FIRE LOAD IN STUDENTS' DORMITORY BUILDINGS

Wei Gao [1,*], Jinhua Sun[2], Ying Zhang[3] & Jianzhong Rong[4]

[1] Department of Chemical System Engineering, The University of Tokyo, Tokyo 113-8656, Japan

[2] State Key Laboratory of Fire Science, University of Science and Technology of China, Hefei 230027, China

[3] School of Natural Resources and Environmental Engineering, Wuhan University of Technology, Wuhan 430070, China

[4] Sichuan Fire Research Institute of Ministry of Public Security, Chengdu 610036, China

ABSTRACT

This paper presents the results of a survey conducted in China to characterize fire loads in students' dormitory buildings. The influence of room type, students' grade and the contribution of different types of combustibles are discussed in detail. The fire load densities of all the surveyed buildings show a normal distribution with the mean value of 537.3MJ/m^2, the maximum value of 812MJ/m^2, the minimum value of 234MJ/m^2, and the standard deviation of 140. Based on the survey results, the fire dynamical theory and the characteristics of building fire, the evaluation methods of the fire duration time and the collapse probability caused by fire are also developed in this paper.

Keywords: *Fire load, Normal distribution, Fire duration time, Collapse probability.*

1. INTRODUCTION

The fires used for evaluating fire protection designs are called design fires, which are characterized by the heat release rate and the production of toxic gases with time. Both are affected by the types of combustibles and their distributions. The total amount of fuel and the ventilation characteristics in the compartment govern the intensity and duration of the fire. The former is known as the fire load [1].

The term "fire load" is defined as the total heat content upon complete combustion of all the combustible materials contained inside the fire compartment. In that case, the heat content per unit area is called the fire load density, it is given as [2]:

$$q = \frac{\sum M_V \Delta h_c}{A_f} \tag{1}$$

Where q is the fire load density, (MJ/m^2). M_v is the total weight of each single combustible item in the fire compartment, (kg). Δh_c is the effective calorific value of each combustible item, (MJ/kg). A_f is the floor area of the fire compartment, (m^2).

The fire loads are random in nature, time dependent and often depend on living habits, standards and many cultural and social aspects. It is thus necessary to conduct load surveys periodically to review the validity of prevailing loads. Surveys have shown that fire load is dependent on occupancy, for example, residences, offices, libraries and hotels have different kinds of fire loads. At present only meagre data exist concerning the value of a fire load in students' dormitory buildings [3,4].

This paper presents the results of a survey, which was conducted in China to characterize fire loads in students' dormitory buildings. The survey includes double rooms, quad rooms, six beds rooms, eight beds rooms and twelve beds rooms.

2. SURVEY METHODOLOGY

Many published fire load surveys have been conducted by physically entering a building and listing the contents and their pertinent characteristics. This method is laborious, time consuming and progress can be hampered by privacy concerns. In addition, the judgement of the characteristics of the combustibles is done largely subjectively because it is impracticable to measure and determine the material composition of every combustible item in the room precisely.

This survey was conducted using a carefully-prepared internet questionnaire in order to take advantage of the widespread use of internet communication to survey a larger number of students' dormitory buildings across a country than has ever been achieved in any survey.

The questionnaire had 25 questions. The author's friends at different universities were selected for the survey because of the ease of distributing the questionnaire. The request for participants was sent out by e-mail. A hyperlink to the web page for the questionnaire was included in the e-mail. Respondents followed the hyperlink to complete the questionnaire and upon completion, their anonymous numerical responses were stored on a web server and could be retrieved for analysis at any time.

The questionnaire had a predetermined list of items, which are commonly found in students' dormitories. Drop-down boxes or textboxes were placed beside each item, from which quantities, dimensions, materials and other pertinent attributes could be selected. According to the dimensions, the mass was then computed by multiplying the volume by the density of the material [5,6,7]. The calorific values of combustible substances given in table 1 were used in the fire load calculations [8]. For some special combustible substances such as computers, the heat of combustion could be determined by consulting literatures.

Table 1. Calorific values of common combustible materials

Materials	Calorific value(MJ/kg)	Materials	Calorific Value(MJ/kg)
Clothes	18.80	Wool	23.00
Kerosene	37.20	ABS	36.00
Leather	18.60	Linoleum	20.00
LPG	49.90	Silk	19.00
Paper	16.30	Rubber	39.50
Plastic	22.10	Wood(average)	18.60
Epoxy Resin	34.00	Urea Formaldehyde Foam	14.00

3. SURVEY RESULTS

3.1. Influence of Room Type

Room type may play a significant effect on the composition and magnitude of the fire load in students' dormitory buildings. For each room type, a summary of statistical calculations is shown in table 2. Figure 1 is the corresponding columnar section. For all rooms, the mean and standard deviation of fire load were obtained as 537MJ/m^2 and 140, respectively. The maximum fire load of 812MJ/m^2 was encountered in a six beds room. Six beds rooms were most heavily loaded, followed by eight beds rooms. However, the variation tendency of the minimum load is different from the mean load. The least minimum load was found in the quad rooms. As for the double rooms, quad rooms and six beds room which have similar floor areas, fire load increases as the number of person increases which results in the increasing furnitures, books, computers, bedclothes, etc. As for the eight beds rooms and twelve beds rooms, the floor area increases as the number of person increases, which leads to the lower fire load density.

