

FIRE LOAD AND CHARACTERISTICS OF MODERN HIGH-RISE
RESIDENTIAL BUILDINGS

by

Aykut Onursal

B.S., Civil Engineering, Yıldız Technical University, 2017

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Civil Engineering
Boğaziçi University

2021

ACKNOWLEDGEMENTS

I would first like to thank my thesis advisor Assoc. Prof. Serdar Selamet. The door to Prof. Selamet's office was always open whenever I ran into a trouble spot or had a question about my research or writing. He consistently allowed this paper to be my own work, but steered me in the right the direction whenever he thought I needed it.

I would also like to express my gratitude to members of my thesis committee, Prof. Dr. Serdar Soyöz and Assoc. Prof. Dr. Neşe Çakıcı Alp who devoted their valuable time for the presentation and for their precious suggestions for the final edition of this thesis.

I would also like to express my very profound gratitude to my parents and to my wife Özlem Adalı for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

ABSTRACT

FIRE LOAD AND CHARACTERISTICS OF MODERN HIGH-RISE RESIDENTIAL BUILDINGS

This thesis investigates the energy content of modern high-rise residential buildings in Istanbul. High-rise residential buildings are rapidly increasing due to urbanization and they are mainly constructed in dense areas of the city. Therefore, a fire that occurs in one of these residential buildings might have significant consequences. In order to perform a fire analysis, a fire has to be designed according to the energy content of fire load of the compartments. Regulations have predefined fire load for dwellings; but it does not always represent the fire load of a real fire scenario. Two different high-rise residential buildings and 3 different low-rise buildings in Istanbul are investigated. In these surveys; items inside the rooms, their dimensions and dimensions of the rooms were noted. Knowing the energy content of the rooms fire load is calculated for the rooms and apartments which resulted in calculating the fire load of these modern residential buildings. An application is written in order to estimate the heat release rate of the rooms which is used to compare the energy values between the curve and the surveyed values. In total 5 different FDS analysis was performed and it was found that fire spread can be slowed down or prevented if the furniture is placed with 1.5 m spacing. It was also found that as the ventilation factor of the compartment approached to 0.1, heat flux values increased. Energy content of these high-rise residential buildings and low-rise dwellings compare well with mean values stated in Eurocode standards for dwellings and specific rooms in order to estimate any residential buildings hrr and fire load.

ÖZET

YÜKSEK KATLI MODERN KONUT BİNALARININ YANGIN YÜKÜ VE ÖZELLİKLERİ

Bu tez İstanbul'un içindeki modern yüksek katlı konut binalarının enerji içeriğini incelemektedir. Yüksek katlı modern konut binalarının sayısı kentleşmeye bağlı olarak çok hızlı artmaktadır ve bu binalar genellikle şehrin en yoğun bölgelerinde inşa edilmektedir. Bu sebepten dolayı, bu binalardan birinde ortaya çıkacak olan bir yangının çok ciddi sonuçları olabilir. Bu yangınların analizlerini yapabilmek için öncelikle bu binaların enerji içeriği ve yangın yükünün bilinmesi gerekmektedir. Yönetmeliklerde konutlar için belirlenmiş bir yangın yükü bulunmaktadır; fakat bu yangın yükü tüm konutlar için sabit olduğundan, gerçek bir yangın senaryosunu doğru temsil edememektedir. İstanbul içerisinde bulunan 2 farklı yüksek katlı konut binası ve 3 farklı alçak katlı konut binası incelenmiştir. Bu incelemelerde, binaların içinde bulunan eşyalar, eşyaların boyutları ve odaların boyutları not edilmiştir. Odaların enerji içerikleri hesaplandıktan sonra, dairelerin yangın yükleri hesaplanmıştır ve sonuç olarak modern konut binaların toplam yangın yükü hesaplanmıştır. Matlab kullanılarak bir uygulama yazılmıştır ve bu uygulama ile odaların ısı salınım hızı eğrileri hesaplanarak açığa çıkan enerji ile hesaplanan enerji değerleri karşılaştırılmıştır. Toplamda 5 farklı yangın simülasyonu yapılarak, eşyaların yerleştirilme mesafelerine bağlı olarak yangın yayılımının yavaşlatılabileceği veya 1.5 m'den daha büyük aralıklarla yerleştirilirse tamamen engellenebileceği bulunmuştur. Bu analizlerin sonucunda, kompartmanın açıklık faktörü 0.1'e yaklaştıkça ısı akısının değerlerinin arttığı bulunmuştur. Bu binaların enerji içeriği Eurocode standartlarının önerdiği ortalama değerler ile yakın olup bu değerlerden yararlanılarak İstanbul'da bulunan konut binaları ve bu binaların içerisinde bulunan her bir oda için ortalama bir enerji içeriği değeri hesaplanmıştır.

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LIST OF SYMBOLS

a_{ij}	Description of a_{ij}
A_f	Floor Area
A	State transition matrix of a hidden Markov model
E	Energy contained in the fuel
ΔH_c	Calorific Value of fuel
M	Mass
V	Volume
α	Blending parameter <i>or</i> scale
$\beta_t(i)$	Backward variable
ρ	Density
Θ	Parameter set

LIST OF ACRONYMS/ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AAM	Active Appearance Model
CFD	Computational Fluid Dynamics
FDS	Fire Dynamics Simulator
FLD	Fire Load Density
FLED	Fire Load Energy Density
ASM	Active Shape Model
HRR	Heat Release Rate
NFPA	National Fire Protection Association
MJ	Megajoule
SFPE	Society of Fire Protection Engineering

1. INTRODUCTION

The urbanization around the world increases each passing year and as a result high-rise buildings become more popular due to high population density and land price. Therefore, researchers started investigating the effects of natural disasters on these buildings due to the fact that a high-rise building houses much more people compared to a low-rise building. High-rise structures are complex structures which behaves differently compared to a low-rise structure. Unfortunately, while the earthquake effects on high-rise buildings are widely researched, how fire affects these types of buildings is not researched as much. There are earthquake risk maps, community resilience plans that allows for a community to rebuild after an earthquake; but there is not a fire risk map or fire resilience graphs. This is due to fire safety is still considered on individual buildings. However, studies show that fire disaster could have devastating effects to the community [1].

National Fire Protection Association(NFPA) provides fire loss data for US. Approximately 15,400 reported high-rise structure fires resulted in 46 civilian deaths, 530 civilian injuries and \$219 million in direct property damage between 2007-2011 per year [2]. One of the most catastrophic fire event is the falling of World Trade Centres on September 11th terrorist attack in America which resulted in 2763 civilian casualties. The collapse of these two buildings were caused by the fire fueled with vast fire load from the impact of two airplanes [3]. Another unfortunate event took place in 2017, London. Grenfell Tower fire started on fourth floor and spread through the entire building almost in 10 minutes. Grenfell Tower fire lasted for sixty hours with more than 250 firefighters trying to put out the fire. 72 people died in Grenfell Tower fire which could've been evaded; but there was not a safe route for the occupants to take so they could not evacuate in time.

In 2015 two year before the Grenfell Tower fire, an hotel named Address Downtown, a 63-storey high-rise building in Dubai caught on fire. Fire started at 20th floor and rapidly spread through the whole building like the Grenfell Tower fire; but there was not any casualties, only 14 people getting slightly injured and 1 moderately injured. This proves that, with proper fire safety design casualties can be avoided in a severe fire disaster. It took four hours for firefighters to put out the fire and it took two years to repair the fire damage. In 2012, Polat Tower Residence a 42-storey office building caught on fire due to a faulty air conditioner. Fire rapidly spread through the external insulation; but with the building's fire-extinguishing system and firefighters' help there were no casualties and the fire was put out. In 2009, Beijing Television Cultural Center caught on fire due to unauthorized fireworks, it took six hours to put out the fire with six hundred firefighters. In the end there was only one death and seven injured people with more than \$588 million damage.

It is very important to represent the fire scenario as accurately as possible in order to have correct firefighting measures. According to NFPA most high-rise building fires begin on floors higher than the 6th story. High-rise buildings are also more likely to have fire detection, sprinklers which results in fires to not spread beyond their origin room [4]. However, as the height of these high-rise buildings increases, amount and the variety of combustible materials also increases which results in a higher fire load. Therefore, in this study fire load and energy content of the high-rise buildings are also investigated and provided for each apartment room by room. This way from the item data collected for each room, room with the most fire load can be identified.

1.1. Background

Fire load is divided into two categories; movable fire load and non-movable fire load. Movable fire load is mainly furniture and non-movable fire load is mainly built-in structural elements and floor coverings. Fire load can be converted into gas temperature related with time for a given compartment. Therefore, knowing the fire load of a compartment; one can obtain maximum temperature, heat release rate, soot release rate data of the compartment. The relation between fire load data and gas temperature

is given in Eurocode and The Society of Fire Protection Engineering(SFPE) standard. Regulations give a deterministic fire load density value for each type of building and this value might be conservative for some buildings. These deterministic values for regulations are also set with the past conducted surveys; but building materials and building contents change over time. Therefore, fire load data should be updated with fire load surveys [5].

In 1990 a fire load survey was performed in India and both movable, non-movable fire load was taken into account. Also room use, floor area and floor level on fire load was analyzed. It was found out that the mean fire load was between $278MJ/m^2$ to $852MJ/m^2$. Kumar and Rao also noted that the mean and maximum fire load had an inverse proportion with the floor area and the building height had no effect to fire load [6].

A series of surveys performed in Canada for low-rise buildings and apartments show that the average fire load densities in rooms are: Kitchens – $807 (940) MJ/m^2$; dining rooms – $393 (576) MJ/m^2$; living rooms – $412 (610) MJ/m^2$; basement living rooms – $288 (450) MJ/m^2$; primary bedrooms – $534 (753) MJ/m^2$; secondary bedrooms – $594 (846) MJ/m^2$. The values in the brackets represents 95^{th} fractile values. Kitchen has the highest fire load density compared to other rooms; but it is also noted that bedrooms have the highest fire load due to high calorific values present in the bedrooms [7].

There have been couple of fire load surveys performed in Hong Kong. First one was performed in 2007 on 8 high-rise buildings. They found out that half of these high-rise buildings had fire load density higher than $1135 MJ/m^2$ [8]. Three years later another fire load survey has been conducted by a company for 50 high-rise residential buildings, and it has been found out that the average fire load density of these high-rise buildings was $1400 MJ/m^2$ [9]. Table 1.1 summarizes and shows the fire load density results from the previous surveys explained so far.

In conclusion, Kumar and Rao found that the mean and maximum fire load had an inverse proportion with the floor area and the building height had no effect to fire load. Bwalya found from his studies that the kitchen has the highest fire load density and bedrooms have the highest fire load due to high calorific values present in the bedrooms.

Table 1.1. Summarized fire load survey results.

PREVIOUS FIRE LOAD SURVEYS	
Researchers	Results
Kumar and Rao	The mean fire load was between $278 MJ/m^2$ to $852 MJ/m^2$. The mean and maximum fire load had an inverse proportion with the floor area and the building height had no effect on fire load.
A.C. Bwalya, G. Loughheed, A. Kashef and H. Saber	Kitchens – $807 MJ/m^2$; dining rooms – $393 MJ/m^2$; living rooms – $412 MJ/m^2$; basement living rooms – $288 MJ/m^2$; primary bedrooms – $534 MJ/m^2$; secondary bedrooms – $594 MJ/m^2$.
Ngan, S. and G. Lui	Out of 8 high-rise buildings, half of it had fire load density higher than $1135 MJ/m^2$.
Arup	50 high-rise buildings surveyed in Hong Kong had an average fire load density of $1400 MJ/m^2$.

1.2. Objective and Scope of Study

There is not any fire load survey about high-rise buildings in Istanbul in the literature. Therefore, in order to perform a fire analysis in Turkey, a fire load survey has to be conducted. Buildings must be classified according to their fire load and designed to meet the Turkish Building Fire Safety Regulations. Therefore, the objective of this thesis is to provide fire load values for the high-rise buildings. In order to do this, the gathered survey data is used to determine the fire loads for the high-rise residential buildings. These 3 different fire load survey data is used to make an estimation on the fire load for any high-rise building. This estimation can be divided into room types and floor areas in order to estimate the fire load of individual rooms. Then, the heat release rate is calculated for each compartment using the matlab code provided in this thesis. This way an estimation on the maximum room temperature can be made in case of a fire.

