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Fire Risk Assessment of Residential Buildings Based on Fire Statistics from China

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Abstract. Fire statistics provide valuable information for the assessment of future fire risks. The paper analyses the fire situation in China from 1991 to 2010. The temporal, spatial, and causal fire incident data for the last 6 years have been analyzed to gain an understanding of fire characteristics and the elements affecting fire risks. It is found that the number of fires was observed to be higher during cold winter months, and fires were more frequent during the weekend. The number of fires was lower during nighttime, whereas the number of fire deaths between midnight and 4 a.m. was much higher than at other times of the day. Most fire incidents occurred in residential buildings. In economically developed East China, the fire situation is much more serious. Electrical failures and improperly fire use in daily life were major causes of fire incidents. Based on the statistical data from China's fire services and the China Statistical Yearbook, the risk of occupant deaths and the risk of direct property loss are calculated to express the risk level in residential buildings. It is found that the risk of occupant deaths had a declining trend over the years. Statistics is considered a useful tool for learning from the actual events, and it helps decision makers develop proactive fire protection measures to reduce fatalities and financial losses caused by fires.

Keywords: Fire risk, Residential buildings, Statistics, Probability of fire occurrence, Consequences of fire occurrence

1. Introduction

Fire plays a significant part role in society from the viewpoints of human safety and economics, and it has become an important aspect of human civilization. With the rapid development of China's national economy, fire constitutes a major threat to life and property in urban and rural areas. According to the data offered by the Fire Service Bureau of the Ministry of Public Security, a total of 132,497 fires were reported in mainland China in 2010, with 1,205 civilian deaths, 624

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civilian injuries, and 195.9×10^8 Yuan (RMB) in direct property losses [1]. Examples are the November 15, 2010, Shanghai high-rise apartment building fire, with a death toll of 59, and the June 30, 2012, Tianjin commercial building fire, with a death toll of ten. To lower fire risk, it is necessary to better understand the main causes of fires, and to study fire characteristics carefully.

There are numerous models that calculate the fire risks in buildings. FIRECAM [2] and FIERA system [3] are used to calculate the expected life risk and fire cost expectation. The Bayesian belief net model is used to assess risk of human fatality in building fires [4]. However, these models cannot represent fire factors, such as how time, vocation, district or cause influence the number of fire occurrences and occupant deaths.

The goal of this paper is to utilize statistics to collect information and gain an understanding of elements affecting fire risk. The fire situation of mainland China from 1991 to 2010 is outlined, and a comparison of fire deaths with other countries is performed. The temporal, spatial, and causal patterns of all fires in China are illustrated. Fire risks in residential buildings can be predicted based on fire statistics to better respond to fire incidents when and where they happen. Moreover, fire statistics data offer an excellent way to learn from actual events, and the opportunity to explore potential approaches to fire loss reduction.

2. Fire Situation Analysis Since 1991

Many countries collect fire statistics to obtain valuable information for the assessment of future fire risks. Statistical information includes both general information on the fire situation in the country and detailed information that can be used for fire risk assessment.

2.1. Fire Statistics in China

The Fire Service Bureau of the Ministry of Public Security in China produces annual reports on fire losses, fire deaths and fire injuries. Figure 1 shows the fire occurrence rate and death rate (per 10^5 persons) from 1991 to 2010 in China. As can be seen from the figure, the fire occurrence rate per 10^5 persons followed a rising trend from 3.9 in 1991 to 9.9 in 2010, and the death rate per 10^5 persons followed a declining trend, from 0.18 in 1991 to 0.09 in 2010. The number of fires and direct property losses are shown in Figure 2. The Figure shows that the number of fire incidents and direct property losses from 1991 to 1996 were relatively stable. The annual average number of fires and direct property losses were 67,640 and 95.1×10^8 Yuan, respectively. From 1997 to 2010, the number of fires and direct property losses rose dramatically. The highest number of fires was 258,315 in 2002, and the lowest direct property losses were 86.0×10^8 Yuan in 2006 [1]. This rise may be due to China entered an accelerated period of urbanization after 1996, and the method of collecting fire statistics has changed since 1997 [5].

