sanhe City in China, investigated a process in which the indoor personnel density varied with time, analyzed and studied the indoor personnel densities of various key targets in different time periods of a 24-hour cycle on weekdays and holidays (weekends and rest days), summarized and compared the time distribution characteristics and differences of personnel densities in different types of key targets, and provided basic reference basis for the rapid and scientific rescue decision-making after the earthquake.

2. Survey Method for Personnel Density in Key Building Targets

Limited to trade secrets or other reasons, we were unable to directly obtain data on the indoor personnel density or passenger flow volume of key building targets from their practitioners, which must be obtained through field surveys and statistics. In the survey, the following four methods were adopted according to the specific circumstances and personnel flow characteristics of the key building targets.

(1) Direct survey method for indoor personnel density. The number of indoor personnel was counted for each key target at regular time intervals, and the time distribution of personnel density could be directly obtained. This is the most basic and straightforward method, and it is suitable for key target buildings with large houses and small number of rooms.

(2) Real-time measurement method for entrance and exit. The time during the day when there were indoor personnel in the key target was divided into N equal time periods, the numbers of personnel flowing in and out were counted at the entrance and exit respectively from the moment when the personnel entered, and then the personnel density in the *i*-th time period was:

$$\rho_i = \sum_{j=1}^{i} \left(a_j - b_j\right) / S \tag{1}$$

In equation (1), ρ_i was the personnel density in the *i*-th time period, *S* was the total area of the key target, and a_i was the number of personnel flowing in the *j*-th period, b_i was the number of personnel flowing out in the *j*-th period. This method is more suitable for key targets with fewer entrances and exits, more personnel and more rooms, and it is not suitable for key targets with many entrances and exits.

(3) Relative quantity survey method. This method was mainly applicable to surveys in which the total number of personnel in the buildings such as schools was known and fixed, and a single inflow (or outflow) of personnel was concentrated in a short period of time. *N* was set as the total number of personnel in the school, and *S* was set as the total construction area of the teaching building. In the period of personnel flowing in (out), for a designated area between the gate of the school and the teaching building, the number of investigations in equal intervals was set as *m*, the number of personnel corresponding to the *i*-th investigation was set as n_i, and the number of personnel corresponding to the *j*-th investigation was set as n_j, when the personnel began to flow in until the time of full capacity, the personnel density ρ_i at the moment of *i* was:

$$\rho_i = \frac{N}{S} \sum_{j=1}^{i} n_j \Big/ \sum_{j=1}^{m} n_j \tag{2}$$

When the school began to dismiss the class and the personnel flew out from full to empty, the indoor personnel density at the time of the *i*-th investigation was:

IOP Conf. Series: Materials Science and Engineering **562** (2019) 012055 doi:10.1088/1757-899X/562/1/012055

$$\rho_i = \frac{N}{S}\left(1 - \sum_{j=1}^{i} n_j \Big/ \sum_{j=1}^{m} n_j\right) \tag{3}$$

The difference between the method (3) and the method (2) was that the method (3) was applicable to the fact that the maximum personnel density (such as the total number of students in school) was known, and the personnel simply flew in (or flew out) in the varying time period, so that as long as the personnel densities at certain moments in a representative area of the investigation point were recorded, normalization processing could be performed, and the changing value of the personnel density over time was calculated based on the total number of personnel at full capacity and the house area. It was not necessary to count the absolute number or density of personnel in the entire object area in the whole time course.

(4) Questionnaire method. The above three methods cannot be used for the survey of the indoor personnel density in the residential area, because it is not a specific target. It is feasible to use the questionnaire survey method.

