A Survey of Fire Loads for Different Room Types found in a Third Level Educational Building

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Abstract: This paper presents the results of fire load surveys undertaken at a third level educational building, the Cork Institute of Technology in Cork, Ireland. The results show that movable fire load densities for canteen areas, classrooms with fixed and movable seating arrangements, exam halls and libraries are less than those previously published in literature while computer rooms, administration offices and lecturer offices are higher than published values. It was found during the fire load calculation process that much of the calorific values of the materials found in these rooms were unknown. Extensive oxygen bomb calorimetry tests were performed on over 170 representative materials ranging from carpets, ceiling tiles, furniture laminates, marmoleum samples, paints, plastics, structural materials, tiles, upholstery foams and fabrics, wall linings and insulations, wallpapers, window blinds, wiring samples, woods and miscellaneous items such as printed circuit boards and paper based building contents. These test results are also presented in this paper.

Keywords: Calorific value, characteristic fire load density, design fire load density, fire load survey, third level educational building

1. Introduction

Fire loads can be seen to be the basis on which the potential severity, size and duration of a fire can be evaluated when used in unison with other data such as building ventilation characteristics. Once known, these values can be used to further determine the smoke and heat produced from a fire whereby the smoke produced will be a key factor in the time available for occupants to egress from the building and the heat will impact on the structure causing unprotected structural members to weaken.

Fire load data is used by a range of professionals which include architects, building control officers, fire modellers, fire investigation bodies, fire risk assessors, fire safety engineers and insurance assessors. These are instrumental for a multitude of reasons such as when 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 when assessing insurance premiums. They are also useful in establishing building risk profiles when preparing fire safety risk assessments.

2. Objective

In the past, fire load surveys have been conducted on numerous buildings encompassing residential, commercial, institutional and industrial occupancies which are summarised by Yii (2000); however, educational buildings were seen to be the least surveyed occupancy type. In terms of previously published data for educational buildings, fire load data was found to be limited to European, Dutch, Swiss and American data for schools in the CIB W14 report (1983), Canadian elementary and high schools by Hadjisophocleous and Chen (2010) and Australian primary and secondary schools by Barnett (2015). In the search for previously published fire load data for educational buildings, information for third level educational buildings was found to be extremely limited.

To help fill this gap, a fire load study at the Cork Institute of Technology, Cork, Ireland (CIT) was undertaken and assumed to be a typical representation for this occupancy type. A survey was conducted to quantify the types and frequency of all the different types of rooms present in the main campus building. This entailed a walk-about survey using building drawings and recording room numbers, the types of rooms and floor coverings for a sample floor area of 25,000m^2. The results of this survey can be seen in Figure 1. In an effort to better evaluate room types with the largest proportion of floor areas, room types with floor areas less than 3% of the total building floor area were eliminated from the study. Furthermore, workshops and laboratories were also omitted from the study due to difficulties with materials and contents typically found here.