The number of casualties from 1991 to 2010 in China is shown in Figure 3. The number of fire casualties decreased significantly over these 20 years. The annual average number of deaths and injuries were 2,207 and 3,187 respectively. This

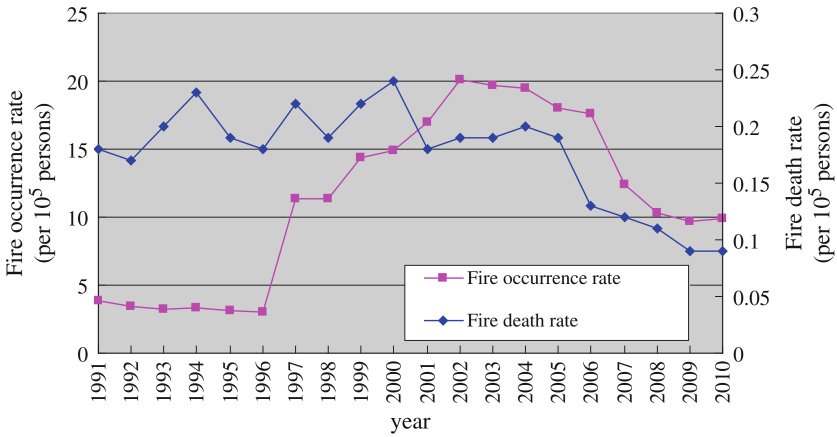

Figure 1. Fire occurrence rate and death rate (per 10^5 persons) from 1991 to 2010 in China.

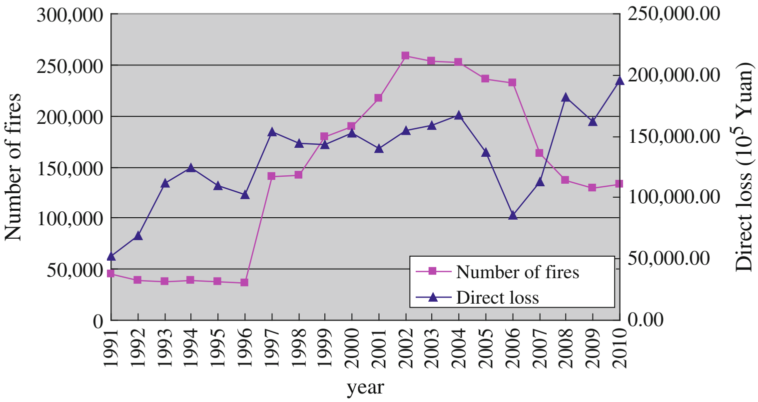

Figure 2. Number of fires and direct property losses from 1991 to 2010 in China.

reduction may be due to the great efforts and progress in fire safety science and technology in China [6].

2.2. International Fire Statistics

A comparison of international fire statistics allows various countries to examine their own fire situation in relation to others and determine whether this has improved or deteriorated. Table 1, for example, shows the Canadian and Chinese annual reports on the number of fires, fire losses, fire deaths and fire injuries [1, 7] during 1992 to 2001. The table shows not only the general information on fire losses, fire deaths and fire injuries but also the trend over a 10-year period.

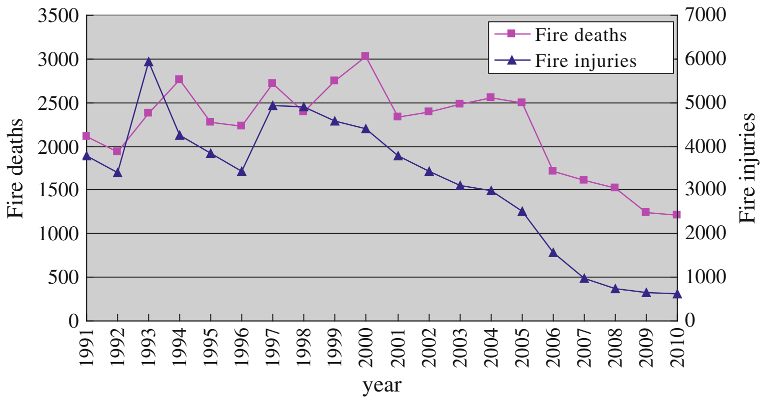

Figure 3. Number of casualties from 1991 to 2010 in China.