3. Investigation and Analysis of the Changing Law of the Indoor Personnel Density of Key Targets over Time

In the Yanjiao Development Zone of Sanhe City, 4 supermarkets and department stores, 2 cinemas, 3 hospital clinics, 2 secondary schools and 2 primary schools were randomly selected. The indoor personnel density was investigated once for these key targets respectively on weekdays and rest days (Saturday or Sunday) in the spring of 2-3 months, and the characteristics and laws of the personnel distribution were initially analyzed. The primary and secondary schools did not have classes on Saturday and Sunday, and thus the investigation was only conducted on weekdays. In addition, a investigation of indoor personnel density in family houses on weekdays (working days) was conducted by random questionnaire, and 31 questionnaires were obtained. The specific names of key targets were not mentioned in this paper.

3.1. Primary and Secondary Schools

The personnel density in the school is the ratio of the total number of personnel in the school to the area of the teaching building. The canteen, auditorium and reception room were not included. Two secondary schools and two primary schools were investigated. The changing laws of indoor personnel densities with time in primary and secondary schools were highly similar, and the change in one day depended on the school schedule. A primary school in Yanjiao was taken as an example, this was a non-residential primary school. The spring schedule of the school was: the school gate was opened at 7:20 in the morning, the self-study class started at 7:40, and the official classes started at 8:00. A policy of dismissing the students at different times was carried out at noon. The leaving school time for the students of low, middle and high grades were 10:50, 10:55 and 11:00 respectively; the school gate was opened at 13:40 and the classes started at 14:00 in the afternoon; the students of low, middle and high grades leaved the school in proper order respectively at 16:20, 16:25 and 16:30. The changing law of the indoor personnel density during one day was shown in figure 1,figure 2(a) and figure 2(b) were detail drawings of variation diagrams of personnel density ratio during the time periods of going to and leaving school, respectively .In the figure 2, the time "0" on the horizontal axis was the start or end of classes, and the density ratio on the vertical axis was the personnel density ratio relative to the full attendance. It can be seen from the figure 2. that the school personnel density had the following basic rules: (1) Both the time for going to school and the time for leaving school were 20 minutes, from empty room to full room or from full room to empty room; (2) There was a difference in the changing raw of indoor personnel density between the two time periods for students to going to and leaving school. The former showed a semi parabola like change in the indoor personnel density, and reached a half value of the full personnel density at 15 minutes before class. The attenuation of personnel density during the time for leaving school was close to linear change, and the time for half value of full personnel density was about 10 minutes. This was actually caused by the policy of dismissing the students of low, middle and high grades at different times which was commonly adopted in local primary and secondary schools. In addition, the full personnel density of the surveyed primary and secondary schools was between 0.16 and 0.35 person/m^2, and the difference was determined by the school enrollment numbers and the teaching building conditions.

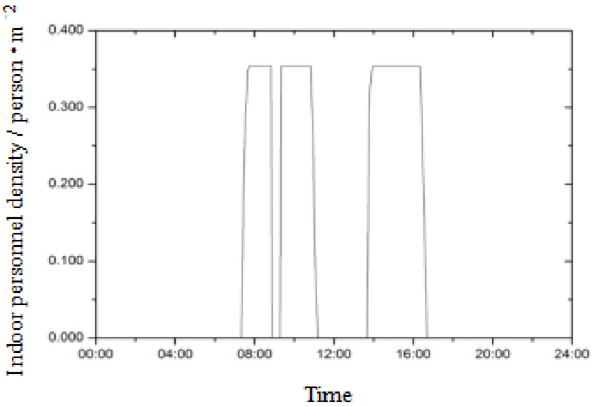
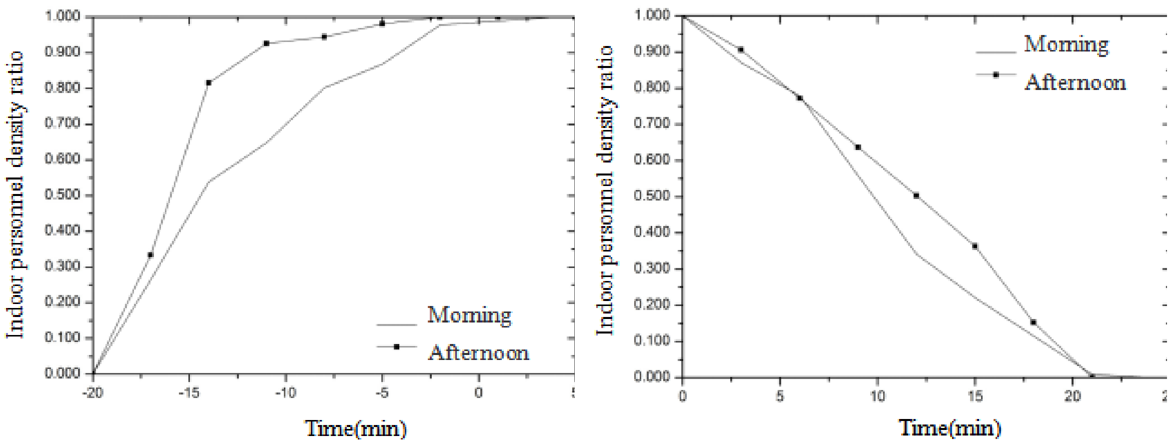