1.3. Organization of Thesis

The thesis is divided into five chapters.

- Chapter 1 gives the introduction of thesis, reviews the surveys performed before and their resultant fire loads and explains the objective of this thesis.
- Chapter 2 reviews the literature for similar topics discussed in this thesis. Fire loads surveys for all types of buildings and heights are also discussed in this chapter. Literature on design fires and fire scenarios, fire modelling are also given in this chapter.
- Chapter 3 explains the methodology behind how the fire load survey is performed and how the fire characteristics of the items are found.
- Chapter 4 shows the results of the fire load surveys for each residential building and the fire characteristics of the items are also given. FDS analyses were performed to find the fire spread time and conditions.
- Chapter 5 presents the conclusions of this study and recommendations for future work.

2. LITERATURE REVIEW

In recent years, researches have started to investigate the fire load in car parks [10], dwellings [11], [12], [13]. They conducted surveys to find the fire loads and determine the safety of high-rise buildings [14] and some conducted surveys to create a fuel load mapping [15]; but in the scope of this thesis dwellings are investigated.

2.1. High-Rise Buildings

NFPA classifies a building as a high-rise building if the building has an occupied floor which has a height greater than 23m above the lowest level where the fire department vehicle can access the building [2]. High-rise buildings offer greater views compared to low-rise buildings, they are generally constructed in central urban locations and have many services, transportation options near to them. Also the large number of neighbours creates more chance to socialize [16]. Therefore, high-rise buildings tend to have more occupants and a longer distance to the exit, fire protection becomes essential [4].

2.1.1. Fire Safety in High-Rise Buildings

Fire safety in any building is analysed for the following fire safety concerns [17]:

- Control of ignition

Ignition is the start of flaming combustion which marks the transition to the growth period of fire [18]. This can be done by controlling the flammability of the material inside the structure.

- Detection

In the incipient period of a fire, detection can be achieved by humans or detectors such as smoke detectors or sprinklers. Sprinklers are activated by the heat detectors installed inside them in order to control the fire or extinguish it completely.

Smoke detectors are more sensitive than heat detectors and they alarm the occupants and firefighters.

- Prevention of structural damage

This can be explained as maintaining the structural integrity and stability in case of a fire at elevated temperatures, in order to prevent the collapse of the building.

2.2. Fire Load Surveys and Fire Loads

Fire load depends on the combustible materials inside a building. Fire load is generally given as fire load density (FLD) or fire load energy density (FLED) which represents the fire load energy per square meter of floor area [18]. In order to calculate the FLED, total energy which will be released from the complete combustion of all combustible materials inside the compartment must be calculated. Energy (MJ) contained in a dry fuel is calculated with the equation (2.1) and for fuels that has moisture, equation (2.2) is used [18]

$$E = M\Delta H_c \quad (2.1)$$

$$E = M\Delta H_{c,n}. \quad (2.2)$$

Fire load density e_f (MJ/m² floor area) for an area is calculated with the equation

$$e_f = E/A_f. \quad (2.3)$$

Fire duration and heat release rate determines how dangerous the fire is, where they both rely on the fire load density of the compartment. Fire load density is calculated with the equation (2.3) or with the total bounding surface area of the compartment (A_t) [18].

In a fire load survey; the combustible materials and their types, their location, amount of the materials are noted. Additional information such as occupant characteristics and potential sources of ignition is also collected. Fire load surveys need to be updated regularly since the construction materials and material content inside the apartments change with time [5]. The design fire loads given in regulations are also determined like the earthquake loads, where the most extreme case is chosen to represent the possible fire scenarios. Fire loads in the regulations are given as average, 80th and 95th fractile; but generally chosen between 80th and 95th fractile for design fires [18]. Design fire load values are determined through fire load surveys where fixed and movable fire loads are noted. Movable fire loads are the furniture, books and electronic items. Fixed fire loads are the combustible fixed materials such as; floor finishes, doors, windows frames and cupboards [19]. Most of the times fixed fire loads are the main contributors for a compartments total fire load. Culver found out that factors like; location of the building, height of the building, age of the building, occupancy characteristics of the room and room size also affected the fire load of a building or a compartment [5]. Fire load surveys are done in four different methods:

- Weighing method
- Inventory method
- Combination of weighing and inventory method
- Questionnaire method

2.2.1. Weighing Method

Weighing method requires a physical entry to the compartment by the surveyor in order to document the characteristics of the combustible materials inside the compartment. Here the masses of the combustible items are obtained by the direct weighing.

Six office buildings were surveyed by Caro using direct weighing method. All combustible items inside the compartment were taken and then weighed. Then the fuel load for the combustible items were calculated and for the enclosed combustible items a factor was used to decrease their fire load properly.

Fuel load for the offices were grouped into categories of similar material composition. Fuel load for these offices were calculated as a ratio of the total equivalent weight over the floor area [20].

Ingberg performed a thorough fire load survey with the weighing method, where the report showed fire loads for apartments, residences, schools and hospitals. Combustible fire loads per floor area for the whole compartment were found out with the weighing of the combustible materials in the representative area for that compartment. The report shows that, in the fire load survey both fixed and movable combustible fire load were taken into account [21].

Weighing method is not preferred as often compared to inventory method, but it is generally used within the inventory method. Reason behind it that fixed fire loads are hard to weigh and it is impractical most of the times. Therefore, fixed fire loads are ignored for the weighing methods. Also some movable combustible items have incombustible materials inside, which becomes hard to identify the percentage of the incombustible material inside the combustible content. Another reason is that when the surveyor tries to perform weighing method it also prevents the people working inside from doing their job. Finally weighing method is very time consuming since every combustible item inside the compartment will be weighed individually. [22]

2.2.2. Inventory Method

Inventory method is the determination of the mass of an item based on its measured volume and corresponding density [23]. Therefore, surveyor needs to enter the compartment to list the combustible content and characteristics of the items. After gathering the required data, mass of the items can be calculated using their densities and measured volumes [23]. Using the data based on the net heat of combustion of the fuel package, combustible energy of the compartment contents can be calculated [22].

Culver and Kushner performed a fire survey with the inventory method in 1975, collecting the visual data, such as observable physical characteristics of the items inside the compartment. The idea behind this method is that, there is a relationship between the weight of the items and their measured dimensions (visual characteristics). This relationship can be explained as a transfer function for weight expressed as physical characteristics. Items' masses were developed from these transfer functions and weights of the items used for the transfer functions were taken from the manufacturers catalogues and previously weighed items. Total of 23 office buildings were surveyed in the United States and the following information were gathered for the items:

- Item type
- Construction material
- Dimensions

Transfer functions were used for the surveys. The fire loads shown in the study were obtained by converting the weights of the items to equivalent weights of combustible having a calorific value of 18.5 MJ/kg [24].

Another fire load survey using the inventory method was performed by Kumar in 1993. The aim of this fire load survey was to update the existing fire load survey data and Kumar performed the survey in a similar way Culver did. 8 office buildings were surveyed in Kanpur, India. Like Culver, no reducing factors were used for enclosed combustible items. The reason for using a reducing factor for enclosed items, can be explained as the enclosed items are not going to get ignited. According to Kumar, he did not use a reducing factor for enclosed items; because he assumed that the cabinets or other kind of boxes, containers door could be open during a fire event. Kumar found out that fire load intensities reported might be reduced by 10% when using a reducing factor. Fire loads were calculated with the multiplication of items with their calorific values [6].

Issen added to Culver's work and performed a fire load survey in 1980 for a residential compartment. Issen also used transfer functions to calculate the weight of the items. Issen said that the market place and available furniture during that time had the same weight characteristics. Issen also did not use reducing factor for enclosed items. Fire loads were calculated using the heat of combustion value for wood($18.5 MJ/kg$) [25].

The difficulties of the inventory method is given in the following:

- De-rating(reducing) factors
- Transfer functions
- Fire load estimation
- Disruption of privacy

Reducing factors were not used by any of the people given here since the usage of reducing factors have not been clearly defined. Even so, if people were to use reducing factors; for the same enclosed item two different reducing factor could've been used resulting in a different fire load. Reviewing the surveys that has used reducing factors, Kumar found out that the difference would've been up to 10% [6].

Transfer functions without correct approximations for irregular shaped objects drastically change the outcome of the fire load survey. If transfer functions which have been used for the method, assumed that the items were standardized in size and material; this will also effect the outcome of the survey, significantly. The low standardization in the industry for furniture causes transfer functions to yield incorrect results. Identifying and matching the pre-weighed items to the surveyed items inside the compartment is essential to get quality survey results. Finally, to find the fire load of the compartment Culver and Issen used the heat release rate of wood($18.5 MJ/kg$). This might lead to very inaccurate results for compartments that have different items such as liquid fuels, plastics and so on.

2.2.3. Combination of Weighing and Inventory Method

This method combines the inventory method and direct weighing method to find the fire load of the surveyed compartment. The surveyor can use both methods depending on the situation to get the most accurate fire load data for the compartment.

In 1942 fire load surveys performed by a research group which used both weighing and inventory method was reported in Building Materials Science (BMS) Report by the National Bureau of Standards. In this fire load survey, residential buildings, offices, hospitals and warehouses were covered. Direct weighing method was used for the items that could be easily weighed; but for the floors and other fixed fire loads inventory method was used. Windows, door frames and doors were used in the calculation with their half weight. Research group did not use any reducing factors for the enclosed fire loads inside the buildings. They also did not account for the items inside the cabinets or desks. Like Culver and Issen they have taken the calorific value as $18.5 MJ/kg$ to calculate the fire load. Fire load was assumed to be uniformly distributed among the floor area [26].

In order to test how surface area and thickness affects fire loads, Yii conducted a test in six sample university rooms, one sample of motel and several bedrooms in flats. A fire load data sheet was created to simplify the data collection. Yii collected both fixed and movable fire loads. She also divided the fuel loads into different types of materials; plastic, wood and etc. Dimensions and mass were the most important parameters that was recorded. Some of the combustible objects which was too heavy or too large, their volume was used to calculate the mass using the materials density. Surface area of the fuel exposed to the fire was also taken into account for the research [27].

Zalok surveyed commercial stores using, direct weighing method and inventory method. He reported that using both methods simplified the survey process. Zalok individually questioned the store owners to have a high quality survey and to collect data as accurately as possible.

A questionnaire was created to have a systematic and consistent data for the survey and the fire load survey followed a similar procedure for all compartments. Zalok classified the combustible content into three categories; textiles, plastics and cellulosic. Similar to Yii, Zalok used direct weighing method for light-weight items and also noted the material composition. Material percentages for combustible items that had more than single material layer. Volumes for the items that are too heavy to weigh was measured in order to calculate their masses using material densities. For surface finishings and carpets Zalok calculated their masses with their volumes. Unlike Culver and Issen; Zalok used items' specific calorific values to calculate their energies. After calculating energy values for all the items inside a compartment he calculated the fire load density [28].

Direct weighing method and inventory method has some limitations when used alone which will affect surveys vastly. Therefore, surveyors have used both of them on their surveys depending on the situations that required the correct method. If inventory method is used to determine an items' weight, there will be an error up to 20%, depending on the surveyor, compared to direct weighing method [24]. Culver says that the reason behind the difference between methods, is the estimation required by the inventory method. Therefore, using direct weighing method will result in a more accurate survey. Although it will not be as practical since it requires weighing of every item inside the compartment and fixed items will slow down the process greatly. So, the best course of action is using direct weighing method for small items and inventory method for fixed items to reduce the time of the survey while keeping the error margin as low as possible. Unfortunately, combination method also requires some approximations and from the past studies it is seen that inventory method is generally used to fasten up the process [27,28]. Since there is not a regulation or standardization for furniture items used inside the buildings, surveyor needs to be good at matching the items inside the compartment with the pre-weighed items. This methodology also disrupts the privacy and may affect the business depending on how much time the survey will take. Even though combination survey is faster both direct weighing method and inventory method, if the survey is performed on a large building it will still take a great amount of time to complete the survey.