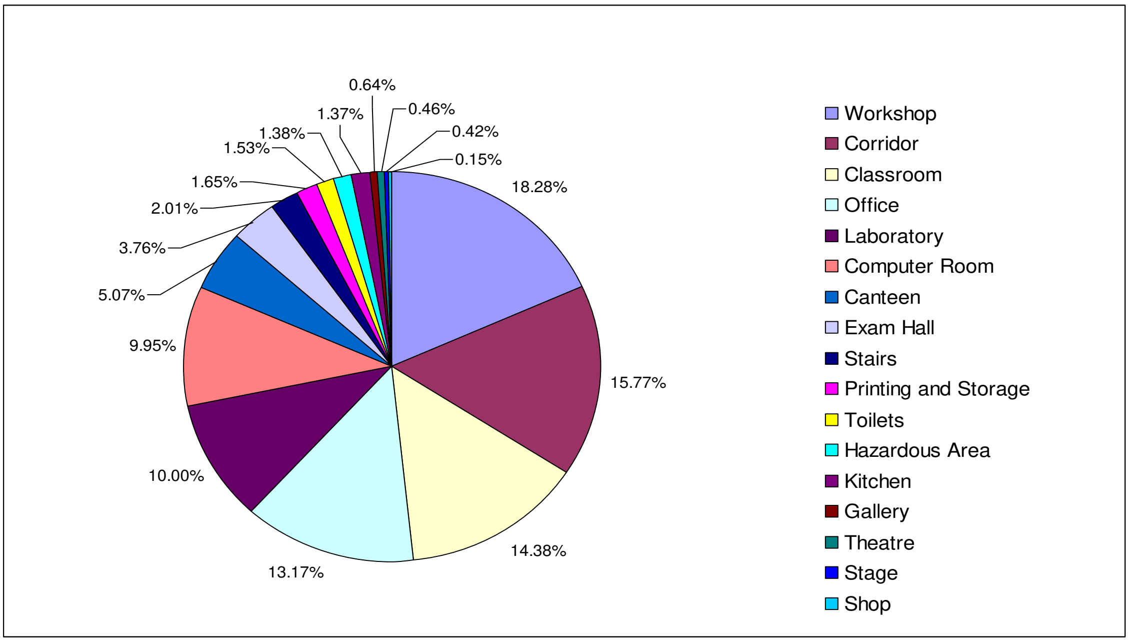

Fig. 1. Room types in the main CIT campus building

Fire load surveys were conducted for each of the remaining room types which were classified under exam halls, canteens, computer rooms, administration offices, lecturer offices, classrooms with fixed seating, classrooms with movable seating and corridors. Subsequently, as libraries are a significant space in educational buildings, this room type was also surveyed. A total of five surveys for each of the aforementioned room types were performed as recommended by BS PD 7974-1 (2003), encompassing a total surveyed floor area of 2,984m^2. In an effort to be as accurate as possible, a number of building materials typically found here was also tested in order to obtain their true fire loading contributions. This paper describes the calculation of fire loads and the determination of characteristic and design fire load densities for these room types in addition to their comparison with previously published values for similar room types.

3. Fire Load Calculation and Methodology

The fire load of a compartment, in its basic form, is the total heat or energy content released stemming from the complete combustion of all the combustible materials located there and can be either permanent or movable. Permanent fire loads are loads from combustible materials which are unlikely to vary over the life of the compartment and include fire loads from structural materials, built-in furniture and permanently installed equipment such as air-conditioning units. Movable fire loads are loads from combustible materials which do vary over the life of the compartment and include fire loads from free-standing furniture, soft furnishings and electrical equipment such as computers.

The determination of fire loads is generally completed by either conducting fire load surveys or using previously published generic fire load data. These are typically discussed in terms of fire load densities which is simply the total fire load in the compartment divided by the area of the compartment. In older fire load surveys and calculations, fire loads were characterised in terms of inner compartmental surface areas whereas modern fire load densities are outputted in terms of compartmental floor areas. Characteristic fire load densities can be evaluated using equation (1) from BS PD 7974-1 (2003).

$$q_k = \sum \frac{m_c H_c}{A_f} \tag{1}$$

Where:

q_k = characteristic fire load density (MJ/m^2),
m_c = total mass of each combustible item (kg),
H_c = effective or net calorific value of each combustible item (MJ/kg) and
A_f = total internal floor area (m^2).

Nowadays, fire loads used in modern fire design principles are called design fire loads. These are effectively characteristic fire loads but modified to take various factors into account such as the room size, space usage and active firefighting measures present. This paper will present the determination of characteristic and design fire load densities for the different room types examined in CIT which were found using the most modern procedures descirbed in the Eurocodes and associated Irish National Annex, NFPA 557 and the SFPE Handbook of Fire Protection Engineering.

3.1 Mass of Combustible Items

In terms of recording the mass of combustible items in the rooms surveyed, three survey techniques were employed; the inventory method, direct weighing method and combination method. The inventory method involves the measurement of material dimensions and extracting associated densities from property tables to obtain material volumes and densities. The product of these values outputs combustible item weights. The direct weighing method requires the use of weighing equipment to find the weights of combustible items while the combination method allows for the use of the two aforementioned techniques in conjunction with one another to obtain combustible item weights.

