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RESEARCH PAPER

Assessment of Fire Load and Probabilistic Temperature for Office Buildings in Pakistan

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ABSTRACT: This paper presents the results from 92 fire load density surveys conducted in 52 office buildings of Pakistan. The combination method of surveying that includes both inventory and weighing methods is used to determine the fire load of 92 office rooms, including 44 private and 48 government offices. Multiple linear regression analysis techniques are applied to assess the relationship of Fire Load Density (FLD) with variables according to the characteristics of the office rooms, such as office type, category, combustible materials, room dimensions, and ventilation conditions. Probabilistic models for FLD are developed using the regression analysis of the survey data. The survey data is further used to determine the maximum fire intensity in office buildings in Pakistan. The survey results show that the FLD increases with the increase in the area of the office. The percentage of wood is found to be the most contributing factor in the fire load. It has been noted that the fire load values are different for government and private offices, whereas the Building Code of Pakistan (BCP) has the same value for both. Statistical results presented in this study will be helpful in the fire safety and fire-resistant structure design of buildings in Pakistan.

Keywords: Fire Load Density, Office Buildings, Pakistan Building Code, Regression Analysis.

1. Introduction

Fire load can be seen as the basis for evaluating the duration and intensity of fire when combined with building characteristics such as openings for ventilation and the size of the compartment. Once these are known, other factors such as heat release and the extent and spread of smoke can be determined to a certain extent. The smoke production is a crucial factor in determining the available time for occupants to evacuate the building, whereas the heat intensity and duration determine

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the residual strength of the structure. The fire spread may lead to various failures that can be in the form of structural failure (Mazza, 2015; Moradi et al., 2022, 2021; Noman et al., 2022; Sharma et al., 2014; Tavakoli and Kiakojouri, 2015), or other failures like material failure (Mazza, 2016; Noman et al., 2022; Tufail et al., 2016), element failure (Mazza, 2017; Noman and Yaqub, 2021), cracks in the walls and floors, insulation failure (the increased temperature at the unexposed side of the fire compartment), and spread through openings (e.g., windows and doors). To know about the resistance of the structure to the fire, the probable period of the fire should be known, which can be calculated from the fire load and desired conditions.

Fire load is the total combustible materials present in a compartment (Fontana et al., 2016). Usually, fire loads are uneven, and therefore the term Fire Load Density (FLD) is used, which is the total amount of combustible material per unit floor area of a compartment (MJ/m^2) (Buchanan and Abu, 2017b). Fire load data is used by a range of professionals, including architects, building control officers, fire modelers, fire investigation bodies, fire risk assessors, fire safety engineers, and insurance assessors. These are instrumental for many reasons, such as evaluating active and passive protection systems required in a building, conducting fire scene investigations, modelling the movement of fire, smoke, and gases in buildings, and assessing insurance premiums.

Fire load can be determined using several methods. The NFPA 557 (NFPA, 2023) recommends two ways for the determination of fire load; the weighing method (weighing of the combustible items) and the inventory method (determination of the mass of an object based on its measured volume and corresponding density). A combination of both methods can also be used. Fire load surveys in the past have used different survey methodologies (Culver, 1978; Kumar, 1995; Zalok and Eduful, 2013), including the inventory method (Culver, 1978; Issen, 1980; Korpela, 2000; Kumar, 1995), the weighing method (Baldwin et al., 1970; Ingberg et al., 1957), a combination of inventory and weighing (Barnett, 1984; Doyle and Macilwraith, 2019; Green, 1977), use of questionnaires (Bwalya, 2008; Bwalya et al., 2010), and web-based photographs of real estate sites. Each of the survey methods is associated with some uncertainties and shows a difference in results. However, a combination of inventory and weighing methods is found to provide more accurate results and the least uncertainty of fire loads (Zalok and Eduful, 2013). In this study, the combination method is used for determination of the FLD.