Table 2. Influence of room type on fire load

Room Type	Fire Load(MJ/m^2)			
	Minimum Load	Maximum Load	Mean Load	Standard Deviation
Double room	276	391	336	58
Quad room	234	709	505	118
Six beds room	428	812	643	157
Eight beds room	488	761	595	91
Twelve beds room	350	350	--	--
All rooms	234	812	537	140

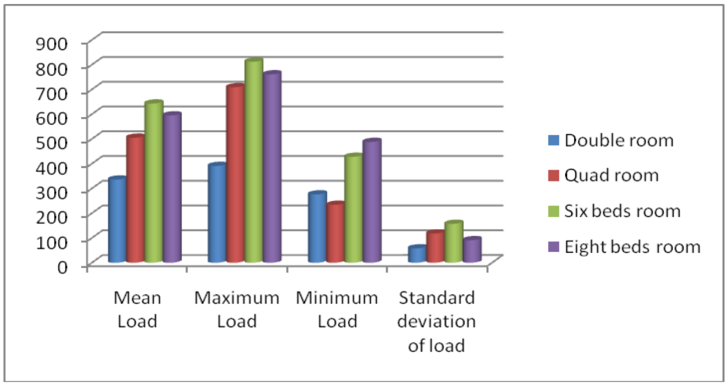

Figure 1. Fire load histogram-influence of room type

3.2. *Influence of Students' Grade*

The fire load density is greatly dependent on the students' grade. Table 3 shows the influence of students' grade on the fire load.

Table 3. Influence of students' grade on fire load

Room Type	Students' Grade	Fire Load Density(MJ/m^2)
Old six beds rooms in USTC	Senior	812
	Junior	751
	Sophomore	682
	Freshman	505
Old quad rooms in USTC	Senior	550
	Junior	520
	Sophomore	515
	Freshman	455
New quad rooms in USTC	Senior	695
	Junior	601
	Sophomore	545
	Freshman	509

It can be seen that fire load increases with increasing the grade in the same university. This is because the university life is stable and the goods are fixed, the students' goods gradually accumulated from year to year.

3.3. Contribution of Different Types of Combustibles

Figure 2 shows the range of contributions of different types of combustibles to the total fire load. Six typical combustibles usually found in students' dormitory buildings were selected. The six groups are wood, computer, clothes, paper, plastic and foodstuff. Wood is the main combustible, contributing over 50% of the total fire load density, while food has a lower contribution to the total fire load.

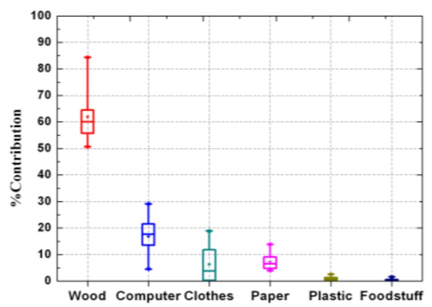

Figure 2. Contribution of combustibles to the fire load in the surveyed students' dormitories

Figure 3 is the mean contribution of combustibles to the fire load in the students' dormitory buildings. It can be seen from that wood occupies 62% of the total fire load, computer takes the second place and food has the lowest contribution to the total fire load.

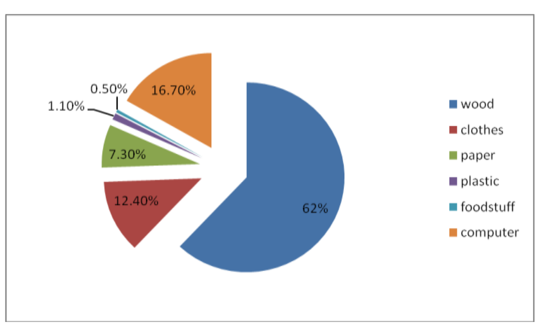

Figure 3. Mean contribution of combustibles to the fire load

3.4. Statistical Interpretation of Fire Load Density

Figure 4 shows the frequency distribution of fire load densities of all the surveyed rooms. It can be seen that the frequency distribution is similar with the normal distribution form. The characteristics of the fire load for all the rooms are presented in table 4, in which the skewness closes to zero also indicates the data collected show the normal distribution regularity. The standard normal probability density function is as follows [9]:

$$f(x)=\frac{1}{\sqrt{2\pi}x\sigma}e^{-\frac{1}{2}(\frac{\ln x-\mu}{\sigma})^2} \quad (2)$$