3.2 Calorific Values of Combustible Items

Calorific values are a measurement of the energy released as heat which is produced by the complete combustion of a specified amount of a compound with oxygen and is commonly measured in units of Megajoules per kilogram (MJ/kg). In general, the greater the calorific value of a compound, the higher the energy content in the compound. This principle is what makes gasoline (46.7 MJ/kg) ideal for vehicle fuel as it has a much higher calorific value in comparison with that of ethanol (29.67 MJ/kg), with values provided in the NFPA Fire Protection Handbook (2008).

Calorific values are classified into two categories; gross and net. The gross calorific value of a material or substance is essentially its total energy content and may be found using bomb calorimetry. Following its combustion, the resultant water is in the form of steam and as it cools and condenses to liquid water, it releases heat energy. Thus, gross calorific values include this second energy source in its measurement of energy contents. In comparison with the determination of gross calorific values whereby energy released from the condensing of steam to liquid water is added to the energy of the substance, net calorific values do not include this second energy source in its measurement.

Recent research by Doyle (2011) has concluded that there is a significant lack of available calorific data for building materials, internal finishes and contents which are most certainly required when completing fire load calculations. It was seen that available data previously published is quite limited and to overcome this issue the testing of numerous building materials for their calorific values was completed.

Determination of Gross Calorific Values

Oxygen bomb calorimetry is the most commonly used scientific technique for determining the gross calorific values of solid and liquid compounds. In contrast, those of gaseous elements are found using gas chromatography. For the testing of building materials, a PARR 6200 isoperibol oxygen bomb calorimeter was employed. This instrument, which can be seen in Figure 2, has a precision class of between 0.05% and 0.1%.

Fig. 2. PARR 6200 Oxygen Bomb Calorimeter

In this, a sample with a typical weight of 1g is burned in an oxygen-filled bomb within an accurately weighed water bath surrounded by an insulating jacket and the temperature of the water is plotted throughout this process. By knowing the heat capacities of the bomb calorimeter materials, components and the water, the heat of combustion of the sample can be determined. The gross calorific value of the sample can then be calculated by dividing this heat of combustion by the initial mass of the sample. Three tests on each sample were conducted in accordance with BS EN ISO 1716 (2010) and the test results were validated using code criteria also found in this document. In total, more than 900 individual bomb calorimetry tests were performed on over 170 building materials in order to evaluate their gross calorific values.

Determination of Net Calorific Values

It can be seen from equation (1) that the formula for determining characteristic fire loads requires the input of net calorific data. This is because the implementation of gross calorific data would result in unrealistic fire loads. Unlike the determination of gross calorific values, there are no direct experimental techniques available for assessing the net calorific values of substances and materials. To overcome this, approximation methods were implemented to transpose the gross to net calorific values of tested materials which involved researching the hydrogen content of previously published material data. Table 1 presents the net calorific values of materials tested.

Table 1. Net Calorific Values of Assorted Materials Tested

Material	Net Calorific Value (MJ/kg)	Material	Net Calorific Value (MJ/kg)
Carpet Underlay	20.29	Upholstery Foams	
Carpets		Polyurethane	23.86 – 24.15
Polypropylene pile fibres		Recycled	25.43
with bitumen backing	33.45 – 36.83		
Nylon pile fibres		Window blinds	
with hessian/jute backing	12.06 – 23.02	75% PVC & 25% Fiberglass	13.68 – 14.19
Nylon pile fibres		100% Polyester	13.74 – 18.91
with polyethersulfone backing	12.71 – 15.93	50% Cotton & 50% Polyester	21.85
Ceiling Tiles	1.88 – 2.76		
Furniture Laminates	17.15 – 18.12	Wiring	
Marmoleum	15.74 – 17.66	Blue Conductor Cable	6.83
Acrylic	29.27 – 29.32	Red/Brown Cable	6.10
Canteen Tray	18.88	Green/Yellow Cable	5.72
Printed Circuit Board	7.28	White Four Conductor Cable	11.00
Paper Based Building Contents	11.11 – 17.26		
Oil Based Paints		Wall Insulation	
Cream	7.87	Phenolic Insulation	26.33
Grey	11.53		
Purple	13.38	Wallpapers	
White	5.69	Pasted	12.20 – 14.81
Red	16.57	Unpasted	13.03 – 15.37
Yellow	11.19		
Gloss Paints		Woods	
Black	26.46	Beech	16.39
		Iroko Teak	16.58
Plastics		MDF	16.91
Black Bag	41.39	Plywood	16.46
Seating Plastics	34.25 – 42.21	Red Deal	17.39
Electronic Casing	30.88	Red Oak	16.42
Projector Screen	7.34	Sapele Mahogany	16.27
Polystyrene	39.23	Southern Yellow Pine	17.24
PVCu Wire Casing	19.26	White Ash	16.81
Red Safety Flooring	18.64	White Deal	16.52
		Walnut	16.60
Upholstery Fabrics		White Oak	16.61
Wool, Polypropylene and Viscose	16.38 – 34.07		
Vinyl	19.84 – 21.15		