One of the very initial and detailed works on FLD was carried out by Culver (1976), whose work was further analyzed by Khorasani et al. (2014), proposing a probabilistic FLD model. Xie et al. (2019) further updated the FLD model of Khorasani et al. (2014), using the Bayesian approach by incorporating the data from recent fire load surveys. Ingberg et al. (1957) reported the FLD of 1270 MJ/m^2 in office buildings of America. Baldwin et al. (1970) reported the FLD of 400 MJ/m^2 in the office buildings of the UK. Bryson and Gross (1968) reported the FLD of 527 MJ/m^2. Culver's (1978) survey resulted in a much closer value of FLD (960 MJ/m^2) compared to that of Ingberg et al. (1957). On the other hand, Barnet (1984) reported a FLD of 440 MJ/m^2 for office buildings in New Zealand. The average FLD for office buildings in India was 348 MJ/m^2, as reported by Kumar and Rao (1997). Caro and Milke (1996), Milke and Caro (1996), Korpela and Kushner (2000), and Yii (2000) also determined the average FLD of offices as 1298 MJ/m^2, 1000 MJ/m^2, and 950 MJ/m^2 respectively. Some of the recent studies conducted in France (Thauvoye et al., 2008), Canada (Eduful, 2012), and China (Zhai, 2013) provided the information of average FLD in office buildings to be 657 MJ/m^2, 852 MJ/m^2, and 652 MJ/m^2, respectively. Elhami-Khorasani et al. (2020) and Gernay et al. (2019) developed a new methodology for facilitating FLD. The methodology consists of four steps including digital inventory, organization of data, items matching using computer vision, and fuel load estimation. The values (1468 MJ/m^2) from the new methodology of the fire load survey were found to be much larger than the old survey methods. The main reasons for variation in survey results are regional differences, the difference in surveying techniques, and advancements in technology (new gadgets replacing paper and large desktop computers etc.).

Pakistan is a developing country, and with its development in the commercial sector, medium and large-sized shopping malls, office buildings, hotels, and other facilities are emerging, which has led to an increase in the number of fire incidents. Statistical data from Pakistan's National Disaster Management Authority (NDMA) indicates a steep upward trend in fire incidents (NDMA, 2016). Pakistan-Fire Safety Provisions in the Building Code of Pakistan (Pakistan, 2016) were formally launched in 2017. However, most of the portion is adapted from the National Fire Protection Authority (NFPA) standards. A proper FLD survey and its probabilistic models are not investigated.

In this paper, FLD for office buildings of Pakistan is investigated by surveying a representative model of the office buildings of concern and making a list of the compartments' sizes, fixed and movable combustibles, ventilation conditions, and their relevant features using the combination method. The study also differentiates government offices from private offices. The data is analyzed using regression analysis, and probabilistic models are developed. The information is further used to determine the maximum intensity of fires in office buildings in Pakistan. The results are then compared with various survey results across the world.

2. Fire Load Survey

The survey was conducted for the determination of fire load in office buildings in different sectors of Islamabad, Pakistan. A total of 92 office rooms were surveyed from 52 buildings, including 44 private offices and 48 government offices. The survey method adopted for this research was the combination method (Džolev et al., 2021) that includes the weighing method (direct weighing) and inventory method (determining the volume and multiplying with the unit weight) of the combustible items. The FLD in MJ/m^2 was calculated using the corresponding material's net calorific value using the following equation.

$$FLD = weight \times \frac{Calorific\_value}{Area} \quad (\frac{MJ}{m^2}) \tag{1}$$

Fire load of combustible materials that could be easily handled, such as paper, plastic, furniture, etc., are determined using the direct weighing method, whereas the inventory method was used for the fire load of the combustible ceiling, wooden partitions, or woodwork on walls, doors, window frames, and heavy furniture.

A survey form was developed to record the data collected during the survey and organise all room characteristics to calculate fire load density in an office room (Appendix). The survey sheet was based on the required data for the evaluation of FLD for office buildings in Pakistan that can be incorporated into the building code of Pakistan. The survey form was divided into three sections:

i. The first section consisted of building information such as the name of the building, category and type of room, and room characteristics such as room area, ceiling height (m), fuel load arrangement, and the number of openings. These all characteristics of the room were recorded in the form during the survey.

ii. The second section consisted of the weight of combustible items that exist in an office room. It was further divided according to the type of combustible material like wood, plastic, papers, and other combustible items. This section also included a column for the number of elements. This column was for heavy and fixed combustible items that could not be weighed directly and had to be converted into several elements. These elements exist separately to determine their volume by length, width, height, and the total volume of the elements. The weight of the combustible items was calculated using the following equation.

$$Weight\ (kg) = volume\ (m^3) * density\ \left(\frac{kg}{m^3}\right) \tag{2}$$

In the last column, the fire load density of an item was calculated using the calorific value of the corresponding material of an item and divided by the total area of the office room.

iii. The third section consists of information regarding members that conduct the survey and general notes for the material of combustible items such as density and calorific value. The time and date of the survey conduction are also mentioned in this section.