Table 1
Canadian and Chinese Fire Losses, Fire Deaths and Fire Injuries

Item year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Canada										
Number of fires ($\times 10^3$)	66.0	65.9	66.7	64.3	60.1	56.3	57.6	55.2	53.7	55.3
Loss ($\times 10^6$ $)	1,241	1,182	1,152	1,111	1,163	1,292	1,176	1,232	1,185	1,421
Deaths	401	417	377	400	374	416	337	388	327	338
Death rate (per 10^5 persons)	1.41	1.45	1.30	1.36	1.26	1.39	1.11	1.27	1.06	1.09
Injuries	3,874	3,463	3,539	3,551	3,152	3,149	2,697	2,287	2,490	2,310
Injury rate (per 10^5 persons)	13.7	12.1	12.2	12.1	10.6	10.5	8.9	7.5	8.1	7.4
China										
Number of fires ($\times 10^3$)	39.4	38.1	39.3	37.9	36.9	140.3	142.3	180.0	189.2	216.8
Direct losses ($\times 10^8$ Yuan)	69.0	111.7	124.4	110.3	102.9	154.1	144.3	143.4	152.2	140.3
Deaths	1,937	2,378	2,765	2,278	2,225	2,722	2,389	2,744	3,021	2,334
Death rate (per 10^5 persons)	0.17	0.20	0.23	0.19	0.18	0.22	0.19	0.22	0.24	0.18
Injuries	3,388	5,937	4,249	3,838	3,428	4,930	4,905	4,572	4,404	3,781
Injury rate (per 10^5 persons)	0.29	0.50	0.35	0.32	0.28	0.40	0.39	0.37	0.35	0.30

Figure 4 shows a comparison of fire deaths in China and Canada over a period of 10 years. It can be seen that the fire death rates (per 10^5 persons) in the two countries follow a similar relatively stable trend, but that the death rate in Canada is higher than that in China.

Comparable data of fire death rates per 10^5 persons for ten countries in 2008 [8] are shown in Figure 5. The Figure shows that the fire death rate per 10^5 persons in China was lower than that of developed countries, but that the absolute number of fire deaths in China was high. For example, in China, fire death rate per

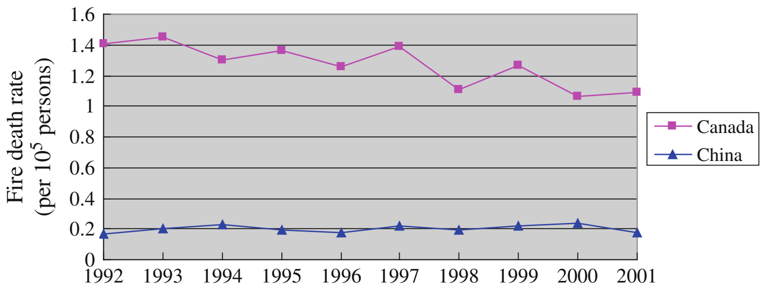

Figure 4. Fire deaths during 1992 to 2001 in China and Canada.

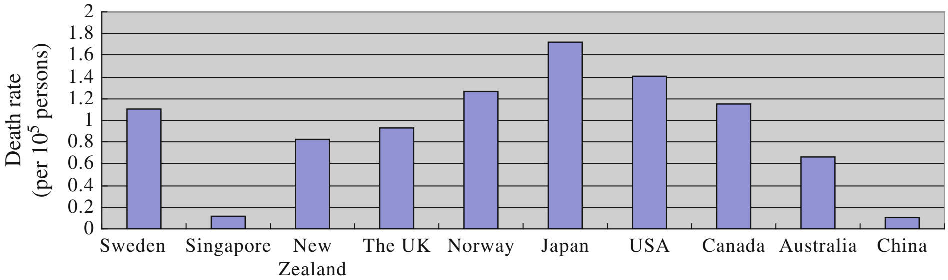

Figure 5. Comparison of fire deaths of various countries.

