Fire Load Survey of Historic Buildings: A Case Study

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ABSTRACT: The results of a fire load density survey carried out in Ouro Preto in the state of Minas Gerais, Brazil are presented. The inventory method is used and details of the survey methodology and processing are given. Forty-three buildings are surveyed and the determination of fire load density is made for 39 occupancies, each occupancy comprising one or more rooms, or even an entire building. The average fire load density is 2989 MJ/m^2 and the standard deviation is 2833 MJ/m^2. Commercial stores are found to be the most heavily loaded but a single maximum fire load density of 14,560 MJ/m^2 is found in a drugstore. Because of new extensions of old buildings, some rooms have relatively low fire loads. It is observed that wood contributes a substantial portion of fire load, being 35% of movable fire load and 37% of fixed fire load. Comparison of the results, with those established by Brazilian standard NBR 14432, indicate that measured values could exceed standard values by up to a factor of 10.

KEY WORDS: historic buildings, fire load survey, fire load composition.

INTRODUCTION

THE HISTORIC BUILDINGS of Ouro Preto, in the state of Minas Gerais, Brazil, have suffered some severe damage as a result of fires during the last few decades. The city was declared a World Human Heritage site in 1982

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by the United Nations Education, Sciences and Cultural Organization. Tourism is a major source of income for the local population. Recently, on 14th April 2003, a severe fire destroyed the old Hotel do Pilao building located in the main square of the city, causing great consternation among the inhabitants.

The baroque buildings of Ouro Preto, some of which were built in the latter part of the 17th century, are particularly vulnerable to fires, mainly because of the following:

1. the use of timber and stones as construction materials and low rigidity connections of beams and columns that results in the stability of buildings being very sensitive to elevated temperature, degrading easily, and facilitating fire propagation;
2. building designs that do not consider any means of fire protection, frequently with low fire resistance geminate (effectively hollow) walls, and no fire separated roofs;
3. building occupancies continuously adapted to new uses, often being transformed from old residences with their sparse original heavy wooden furniture into commercial stores, restaurants, small hotels, and offices crammed with light modern furniture; and
4. the urban space of most baroque cities makes fire fighting very difficult because narrow streets restrict access to buildings.

After the Hotel do Pilao fire, some initiatives were proposed to provide the more than one thousand old buildings of the historic perimeter of Ouro Preto with an acceptable minimum level of fire safety. As a basis for developing future action in this direction, a project to evaluate fire load density of a typical set of baroque buildings was established. The Saint Joseph Street buildings, set in the very center of the city, were chosen as the representative target for this survey project.

METHODOLOGY

The survey covered the 43 buildings of Saint Joseph Street, all divided in a variety of occupancies, with residences and commercial stores being the most frequent. The inventory method [1] was used with all buildings, which were researched for their movable and fixed combustible contents. The data collected for each item within the building included its type, material, and measured dimensions. Volumes were calculated from the measured dimensions and masses were determined using corresponding densities. The old wooden furniture pieces remaining were measured in detail, while the masses of modern furniture were obtained from their manufacturers.

Table 1. Calorific values and energy released by some building contents.

Object	Calorific value	Object	Calorific value
TV set	21*	Washing machine	31*
Stereo system	21*	Dryer	32*
DVD player	21*	Microwave oven	28*
Freezer	28*	Electric stove	28*
Armchair	19*	Office chair	22*
Computer	492**	VCR	20*
Printer	146**	Computer	492**
Sofa 2 seats	904**	Sofa 3 seats	983**

*Calorific value in MJ/kg.
**Energy released in MJ.

Masses of combustible materials were multiplied by their calorific values and then added to get the total amount of fire load. Dividing total fire load by the floor area of the compartment then gave fire load density. Calorific values of common combustible materials were obtained from the technical literature, specifically those found in Buchanann [2]. Some of the contents had their fire load obtained from tests conducted to determine the heat release rate curve [2,3]. Having the curve of heat release rate as a function of time [3,4], a calorific value assigned to an object per unit mass or the total energy released by an object can be determined by simple integration. Table 1 gives a list of the special data used in this research.

Most buildings have timber-framed internal walls filled with a rough plaster of argyle, sand, and lime. As these walls are frequently susceptible to cracking and heating, and linings are not sufficient to protect timber posts against fire, they were taken as a fire load with a calorific value between 115 and 150 MJ/m^2 depending upon their thickness. Taking into account their structure, wooden floors and ceilings give 1338 MJ/m^2 to add to the total fire load density. Doors and windows in between two rooms were considered as a fire load in both rooms. Cupboards and drawers were considered full at 70% of their capacity. Materials deposited on the ground surface had the volume approximated by a pyramid and mass was determined considering a void rate of 30%.