The buildings were selected from each sector of Islamabad, depending upon availability and permissions to conduct surveys. It was made sure that at least two offices for each category be surveyed from each sector in the Capital. The parameters of interest during the survey include the fire load, type of office (general, clerical, and storage), office category (Government, private), room dimensions, room ventilation, and fire safety equipment. The buildings were selected from each sector of Islamabad, depending upon availability and permissions to conduct surveys. It was made sure that at least two offices for each category must be surveyed from each sector in the Capital. SPSS software (Frey, 2017) was used for the statistical analysis of the surveyed data. Multiple linear regression analysis techniques were applied to the survey data using different variables according to the characteristics of the office room like office type, category (government or private), combustible materials, room dimensions, and ventilation conditions.

3. Descriptive Statistics

3.1. Relationship Between FLD and Office Type

The office rooms are distributed into three types, i.e., general office rooms, clerical office rooms, and storage and file rooms. The impact of various types of office rooms on fire load (including range, mean and standard deviation) is given in Table 1. Clerical office rooms are usually small but congested and loaded with record material; therefore, these office rooms are separated from other general office rooms. The maximum mean fire load (1322 MJ/m^2) was found in storage and file rooms. The reason for this high fire load is the huge bulk of files and papers, which are mostly placed in storage rooms for a much longer time. Clerical office rooms have a higher standard deviation value, possibly due to the huge difference in FLD between government office rooms and private office rooms.

Table 1. Impact of office room type on fire load density

Office type	**Fire load (MJ/m^2)**			
	Mean	**Minimum**	**Maximum**	**Standard deviation**
General	386	247	617	103
Clerical	681	256	1184	246
Storage and file rooms	1322	1125	1468	146
All office rooms	602	247	1468	322

3.2. Relationship between FLD and Office Category (Private/Government)

The office setups and distribution of fire load vary a lot while considering the difference between government and private sector offices. The survey results in Table 2 show a mean difference of 1.8 times more for government offices than that for private offices. The difference is probably because the small private sector is well managed and properly arranged compared to government offices that are more congested and not well managed. Apart from that, government offices are still using old techniques of file systems and lots of paperwork which stays in offices for a longer period, whereas in the private sector, most of the paperwork is replaced by computers and data storage is shifted to computer or cloud storage. A comparison of fire load for various types of office rooms concerning government and private office rooms is presented in Figure 1.

3.3. Relationship between FLD and Combustibles Items

Fire occurs when combustible items come into contact with oxygen in the presence of heat. The fire, which usually starts with burning one item, gradually spreads to other nearby items and grows in size and intensity as pre flashover fire (Buchanan and Abu, 2017a). The combustible items provide valuable information about the trend of fire load. Wood, paper, and plastic are the major contributing items to the fire load in an office building. The survey results were analyzed for these combustible items to find their relationship with different categories of office buildings.

Figure 2 shows the impact on fire load due to the percentage of wood present in office rooms. Although having a larger amount of fire load, the government office rooms have a lesser contribution from wood than private office rooms where the wood is a major contributing combustion material towards the fire load. The percentage of wood in government offices mostly lies between 30% to 70%, with a dispersed spread of fire load in the graph. However, in the case of private offices, the data is more concentrated, and the percentage of wood in fire load varies between 55% and 90%. The reason for the difference is that government office rooms have less furniture, but huge piles of paper as compared to the private office room where the offices are well furnished with wooden furniture.