10^5 persons was 0.11 in 2008, but the total fire deaths were 1,521. This result may be partially due to Chinese policies and differences in the definitions or reporting systems for fire incidents [9]. In China, the local officials prefer to report the fire situation as low as possible. If the fire situation were very serious, the officials of that region would be punished. Moreover, fires in mainland China, excluding forest fires, grass fires and military fires are reported in fire statistical report in China.

3. Fire Characteristics Analysis in China

Fire records provided by the Fire Service Bureau of the Ministry of Public Security in China from 2005 to 2010 are used in the study [1, 10–14]. Each record includes a list of attributes, such as vocation, district, causes of fire incidents, estimated direct property losses, number of fatalities, and number of injuries. Additional attributes for each record, such as time of day, day of the week and month of the year, are also created.

3.1. Time Distribution of Fire Incidents

The time distributions of all fire alarms in China during the years 2005 to 2010 are presented. The periods are month of the year, day of the week, and hour of the day. The monthly distribution of the percentage of the number of fires is

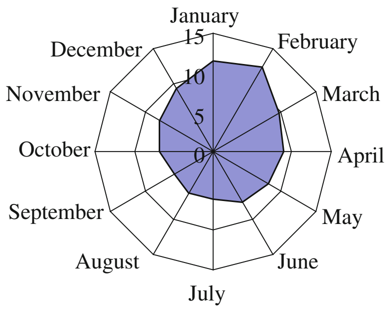

Figure 6. Distribution of total fire incidents by month of year.

considered and shown in Figure 6. As can be seen, the number of fires was higher during the cold winter months of January and February and lower in autumn in August and September. This characteristic is the same as in other countries [15, 16]. The number of fires in February showed the highest percentage (average 12.5% of the total) and the lowest percentage (average 5.65% of the total) was found in September. This result may be due the weather in China becoming cold in the winter, with people warming themselves using various heating means.

The daily distribution of the percentage of the number of fires is considered and shown in Figure 7. As can be seen, the weekday variation was rather small. Fires were more frequent during the weekend, and the number of fires on Sunday have the highest percentage (average 15.0% of the total), perhaps because it is a day when most people are off work and stay at home.

The distribution of the percentage of the number of fires by time of day in China during the years 2005 to 2010 is shown in Figure 8. The Figure illustrates that the number of fires was lower during nighttime and higher during daytime. The number of fires starts to rise after 6 a.m., exceeds the diurnal average after 10 a.m., and remains above average until 10 p.m. The possible reasons for this trend include people resting at home, the presence of children in homes and inadequate surveillance capabilities at abandoned workplaces. Arson activities may also

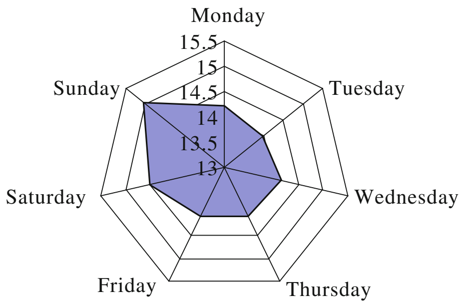

Figure 7. Distribution of total fire incidents by day of week.

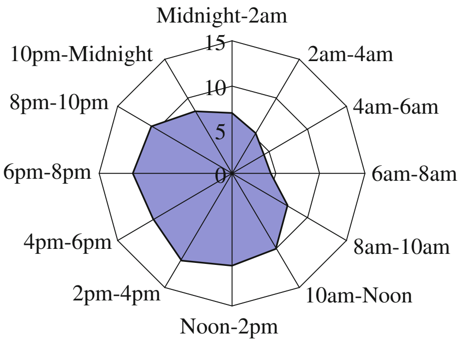

Figure 8. Hourly distribution of total fire incidents.

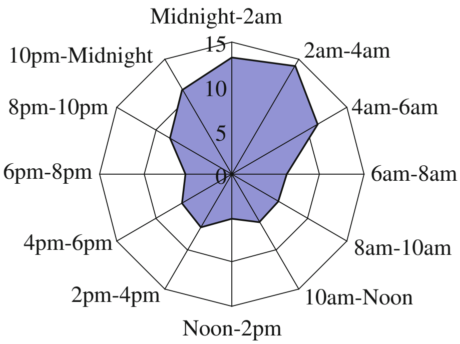

Figure 9. Hourly distribution of fire deaths.

increase during these times. The results indicate that human activity has an impact on the fire ignition.