Finally, combination methodology also suffers from the uncertainty of determining the total energy released from the compartment as it depends on the heat of combustion taken for the items inside the compartment.

2.2.4. Questionnaire Method

Questionnaires are prepared depending on the building types and given to the occupants of the buildings. Questionnaires have an explanation sheet attached to them and the method depends on the measurements and then furniture selection tables in order to compute the fire loads [22]. After the selection, heat of combustion values for the selected items will be multiplied with their weight to estimate the fire load.

Kose surveyed single-family dwellings with the questionnaire method. Kose prepared a questionnaire that had a list of standard furniture and goods commonly found inside the apartments. The questionnaire also had a sheet with figures of the furniture attached and questionnaire were then sent to the occupants. The survey did not account for the clothing stored inside the compartments and some measurements were needed to be done by the occupants [29].

Bwalya et al. completed a pilot survey for 74 residences with a web-based questionnaire method. The questionnaire was mainly sent to the employees of the Institute for Research in Construction (IRC) at the National Research Council of Canada. Like Kose, the questionnaire had a pre-determined list of household items found inside the dwellings. Participants were also able to choose the items' size, quantity and what materials they were made of. Unlike Kose, Bwalya did not send any figures for the furniture and Bwalya also did not collect any measured physical data regarding the items. Therefore, items inside the compartment and how they were placed heavily relied on the assumptions. The survey collected data about the rooms inside the building. Such as the type of the building, number of windows and number of exits for the room. Finally, Bwalya calculated the fire load using the highest values of heat of combustion and weight which resulted in very high fuel loads than the actual fuel load values [30].

Questionnaire method collects subjective data which affects fire load found from the survey heavily. For example Kose did not collect any information about the gaps inside the bookshelves. Therefore, holes inside bookshelves, drawers and wardrobes were based on assumptions. Verification of the data collected from questionnaires is not easy. Inaccurate measurements performed by the occupants for Kose's case shows the disadvantage of questionnaire method. It can also be said that it is one of the biggest drawback of this method compared to the direct weighing method and inventory method. The advantages and disadvantages for the survey methods are summarized in Table 2.1. In this thesis inventory and questionnaire method was used.

Table 2.1. Advantages and disadvantages of existing surveying methodologies.

	Advantages	Disadvantages
Direct Weighing	Has the highest accuracy amongst the survey methods for the movable fire load Good estimation of fire load value for irregular shaped objects	Cannot identify fixed fire loads Takes too much time compared to the other surveys
Inventory	Fire load calculation for both fixed and movable items Accurate values for fixed items	Disruption of privacy Transfer functions
Combination	Inaccuracy for the movable items removed with direct weighing method The most accurate survey method between the 4 methods	Disruption of privacy and functionality Long survey time
Questionnaire	Requires the least survey time No disruptions of privacy or functionality of business	Difficult to verify data Inaccurate and insufficient data

2.3. Design Fires and Fire Scenarios

Design fires are used in the design of buildings against possible fire scenarios. To obtain the design fires; aside from surveys, hand calculations, published curves or parametric fire equations are used [18]. Buildings are designed with performance-based fire safety and are also analyzed for their fire protection with the performance-based design. In order to perform a fire safety analysis, proper selection of the design fire or design fires according to the fire safety design objectives given in the regulations is needed. SFPE explains how to create a fire scenario in order to do a performance-based fire safety analysis. Fire scenarios have different conditions such as the characteristics of the fire, geometry of the compartment and the occupants inside the building [31], hence every fire scenario is unique.

According to SFPE [31] fire characteristics are given as:

- Ignition sources
- Growth
- Flashover
- Full development
- Extinction

Design fire scenarios are chosen from the available data on fires and with using engineering judgement to identify probable and impactful fire scenarios [31]. These characteristics represents the stages of a fire event and it is shown in Figure 2.1.

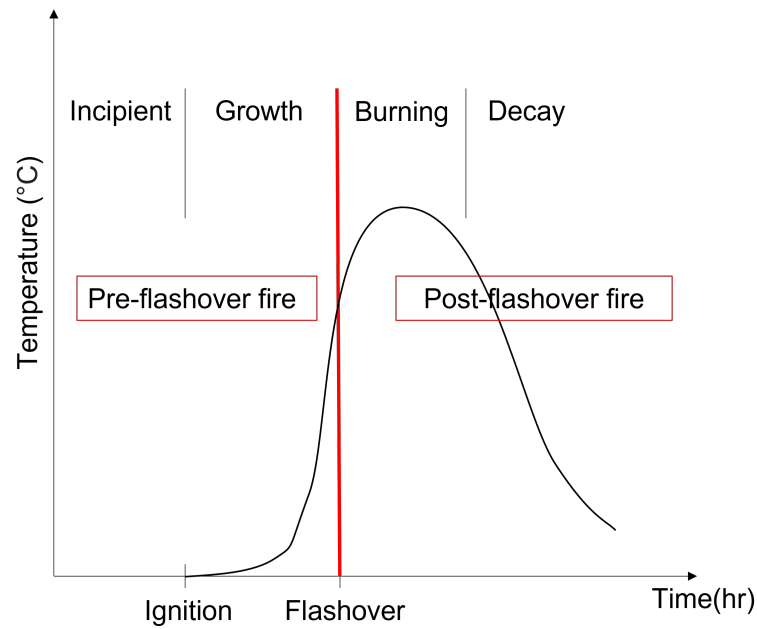


Figure 2.1. Stages of a fire.

In order to observe a fire event, an external source of heat is needed to raise the temperature of an object to its ignition temperature [18]. These external ignition sources can be gas heaters, cigarettes, candles, etc. After ignition fire starts to grow which is called the growth stage. Incipient stage ends with the ignition and the start of the growth stage. Fire growth depends the combustible materials type, amount and how they are placed inside the fire compartment. Fire keeps growing until it reaches to a point where the external heat source is no longer needed. Fire starts to spread through other flammable objects and hot gases and smoke form a thick layer on the ceiling due to buoyancy. Therefore, it is important to note that flashover can not occur in an open fire [18]. Hot layer at the ceiling results in a temperature increase and when the temperature reaches 600°C flashover occurs. Drysdale states that flashover is not a precise event, instead it must be considered as the transition from a localized fire to combustion of all exposed combustible surfaces inside the fire compartment [32].

After flashover event, heat release rate increases rapidly until it reaches the maximum value and fire becomes fully developed at this point. Fully developed fire has a steady heat release rate at peak value.

The peak heat release rate value depends on the fire area and the available fuel inside the fire compartment [31]. Fully-developed fires' duration and the peak heat release rate value govern the response of the structural elements [28]. A fully-developed room fire is either fuel controlled or ventilation controlled. It depends on the amount and size of the openings, such as windows and doors, to determine if the fire is ventilation controlled or not. In order to estimate the decay and extinction of the fire, it is important to figure out what is controlling the fire. In ventilation controlled fires, fire burns out due to the lack of oxygen which sustains the fire; but in fuel controlled fire, fire burns out when all the fuel runs out.

Fire event can be divided into two parts, pre-flashover fire and post-flashover where pre-flashover governs the incipient stage and growth stage. During pre-flashover phase toxic gas production, smoke release rate, temperature and heat release rate keeps increasing. Eurocode assumes heat release rate as a linear increase for design fires at pre-flashover phase [33]. Generally this correlation is expressed as a function of time which is given in equation (2.4) [34] or equation (2.5). Both equations can be used for t-squared fire curves. For equation (2.4) \dot{Q} is heat release rate(kW), t is time after effective ignition(s), α is fire growth coefficient(kW/s^2). In equation (2.5) \dot{Q} is heat release rate(MW), t is the time(s), k is a growth constant ($s/\sqrt{(MW)}$) [18]

$$\dot{Q} = \alpha t^2 \quad (2.4)$$

$$\dot{Q} = (t/k)^2. \quad (2.5)$$

Growth rate coefficient is the fire characteristic that defines how fast a fire grows. A fire engineer can use the standards, such as Eurocode 1: Actions on structures exposed to fire [33], in order to determine the fire growth rate coefficient of the compartment. Values for the growth rate coefficient or the growth rate constant are given in Table 2.2 for slow, medium, fast and ultra-fast fires. These values produce the heat release rate curves given in Figure 2.2. Growth rate constant is the time for the fire to reach a size of 1.055 MW [18]. The choice of k depends on the geometry and the type of the fuel.

Numerical values for k and peak heat release rate for many different burning items are calculated by Babrauskas [35].

Table 2.2. Fire growth rates for t^2 fires [18].

Fire growth rate	Value of k	Value of α	Typical real fire
Slow	600	0.00293	Densely packed wood products
Medium	300	0.0117	Solid wood furniture such as desks Individual furniture items with small amounts of plastic
Fast	150	0.0466	Some upholstered furniture High stacked wood pallets Cartons on pallets
Ultrafast	75	0.1874	Most upholstered furniture High stacked plastic materials Thin wood furniture such as wardrobes

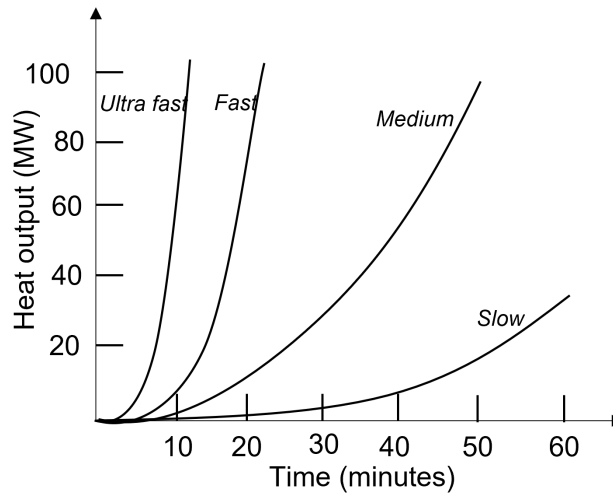


Figure 2.2. Heat release rate for t^2 fires.

Post-flashover stage is the stage where fire is fully developed and compartment becomes untenable due to temperature being higher than $600^{\circ}C$. Therefore at this stage of fire, property protection and structural safety becomes the priority. Post-flashover fires can be either fuel controlled or ventilation controlled.

Most of the fires inside the buildings are ventilation controlled which means the oxygen inside the room can not sustain the fire after some time. Glass will break at high temperature, so windows are considered to be open after flashover [18]. This allows more oxygen to flow into the room. Buchanan [18], Petterson et al. [36] explains how to calculate temperature for post-flashover fires.

Heat release rate is the most important variable that defines design fires [34]. Therefore there have been many studies in order to find heat release rate of furniture items. Heat release rate of furniture items are found with full-scale calorimeter tests done by researchers. In this study for HRR calculations, required data is taken from Kim and Lilley's study [37]. These experimental values do not represent the real fires in a perfect manner; because laboratory tests can not take radiation feedback into account. According to Buchanan radiation feedback plays a key role in compartment fires [18]; but it can not be replicated in cone-calorimeter tests.

2.4. Fire Modelling

Fires are categorized into pre-flashover and post-flashover fires as shown in section 2.3. Post-flashover fires are used for structural design; because post-flashover structural members' temperature increases to a point where they experience a significant reduction in their capacity [18]. Pre and post-flashover fires can be represented by zone models or computational fluid dynamic models. Generally pre-flashover fires are observed in large open spaces such as car parks or fires inside a building with a sprinkler that puts out the fire before it reaches higher temperatures. Since most of the buildings have sprinklers it is important to appropriately model these fires. Zone models are separated into two, these are two-zone models and one-zone models.

2.4.1. Two-Zone Modelling

In a fire event the fire is represented as a plume which produces energy and mass, this behaves like a pump for the mass from the lower zone to the upper zone through a process called entrainment.

During pre-flashover stage the compartment has two layers, hot layer and the cold layer. Upper zone represents the hot layer and lower zone represents the cold layer, hence the two-zone. In order to calculate the fire curve in a compartment fire, smoke accumulation from the burning object, radiation effects and hot gas leaving the compartment while fresh air coming in must be considered for the equilibrium equations.