Fire Compartments

True fire compartments in a set of old historic buildings like that of Ouro Preto are rarely found. In general, these buildings are geminate with no fire-resistant common walls, floors and ceilings are combustible, and roofs are not separated. Thus, the main fire risk in these historic buildings is fire propagation from one building to another, resulting in very severe events.

Except in cases of renovated buildings where brick cladding and concrete floors and ceilings are used, a set of geminate historic buildings make only one fire compartment. However, this compartment is normally divided into several parts that are used for distinct main occupancies with a combination of storage occupancies, commercial stores, and residences very common. Thus, when reference is made to a specific main occupancy, rooms that can have secondary occupancies may be involved; when reference is made to a building, one or more main occupancies may be involved.

Although the survey extended over the 43 buildings of Saint Joseph Street, calculation of fire load density was made over 39 distinct occupancies chosen in 10 buildings regardless of whether there are true fire compartments or not. This is justifiable on the grounds that, for fire safety, it is desirable that distinct occupancies form true fire compartments. In some cases, one entire building is referred to as an occupancy and the fire load density is taken as the average of fire load density in each room. In other cases, a building comprises two or more distinct occupancies and fire load density is reported separately, with each occupancy being in fact the average fire load of its rooms.

Average Fire Load Density

The average fire load density and standard deviation for all occupancies was 2989 and 2833 MJ/m^2 respectively. Figure 1 shows that the maximum

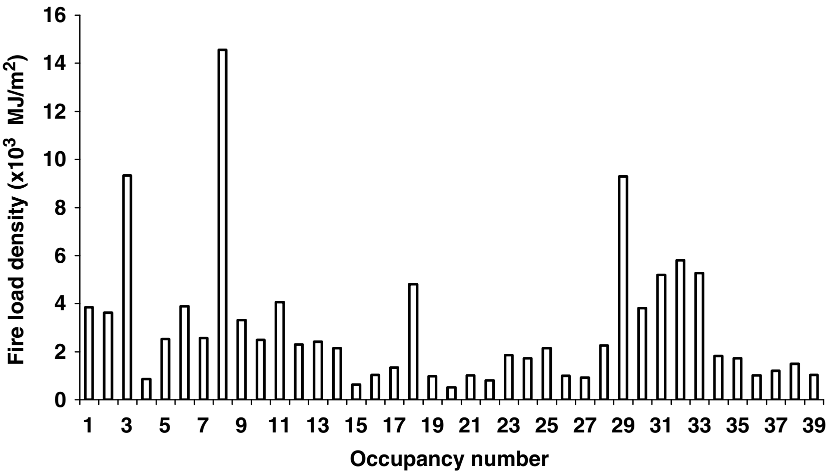

Figure 1. *Average fire load density.*

Table 2. Influence of room use on fire load.

Room use	Number of rooms	Floor area (m^2)	Fire load density (MJ/m^2)			
			Maximum	Minimum	Mean	Standard deviation
Bedroom	29	487	4988	801	1238	2716
Commercial stores	11	623	8072	623	2156	3251
Storage occupancies	10	308	14560	1815	4332	6398
Dining room	6	148	2691	515	782	1624
Kitchen	13	206	2965	596	740	1706
Offices	6	183	3820	1862	571	2361
TV room	9	208	7346	682	1965	2433

average fire load density was 14,560 MJ/m^2 and the minimum was 520 MJ/m^2. The maximum fire load was found in a drugstore room and the minimum in a dwelling house. The huge variation of the average fire loads reflects the fact that some old buildings have new extensions where wooden floors, ceiling, and structures were replaced by concrete ones, generating minimum fire load densities. On the other hand, some of the authentic historic buildings have been adapted for new uses, and storage areas were created in inappropriate rooms with insufficient floor area generating maximum fire load densities.

The influence of various types of room uses on fire load is taken from Table 2. Observe that commercial stores, storage occupancies, and offices designate main occupancies and consist of a set of rooms having the average fire load referred to in the table. On the other hand, bedroom, dining room, kitchen, and TV room are secondary occupancies of residential buildings. Storage occupancies are responsible for the maximum average fire load density followed by commercial stores and bedrooms.

Distributions of fire load on underground level rooms, ground level rooms, first level, and second ground level rooms are shown in Figures 2–5. Table 3 shows the mean fire load densities and standard deviation as a function of room level. It is seen that underground rooms contain the highest fire loads, indicating that these rooms are frequently used as storage occupancies. Ground level rooms are frequently used as commercial stores with storage occupancies on the underground levels. First and second level rooms are typically used as residences, and the high average value observed at second level rooms may be due to the presence of bedrooms.

Figure 6 gives the cumulative frequency distribution for all rooms considered. The 95th percentile of fire load density on Saint Joseph Street is 9000 MJ/m^2.