Table 2. Impact of office category on fire load density

Office category	Fire load (MJ/m^2) Mean	Minimum	Maximum	Standard deviation
Private	431	256	612	108
Government	763	247	1468	368

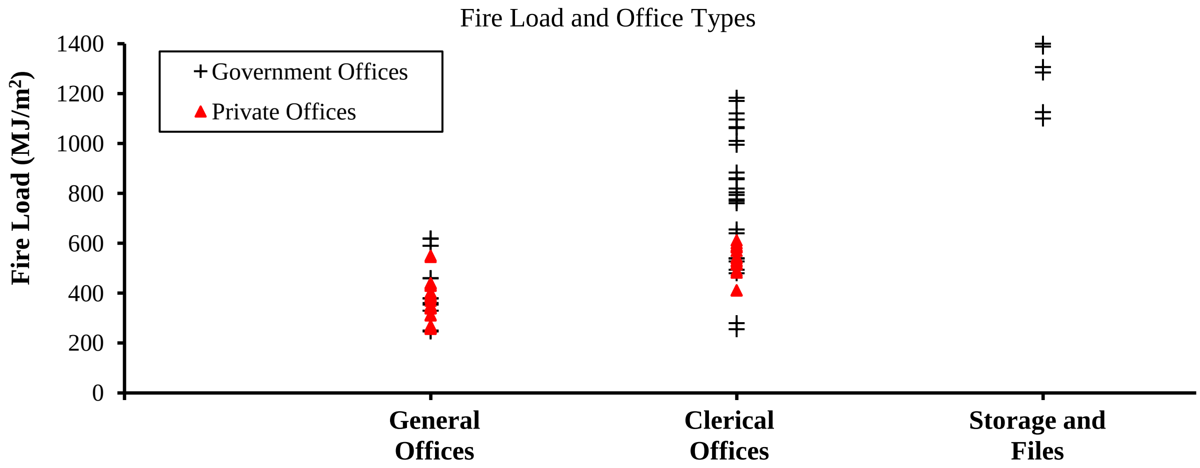


Fig. 1. Fire load in different types of office rooms

The percentage of plastic in comparison to fire load for private and government offices is shown in Figure 3. The contribution of plastic is found to be lesser as compared to the percentage of wood. Most of the plastic load lies below 40% of the total fire load. Despite the large fire load in government office rooms, the contribution of plastic is less. Pakistan is a developing country and is still using outdated methods (paper files, folders, shelves, cardboards, etc.) for record-keeping. It is expected that with time, the plastic load in offices will increase and replace the paper and wood in the offices.

The survey results in Figure 4 show the contribution of paper percentage to the total fire load. Private office rooms in Figure 4 show the lesser contribution of paper in fire load due to the reason that the private office rooms are already moved or are in the process of moving towards digitalization. However, the government office rooms are still abundant with paper and file work. The percentage of paper in most of the private office rooms is not more than 30% whereas, in the case of government office rooms, the percentage exceeds more than 60%.