Figure 1. Changes in indoor personnel density throughout the weekdays



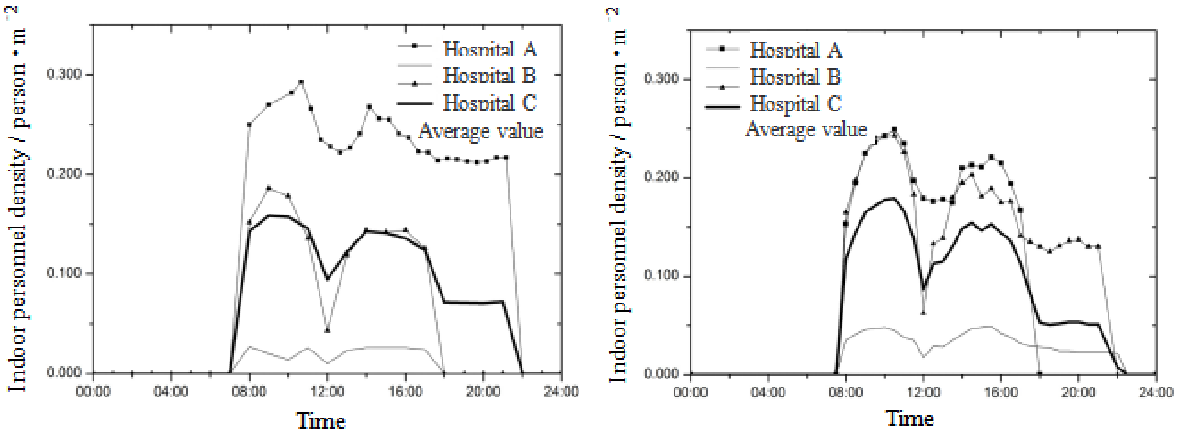
(a) Go to school (b) Leave school

Figure 2. The changing law of indoor personnel density of a primary school over time

3.2. Hospital Clinics

The indoor personnel density in the hospital clinics varied greatly with the business hours, which was different from the law that the indoor personnel density in the inpatient department was less fluctuating within a day and night. Figure 3 showed the relationship among the clinic personnel densities of three surveyed hospitals on weekdays and holidays (Saturday, Sunday)which changed over time during a day and night. It can be seen from the figure 3: (1) The hospital clinics clearly showed three peak periods, namely morning, afternoon and evening, regardless of the working day or weekend holiday, and the personnel density values of these three peak periods decreased successively. The morning and afternoon peak intervals were separated by a low ebb of density at noon, while the emergency clinic in the afternoon from the end of workday until around 10 o'clock in the evening was a platform period without low ebb. (2) The personnel density in hospital clinics on weekdays was close to that on holidays. (3) Due to the difference in medical level among hospitals of different specifications and grades, the personnel density varied greatly. For example, in the surveyed samples, the peak personnel density of hospital A was between 0.25 and 0.3 person/m^2, while the personnel density of hospital C was between 0.02 and 0.04 person/m^2. The difference between the two hospitals was about 10 times. (4) The working hours of the hospital started at 8 o'clock in the morning, but some patients actually entered the hall to wait for registration at 7 o'clock, and the personnel density reached half value of the peak density at 30 minutes before the official start of medical work.