Temperature in both layers are calculated separately with mass conservation and energy balance differential equations, using time as the variable. Interaction between hot and cold layers are calculated with mass and energy balance for each layer at each time step is given in equation (2.6). Here, the first term is work done by hot gases, the second term defines the work done by pressure of hot gases and the third term relates to the net energy intake of the compartment by ventilation. On the right hand side of the equation, the heat release rate of fire as well as heat loss rate into the thermal boundaries (walls, floor and ceiling) are stated. The solution of this differential equation is performed at each time step and such numerical procedure is called "Two-Zone Modelling". Two-zone modelling is mainly performed in CFast [38], which calculates the movement of smoke and hot gases in compartments [18]. It also calculates the maximum temperature reached inside the compartment for a given fire scenario

$$\rho c_p z A \frac{dT}{dt} - z A \frac{dp}{dt} + c_p \sum_{j=1}^J \dot{m}_j (T_j - T) = Q_f - Q_{wall} - Q_{rad}. \quad (2.6)$$

2.4.1.1. Localized Fires. A localized fire is described as an open-air fire with unlimited ventilation where the fire keeps growing as a function of time. Hot gases and smoke are generally unconfined. Most of the fires in growth stage are considered as local fires. These types of fires may be observed in large spaces such as atriums, theaters and car parks. Local fire burning duration is controlled only by fuel type and fuel amount not by ventilation.

In local fires there are two different methods to calculate the temperatures at a specific flame height. Flame height is calculated with equation (2.7) and here, D (m) represents fire diameter, Q (W) represents the heat release rate. Flame height determines which method to use for temperature calculations. As fire gets larger, the flame height decreases, and as fire intensity gets larger, the flame height increases. If fire impacts the ceiling Hasemi method is used, otherwise Heskestad method is used. Heskestad Method and Hasemi Method localized fire illustrations are shown in Figure 2.3. Here H represents height, L_f represents flame length and D represents the fire diameter. The temperature calculations for localized fires can be found in Eurocode 3: Part 1-2 (2005)

$$L_f = -1.02D + 0.148Q^{0.4}. \quad (2.7)$$

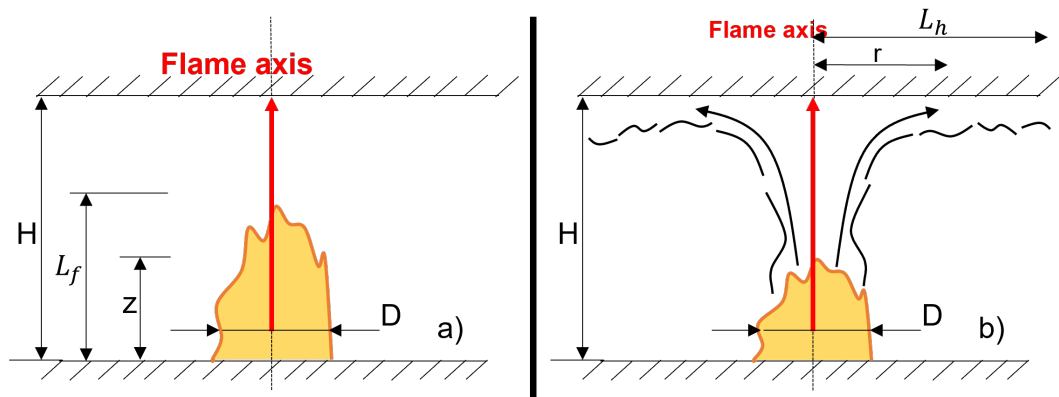


Figure 2.3. Fire Illustrations: (a) Heskestad Method, (b) Hasemi Method.

2.4.2. One-Zone Modelling

In post-flashover stage the division between the hot layer and cold layer is gone and the compartment only has hot layer in it. Therefore two-zone transitions into a one-zone model. In order to calculate temperature-time curve for a post-flashover fire, Petterson et al. [36] has suggested the equation (2.8). Here T_g shows the temperature for the given time step, I_c shows the constant heat release rate, it is chosen as a fixed value depending on the fire load of the compartment, I_R is the radiation term. More information on how the equation was derived can be found in the journal.

Two-zone modelling is almost never used in calculation of post-flashover temperature values due to the assumptions made for the two-zone modelling being incorrect for the post-flashover stage. For one zone modelling instead of CFast, OZone [39] is mainly used. OZone was developed as a one-zone model calculator in Europe and now it can also calculate the temperature inside a compartment using two-zone modelling. Mainly it uses two-zone modelling for pre-flashover stage and automatically switches to one-zone modelling for post-flashover stage. OZone follows a similar procedure suggested by Petterson et al. [36] for calculating the temperature

$$T_g = \frac{I_c + xc_p A \sqrt{h} T_0 + (A_t - A) \frac{1}{\frac{1}{\alpha_i} + \frac{\Delta x_1}{2\lambda}} T_1 - I_R}{xc_p A \sqrt{h} T_0 + (A_t - A) \frac{1}{\frac{1}{\alpha_i} + \frac{\Delta x_1}{2\lambda}}}. \quad (2.8)$$

2.4.3. Field Models

Compartment fires can also be modelled and solved using computational fluid dynamics field analysis, which is a more complex approach compared to zone models. Field models give thermo-dynamic and aero-dynamic variables for all discrete points in a fire region. These computer programs use Computational Fluid Dynamics (CFD) to model fires using a large number of discrete zones in a three-dimensional grid. Field models are harder to execute and read compared to zone modelling, therefore they are used for research purposes mainly. NIST developed a Fire Dynamics Simulator (FDS) which simplified the CFD process. Nowadays FDS is used by designers to model pre-flashover fires, but both zone modelling and field modelling can not accurately represent post-flashover fires [18].

2.5. Summary

High-rise buildings are classified as buildings of heights greater than 23m above the lowest level. In this project only 3 unique high-rise building was investigated. According to the EN 1991-1-2 part 1, dwellings have a fire load of 948 MJ/m².

This value will be taken into consideration when comparing the case study fire load results with the standard values, since there is not a fire load value given in Turkish Buildings Fire Safety Regulations. In Turkish standard buildings are divided into risk categories depending on their compartment properties. Depending on these properties the standard suggests a fire rating for the structural members. Load carrying members can be analyzed for the required fire rating given by the standard; but that would be an unrealistic way to check the members' fire safety for a real fire scenario.

In order to check the fire safety of the structural members, it is important to design an accurate design fire for the given building or the compartment. Therefore, first the fire scenarios have to be identified for the following building and then the appropriate ones must be selected for the design fire scenarios. These scenarios should define the characteristics of the building, fire and occupants. In order to create a design fire, properties of the combustible materials inside the fire compartment needs to be known. These are types of the combustible materials, amount of the combustible materials and how they are distributed inside the fire compartment. For a real building, these can only be found by performing a field survey for fire load or the fire load given in EN 1991-1-2 for dwellings can be used; but it will be less accurate. Fire load surveys are also useful in determining occupant characteristics and potential sources of ignition. Potential sources of ignition which also effects the development, growth and other effects of a fire are determined through the review statistics of fire events.

Fire researchers are constantly doing fire load surveys as time passes, their accuracy becomes lower hence researchers perform more surveys. Still, these surveys are not easy to perform and their data is still relevant which can be used for comparison. Fire load survey methods are; web surveys, inventory, weighing and combination of weighing and inventory method. In this thesis inventory method was used for the fire load surveys.

Fire load is used to estimate the heat release rate for the design fire. If heat release rate is known for a fire, then the fire engineer can perform the fire analysis of the compartment. In this thesis an assumption was made to estimate the heat release rate of the compartments which used the heat release data given by Kim [37] and then scaled vertically depending on the fire load of the current compartment.

3. METHODOLOGY

Bwalya said that heat release rate is the most important variable for a design fire [34]. Research and statistics show that, most of the high-rise buildings that occur only remain inside their origin room due to the watering system(sprinklers) [4]. In case it does not, a fire engineer needs to design a fire with appropriate heat release rate curve and point of origin. If the fire load and heat release rate is known for each room, design fire can be modelled easily. Most of the fire modelling programs require fire load, geometry of the fire compartment/apartment and heat release rate to calculate the resulting temperatures of the fire. In order to find the heat release rate for a given compartment in a building, a fire load survey needs to be conducted. Fire load surveys are not easy to perform and they take time. Therefore, finding an efficient method which reduces the time required for surveys is important. After the required data is gathered, this data needs to be converted into fire load of the building. The accuracy depends on how the survey is performed and it is not an easy task. Mainly inventory method and combination methods are used for the surveys, as direct weighing method takes too much time. Finally, after calculating the fire load density and energy values of the desired compartments, a matlab code written in this thesis is used to calculate the heat release rate for these compartments.

3.1. Fire Load Survey

Researchers have performed many fire load surveys as mentioned in literature review section. Inventory method was used to survey the buildings. Although it was not possible to add fixed fire load for the heat release rate calculation performed on Matlab [40], it was still noted for the fire load calculation. Only 1 apartment type is surveyed for each building. For example; a high rise building that had 4 types of apartment, 1+1, 2+1, 3+1 and 4+1. Here +1 shows the amount of living rooms inside the apartment and the number before the "+" sign shows the amount of extra rooms. These are; bedrooms, kids rooms or study rooms.

A modern high-rise building has more than 60 apartments inside. Therefore, only one 1+1, 2+1, 3+1 and 4+1 apartment type was surveyed for this given high-rise building. It was assumed that every 1+1, 2+1, 3+1 and 4+1 had the exact same layout for their corresponding types. Toilets and hallways are excluded in the survey. It was found out that bathrooms have a very low fire load compared to the other rooms inside the apartment which lead to the conclusion that bathrooms could be neglected. Since the fixed fire load is excluded in this work, it is also important to determine which furniture is combustible and which is not. Stainless steel is a common material that is found inside the modern refrigerators and ovens. Stainless steel is a non-combustible material and it should not be taken into account for fire load calculation. After determining which furniture will be excluded in the survey, dimensions of the remaining furniture needs to be taken. If the floor area of the rooms are unknown, it must be measured as well. It is also assumed that if there is an item which is used in both apartments, that item will have the same materials. This means that a living room inside a 1+1 apartment and a living rooms inside a 2+1 apartment had same type of sofa for the building that is being investigated. The difference between 2 sofas are the dimensions which will change the resulting fire load. This way, it is possible to determine the fire load densities for each type of room inside an apartment. The data collected from the fire surveys are noted in the excel sheet prepared in this thesis to calculate the furniture energy release. A survey template has been made and also used in this thesis to facilitate the survey process and guide users on how to perform the fire survey so they can use the provided excel file accurately. Users need to mark the type of house they are investigating as the first step and then the total area of the apartment needs to be measured. After this step users need to start surveying each room and taking photographs of the furniture inside. How the apartment will be surveyed is also explained in the survey. These steps are also numbered in the fire load survey which is shown in Figure 3.1 and in Figure 3.2.

FIRE LOAD SURVEY

1. What is the type of apartment that is being surveyed?

1+1 2+1 3+1 4+1 5+1

2. Total floor area of the surveyed apartment (m²).

3. Fill the following tables for the surveyed apartment.

Things to consider while filling the tables are given below:

- All the items that are taken into consideration should be photographed, so they can be investigated later while filling the excel sheet.
- Items can only be composed of 3 materials maximum. These materials are:

Materials	Materials Continued
Acrylics	Latex Foam
Aluminum	LPG
Brass	Nylon
Ceramic	Other food
Cooking Oil	Pine wood (Soft wood)
Copper	Plywood
Cotton	Polyster
Fabric	Polystyrene
Fiber	Polyurethane foam
Fiberglass:Glass wool	PVC
Flexible PVC	Rice
Foam	Rubber
Glass	Stainless Steel
Gypsum/Plaster board	Wood-Heavy Wood
Kerosene	Wool

- Fraction is the percentage for the chosen material inside the item. Fraction must be a number between 0 – 1 and summation of the fraction values must be equal to 1.

Figure 3.1. Fire Survey Part 1.

- Common room items are summarized in the following table.