The distribution of the percentage of fire deaths by time of day in China during the years 2005 to 2010 is shown in Figure 9. As can be seen from the figure, the number of fire deaths between midnight and 4 a.m. is much higher than at other times of the day. One explanation for this result may be that most people sleep more deeply during this period.

3.2. Vocation Distribution of Fire Incidents

Table 2 summarizes the number of fires and fire deaths by vocation in China from 2007 to 2010. Fire incidents by vocation are divided into six major groups as follows: residence, industry, public, agriculture, transportation, and other. The percentage of fire numbers and fire deaths by vocation are shown in Figure 10. As can be seen from the figure, the average share of fire numbers and fire deaths are observed to be the highest in residence, and are approximately 39.1% and 69.6% of the total, respectively. This result may be due to the increasing number of residential buildings that have been constructed with the development of China's

Table 2
Number of Fire Incidents and Fire Deaths by Vocation in China 2007 to 2010

Vocation	2007		2008		2009		2010	
	Fire number	Fire deaths	Fire number	Fire deaths	Fire number	Fire deaths	Fire number	Fire deaths
Residence								
Dwelling	42,784	859	36,915	803	37,507	736	39,078	717
Dormitory	19,498	220	16,223	258	13,867	141	13,583	136
Industry								
Workshop	9,038	82	7,382	51	6,831	30	7,181	53
Warehouse	9,236	23	7,963	39	6,959	11	6,344	19
Public								
Commerce	6,870	133	5,956	121	5,634	125	5,259	90
Restaurant	4,680	53	3,521	11	3,521	13	3,537	25
Office	1,715	3	1,484	10	1,319	10	1,311	22
School	1,094	1	824	0	761	1	637	0
Hospital	418	2	323	0	313	2	294	0
Nursing home	46	12	44	22	53	8	46	13
Recreation	1,107	44	859	66	695	27	684	11
Hotel	1,203	12	916	19	778	11	788	16
Agriculture	14,211	20	8,595	8	8,763	11	8,303	13
Transportation	13,847	6	11,994	11	11,879	22	14,121	4
Other	37,774	147	33,836	102	30,502	88	31,331	86
Total	163,521	1,617	136,835	1,521	129,382	1,236	132,497	1,205

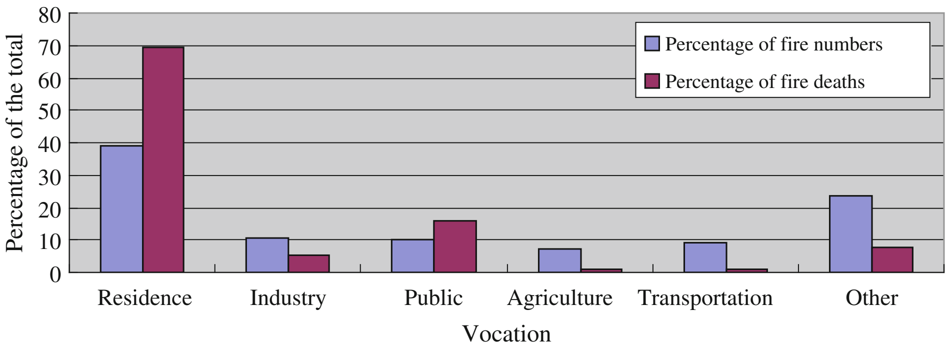

Figure 10. Distributions of the fire numbers and fire deaths by vocation.

economy. Thus, special attention should be paid to residential buildings when taking fire protection measures.