Materials which were found to be non-combustible include ceramic and porcelain tiles, concrete, glass, stone and gypsum products. Over the course of the fire load surveying process, these values were used in the determination of fire loads. For the small proportion of materials present in rooms which could not be tested, calorific data was taken from the NFPA Fire Protection Handbook (2008) as this contained the most extensive list of published material calorific data.

3.3 Total Internal Floor Areas

The total internal floor areas were obtained using measuring tapes and by reading room dimensions from building drawings in AutoCAD. Both techniques were combined together during the fire load surveying process to effectively evaluate floor areas for the rooms examined.

4. Fire Load Classifications

The different room types surveyed were categorised into low, moderate and high risk areas depending upon their total fire load densities which is based upon previous studies summarised in the NFPA Fire Protection Handbook (2008). Here, low risk areas are described as having an average total fire load not greater than 1,134 MJ/m^2; however, this can be increased to 2,268 MJ/m^2 if the storage of combustible materials are protected. Subsequently, these can be described as moderate risk areas if their average total fire load lies between 1,134 – 2,268 MJ/m^2 which can be increased to 4,540 MJ/m^2 provided that the storage of combustible materials here are protected. Lastly, high risk areas are those whose average total fire load densities exceed 2,268 MJ/m^2 but are less than 4,450 MJ/m^2 and this can be increased to 9,080 MJ/m^2 if the storage of combustible materials are once again protected.

5. Fire Load Survey Results

5.1 Characteristic Fire Load Densities

A total of five sections of the West Atrium canteen at CIT were surveyed, each with a floor area of 53.51m^2. Four of these sections had similar furniture while the other section was furnished differently. Here, the average total fire load density was found to be 148.24 MJ/m^2. Results indicated that the fire load from movable furniture could be reduced by 47.38% depending upon the furniture materials used. Interestingly, the additional fire load due to the presence of food within these areas was estimated between 16.43 – 20.79 MJ/m^2. Canteens were found to be low risk areas.

Five classrooms with fixed seating arrangements were also investigated. These are classrooms which bolt or permanently fasten seating units to the floor making different seating arrangements problematic to achieve. The average total fire load density here was found to be 272.86 MJ/m^2. Furthermore, an additional fire load density of 44.50 – 59.33 MJ/m^2 could be included to account for student belongings which assumes a class attendance of between 75 – 100% and a backpack, two books and two refill pads per student. This room type falls under the classification of a low risk area.

In comparison, five surveys of classrooms with movable seating arrangements concluded an average total fire load density of 271.52 MJ/m^2, which is almost identical to that of classrooms with fixed seating and categorizes this room type as a low risk area too. Once again, assuming class attendances of between 75 – 100% and a backpack, two books and two refill pads per student, the additional fire load from student belongings was found to be in the region of 21.33 – 28.44 MJ/m^2. Although this is much lower in comparison to classrooms with fixed seating arrangements, this can be attributed to the lower capacities of classrooms with movable seating arrangements to accommodate students.