COMMON ROOM ITEMS			
Must Have Items in Corresponding Rooms			
Living Room	Kitchen	Extra Room	Bedroom
L sofa	Cupboard	Wardrobe	Side table
Armchair	Oven	Carpet	Bed
Carpet		Bed	Carpet
Television		Desk	Wardrobe
Tv Unit		Side table	Floor Pouf
Chair		Chair	Desk
Dining Table			
Cabinet			
Coffee Table			
Curtain			
Uncommon Room Items			
Living Room	Kitchen	Extra Room	Bedroom
Christmas Tree	Table	Computer	Television
Wardrobe	Chair	Sofa	Sofa
Bookshelf		Small Dresser	Small Dresser
		Bookshelf	

- General material composition for room items, use these if you do not know the material composition. Fractions for the corresponding material is given inside the parentheses.

Items	Material Composition
L sofa/Sofa	Polyurethane Foam (0.6), Fabric (0.2), wood-heavy wood (0.2)
Carpet	Acrylics (0.5), polystyrene (0.5)
Television	Glass (0.9), copper (0.1)
Tv unit	Plywood (1.0)
Chair	Polyurethane foam (0.6), fabric (0.2), wood-heavy wood (0.2)
Dining Table	Wood-heavy wood (1.0)
Oven	Stainless steel (0 no ignition), glass (1.0)
Bed	Latex foam (0.6), cotton (0.3), wood-heavy wood (0.1)
Desk	Plywood (1.0) or wood-heavy wood(1.0)
Side table	Plywood (1.0) or wood-heavy wood(1.0)
Floor Pouf	Cotton (0.8), fabric (0.2)
Wardrobe	Plywood (1.0) or wood-heavy wood(1.0)
Cabinet	Plywood (1.0) or wood-heavy wood(1.0)
Curtain	Cotton (1.0)

Figure 3.2. Fire Survey Part 2.

Materials that are available in the excel which are commonly used in modern furniture are given in the survey as well. Material composition for the furniture are also given in the survey for the items that are unknown to the users. This way users can take the fractions given in the table to perform the analysis. For fixed fire load 3 different floor types provided.

If the floor is a different type which is not provided in the template, user needs to find the material composition. Tables are also provided for each room in order to help the users note the furniture for the appropriate rooms. Survey template is made for apartment types that have 1 living room, 1 bedroom, 1 kitchen and 3 extra rooms in total. Table numbers can be modified for the apartment types that have more or less rooms. These tables are given in Figure 3.3. Finally a table is also given for the users to note floor area for each room which is shown in Figure 3.4.

- Common floor types are given in the following table. If floor type is ceramic, marble they will not burn. Rarely walls will also be composed of the given floor type items. If this is the case, please note it under floor fire load.

FLOOR TYPES		
Floor Type	Material Composition	Thickness (cm)
Laminate (most common)	Plywood and thin plastic layer	1
Solid Hardwood	Wood-Heavy wood	1.4
Carpet (less likely)	50% polyester 50% wool	0.5

Tables:

Living Room									
Items	Dimensions (cm)			Material Composition	Fraction	Number of items			
	Width (cm)	Depth (cm)	Height (cm)						
Floor Fire Load									

Kitchen									
Items	Dimensions (cm)			Material Composition	Fraction	Number of items			
	Width (cm)	Depth (cm)	Height (cm)						
Floor Fire Load									

Figure 3.3. Fire Survey Part 3.

4. Floor area of the rooms.

Room Names	Floor Area (m²)
Living Room	
Kitchen	
Bedroom	
Extra Room 1	
Extra Room 2	
Extra Room 3	

Figure 3.4. Fire Survey Part 4.

3.2. Excel Sheet Calculation

In this thesis an excel sheet is prepared to calculate the energy release from surveyed room items and then adding these energy values to calculate the total energy released from a room in a fire scenario. Excel is the step 2 for the calculation of fire load of a compartment. Worked examples will be given in the case studies and results chapter.

Living Room	DIMENSIONS(x,y,z)(cm)	VOID RATIO	VOLUME(m ³)	TOTAL FIRE LOAD				ENERGY RELEASED		
				MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)		Number of Items	
			0	Polyurethane foam	Fabric	Wood-Heavy Wood		0	0	0.00
			0	Polyurethane foam	Fabric	Wood-Heavy Wood		0	0	0.00
			0	Acrylics	Polystyrene	LPG		0	0	0.00
			0	Acrylics	Polystyrene	LPG		0	0	0.00
			0	Glass	Copper	LPG		0	0	0.00
			0	Plywood	LPG	LPG		0	0	0.00
			0	Wood-Heavy Wood	Polyurethane foam	Fabric		0	0	0.00
			0	Cotton	LPG	LPG		0	0	0.00
			0	Wood-Heavy Wood	LPG	LPG		0	0	0.00
			0	Wood-Heavy Wood	LPG	LPG		0	0	0.00
			0	Plywood	LPG	LPG		0	0	0.00
			0	Polyurethane foam	Fabric	Wood-Heavy Wood		0	0	0.00
			0	Plywood	LPG	LPG		0	0	0.00

Figure 3.5. Empty excel sheet.

Users need to input the following information:

- Item Names and Dimensions
- Void Ratio
- Material Composition and Fractions

3.2.1. Item Names and Dimensions

Item names are written under their corresponding room name. This way the user can track the items. This is the first column in the excel table which can be seen in Figure 3.6.

Living Room	DIMENSIONS(x,y,z)(cm)			VOID RATIO	VOLUME(m ³)
					0
					0
					0
					0
					0
					0
					0
					0
					0
					0
					0
					0
					0
					0
					0

Figure 3.6. Item names, dimensions, void ratio and volume.

Item dimensions are width, depth and height. User needs to input these data as centimeters. Here width and depth can be written under x and y columns, z column represents height. The important part here is the volumetric approach. Volumetric approach, assumes every object as a box.

Therefore, for this assumption to work accurately, items that have shapes different from a rectangular prism such as; sofa, chair or tables, maximum distances will be measured. Using these distances a rectangular prism shaped item will be created which will represent the item. How these distances are taken is also shown in figure 3.7.



Figure 3.7. Chair dimensions.

3.2.2. Void Ratio

Void ratio is the second crucial part of the volumetric approach. After user measures the max distances of an item, the void ratio has to be estimated in order to calculate the volume of the item. An imaginary prism will be created with the width, depth and height of the chair shown in Figure 3.7, but this will be an overestimation for the volume of this chair. Approximately this chair will have only 20% of the prisms volume hence the void ratio will be chosen as 0.8 for this item. Using the equation given in (3.1) volume of the chair is calculated

$$Volume = x * y * z - x * y * z * (voidratio). \quad (3.1)$$

3.2.3. Material Composition and Fractions

In order to calculate the energy value of an item 3 variables are needed. These are density, calorific heat value and volume of the item unless the mass is known. If the mass of the item is known, then calorific heat value and mass will be enough to calculate the energy. In this study, inventory method was used for the fire load survey which means that dimensions of the items are known; but the mass is unknown. Although the mass is unknown, material composition of the items inside the rooms can be found. Most of the materials are commonly used in the world and their density, calorific heat values are known. Materials that are available in the excel are taken from the values given in SFPE handbook [31]. Their density values and calorific heat values are shown in Figure 3.9. Here users will pick the furniture material composition from a drop-down menu, shown in Figure 3.8, that uses the material table given in Figure 3.9.

MATERIAL TYPE		
Polyurethane foam	Fabric	Wood-Heavy Wood
Polystyrene	Fabric	Wood-Heavy Wood
Polyurethane foam	Polystyrene	LPG
PVC	Polystyrene	LPG
Rice	Copper	LPG
Rubber	LPG	LPG
Stainless Steel	LPG	LPG
Wood-Heavy Wood	Polyurethane foam	Fabric
Wool	LPG	LPG
Wood-Heavy Wood	LPG	LPG
Cotton	LPG	LPG
Wood-Heavy Wood	LPG	LPG
Wood-Heavy Wood	LPG	LPG
Plywood	LPG	LPG
Polyurethane foam	Fabric	Wood-Heavy Wood
Plywood	LPG	LPG

Figure 3.8. Material composition drop-down menu.

CALORIFIC VALUES		
Materials	Cal. Values(MJ/kg)	Density(kg/m ³)
Acrylics	30,5	1190
Aluminum	31,06	2700
Brass	9,5	8400
Ceramic	0	3000
Cooking Oil	39,92	1
Copper	2,5	8940
Cotton	18	80
Fabric	15	100
Fiber	14,52	16
Fiberglass:Glass wool	26,1	16
Flexible PVC	22,1	1100
Foam	25,44	28
Glass	21	2700
Gypsum/Plaster board	0	800
Kerosene	48,78	820
Latex Foam	40,6	81
LPG	48,78	820
Marble	0	2711
Nylon	2,4	1169
Other food	12,61	1
Pine wood (Soft wood)	19,5	415
Plywood	18,05	544,6
Polyster	30	1345
Polystyrene	41,96	1035
Polyurethane foam	24	48
PVC	22,1	1400
Rice	14,71	801
Rubber	35	1100
Stainless Steel	28,9	7900
Wood-Heavy Wood	18,59	680
Wool	23	1,5

Figure 3.9. Material density and calorific heat values.

Household furniture items are mainly made of 2 or 3 materials. Common items such as; table, wardrobe, desk, cupboards, side tables, small dressers, coffee tables or curtains are made of a single material. In opposition; sofa, chair, floor poufs or cushions are made of 2 or 3 materials. After choosing the materials from the drop-down menu for the items, users must enter the fraction for the corresponding material in order to calculate the energy release value. Each materials' calorific value and density will be multiplied with its' fraction value and added up to calculate the furniture density and calorific value. Users must enter the fraction values under the fraction part, total fraction value must be equal to (1.0).

3.3. Heat Release Rate Calculator

Matlab R2020a [40] is used in creation of this application. Heat release rate calculator, calculates and draws the heat release rate curve for items chosen by the user and it also calculates the total energy release value from the area under the curve. The application has 3 tabs, main tab is the Hrr_calc where user chooses the items that have similar properties to the items they have surveyed. Application uses the data given by Kim [37] and combines the heat release rate data of individual items with linear interpolation to create the hrr curve. Fire is assumed to be in post-flashover state to use the combination method in order to draw the graph. Here, since the items are not exactly the same material or size, energy release of these items will not be the same of the surveyed room. Currently, there is not any method available to calculate the hrr of an item exactly other than burning the item inside a full-sized calorimeter. To solve this problem, vertical scaling of the graph is assumed where the area under the graph will be equal to the energy release of the surveyed items inside the room. Items Info tab has information for all the items that are provided inside the application, such as material composition. These items information are also taken from the Kim's work [37]. Although, some experiments are way too old and missing detailed explanation regarding their material composition. Room Items tab provides information regarding the items that are common for each room type of a dwelling. It also provides average fire load values for room types as well as entire dwelling, these values are calculated from the surveys performed for the thesis. This way the user can compare their values with the provided values or just use the values given inside the application to create an accurate hrr graph to perform their fire analysis. Items info tab and room items tab are given in Figure 3.12 and Figure 3.13.