3.3. District Distribution of Fire Incidents

The distributions of the number of fires, fire deaths, fire injuries and fire losses by district in China during the years 2005 to 2010 [10–14] are shown in Figure 11. As

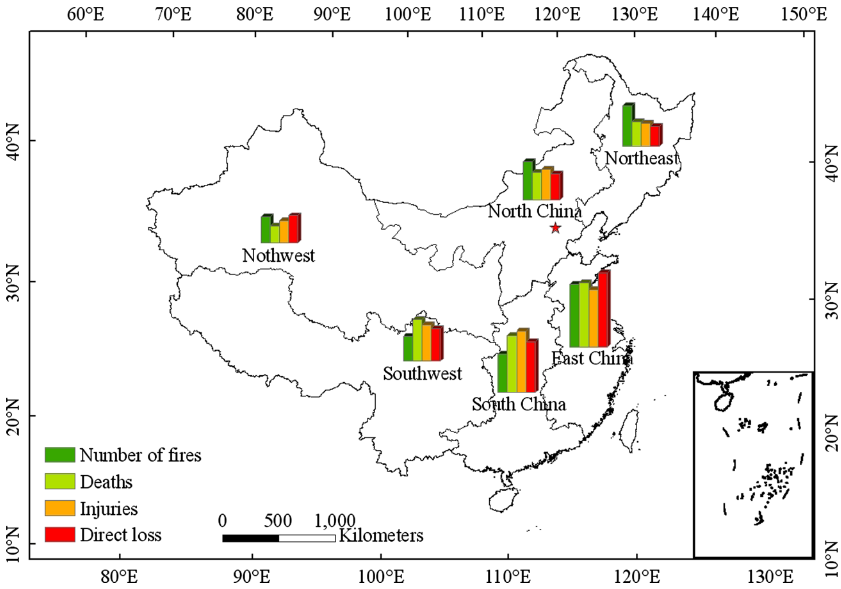

Figure 11. Distributions of the number of fires, fire deaths, fire injuries and fire losses by district.

can be seen, the percentage of the number of fires and direct property losses in East China, one of the most developed regions of China, are higher than are those in other districts of China. This characteristic may be related to the economic situations of the different districts: the more developed the economy, the more serious the fire hazard.

3.4. Cause Distribution of Fire Incidents

In this study, we divided causes of fires into ten major groups as follows: arson, electrical failures, disregard of safety rules, smoking, improperly use of fire in daily life, playing with fire, lightning strikes and static, spontaneous combustion, others and unknown. The distribution of the number of fires by various causes in China during the years 2005 to 2010 is shown in Figure 12. As can be seen from the figure, the percentage of the number of fires caused by electrical failures and improper fire use in daily life are 27.4% and 24.3% of total fire, respectively.

The distribution of fire losses by various causes in China during the years 2005 to 2010 is shown in Figure 13. As can be seen, the fire loss caused by electrical failures is the highest, with 34.3% of total fires. This characteristic is different from that of Canada [17]. The proper design of wires, the regular inspection and maintenance of electric equipment, and the reduction of human errors could control fires and reduce fire losses effectively.

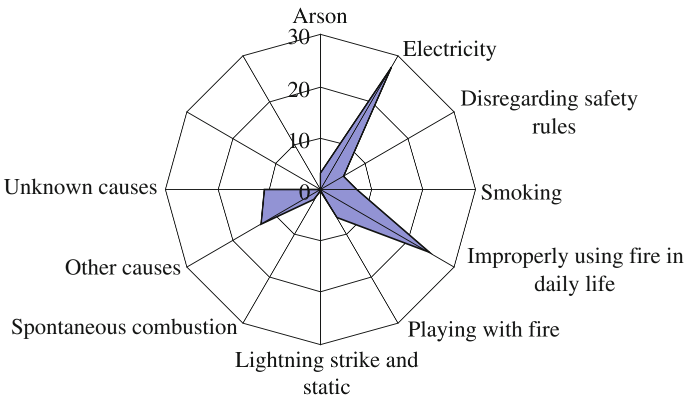

Figure 12. Distribution of the number of fires by cause in China.