Five computer rooms were also surveyed and results yielded and average total fire load density for this room type of 625.07 MJ/m^2. This can be seen to be quite high in comparison with aforementioned densities; however, this can be attributed to the use of carpets, fixed computer benches and electrical cabling present in these rooms. Computer rooms were deemed to be low risk areas.

In terms of corridors, the average total fire load density from five surveys was determined to be 119.68 MJ/m^2, making these low risk areas also. This is quite small compared with previously discussed room types; however, this can be attributed to the almost non-existent presence of furniture and contents located which amounted to an almost negligible 3.41 MJ/m^2.

The average total fire load for exam halls and library sections investigated were found to be 228.30 MJ/m^2 and 518.73 MJ/m^2 respectively following five surveys of each. As anticipated, library fire load density values were expected to be large due to the high presence of combustible materials such as books, shelving units and study benches typically found here. Surprisingly, both of these can be seen to be low risk areas.

Five administration and five lecturer offices were also examined and found to have average total fire loads of 1,897.12 MJ/m^2 and 1,474.21 MJ/m^2 in that order. In comparison with other room types, the fire loads here are exceptionally large and this can be mainly attributed to the presence of combustible materials found in these rooms such as books, folders and papers. Finally, in comparison with other room types which were all seen to be low risk areas, offices ranged between low, moderate and high risk areas.

Table 2 summarizes the movable and total (including permanent) characteristic fire load densities found for the different room types surveyed in CIT using equation (1). In comparison, Table 3 illustrates the average total characteristic fire load densities for the surveyed room types using guidance provided in IS EN 1991-1-2 (2002), NA to IS EN 1991-1-2 (2002), NFPA 557 (2012) and the SFPE Handbook of Fire Protection Engineering (2002).

Table 2. Movable and Total Characteristic Fire Load Densities at CIT based on Equation (1)

Room Type	Movable Fire Load Density (MJ/m^2)				Total Fire Load Density (MJ/m^2)			
	Min.	**Max.**	**Average**	**S.D.***	**Min.**	**Max.**	**Average**	**S.D.***
Canteens	85.79	182.92	147.86	39.62	86.17	183.30	148.24	39.62
Classrooms with Fixed Seating	41.88	69.02	58.50	10.05	240.21	311.58	272.86	26.20
Class with Movable Seating	133.34	275.68	186.88	55.13	193.60	381.70	271.52	71.14
Computer Rooms	189.08	385.01	298.34	75.23	430.21	718.80	625.07	122.85
Corridors	1.84	4.88	3.41	1.32	73.43	158.95	119.68	33.16
Exam Halls	170.80	220.18	198.73	17.80	171.14	349.96	228.30	70.25
Libraries	241.21	382.79	307.25	64.14	409.19	640.90	518.73	105.07
Administration Offices	687.54	2550.09	1752.90	683.83	873.46	2678.34	1897.12	660.69
Lecturer Offices	603.31	2257.56	1358.60	849.92	859.63	2445.29	1474.21	860.85

* Standard Deviation

Table 3. Total Characteristic Fire Load Densities at CIT using formula from different design guidelines

Room Type	IS EN 1991-1-2 Characteristic Fire Load Density (MJ/m^2)	Irish National Annex Characteristic Fire Load Density (MJ/m^2)	NFPA 557 Characteristic Fire Load Density (MJ/m^2)	SFPE Handbook Characteristic Fire Load Density (MJ/m^2)
Canteens	148.24	148.24	118.59	148.24
Classrooms with Fixed Seating	272.86	272.86	218.29	272.86
Class with Movable Seating	271.52	271.52	217.21	271.52
Computer Rooms	625.07	625.07	500.06	625.07
Corridors	119.68	119.68	95.75	119.68
Exam Halls	228.29	228.29	182.64	228.29
Libraries	518.73	518.73	414.98	518.73
Administration Offices	1,897.13	1,897.13	1,517.70	1,897.13
Lecturer Offices	1,474.21	1,474.21	1,179.37	1,474.21

5.2 Design Fire Load Densities

Design fire load densities were calculated for the room types surveyed in accordance with procedures outlined in IS EN 1991-1-2 (2002), NA to IS EN 1991-1-2 (2002), NFPA 557 (2012) and the SFPE Handbook of Fire Protection Engineering (2002).