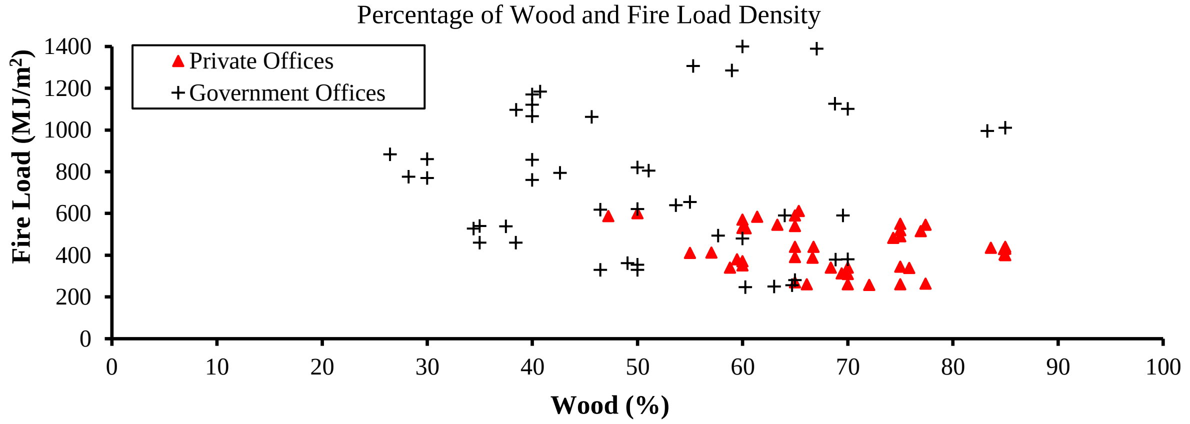


Fig. 2. FLD and percentage of wood for both government and private offices

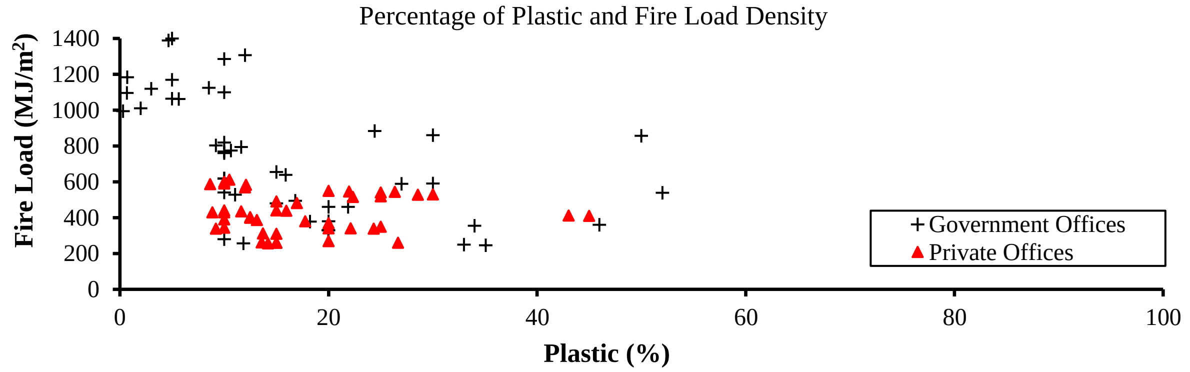


Fig. 3. FLD and percentage of plastic government and private offices

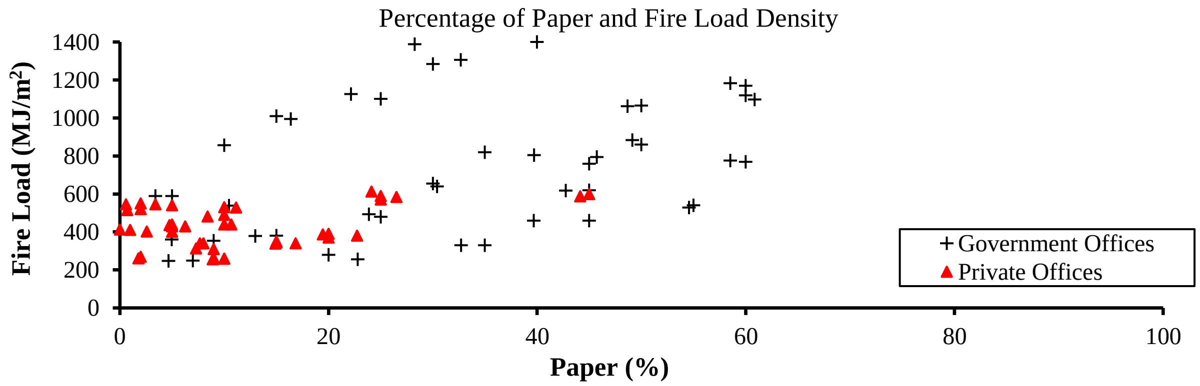


Fig. 4. FLD and percentage of paper for government and private office rooms

4. Regression Analysis

4.1. Model Summary

The surveyed offices were divided into three categories such as: i) Private Offices (PO), ii) Government Offices (GO), and iii) A Combination of Government and Private offices (CGP). Multiple linear regression analysis techniques were applied to surveyed data from 44 private office rooms, 48 government rooms, and a combination of both.

Fire load density was considered as a dependent variable in the office room, whereas Wood Percentage (WP), Office Type (OT), and Area of the Room (AR) were considered independent variables. An additional variable Office Category (OC) was considered for the combination of both offices. The reason for selecting the WP as an independent variable instead of paper or plastic is due to the results from the descriptive statistics showing a higher contribution of wood in FLD as compared to others. In the analysis, the categorical variable OT is found to be the most significant factor for all government offices, private offices, and a combination of both offices. Apart from office type, the office category is found to be a significant factor for the CGP offices. This is most probably because the difference between the FLD of government and private offices is quite large; therefore, changing this variable affects the model equation.