Therefore, when providing guidance for earthquake emergency rescue, it was still necessary to establish indicators of hospital reputation, grade level and scale to determine which curve with a personnel density varying with time to use, and attention should be paid to the density level of personnel who register in advance.

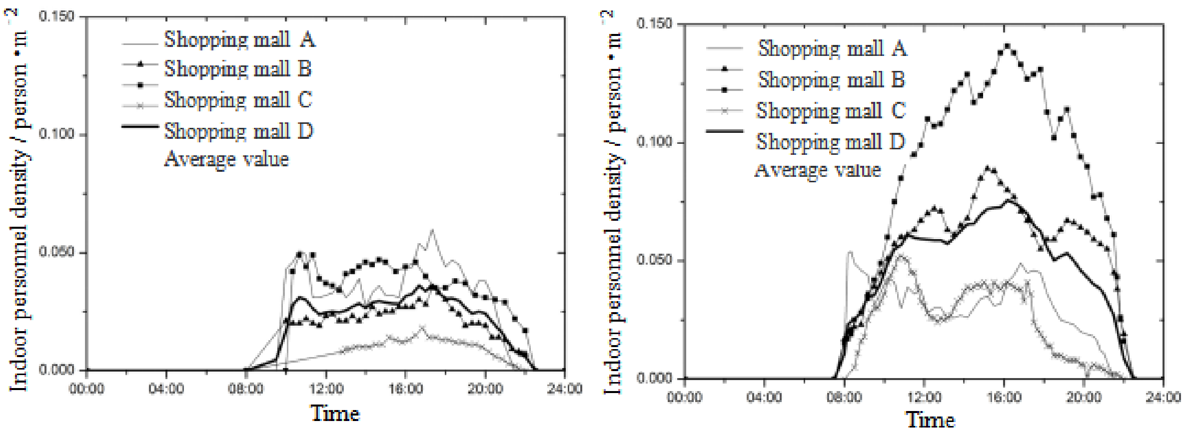


(a) Weekdays (b) Weekend

Figure 3. Indoor personnel density in hospital clinics

3.3. Shopping Malls and Supermarkets

The four shopping malls in the random sampling survey were large and medium-sized comprehensive service shopping malls in the form of supermarkets integrating comprehensive shopping and catering, wherein, there were both domestic wholly-owned shops and international brand chain stores, and the goods and businesses in the stores were diversified. Figure 4 showed the results of a survey on indoor personnel density of the selected four shopping malls on weekdays and holidays (Saturday or Sunday). As can be seen from the figure 4: (1) The indoor personnel density of the shopping mall on holidays (including Saturday and Sunday) was about 2 to 4 times that on weekdays. (2) The indoor personnel density of Shopping malls was generally in the shape of a mountain bag during the business hours of a whole day, it could be expressed with a parabolic curve. The peak of indoor personnel density usually occurred around 3 to 5 PM. In some shopping malls , a peak of indoor personnel density occurred in the morning and a small trough of indoor personnel density occurred from 12:00 AM to about 2:00 PM.(3) The difference in indoor personnel density among the four investigated shopping malls was also greater, the peak indoor personnel density was between 0.05 and 0.13 person/m^2 on holidays and between 0.02 and 0.05 person/m^2 on weekdays.