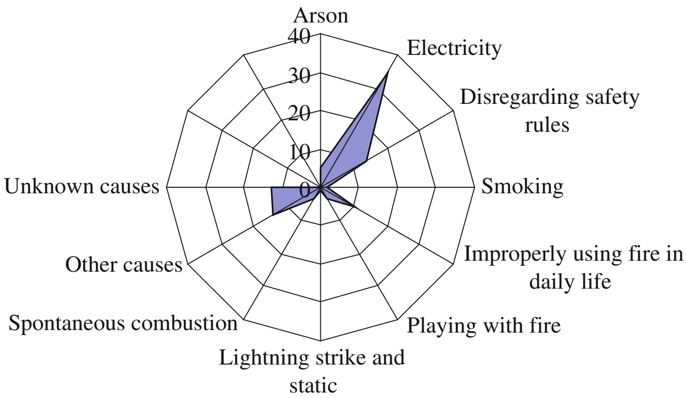

Figure 13. Distribution of fire losses by cause in China.

4. Residential Building Fire Risk Assessment Using Fire Statistics

4.1. Fire Risk Assessment

Fire risk is defined as the product of the probability of fire occurrence and the consequence or extent of damage to be expected on the occurrence of fire [18]. Fire risk assessment refers to assessing risks to both people and property as a consequence of unwanted fires [19]. The use of fire risk assessment seeks to avoid fatalities, ensure human safety, and reduce financial losses [20, 21].

There are many quantitative measures for fire risk, such as fire death rate per 10^5 population, annual mortality rate, and loss of life expectancy. In this study, the risk of occupant deaths (FR_O) and the risk of the direct property loss (FR_P) are selected as fire risk indexes to quantify fire risk in residential buildings:

$$FR_O = P_f . C_{O/f} \quad (1)$$

$$FR_P = P_f . C_{P/f} \quad (2)$$

where, P_f is the probability of fire occurrence, $C_{O/f}$ is the number of deaths due to the occurrence of fire accidents, and $C_{P/f}$ is the direct property loss due to the occurrence of fire accidents.

4.2. Probability of Fire Occurrence

To quantitatively estimate fire risks, reliable knowledge of the probability of fire occurrence derived from fire statistics is necessary. By setting the time unit to 1 year, the probability of fire occurrence is defined as the number of fire occurrences per area unit within 1 year with the unit being "times/year m^2".

As seen in Figure 10, almost 39.1% of the number of fire incidents occurred in residential buildings. Residential buildings are used as an example category in the study. Both time and the floor area of the residential building are taken into consideration to determine the probability of fire occurrence. Previous studies [22] have shown that the probability of fire occurrence is dependent on the floor area of the building. Therefore, the probability of fire occurrence in the assessed residential building is computed by multiplying the fire probability by the floor area.

According to the China Statistical Yearbook 2010 to 2011 [23, 24], the total floor area of residential buildings is a product of per capita residential building area and urban population, as displayed in Table 3. The number of fire incidents in residential buildings can be derived from China Fire Services. By combining these two statistical data, the average probability of fire occurrence can be obtained by dividing the number of fire incidents by the total floor area. As seen in Table 3, the fire probability of the residential buildings decreased every year. The annual average probability was 3.00×10^{-6} times/year m^2, which is lower than that of Taiwan [25], Switzerland [26] and Finland [22] (seen in Table 4).

Table 3
Statistics of Floor Area, Fire Numbers, and Probability of Fire Occurrence in Residential Buildings

Item year	Per capita residential building area (m^2)	Population ($\times 10^5$)	Total floor area ($\times 10^6$ m^2)	Fire number (times)	Probability of fire occurrence (times/year m^2)
2005	27.8	56,212	15,627	55,456	3.55×10^{-6}
2006	28.5	58,288	16,612	53,504	3.22×10^{-6}
2007	30.1	60,633	18,251	62,282	3.41×10^{-6}
2008	30.6	62,403	19,095	53,138	2.78×10^{-6}
2009	31.3	64,512	20,192	51,374	2.54×10^{-6}
2010	31.6	66,978	21,165	52,661	2.49×10^{-6}
Annual average	30.0	61,504	18,490	54,736	3.00×10^{-6}

Table 4
Probability of Fire Occurrence (times/year m^2) of Residential Buildings

	Taiwan 1985 to 2008	Switzerland 1986 to 1995	Finland 1996 to 2001
Residential buildings	7.86×10^{-6}	33.3×10^{-6}	6.3×10^{-6}

4.3. Expected Consequences of Fire Occurrence

The consequences of residential building fires involve more than occupant fatalities, they also involve the loss of properties and businesses. In this study, the consequences of residential building fires are restricted to occupant fatalities and direct property losses. Table 5 shows the number of fire deaths, fire injuries and direct property losses in residential buildings from 2005 to 2010 in China. The table illustrates that the number of fire deaths and fire injuries decreased significantly year by year. Direct property loss has a slowly rising trend with the development of the economy in China. The annual average number of fire deaths and direct property losses in residential buildings were 1,154 and 249.54×10^6 Yuan (RMB), respectively.