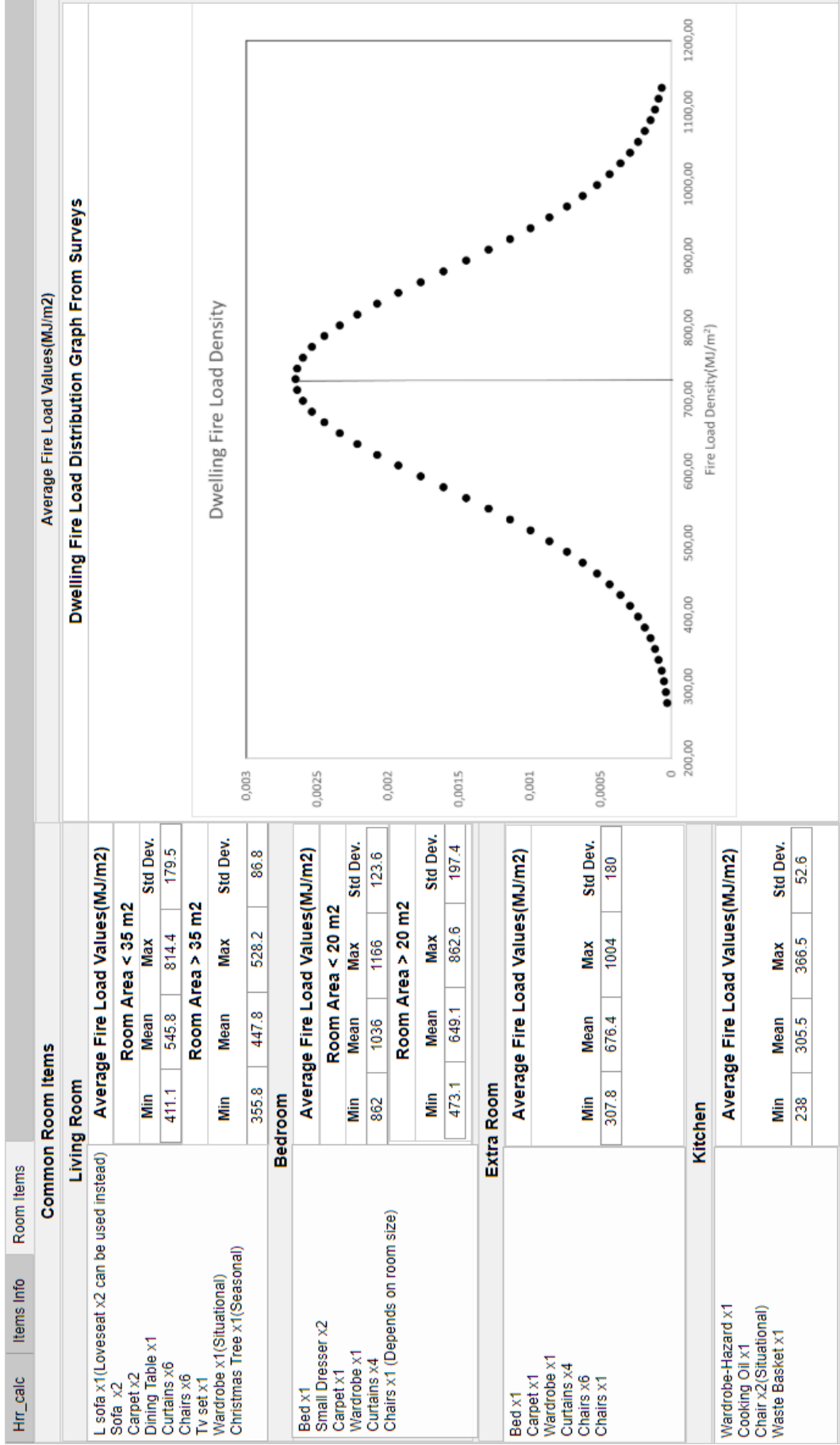


Figure 3.13. Common room items.

Pressing the "Calculate HRR" button will display the heat release rate graph on the left side of the application which is given in Figure 3.14. An information box will also show the peak heat release rate value (MW) and the total energy released (MJ) for the chosen values. Title of the graph is editable, so it can be changed and named after the compartment that is currently being analyzed. Matlab will also provide an excel file where the data points are available for each heat release rate value and its' corresponding time value, these values will be available for both scaled and unscaled scenarios. The excel file will be stored inside the same folder where the application is and it is shown in Figure 3.15.

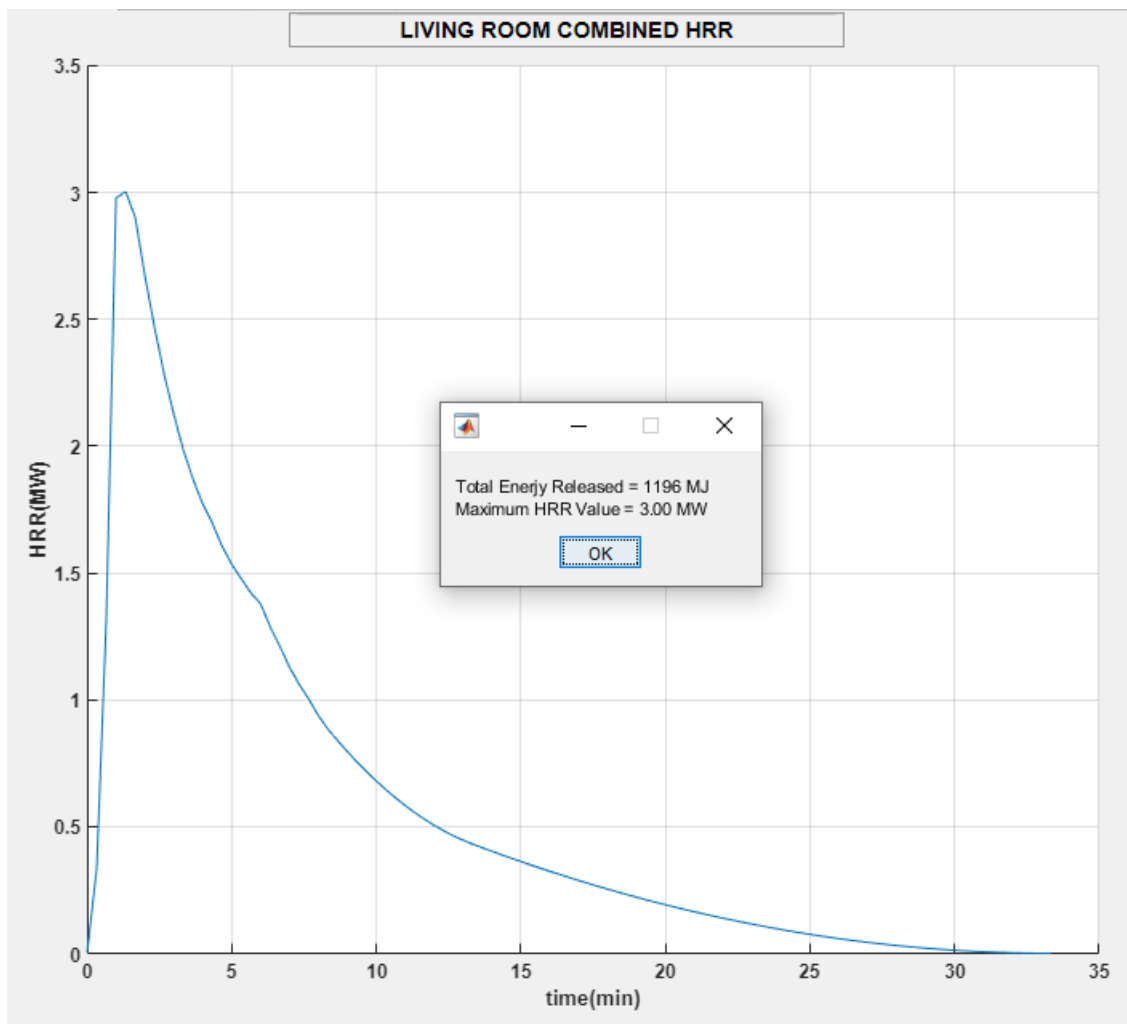


Figure 3.14. Heat release rate graph example.

Time(s)	HRR(MW)		Time(s)	Unscaled HRR(MW)
0	0		0	0
20	0,3333228		20	0,465536354
40	1,3227792		40	1,79092003
60	2,9783692		60	4,047262132
80	3,0043772		80	5,496785056
100	2,902312		100	4,867682318
120	2,6722568		120	4,285972172
140	2,4692592		140	3,780907482
160	2,2833192		160	3,39483549
180	2,1249488		180	3,037993416
200	1,983636		200	2,555070583
220	1,8693808		220	2,110970887
240	1,7721832		240	1,656552961
260	1,6961712		260	1,254694413
280	1,6065288		280	0,908193182
300	1,53468		300	0,620826476
320	1,4768168		320	0,388780148
340	1,4207517		340	0,215668642
360	1,3786722		360	0,096355197
380	1,2877658		380	0,026321872
400	1,210845		400	0,000588188
420	1,1289205		420	0
440	1,0609816		440	0
460	1,00284701		460	0
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Figure 3.15. Heat release rate excel output example.

3.4. Summary

Fire load and heat release rate values are the most important values a fire engineer needs to know in order to perform a fire analysis. Therefore, a fire load survey has to be performed to find out the realistic fire load value of a compartment. Alternatively, if a survey can not be conducted Eurocode [33] fire load density values can be used with lesser accuracy. Generally, a fire survey is conducted for analysis and then either the heat release rate value given by Eurocode is taken for a faster analysis or FDS programs are used with ignition method to calculate the hrr for the room. After the survey is conducted; items are noted in the excel file to calculate the fire load and fire load density values. Finally using the application created in this thesis, heat release rate for individual rooms are calculated.

4. CASE STUDIES AND RESULTS

Turkish Buildings Fire Safety Regulations does not provide any fire load value to design a fire for dwellings. Only option for a fire engineer in Turkey to model a design fire is, either doing a fire load survey or using the fire load values provided for dwellings in Eurocode. Therefore, in this thesis 8 different apartment types were surveyed, 4 3+1, 2 2+1, 1 1+1 and 1 4+1. From 8 of these apartments 4 of these (1 3+1, 1 2+1, 1 4+1 and a 1+1) belong to a high-rise building, Building A, other 2+1 belongs to another high-rise building and the remaining 3 3+1 apartments belong to different low-rise buildings to increase the sample size. Building A 3+1 apartment was physically surveyed, although others were surveyed by the home residents and their fire loads are calculated through the data they have provided with the survey given in section 3.1. After the surveys are performed the steps given in methodology was followed to calculate the energy values of the apartments and heat release rate curves. Finally, heat release rate curves are given for each living room as an example.

4.1. Apartment Type 3+1

4.1.1. Building A

Building A is a high-rise building with 36 storeys. It has a total of 89 1+1 apartments, 47 2+1 apartments, 106 3+1 apartments and 21 4+1 apartments. If the whole building was to be engulfed in flames and assuming that all the furniture was burned (excluding any fire load which would increase the total energy release such as steel, concrete and fixed fire load), a total of $15.72 \times 10^6 MJ$ energy would be released. The building also had a fire load density of $783.4 MJ/m^2$. In the following sections, pictures that were taken during the survey of 3+1 apartment will be shown. Inventory method was used to calculate the fire load of the furniture. There is also a floor plan available for this apartment which is shown in Figure A.1.

4.1.1.1. Kitchen. In the kitchen, only cupboard and the stove was measured, as they were the ones that provided the maximum fire load for kitchen compared to the other furniture and since the fixed fire load was not taken into account due to the floor being ceramic, other furniture that provided way too low fire load were neglected. Fridges' outer shell is made of stainless steel [41] and stainless steel is a material that does not ignite. It is known that fridges might cause fire due to electrical shortcuts; but in modern buildings people buy quality refrigerators which have stainless steel as an outer shell. Therefore, for kitchen, refrigerators are excluded in fire load calculation. Building A kitchen cupboard and oven is shown in Figure 4.1 and in Figure 4.2, respectively.



Figure 4.1. Building A kitchen cupboards.



Figure 4.2. Building A kitchen oven.

In total there are 9 cupboards and a single stove to take into consideration in Building A kitchen. For ease of calculation, a single cupboard was measured and it had a 60x60 cm width and depth with 40 cm height. The oven had a 90 cm length, 60 cm depth and 50 cm height. Cupboards are made of plywood and the oven is mainly made of stainless steel which does not ignite, but the glass is ignitable so only the glass was added to the fire load.

Using the plywood and glass calorific values taken from SFPE Handbook [31], kitchen had a total energy of 2547 MJ. Kitchen has a floor area of $11.35m^2$ and dividing the energy value to the floor area, fire load density for the kitchen is calculated as $345MJ/m^2$. This calculation is given in Figure A.3. Average dwelling fire load density is $780MJ/m^2$ [33] and if a survey was not performed, a fire engineer had to use $780MJ/m^2$ instead of $345MJ/m^2$ while modelling a design fire for a fire scenario inside the kitchen.