In the development of the model for office rooms, three independent variables were compared with a dependent variable, FLD. The categorical variable x_1 represent the percentage of wood in the office room, x_2 represent the office type (for general office rooms x_2 = 1, for clerical office x_2 = 2, and for storage and file rooms x_2 = 3) and x_3 represent the area of the office room in m^2. The coefficients show the weightage of each variable. At the assumed level of significance as α equal to 0.05 (see in Table 3), the coefficient value for variable OT is significant for both private offices and government offices. In the case of the combined government and private offices, the OT and OC show maximum weightage. The OT variable is much more significant than the other independent variables.

4.2. Model Equations (Variance of Analysis)

Table 4 shows the portion of variance analysis, including the sum of squares, the degree of freedom, and the mean square were given in the columns. The F-statistic value is found based on these data. The P-value is less than 0.005, proving that the whole model equation is significant. The confidence level for private offices, government offices, and combined government and private offices are 54%, 59%, and 67%, respectively.

Table 3. Effect of variables on fire load density

	Constant and variables of model	Coefficients (B)	T-statistic	P-value
Private offices	Constant	149.38	0.91	0.38
	Wood Percentage (WP)	0.71	0.37	0.72
	Office Type (OT)	197.58	4.96	0
	Area of office Rooms (AR)	-1.91	-1.42	0.17
Government offices	Constant	-0.67	-0.003	0.99
	Wood Percentage (WP)	0.04	0.01	0.99
	Office Type (OT)	443.41	5.97	0
	Area of office Rooms (AR)	-2.96	-0.64	0.53
Combine government and private offices	Constant	-285.96	-1.3	0.2
	Wood Percentage (WP)	1.49	0.67	0.51
	Office Type (OT)	373.04	7.59	0
	Category (OC)	179.69	2.55	0.015
	Area of rooms	-3.67	-1.59	0.12

Table 4. Model summary for offices

	Model	Sum of Squares (SS)	Degrees of freedom (df)	Mean Square (MS)	F-statistic	P-value
Private offices	Regression	155416.6	3	51805.5	9.1	0.001
	Residual	102262.2	18	5681.2		
	Total	257678.8	21			
Government offices	Regression	2011418.5	3	670472.8	12.0	0
	Residual	1110109.6	20	55505.4		
	Total	3121528.1	23			
Combine offices (Government + Private)	Regression	3282782.6	4	820695.6	24.1	0
	Residual	1394036.2	41	34000.8		
	Total	4676818.9	45			

The equation developed from the regression analysis for the fire load density of private office rooms is:

$$f(x) = 149.38 + 0.71x_1 + 197.58x_2 - 1.91x_3 \quad (3)$$

The R-square value for the equation is 0.60, and the adjusted R-square value is 0.54. The mean and standard deviation of fire load density for all the surveyed private offices was found as 427.18 MJ/m^2 and 110.77 MJ/m^2, respectively.

The equation for the fire load density of government office rooms is:

$$f(x) = -0.67 + 0.04x_1 + 443.41x_2 - 2.96x_3 \quad (4)$$

The R-square value for the equation is 0.64, and the adjusted R-square value is 0.59. The mean and standard deviation of fire load density for all the surveyed government offices was found as 763.41 MJ/m^2 and 368.40 MJ/m^2, respectively.

The equation for the fire load density of combined government and private offices is:

$$f(x) = -285.96 + 1.49x_1 + 373.04x_2 + 179.69x_3 - 3.67x_4 \quad (5)$$

where $f(x)$: represent the fire load density in MJ/m^2, variable x_1: represent the percentage of wood in the office room, x_2: represent the office type (for general office rooms x_2 = 1, for clerical office x_2 = 2, and for storage and file rooms x_2 = 3) and x_3: represent the area of the office room in m^2. A new variable x_4 is added for the category of government and private office buildings.

The R-square value is increased to (0.70), and the adjusted R-square value is (0.67) when combined offices are considered. The mean and standard deviation of fire load density for all the surveyed offices was found as 602.61 MJ/m^2 and 322.38 MJ/m^{2,} respectively.