It can be seen that IS EN 1991-1-2 (2002) seems to output the most reasonable results for design purposes as it takes into account various factors such as the size and types of compartments in addition to active firefighting measures present making design fire loads less than characteristic fire loads. The Irish National Annex does not take these factors into account which results in equal characteristic and design fire loads. The NFPA 557 (2012) procedure for determining fire loads outputs impractical high fire load results, particularly for compartments which were found to have large standard deviation values such as offices. Finally, although the methodology provided in the SFPE Handbook OF Fire Protection Engineering (2002) considers the type of compartment construction, design fire load densities are more conservative in comparison with IS EN 1991-1-2 (2002) design fire load values.

Table 4. Total Design Fire Load Densities at CIT using formula from different design guidelines

Room Type	IS EN 1991-1-2 Design Fire Load Density (MJ/m^2)	Irish National Annex Design Fire Load Density (MJ/m^2)	NFPA 557 Design Fire Load Density (MJ/m^2)	SFPE Handbook Design Fire Load Density (MJ/m^2)
Canteens	99.64	148.24	314.11	126.00
Classrooms with Fixed Seating	215.12	272.86	332.45	231.93
Class with Movable Seating	208.36	271.52	532.26	230.79
Computer Rooms	493.54	625.07	988.33	531.31
Corridors	80.94	119.68	255.49	101.73
Exam Halls	154.52	228.29	516.75	194.05
Libraries	452.89	518.73	790.55	440.92
Administration Offices	1,218.72	1,897.13	4,897.03	1,612.56
Lecturer Offices	947.03	1,474.21	5,374.75	1,253.08

5.3 Fractile Fire Load Densities

Generally, published fire load data is commonly provided in terms of movable fire load densities and lists the average, standard deviation, 80%, 90% and 95% fractile fire load values. For the purpose of the study which had an ultimate goal of producing generic fire load data to be used in future fire design principles for the room types surveyed and for substantially similar room types, this information was developed and can be seen Table 5. The average and standard deviation values were relatively easy to obtain and the statistical distribution software, Easyfit, was employed to determine 80%, 90% and 95% fractile values using a Gumbel distribution as recommended by IS EN 1991-1-2 (2002) and the NFPA 557 (2012).

When using generic fire load data for design purposes, BS PD 7974-1 (2003), IS EN 1991-1-2 (2002) and the NFPA 557 (2012) recommends the use of the 80% fractile movable fire load density value (i.e. the value not exceeded in 80% of rooms examined) as this accounts for local concentrations of fire load. Also to note, the values published in this table are movable fire load densities only and must be summed with permanent fire load densities in order to obtain total fire load densities. This is important as similar rooms may have different permanent fire loads but comparable movable loads. For example, the permanent fire load in a small reinforced concrete office building would be less than that of a similarly sized timber framed building due to structural material combustibility properties.

Table 5. Movable Fire Load Densities at CIT

Room Type	Average (MJ/m^2)	Fractile (MJ/m^2)			Standard Deviation (MJ/m^2)
		80%	90%	95%	
Canteens	147.86	176.37	199.55	221.79	39.62
Classrooms with Fixed Seating	58.50	65.73	71.61	77.25	10.05
Class with Movable Seating	186.88	226.54	258.80	289.74	55.13
Computer Rooms	298.34	352.46	396.48	438.71	75.23
Corridors	3.41	4.36	5.13	5.87	1.32
Exam Halls	198.73	211.53	221.95	231.94	17.80
Libraries	307.25	353.39	390.92	426.92	64.14
Administration Offices	1,752.90	2,244.80	2,645.00	3,028.70	683.83
Lecturer Offices	1,358.60	1,970.00	2,467.30	2,944.30	849.92

5.4 Comparison with Published Data

In addition to the determination of characteristic and design fire loads for the different room types surveyed at CIT, observed results were also compared with those of similar room types which have been previously published. Table 6 presents the comparison of observed movable fire load densities for the room types surveyed with minimum and maximum previously published values for the same or substantially similar room types.