Table 4. Characteristics of the fire load for all the students' dormitories(MJ/m^2)

Statistical Parameter	Statistic	Std. Error
Mean	537.28	19.230
Median	540.00	
Variance	19598.98	
Std. Deviation	140.00	
Minimum	234.00	
Maximum	812.00	
Skewness	-0.037	0.327
Kurtosis	-0.379	0.644

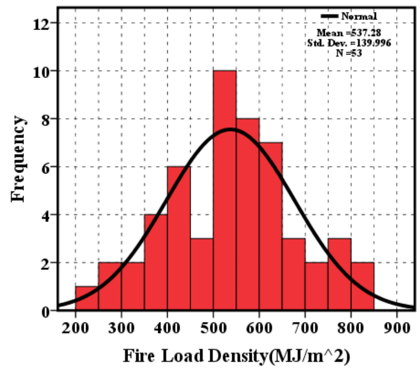

Figure 4. Frequencies of fire load density of all the surveyed students' dormitories

Where μ is the population mean, σ is the standard deviation, for the domain $0\le x\le+\infty$, the parameters $\mu>0$, $\sigma>0$.

In terms of the data collected obey normal distribution or not, three test methods which are normal probability plot, *Jarque-Bera* test and *Lilliefors* test are presented. Figure 5 shows the normal probability plot of fire load in all the rooms. It can be seen that most data conform with the expected value.

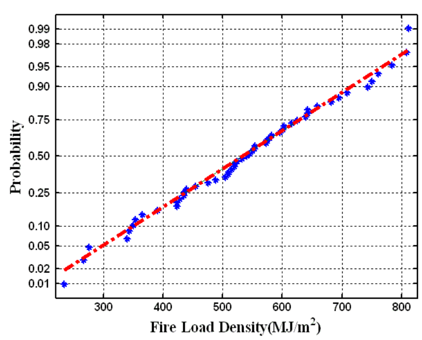

Figure 5. Normal probability plot of fire load

The results of *Jarque-Bera* test and *Lilliefors* test are presented in table 5. If the result of hypothesis testing *H* is equal to 0, the hypothesis that the underlying distribution is a normal distribution could not be rejected. In the table, *P* is the check value. *JBSTAT* and *KSTAT* are the test statistics and *CV* is the critical value. All the three test results clearly confirm that the fire load frequencies have a normal distribution at the 5% significance level [10].

Table 5. The results of Jarque-Bera test and Lilliefors test

		Jarque-Bera test		
DATA	H	P	jbstat	CV
Gaussian noise	0	0.5000	0.4693	5.0208
		Lilliefors test		
DATA	H	P	kstat	CV
Gaussian noise	0	0.5000	0.0692	0.1211

Figure 6 shows the cumulative frequency distribution of all students' dormitories taken together. The 50th, 80th and 90th percentile of fire load are 535.9MJ/m^2, 655.5 MJ/m^2 and 719.8MJ/m^2, respectively.

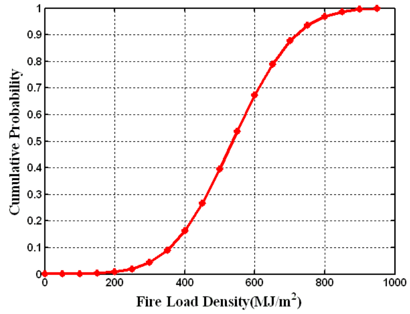

Figure 6. *Cummulative frequency distribution of all students' dormitories*

4. FIRE DURATION TIME

Fire duration time is an important basis for the building fire protection design. The duration time not only depends on the fire load in the buildings, but also the spatial characteristics, opening size and position of the buildings. Assuming the consumption of combustibles during the growth period can be ignored, the fire duration time is given by the fire load density and the mass burning rate [11].

$$t_{dur} = \frac{W}{\dot{m}} \tag{3}$$

Where t_{dur} is the fire duration time, (s). W is the total weight of combustibles in the fire compartment, (kg). $\dot{m}$ is the mass burning rate (kg/s).

During the full development period, the rate of burning is generally controlled by the ventilation conditions, the mass burning rate can be obtained by using [12]:

$$\dot{m} = 0.092A\sqrt{H} \tag{4}$$

Where H is the height of the window, (m). A is the area of the window, (m^2).