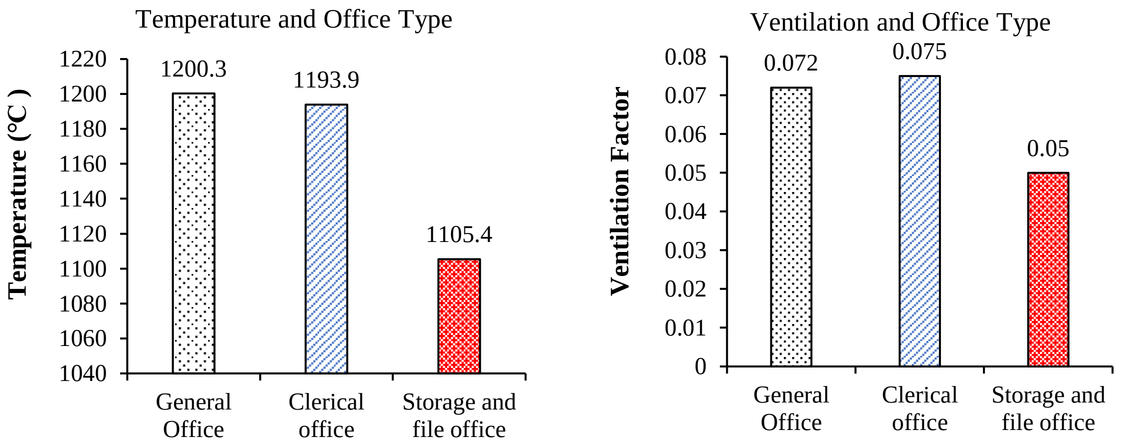
5. Analysis for Maximum Temperature

Using the survey data, including fire loads, office types, categories, office dimensions, and ventilations, maximum temperature T_{max} °C was calculated by using an empirical equation developed by Law (Buchanan and Abu, 2017a). The equations consider the total internal room area (m^2), area of the openings (m^2), and height of the openings (m). The ventilation conditions during the survey included the measuring breadth, depth, and height of each opening from the floor level. The ventilation provides a supply of oxygen, thus increasing the intensity of the fire. The average maximum temperatures determined for various office types of the survey data are presented in Table 5. The average temperature and standard deviation for all the rooms were found to be 1176.88 °C and 52.14 °C, respectively. Despite having the maximum fire load, the storage rooms showed the minimum temperature (930.55 °C) because of the least ventilation. The maximum temperature exists in the clerical office rooms (1210.81 °C) because it has more space and is well ventilated. A graphical comparison of office types with maximum temperature and ventilation factors is shown in Figures 5a and 5b, respectively.

The survey conducted in Pakistan (Islamabad) for total fire load density is 603 MJ/m^2 found by the combination method. The difference in fire load density for government and private offices is found to be much greater (763.42 MJ/m^2 for government offices and 431.49 MJ/m^2 for private offices) and thus cannot be treated as the same while designing an office building for fire safety and fire resistance. The comparison of fire load densities of Pakistan with other worldwide FLD surveys is presented in Figure 6.

6. Conclusions

In this paper, the fire load density for office buildings in Pakistan is investigated by surveying a representative model of the office buildings of concern and making a list of the compartments' sizes, fixed and movable combustibles, ventilation conditions, and their relevant features using the combination method. A total of 92 office rooms were surveyed for fire load, including government and private office rooms in the different sectors of Islamabad. The data were analyzed using the multiple linear regression techniques to develop fire FLD models for private, government, and combination of both types of offices. The analytical methods were also used to analyze data to find the characteristics of fire like temperature, etc., in an office due to the total fire load in the office rooms. The results were compared with various codes across the world, including the building code of Pakistan, to show the fire load values. Based on the survey results following conclusions can be drawn.