Table 6. Comparison of Observed and Previously Published Movable Fire Load Densities

Room Type	Observed Average Movable (MJ/m^2)	Published Average Movable (MJ/m^2)	
		Minimum	Maximum
Canteens	147.86	300.00	500.00
Classrooms with Fixed Seating	58.50	80.00	303.90
Class with Movable Seating	186.88	80.00	303.90
Computer Rooms	298.34	201.00	211.4
Corridors	3.41	0.00	63.00
Exam Halls	198.73	190.00	285.00
Libraries	307.25	537.80	2,129.00
Administration Offices	1,752.90	224.00	750.00
Lecturer Offices	1,358.60	224.00	600.00

The average movable fire load density for canteen areas can be seen to be up to three and a half times less than higher published values found in Thomas (1986), National Building Code of India (2009) and the New Zealand Building Code (2010). One reason for this could be the exclusion of food preparation, kitchen and servery areas from the observed fire load density result; however, it is unknown if published values included these fire load densities as original data sheets and further information on these values were unattainable. Classrooms with fixed seating arrangements can be seen to be 12 – 74% less than previously published values in the CIB W14 report (1983), Thomas (1986), IS EN 1991-1-2 (2002), National Building Code of India (2009), New Zealand Building Code (2010), Hadjisophocleous and Chen (2010) and Barnett (2015). In comparison, classrooms with movable seating arrangements were found to be consistent with lower previously published movable fire load data for classrooms also published in the aforementioned sources.

Subsequently, the average movable fire load density for computer rooms was found to be one and a half times greater than recently published values found by Hadjisophocleous and Chen (2010) and Barnett (2015). In terms of corridors, the average movable fire load density was determined to be almost nineteen times less than the previously published value in BS PD 7974-1 (2003). Although, no previous fire load data was found for exam halls, these room types were compared with general school areas and found to be almost one and a half times less than higher and almost equal to lower previously published values in BS PD 7974-1 (2003). The average movable fire load for portions of the CIT library was found to be between one and a half and six times less than previously published values taken from Thomas (1986), IS EN 1991-1-2 (2002), BS PD 7974-1 (2003) and Claret and Andrade (2007); however, observed results are reasonably consistent with recent findings by Hadjisophocleous and Chen (2010) and Barnett (2015).

For administration offices, analysis of the fire load survey results yielded an average movable fire load density which is up to eight times greater than previously published values found in the CIB W14 report (1983), Barnett (1984), Thomas (1986), Mabin (1994), Narayanan (1995), IS EN 1991-1-2 (2002), Claret and Andrade (2007), National Building Code of India (2009), New Zealand Building Code (2010) and NFPA 557 (2012), In comparison, lecturer offices were found to have an average movable fire load density which is over six times larger than published values found in the aforementioned sources. These fire loads are quite high in comparison with other room types and this was seen to be attributed to the amount of paper present in the offices surveyed. It is quite possible that this fire load may not be present in other similar room types as storage rooms are generally provided in office buildings.

6. Conclusions and Recommendations

Research conducted over the course of the study showed that generic fire load data, which is used in modern design principles, was generally determined in the 1960's. Much of this information has since evolved significantly with modern building life and this has not been reflected in current fire design guidelines. In addition, there is no fire load data for third level educational buildings as it was not found to have been previously surveyed. To add to this, calorific data for materials found in buildings is extremely limited and over thirty years old. This study aimed to combat this by obtaining the calorific values of modern building materials through testing and to use this data in conjunction with fire load surveys to accurately evaluate the fire load densities for different room types found in a typical third level educational building.

Overall findings have found that the average moveable fire load densities of canteens, classrooms with fixed and movable seating arrangements, corridors, exam halls and libraries were all less than previously published values. This implies that fire loads in modern design guidelines are perhaps conservative here. In contrast, the average movable fire load densities of computer rooms, administration offices and lecturer offices were all found to be much larger than those previously published. This indicates an under-estimation of fire loads in these room types if published values are used in their design. Fire load densities determined here should be suitable for all third level educational buildings but the similarity of these values to other buildings should be verified. In addition, new calorific data can now be implemented in future fire load calculations for all types of buildings.