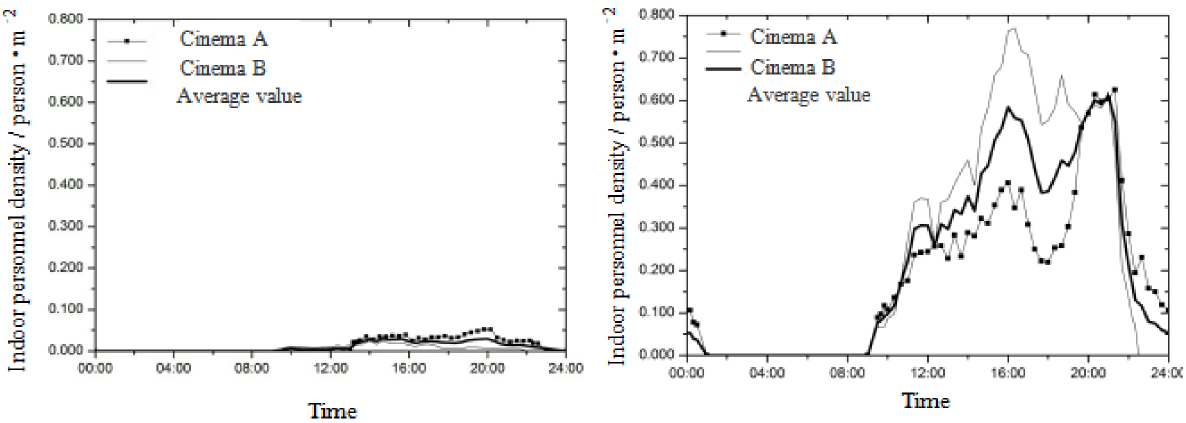


(a) Weekdays (b) Weekend

Figure 4. Indoor personnel density in shopping malls and supermarkets

3.4. Cinemas

Two cinemas in Yanjiao Town were randomly selected, Cinema A was a small and medium-sized professional movie hall, and cinema B was located in a shopping mall and also had a small and medium size. The distributions of indoor personnel densities of two cinemas in 24 hours a day on holidays and Sundays which changed over time were shown in figure 5. As can be seen from the figure 5: (1) No matter on holidays or weekdays, the personnel flow volume in the morning was relatively small, and two personnel density peaks occurred from 3pm to 5pm and 7pm to 10pm in the afternoon, respectively. The peak indoor personnel density in the evening was nearly 1 times larger than that in the afternoon. (2) The cinemas in the supermarkets: driven by the operation of the supermarket, the peak indoor personnel density in the afternoon was slightly higher than that in the evening. (3) The peak indoor personnel densities of two cinemas on weekdays were 0.045 person/m^2 and 0.061 person/m^2, respectively, while the peak indoor personnel densities of two cinemas on the weekend (Saturday, Sunday)were 0.77 person/m^2 and 0.64 person/m^2, respectively, which were far greater than those on weekdays by about 10 to 15 times. (4) The indoor personnel density of the cinema from 11 p.m. in the late at night to 1 a.m. in next morning was close to that during the business hours in the morning of that day.



(a)Weekdays (b) Weekend

Figure 5. Indoor personnel density in cinemas

3.5. Ordinary Folk Houses

In addition to the key targets, this paper also investigated the changes in the dynamic indoor personnel density on weekdays in 31 households of Yanjiao District through random questionnaires. The random respondents included in-service personnel in all walks of life and unemployed residents. The average indoor personnel density in residential building was shown in figure 6.