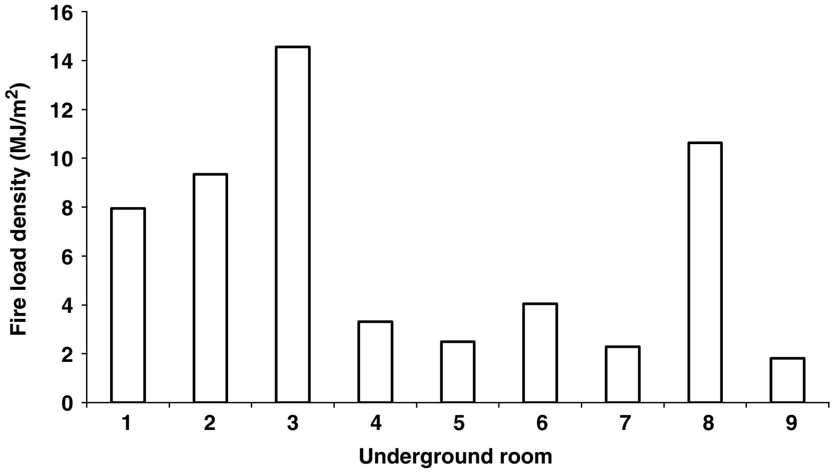

Figure 2. *Fire load density on underground rooms.*

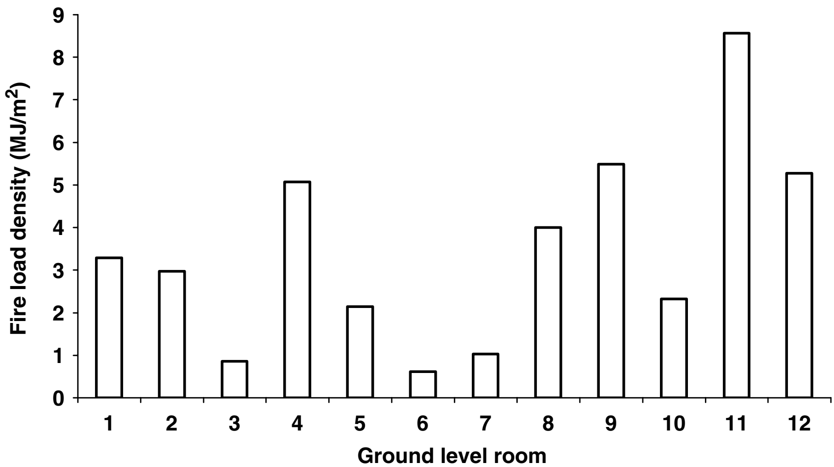

Figure 3. *Fire load density on ground level rooms.*

Fire Load Composition

Table 4 shows the percentage of fire load contributed by different sources of combustible materials with the room use. It is observed that the average contribution of wood is 35% of movable fire load and 37% of fixed fire load for all rooms. The total contribution of wood is an average of 72%. Storage occupancies have a slightly reduced contribution of wood because of the