Given our knowledge to date, we would recommend the replacement of furniture and soft furnishings in older buildings during renovations with those possessing low fire loads, increasing the application of metals and fair-faced masonry into building finishes and choosing building materials extremely carefully at the start of a project. These ultimately play a huge role in the risk profile and fire load in a building.

7. References

1. Yii HW. Effect of surface area and thickness on fire loads. Fire Engineering Research Report 2000/13, University of Canterbury, 2000. ISSN 1173-5996.
2. Thomas, P.H., ''Design Guide: Structure Fire Safety CIB W14 Workshop Report,'' Fire Safety J., Vol. 10, No. 2, 1986, pp. 77–137.
3. George Hadjisophocleous and Zhengrong Chen. A Survey of Fire Loads in Elementary Schools and High Schools. *Journal of Fire Protection Engineering* 2010; 20(1): pp. 55-71.
4. British Standards Institution. PD 7974-1:2003. *Application of fire safety engineering principles to the design of buildings – Part 1: Initiation and development of fire with the enclosure of origin.* London: BSI; 2003.
5. Arthur E. Cote (ed.). *Fire Protection Handbook*. Twentieth Edition. United States of America: National Fire Protection Association; 2008.
6. Graham Doyle. Calorific Values of Building Materials and their effect on the Structural Environment. *Master's Thesis*, Department of Civil, Structural and Environmental Engineering, Cork Institute of Technology, Ireland, 2011.
7. National Standards Authority of Ireland. IS EN 1991-1-2:2002. *Eurocode 1: Actions on Structures – Part 1 – 2: General Actions – Actions on structures exposed to fire*. Dublin: NSAI; 2002.
8. National Standards Authority of Ireland. NA to IS EN 1991-1-2:2002. *Irish National Annex to Eurocode 1: Actions on Structures – Part 1 – 2: General Actions – Actions on structures exposed to fire*. Dublin: NSAI; 2002.
9. National Fire Protection Association. NFPA 557. *Standard for Determination of Fire Load for Use in Structural Fire Protection Design.* Massachusetts: NFPA; 2012.
10. Department of Building and Housing, New Zealand Government. C/VM1 and C/AS1. *Fire Safety*. Wellington. Department of Building and Housing, New Zealand Government; 2010.
11. Bureau of Indian Standards. *National Building Code of India – Part 4 – Fire and Life Safety*. India: Bureau of Indian Standards; 2009.
12. CIB W14. A Conceptual Approach towards Probability Based Design Guide on Structural Safety. *Fire Safety Journal* 1983; 6(1): pp. 1–79.
13. A.M. Claret and A.T. Andrade. Fire Load Survey of Historic Buildings – A Case Study. *Journal of Fire Protection Engineering* 2007; 17(2): pp. 103-112.
14. C.R. Barnett. *Pilot Fire Load Survey Carried out for the New Zealand Fire Protection Association*. MacDonald Barnett Partners. Report Number: 3850; 1984.
15. P. Narayanan. *Fire Severities for Structural Fire Engineering Design*. BRANZ. Report Number 67, 1995.
16. M.B. Mabin. *Report on Fire Loadings*. University of Canterbury. Report Number: Unknown, 1994.
17. British Standards Institution. BS EN ISO 1716:2010. *Reaction to fire tests for products – Determination of the gross heat of combustion (calorific value).* London: BSI; 2010.
18. Society of Fire Protection Engineers. *SFPE Handbook of Fire Protection Engineering*. Third Edition. Quincy, Massachusetts: National Fire Protection Agency; 2002.
19. Andrew Barnett. *Fire Resistance Level Assessments and Development of Appropriate Input Data*. [Online]. Available from: http://www.fpaa.com.au/media/229533/d1-fse-p10-barnett.ppt.pdf [Accessed 20th January 2019].