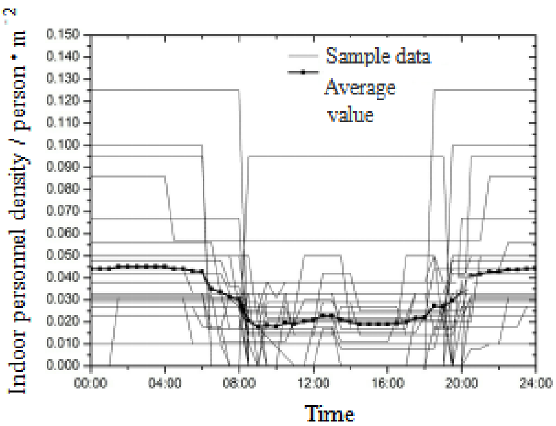


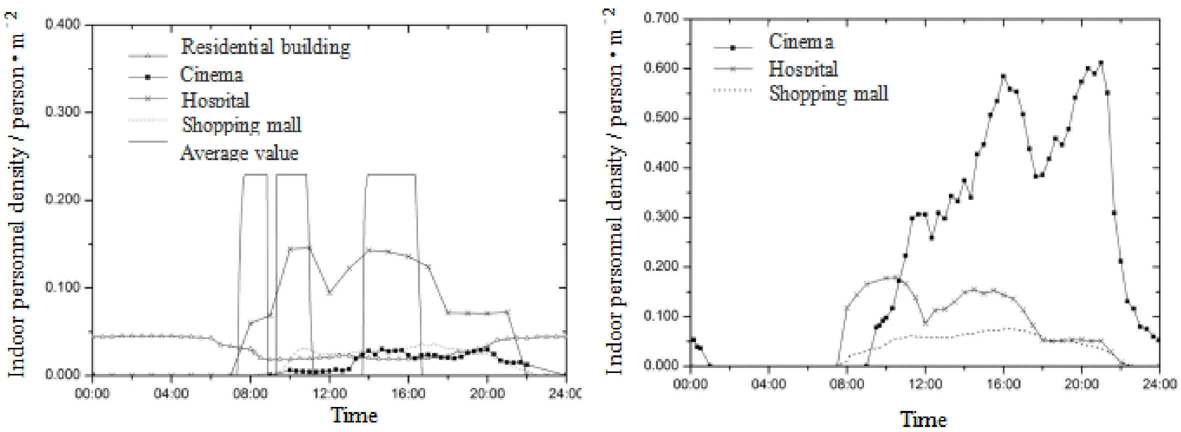
Figure 6. Indoor personnel density in residential buildings

It could be seen from figure 6 that the time period with the highest indoor personnel density in a day was from 10:00 pm in night to 4:00 am in the morning of the next day, which was about 0.046 person/m^2. The time period with lower indoor personnel density in a day was from 8:00 am in the morning to 6 :30 pm in the night. The indoor personnel density increased slightly from 12:00 am at noon to 2:00 pm in the afternoon. The indoor personnel density during the daytime period was approximately 0.015 to 0.02 person/m^2.

4. Comparison of Indoor Personnel Densities of Different Types of Key Targets And Earthquake Rescue Strategies

Figure 7 was comparison charts of the changes in average personnel density of various types of key targets over time which received sampling survey on the weekdays and weekends. The comparison chart on weekdays included the types of schools and residences. On weekdays, the indoor personnel density in the school was the highest, successively followed by hospitals and commercial facilities. The indoor personnel density in the residential buildings was relatively low. The indoor personnel density in the operating cinemas was the lowest in the morning, and was also very low from noon to evening, but similar to the personnel density level of the residential buildings.

When a devastating earthquake occurs, it is assumed that the above mentioned buildings collapse, the urgency of rescue varies greatly according to the time of the earthquake. As shown in figure 7, according to the change in indoor personnel density, on weekdays, the residential area has the highest indoor personnel density between 10 p.m in the night and 7 a.m in the morning of next day. when an earthquake, the first concern is the emergency rescue for residential areas. When the earthquake occurs after 7 o 'clock in the morning on weekdays, it is necessary to consider the emergency rescue for schools and hospitals; when the earthquake occurs after 8:30 a.m, the shopping malls start a business, the urgency of emergency rescue for the shopping malls increases. the urgency of emergency rescue for the cinema during the daytime is similar to that for ordinary residence on weekdays. If the earthquake occurs on a rest day or a holiday, generally it is not necessary to consider the primary and secondary schools as the key points of emergency rescue. If the daytime earthquake occurs within the business scope of shopping malls, cinemas hospitals , the emergency rescue for these key targets must be considered.