After knowing the total weight of combustibles and the mass burning rate, the fire duration time can be calculated by:

$$t_{dur} = \frac{A_f q}{0.092A\sqrt{H}} \tag{5}$$

Substituting k for $\frac{A_f}{0.092A\sqrt{H}}$, where k which is related to the floor area, the height and area of the window is a parameter to characterize the structural features of buildings. Hence, the fire duration time can be expressed:

$$t_{dur} = k \cdot q \tag{6}$$

The distribution regularity of fire load in students' dormitory buildings is normal distribution and the probability density function is as follows:

$$f(q) = \frac{1}{\sqrt{2\pi} * 140} e^{-\frac{1}{2}(\frac{q-537.3}{140})^2} \tag{7}$$

Based on the characteristics of the normal distribution, t_{dur} also obeys the normal distribution. That is:

$$f(t_{dur}) = \frac{1}{\sqrt{2\pi}\sigma_{t_{dur}}} \exp[-\frac{(t_{dur} - \mu_{t_{dur}})^2}{2\sigma^2_{t_{dur}}}] \tag{8}$$

Where $\mu_{\ln t_{dur}}$, $\sigma_{\ln t_{dur}}$ are the mean and standard deviation, respectively.

The mean and standard deviation can be respectively obtained as:

$$\mu_{t_{dur}} = k\mu_q = \frac{A_f}{0.092A\sqrt{H}} \mu_q \tag{9}$$

$$\sigma_{t_{dur}} = k\sigma_q = \frac{A_f}{0.092A\sqrt{H}} \sigma_q \tag{10}$$

Statistical parameters of students' dormitory buildings are presented in table 6.

Table 6. Statistical Parameters of students' dormitory buildings

Statistical Parameters	Value
Mean(kg/m^2)	29.9
Standard deviation (kg/m^2)	7.8
k	76.8

Based on the equation (8), (9), (10) and table 6, the probability density distribution function of the fire duration time can be obtained:

$$f(t_{dur}) = \frac{1}{\sqrt{2\pi} * 599.04} \exp[-\frac{(t_{dur} - 2292.48)^2}{2 * 599.04^2}] \tag{11}$$

Figure 7 gives probability density curve versus fire duration time.

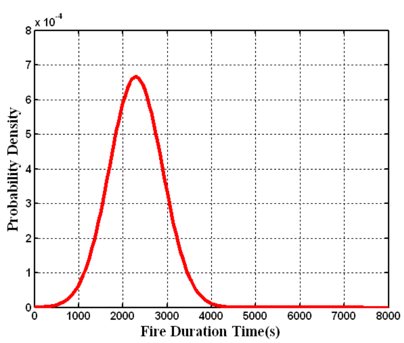

Figure 7. Probability density curve of fire duration time

Fire load in students' dormitory buildings is relatively large. When fire occurs, it generates more heat and lasts for a long time.

5. THE COLLAPSE PROBABILITY

When fire occurs, whether the building will collapse depends on the fire duration time and the fire resistance time. When the fire duration time is more than the fire resistance time t_{max}, the building will collapse. The collapse probability can be expressed in the following way [13,14,15]:

$$P_{fail} = \int_{t_{\max}}^{\infty} f(t_{dur}) dt_{dur} \tag{12}$$

The collapse probability of students' dormitory buildings can be expressed as:

$$P_{fail} = \int_{t_{\max}}^{\infty} \frac{1}{\sqrt{2\pi} * 599.04} \exp[-\frac{(t_{dur} - 2292.48)^2}{2 * 599.04^2}] dt_{dur} \tag{13}$$

Figure 8 shows the relationship between fire resistance time and the collapse probability of students' dormitory buildings.

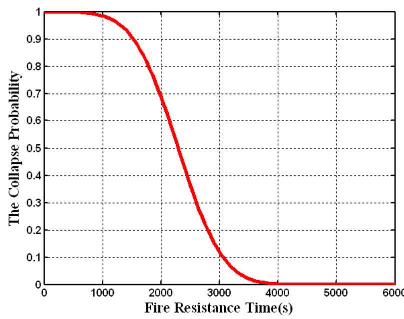

Figure 8. The collapse probability of students' dormitory buildings

From Figure 8 it can be seen that, the collapse probability will decrease with the increasing fire resistance time at the mean fire duration time.

6. CONCLUSIONS

A study has been made into fire loads in students' dormitory buildings of China. The effects of several factors on the fire load were considered in detail. Based on the survey results presented herein, the following conclusions can be drawn.

(1) The magnitude of fire load is related to the room type. Six beds rooms are the most heavily loaded, followed by eight beds rooms.

(2) Students' grade also plays a significant effect on the composition and magnitude of the fire load. Fire load increases with increasing the grade in the same university.

(3) Wood is the main combustible, contributing over 50% of the total fire load density, while food has the lowest contribution to the total fire load in students' dormitory buildings.

(4) The fire load densities of all the surveyed students' dormitory buildings have a normal distribution with the mean value of 537.3 MJ/m^2, the maximum value of 812 MJ/m^2, the minimum value of 234 MJ/m^2, and the standard deviation of 140.

(5) The fire duration time and the collapse probability of building caused by fire were also developed by the corresponding calculation model.

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