4.1.1.2. Living Room. Living room generally has the most furniture due to the high floor area it has inside the apartments. Therefore, it is expected that it would have the most fire load. It would not be a wrong assumption and studies have shown that for dwellings, bedrooms and living rooms have the most fire load [7]. Living room has a floor area of $48m^2$. Here the moving fire load items are:

- L sofa
- Carpet 1
- Carpet 2
- TV unit
- TV
- Chairs
- Curtains
- Dining Table
- Cabinet
- Wardrobe

In order to make calculations faster, all of the items are assumed as square or rectangular boxes which is explained in the methodology section. For example L sofa has a maximum width of 240 cm and a maximum depth of 250 cm with a height of 70 cm. Multiplying the volume with a void ratio of 0.8 volume of the L sofa is found as $0.84 m^3$.

Unlike the previous items given in kitchen, L sofa is not made of a single material but instead it has mainly 3 materials. This means that in order to calculate the calorific value of this L sofa as accurately as possible, a weighted average of these 3 materials needs to be taken. L sofa or sofas in general are made of polyurethane foam, fabric to cover the foam and the legs are made of wood or heavy-wood. Thus, a fraction number is assigned to polyurethane foam, fabric, heavy-wood and these are 0.5, 0.3, 0.2, respectively. In total, L sofa has an energy value of 3227 MJ. Front view of the L sofa is shown in Figure 4.3.



Figure 4.3. Building A living room front view of L sofa.

Modern carpets are made of acrylics and polystyrene [42]. Acrylic has high fire resistance; but it also has a high calorific value. Carpet 1 and carpet 2 has same materials and carpet 1 is shown in Figure 4.3 under the L sofa. Carpet 1 has 500 cm width, 300 cm depth and 0,5 cm height. Carpet 2 has 400 cm width, 250 cm depth and 0,5 cm height. With the help of the dimensions, carpet 1 and carpet 2 energy values are calculated as 3023 MJ and 2015 MJ respectively.

Television units' size depend on the occupants; but in this thesis it is seen that generally for apartment types that are bigger than 2+1, occupants prefer a box type television unit. In this apartment the television unit has 350 cm width, 40 cm depth and 150 cm height. It is made of plywood only. It is the biggest item inside the living room after the L sofa. In a fire scenario, this television unit will release 7225 MJ of energy. Television unit is shown in Figure 4.4.



Figure 4.4. Building A living room front view of the television unit.

Television is made of glass and copper. Television has more glass than copper, such as 70% glass and 30% copper. The television has 140 cm width, 40 cm height and 5 cm depth. Multiplying the density of the television with its calorific value, television will release 1978 MJ energy in a fire scenario. Television is shown in Figure 4.4 which is in the middle of the television unit.

There are 8 chairs inside the living room. Although 2 chairs are different than the other 6, overall they have almost the same materials, so they are assumed as same chairs. Chairs are made of polyurethane foam, fabric and wood. Chairs have slightly more polyurethane foam compared to the sofa and this is included in the material calculation. Therefore, chairs are made of 60% polyurethane foam, 30% fabric and 10% wood-heavy wood. Dimensions of a single chair are, 50 cm width, 40 cm depth and 100 cm height. Taking the weighted average for calorific value and density of these 3 materials and then multiplying the density with the calorific value; chairs release 1001 MJ energy in a fire scenario. Chairs are shown in Figure 4.5 and Figure 4.6.



Figure 4.5. Building A living room dinner table chairs.



Figure 4.6. Building A living room chair number 2.

Curtains are mainly made of cotton. There are 6 curtains inside the living room and a curtain has 120 cm width, 5 cm depth and 290 cm height. Curtains generally have the same height as the storey and they are used in a way that 2 curtain side to side should be enough to cover a wall of the room. In total curtains release 826.85 MJ energy in a fire scenario. Curtains are shown in Figure 4.3.

Dining table is only made of wood-heavy wood. It has 250 cm width, 80 cm depth and 90 cm height. It releases 2275 MJ energy in a fire scenario. Dining table is shown in Figure 4.5.

In living rooms there is a console unit where people store their plates and glasses. In this living room there was a console cabinet which was a little bit small compared to the size of room. Dimensions of this console cabinet are, 220 cm width, 40 cm depth and 30 cm height. The cabinet is made of wood-heavy wood only. In a fire scenario the cabinet releases 2336 MJ energy. Cabinet is shown in Figure 4.5.

Finally the last item inside the living room is wardrobe. Wardrobe is the only item which is different from a regular living room furniture and the reason behind that is the layout of this apartment.

The wardrobe inside the hallway is too close to the living room and there is not a door or wall that separates them, hence the wardrobe is included to living room for the fire load calculation. Wardrobe is made of plywood and it has 100 cm width 50 cm depth and a 200 cm height. Multiplying the volume of this wardrobe with the calorific value of plywood, total energy of this wardrobe is calculated as 2949 MJ. Wardrobe is shown in Figure 4.7. Living room density calculations are given in figure A.2.



Figure 4.7. Building A wardrobe side view.

In conclusion, in a post-flashover event living room releases a total of 33171 MJ energy. Dividing this energy to the floor area of the living room, fire load density is calculated as $691 \text{ MJ}/\text{m}^2$.

Mean value for dwellings fire load density is given as $780 \text{ MJ}/\text{m}^2$ in Eurocode. It is seen that this would be an overestimation for the given room.

4.1.1.3. Kids Room 1. In apartments that have an extra room besides the living room and bedroom; occupants with a child give the room to their kids. Since this might not be the case for every occupant and the extra rooms might have a different use, in this thesis an assumption has been made which takes the average fire load density value for these rooms to calculate the fire load density. In Building A these 2 extra rooms are used as kids room. Kids room 1 has a floor area of $11,55 \text{ m}^2$. Kids room 1 has the following furniture inside the room:

- Wardrobe
- Bed
- Carpet
- Side table
- Desk
- Floor pouf

Wardrobe is made of only plywood and its dimensions are; 150 cm width, 60 cm depth and 290 cm height. Wardrobe yields 2565 MJ energy in a fire scenario. Wardrobe is shown in Figure 4.8.



Figure 4.8. Building A kids room 1 wardrobe front view.

There are a couple of ways to calculate the amount of energy released from a bed during a fire. Generally bed is divided into two pieces as mattress and the wooden frame under it. In this thesis, in order to keep the simplicity, same method has been used where the bed is divided into 3 main materials. These are latex foam, cotton and wood-heavy wood. Bed has 60% latex foam, 30% cotton and 10% wood-heavy wood. It has 200 cm depth, 90 cm width and 50 cm height. Here the height is chosen smaller to the original height to make an accurate rectangular prism representation of the bed. Thus, in a fire scenario bed releases 4000 MJ energy. Bed is shown in Figure 4.9.



Figure 4.9. Building A kids room 1 bed side view.

Kids room carpet is made of acrylics and polystyrene. Carpets in this building have the same material composition. Kids room carpet covers 240 cm width, 210 cm depth and 0,5 cm height. In a fire scenario carpet releases 1015 MJ of energy. Carpet can be seen in Figure 4.9.

Bedrooms and kids rooms have side tables near their bed. In this room there is only 1 side table which is made of plywood only. It is a circular table, but as explained before all of the furniture here is assumed to be a rectangular box and then missing area is deducted from the calculated area. The side table has 40 cm width, 40 cm depth and 65 cm height. Side table releases 205 MJ energy in a fire scenario.

The desk inside the room is not a continuous one. Therefore, in this thesis it is divided into two pieces to get the most accurate result. The desks are made of plywood. First piece of the desk has 87 cm width, 77 cm depth and 5 cm height. Second piece of the desk has 99 cm width, 15 cm depth and 5 cm height. In a fire scenario first piece releases 330 MJ energy and the second piece releases 73 MJ energy. This desk is shown in Figure 4.9.

Finally there is a floor pouf inside the kids room and a plastic chair. Plastic chair is not included in the fire load calculation. The cushion is made of 2 materials and these are cotton, fabric. Material composition is 80% cotton and 20% fabric. Floor poufs dimensions are 48 cm width, 48 cm depth and 60 cm height. In a fire scenario floor pouf releases 202 MJ energy. Floor pouf is shown in Figure 4.9. Fire load calculations of each object using the excel sheet is given in Figure A.2.

In conclusion, in a fire scenario kids room 1 releases a total of 8391 MJ energy which is lower compared to living room. On the contrary the dividing the energy value to the floor area, fire load density is found as $726.51 \text{ MJ}/\text{m}^2$ which is higher than the living room. Kids room 1 also has a closer fire load density when compared to Eurocode's dwelling fire load density value.

4.1.1.4. Kids Room 2. Kids room 2 has a floor area of $10,59 \text{ m}^2$. Kids room 2 has the following furniture inside the room:

- Wardrobe
- Bed
- Carpet
- Desk
- Bookshelf

Wardrobe is made of only plywood and its dimensions are; 150 cm width, 60 cm depth and 290 cm height.

Wardrobe yields 2565 MJ energy in a fire scenario, the wardrobe is identical to the one in the kids room 1. Wardrobe is shown in Figure 4.10.



Figure 4.10. Building A kids room 2 wardrobe side view.

The bed inside the kids room 2 is also almost identical to the bed inside the kids room 1. It has the same material composition and the dimensions, except height of the bed is 55 cm. Bed releases 4401 MJ energy in a fire scenario. Bed is given in Figure 4.11.



Figure 4.11. Building A kids room 2 bed side view.

Kids room 2 carpet covers 240 cm width, 210 cm depth and 0,5 cm height. In a fire scenario carpet releases 1015 MJ of energy. Carpet can be seen in Figure 4.11.

Kids room 2 has a desk that is made of only plywood with dimensions of 120 cm width, 60 cm depth and 60 cm height. In a fire scenario it releases 425 MJ energy. Kids room 2 desk can also be seen in Figure 4.11 behind the bed. Finally kids room 2 has a bookshelf which is made of plywood. The bookshelf has 70 cm width, 40 cm depth and 100 cm height. In a fire scenario it releases 138 MJ energy. Bookshelf is shown in Figure 4.12. Fire load calculations of these items are done by the excel sheet shown in Figure A.2.



Figure 4.12. Building A kids room 2 bookshelf front view.

In conclusion, in a fire scenario kids room 2 releases a total of 8545 MJ energy which is also lower compared to living room. Dividing the energy value to the floor area, kids room 2 has a fire load density of $806.87 \text{ MJ}/\text{m}^2$ which is higher than the living room. Kids room 2 also has a higher fire load density when compared to Eurocode's dwelling fire load density value.

4.1.1.5. Bedroom. Bedroom has a floor area of 18.13 m^2 and from the previous studies, it is expected that the bedroom will have the highest or the second highest energy release in a fire scenario [7]. Bedroom has the following items:

- Wardrobe
- Bed
- Carpet
- Side table
- Desk

- Floor pouf

Bedroom wardrobe has 282 cm width, 60 cm depth and 290 cm height. It is only made of plywood. In a fire scenario wardrobe releases 4824 MJ energy. Wardrobe is shown in Figure 4.13.



Figure 4.13. Building A bedroom half wardrobe.

There is a queen size bed in the bedroom. It is made of latex foam, cotton and wood-heavy wood which means it has the same material composition like the beds inside the kids rooms. The bed has 210 cm width, 160 cm depth and 65 cm height. In a fire scenario it releases 9710 MJ energy. Bed is shown in Figure 4.14. There are also 2 side tables near the bed which is made of plywood.

Both have same dimensions and these are; 70 cm width, 70 cm depth and 60 cm height. In a fire scenario these side tables will release 2315 MJ energy in total. They can also be seen near the bed in Figure 4.14.



Figure 4.14. Building A bedroom queen size bed.

Carpet is made of acrylics and polystyrene. The dimensions of the carpet are; 300 cm width, 195 cm depth and 0.5 cm height. In a fire scenario carpet releases 1180 MJ energy.

The bedroom has a single desk and a floor pouf. The desk is made of plywood and the floor pouf is made of cotton and fabric. The desk has 140 cm width, 45 cm depth and 80 cm height. The floor pouf has 50 cm width, 40 cm depth and 45 cm height. In a fire scenario desk and floor pouf releases 1982 MJ, 132 MJ energy respectively. The desk and the pouf is shown in Figure 4.15. Bedroom fire load calculations are given in Figure A.3.