(a)Weekdays (b) Weekend

Figure 7. Comparison chart of indoor personnel densities of different types of key targets

For emergency rescue of key targets such as hospitals and schools, it is necessary to take into account the characteristics of the industry on the basis of consideration of the daily schedule. For example, in primary and secondary schools, although the schedule of work and rest stipulates that classes start at 8:00 in the morning, more than half of the students will be in the school classroom within 15 minutes before the start of the morning self-study before class. If it is blindly thought

IOP Conf. Series: Materials Science and Engineering **562** (2019) 012055 doi:10.1088/1757-899X/562/1/012055

that the earthquake occurs before 8 o 'clock and no rescue is considered, it is obviously an unrealistic fallacy.

5. Conclusion

According to the sampling survey, the changing laws of the indoor personnel densities of some key targets within 24 hours on weekdays and holidays are analyzed. The difference in change of indoor personnel density is compared among several key targets. The key points of rescue strategies for different types of key targets when earthquake occurs in different time periods are proposed to provide guidance and reference for rescue force allocation during the earthquake.

This study is based on the sampling survey of the Yanjiao Economic and Technological Development Zone in Sanhe City in China, and it is a study on the survey methods of indoor personnel densities of key targets serving as the guidance of emergency rescue and a basic understanding of the changing laws of indoor personnel densities of several key targets and their individual differences. In the future work, it should be extended to the investigation of the indoor personnel density in other types of key targets such as stations, restaurants and factories. As China is a vast country with different customs in different regions, there are great regional difference in the aspects such as indoor personnel density and working and rest time among various key targets, which should be further studied according to the characteristics of specific regions. At the same time, it is necessary to establish a more extensive basic database and study the risk of earthquake collapse risk in combination with the vulnerability of various key targets. On this basis, a key target rescue urgency assessment model can be established to be truly applied to rescue and become the reference basis for guidance of emergency rescue.

6. Acknowledgement

This study was Supported by: Special Fund for Basic Scientific Research Expenses of Institute of Engineering Mechanics (2018A02), China Earthquake Administration.

7. References

[1] Xianfu Bai, Yuqian Dai, Ye Liaoyuan, et al 2018 Assessment models of trapped-victim in earthquake & emergency rescue area based on high-precision building and population data *Journal Of Disaster Prevention.* Vol 34(4) pp 1-12

[2] Jiandong Xu, Fuquan Wei, Laiquan Zhang, et al 2008 Prelim inary study on evaluating the number of casualties and trapped victims by a earthquake——A case study of Zhangzhou City, Fujian Province *Journal Of Seismological Research.* vol31(4) pp 382-387

[3] Tingxia Gan, Xiaogang Xie and Zhongri Hu 2012 Application of sample inventorying methodology in surveying occupant density at public space *Fire Science And Technology.* vol 31(11) pp 1222-1224

[4] Jianing Zhao, lixia Wu, Zhaojun Wang, et al 2004 Investigation and analysis of consumer flow rate in a large supermarket *Heating Ventilating & Air Conditioning.* vol 34(6) pp 53-56

[5] Lei Feng, Changchun Tan, Lu Shouxiang, et al 2009 Statistical analysis and modeling for occupant density in commercial buildings *Fire Safety Science.* vol 18(3) pp 130-137

[6] Dongsheng Xiao, Dingfa Huang, Weifeng Chen, et al 2009 Prediction model for buried personnel probability in earthquake *Journal of Southwest Jiaotong University.* vol 44(4) pp 574-579

[7] Jiayu Cheng 1993 Probability of the original time of earthquake affecting the casualty earthquake. *Journal of Catastrophology.* vol 8(2) pp 13-16