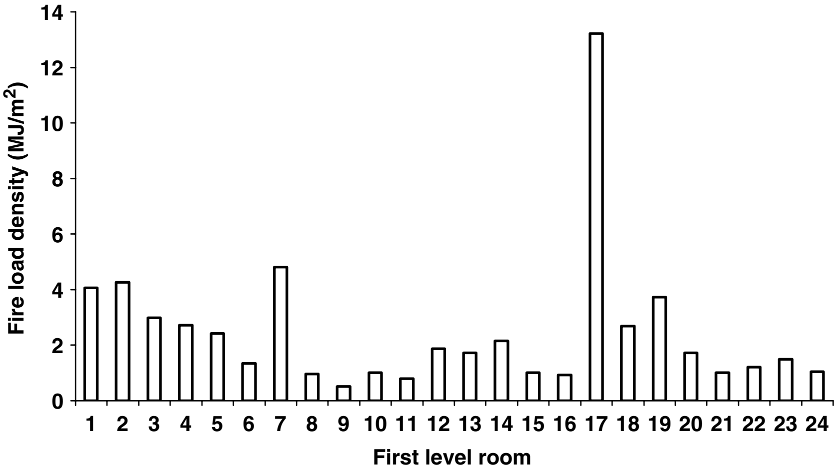

Figure 4. *Fire load density on first level rooms.*

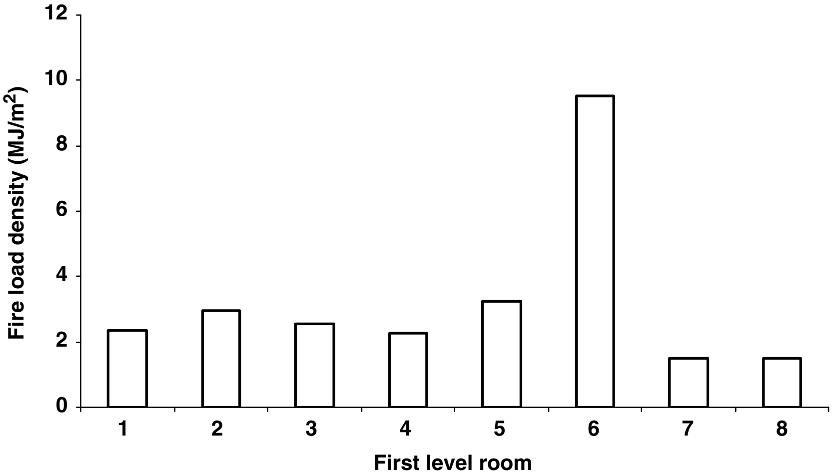

Figure 5. *Fire load density on second level rooms.*

increased contribution of all other combustible materials. The reduced contribution of wood to fixed fire load in commercial stores indicates that buildings are frequently renovated for this purpose. On the other hand, the great contribution of wood for the fixed fire load of bedrooms and dining rooms indicates that old buildings continue to be used as residences.

Table 3. Influence of room level on fire load.

		Fire load density (MJ/m²)	
Room level	**Number of rooms**	**Mean load**	**Standard deviation**
Underground	9	6270	4520
Ground	12	3470	2340
First level	24	2487	2587
Second level	8	3234	2617

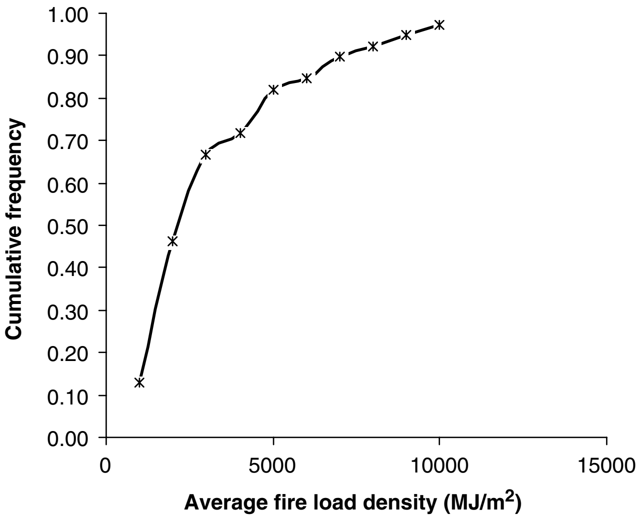

Figure 6. *Distribution of cumulative frequency.*

Table 4. Fire load composition(*) with room use.

	Percent of fire load composition					
	Movable fire load					Fixed fire load
Room use	**Wood**	**Foam**	**Papers**	**Plastics**	**Textiles**	**Wood**
Bedrooms	32	1	10	6	11	39
Commercial stores	33	0.3	1	6	33	26
Commercial occupancies	29	11	15	18	11	16
Dining room	46	0.2	1	0.6	–	52
Offices	27	–	24	6	0.2	42
TV room	45	0.9	8	–	0.3	45

(*)Values may not sum to 100% due to rounding.

Table 5. Comparison with Brazilian Standard fire loads.

	Fire load density (MJ/m^2)		
Room use	**Brazilian standard (1)**	**Present work (2)**	**Ratio (2)/(1)**
Museum	300	2599	9
Clothes store	400	3930	10
Student house	300	1347	4
Laundry	300	1515	5
Library	2000	2129	1
Drugstore	1000	6734	7

Comparison with Standard Values

The results of the present work are compared with those established by the Brazilian National Standard NBR 14432 [5]. Standard values are assumed to be the movable fire load densities needed for evaluation in fire safety projects. Only main occupancies are considered and no distinction is made for historic and new buildings. Table 5 summarizes the comparative values of the present work with those of Brazilian Standard for some main and secondary occupancies. It is observed that, except for the library, the fire loads measured in the present work exceed standard values by up to a factor of 10.

CONCLUSIONS

A study has been conducted to assess fire load density in a set of historic buildings on Saint Joseph Street in the city of Ouro Preto, Minas Gerais State, Brazil. Based on the results, the following conclusions can be drawn. The average fire load density for all buildings is 2989 MJ/m^2 and the standard deviation is 2833 MJ/m^2. Within commercial occupancies, storage occupancies are found to be the most heavily loaded, but a single maximum fire load density of 14,560 MJ/m^2 was found in a drugstore. Because of new extensions in old buildings, some rooms have slightly lower fire loads. It is observed that wood contributes a substantial portion of fire load, being 35% of movable fire load and 37% of fixed fire load for all rooms. Comparing the results with those established by Brazilian Standard NBR 14432, it is observed that measured values can exceed standard values by up to a factor of 10.

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