4.4. Average Fire Risks in Residential Buildings

Table 6 shows the annual average risk of occupant deaths (FR_O) and the direct property losses (FR_P) as calculated by Eqs. (1) and (2).

If all fires in the residential building are included, the cumulative risk of occupant deaths is 3.57×10^{-3} deaths/year m^2. This number can be interpreted in two ways. First, it indicates that the risk of dying in per unit of floor area in a residential building is 3.57 deaths in 1,000 years, which is a small number. However, this number could also mean that with a residential building with a floor area of approximately 100,000 m^2, there is a risk of losing 357 lives in a year, which is not a small number. Similarly, the cumulative risk of direct property loss is 734 Yuan (RMB)/year m^2. This value corresponds to approximately 734,000 Yuan

Table 5
Fire Deaths, Fire Injuries and Direct Property Losses of Residential Buildings

Item year	Fire deaths	Fire injuries	Direct property loss ($\times 10^6$ Yuan (RMB))
2005	1,795	1,008	219.88
2006	1,258	712	189.23
2007	1,079	442	230.06
2008	1,061	376	257.49
2009	877	335	291.25
2010	853	347	309.33
Annual average	1,154	537	249.54

Table 6
Fire Risk Values of Residential Buildings in China

Item year	Risk of occupant deaths/deaths/year m^2	Risk of direct property loss/ Yuan (RMB)/year m^2
2005	6.37×10^{-3}	781
2006	4.05×10^{-3}	609
2007	3.68×10^{-3}	785
2008	2.95×10^{-3}	716
2009	2.23×10^{-3}	741
2010	2.12×10^{-3}	770
Annual average	3.57×10^{-3}	734

(RMB) for a residential building with a floor area of approximately 1,000 m^2 in a year.

5. Conclusions

The fire risks of residential buildings are assessed in this paper based on fire statistics. Although there are numerous factors affecting fire risks, they can generally be reduced to a product of the probability of fire occurrence and the consequences of the fire. The risk of occupant deaths and the risk of direct property losses are used to express the risk level of residential buildings. The data for the probability and the consequences were derived from statistics in China. The fire statistics show that the fire situation in China is related to its climate, economy, and fire safety management, among other factors. An analysis of the time distribution of fire incidents showed that fires occurred easily in cold seasons, and the number of fires and fire deaths were clearly dependent on the time of day. An analysis of the distribution of fire incidents and fire deaths by vocation showed that the percentage of residential building fires was the highest. An analysis of the distribution of fire incidents and direct property losses by district showed that the more developed the economy, the more serious the fire hazard. Electricity and improper use of fire in daily life are the major causes of fires in China. Based on fire statistics, fire risk can be predicted to better respond to fire incidents when and where they happen. Moreover, fire statistics data offer an excellent way to learn from actual events, and potential approaches to casualty and fire loss reduction can be explored.

Although the precise prediction of residential building fires is not yet attainable with current technology, this research endeavors to make a theoretical contribution based on the statistical data to obtain the fire risks. The above assessed risk values are average values for China's residential buildings; not all residential buildings are the same. If fire statistics are unavailable, or not current, a more fundamental approach using mathematical modeling of fire development and occupant evacuation is needed.

The current work is only an example showing how fire statistics can be utilized in fire risk assessment. The study does not consider the changes in fire statistics over time, such as the introduction of new furnishing materials or new fire protection systems. Therefore, the use of fire statistics for fire risk assessment requires careful considerations of factors that are changing. Moreover, uncertain factors such as the sample size and the accuracy of fire statistic information need to be considered in future research.

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