(a) **(b)**

Fig. 5. Comparison of office type with: a) Average maximum temperatures; and b) Ventilation factors

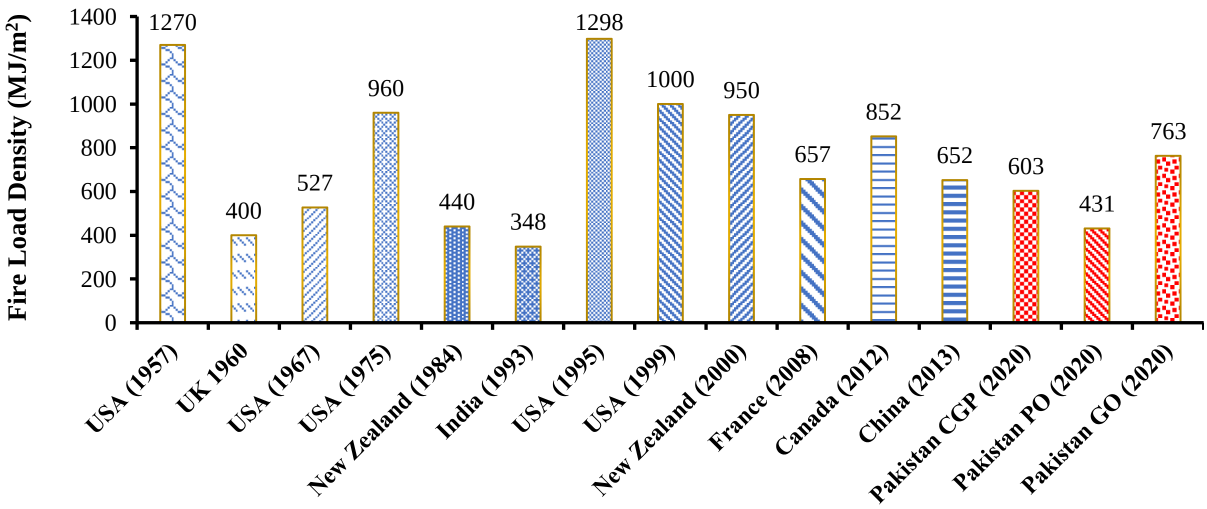


Fig. 6. Comparison of fire load densities from various surveys around the world

Table 5. Office temperatures for various office types using the survey data

Office type	Temperature (℃)			
	Minimum	Maximum	Mean	Standard deviation
General office	1062.18	1210.50	1189.45	34.01
Clerical office	1093.12	1210.81	1177.93	35.24
Storage and file office	930.55	1209.95	1105.36	129.79
All office type	930.55	1210.81	1176.88	52.14

a. The average and standard deviation of the fire load for all the office rooms were 603 MJ/m^2 and 322.38 MJ/m^2, respectively. The present building code of Pakistan lacks this information.
b. The survey results found that the value of fire load changes for office room use. Storerooms contain the heaviest fire load, which was 1468.02 MJ/m^2. The minimum fire load in general office rooms was 247.05 MJ/m^2.
c. Two types of office buildings were surveyed, private office buildings and government office buildings. The survey result shows that the fire load values are different for government and private offices, whereas the building code of Pakistan (which is adapted from NFPA codes) has the same value for both government and private offices.
d. The impact of the percentage of the wood material is more than the other combustible material in the office room. In some office rooms, the wood percentage was found to be more than 80%. The result also shows that the percentage of paper in the office room has less impact on fire load. The plastic contribution is below 30% of the total fire load.
e. The fire load depends on the area and amount of combustible material present in the office room. When the area of the room increases, the fire load also increases because it has the more combustible material in the room and the fire load decrease when the area of the room decreases but has the less combustible materials in the office room. This finding is contrary to other surveys conducted worldwide.

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Appendix

Data collection for fire load (FYP)					
Data releated to building					
Room Type		Room Length (meter)		Building Name	
Room Category		Room Width (meter)			
Fire protection systen		Ceiling Height (meter)		Fire Load Arrangement	
Floor		Area Of Room (m^2)			

An item which is weighing by combining Weighing and Inventory technique

Item	Type	No	No of element	Length (m)	width (m)	Hight (m)	Volume (m^3)	Density (kg/m^3)	Weight (kg)	Total Weight (kg)	net Total weight (kg)	Calorific Value (MJ/kg)	Fire Load (MJ/m^2)
Wood													
Plastic													
Papers													
Others													
											Total Fire Load (MJ/m^2)		0.000

Conducted by:	Approved by:	

Date:_________________ Time:___________ No:__________