Figure 4.15. Building A bedroom desk and the floor pouf.

To summarize, bedroom releases 20138 MJ energy in a fire scenario which is the second highest energy release for this apartment. Dividing 20138 MJ to floor area of bedroom, fire load density is calculated as $1111 \text{ MJ}/\text{m}^2$. Bedroom has the highest fire load density and it makes sense since it has smaller floor area compared to the living room. It also matches Bwalya's studies [34] and other surveys that are performed on dwellings [43]. This means that for this apartment, bedroom provides the most risk in a fire. So, for a fire design a fire engineer should consider designing a fire in living room and bedroom separately.

Table 4.1. Apartment 3+1 of Building A moving fire load and energy values.

3+1			
Room Names	Total Energy(MJ)	Room Area(m ²)	Fire Load(MJ/m ²)
Living Room	25354	48,00	528,21
Kids Room 1	8391	11,55	726,51
Kids Room 2	8545	10,59	806,87
Bedroom	20138	18,13	1110,74
Kitchen	4104	11,35	361,62
Apartment Total:	74348,93	99,62	746,33

Living room has an energy release of 25354 MJ, this value was used to calculate the heat release rate of the living room. Unscaled heat release rate of the living room has initial items that were present in the room, peak hrr value is 10 MW and it releases 3903 MJ. Dividing the original energy value, 25354 to 3903, scale factor is found as 6,5. The graph is scaled vertically with the scale factor and the new peak value is found as 63.55 MW.

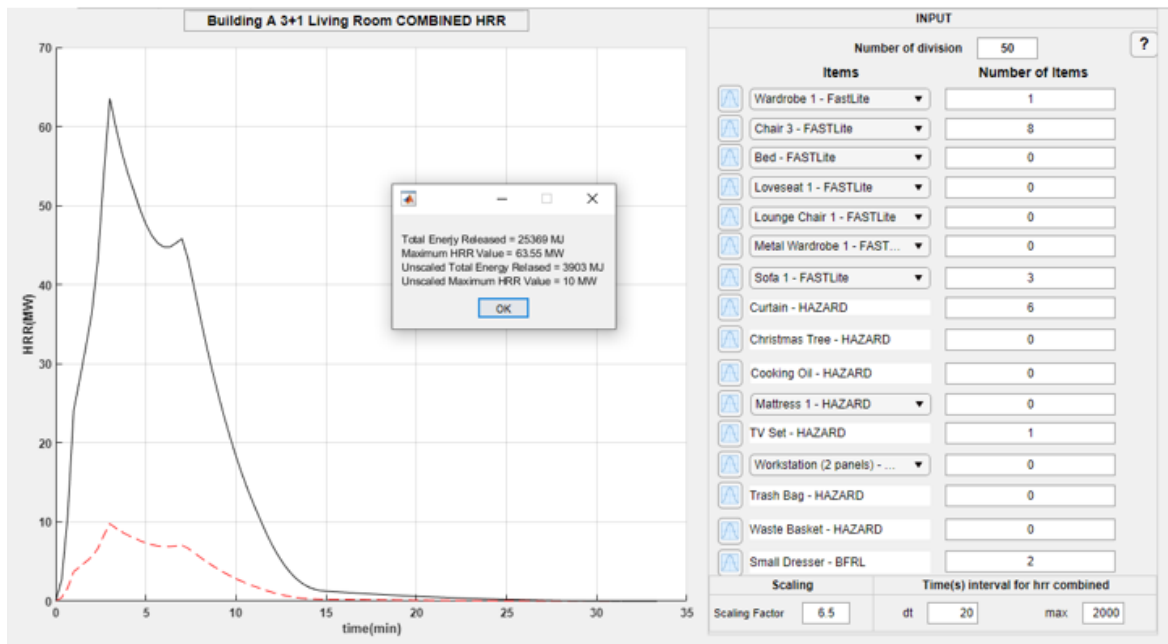


Figure 4.16. Building A living room heat release rate curve.

4.1.2. Low-Rise 3+1 Apartments

In this section there will be only results based on the data provided by the people who filled the survey according to their house. There are 3 3+1 apartments in total, these are apartment A, B and C. Apartment A has a total floor area of 154 m^2 , apartment B has a total floor area of 113.54 m^2 and apartment C has a total floor area of 92.5 m^2 .

4.1.2.1. 3+1 Apartment A. Apartment A has the biggest floor area compared to other 3 3+1 apartments surveyed in this thesis. The survey filled out by the home resident is given in Figure 4.17, Figure 4.18 and Figure 4.19. Here, the material composition was unknown to the person who performed the survey, thus the materials are taken with the compositions and fractions given in the survey table which is shown in Figure 3.2. Using the excel sheets with the information provided by the survey, energy values and fire load densities are found. Excel calculations are shown in section A.2.

FIRE LOAD SURVEY

1. What is the type of apartment that is being surveyed?

1+1	2+1	3+1	4+1	5+1
<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. Total floor area of the surveyed apartment (m^2).

154

Figure 4.17. Fire survey apartment A part 1.

Table 4.2. Apartment A Energy and fire load density values.

3+1 Apartment A			
Room Names	Total Energy(MJ)	Room Area(m2)	Fire Load(MJ/m2)
Living Room	15654	44,00	355,78
Kids Room 1	23068	30,00	768,93
Kids Room 2	6155	20,00	307,76
Bedroom	16558	35,00	473,08
Kitchen	6898	25,00	275,90
Apartment Total:	68333	154,00	443,72
Fixed Load			
Living Room	6055	44,00	137,62
Kids Room 1	4129	30,00	137,62
Kids Room 2	2752	20,00	137,62
Bedroom	4817	35,00	137,62
Kitchen	0	25,00	0,00
Apartment Total:	17753	154,00	115,28

Table 4.2 shows the energy values and fire load densities for each room. Here the living room has $355,78 \text{ MJ/m}^2$ fire load density which is close to the values that are found by other studies [43]. Kids room 1 has the highest fire load density in the apartment. It was expected that bedroom would have the highest density, but due to the high difference in total energy value, kids room 1 has a higher fire load density. Living room releases 15654 energy during a fire, released by the moving fire load. Using the matlab application, hrr curve of this room is given in Figure 4.20. Original input releases 3628 MJ and using this value, scale factor is calculated as 4,31. After vertically scaling the graph with the scale factor, hrr curve for the living room is obtained.

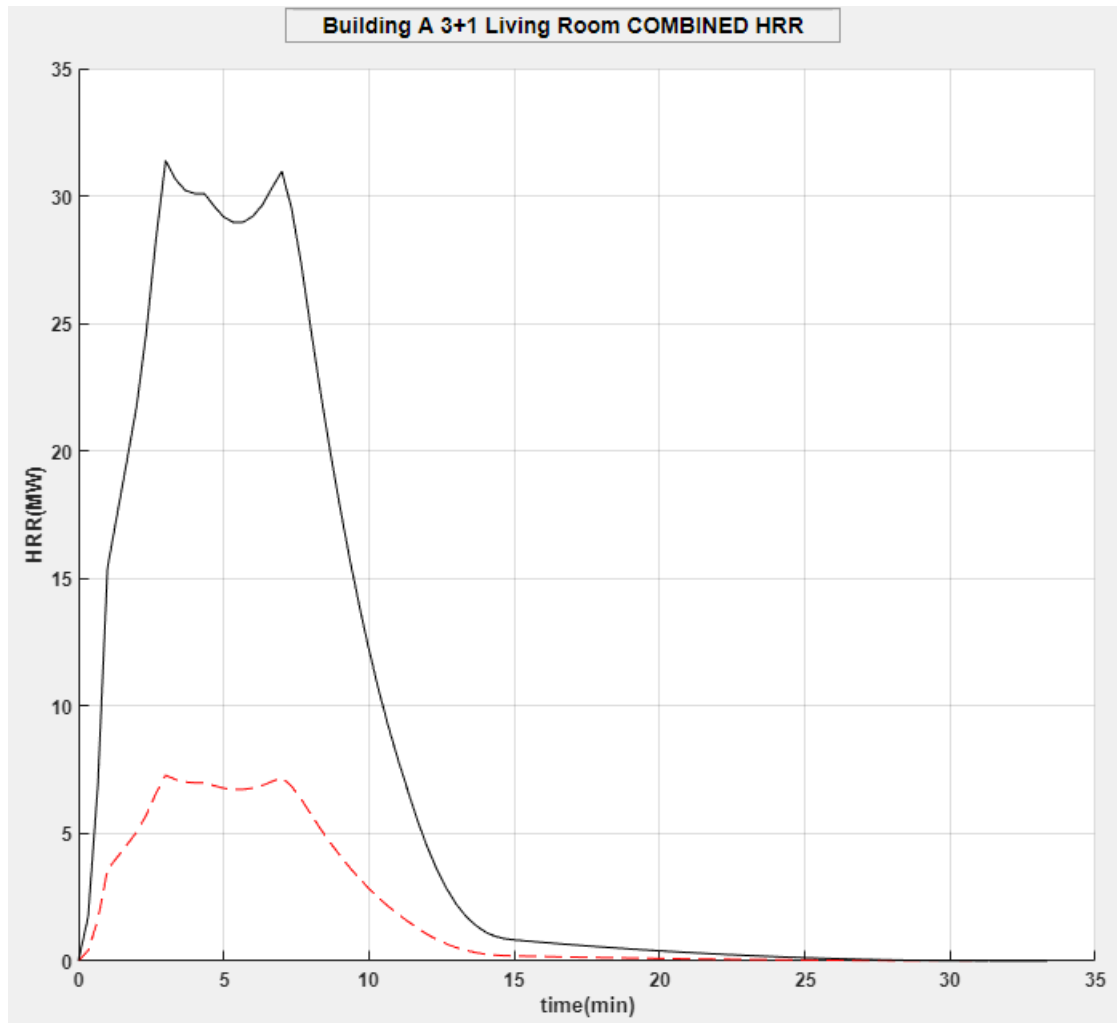


Figure 4.20. Apartment A living room hrr curve.

4.1.2.2. 3+1 Apartment B. Apartment B is the second low-rise apartment that was surveyed and it is the oldest apartment in this study. The survey is filled out by the home resident following the guidance provided by the survey. The person who performed the survey had no trouble in identifying the material compositions of the items that were made with a single material. Material compositions of the items such as sofas and chairs proved to be difficult to identify by the surveyor. Survey results are shown in Figure 4.21, Figure 4.22, Figure 4.23 and Figure 4.24. From all the apartments that are surveyed in this study, this was the only apartment that had solid hardwood as its flooring.

1. What is the type of apartment that is being surveyed?

1+1	2+1	3+1	4+1	5+1
<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. Total floor area of the surveyed apartment (m²).
135

Figure 4.21. Fire survey apartment B part 1.

Tables:

Living Room									
Items	Dimensions (cm)			Material Composition			Fraction		Number of items
	Width (cm)	Depth (cm)	Height (cm)						
Chair	41	45	87						8
Table	100	210	80						1
Loveseat 2	200	80	65						1
Loveseat	150	80	65						1
TV Unit	110	45	50						1
Cabinet	105	90	200						1
Curtain	160	1	295						4
Sofa	80	60	95						2
Floor Fire Load									
Solid Hardwood									

Kitchen									
Items	Dimensions (cm)			Material Composition			Fraction		Number of items
	Width (cm)	Depth (cm)	Height (cm)						
Chair	41	45	87						4
Dining Table	50	105	80						1
Cupboard	40	40	40						4
Oven	90	60	45						
Floor Fire Load									
Ceramic									

Figure 4.22. Fire survey apartment B part 2.

Bedroom									
Items	Dimensions (cm)			Material Composition			Fraction		Number of items
	Width (cm)	Depth (cm)	Height (cm)						
Bed	210	205	40						1
Side table	58	40	44						2
Wardrobe	360	80	200						1
Curtain	160	1	200						1
Floor Fire Load									
Solid Hardwood									

Extra Room 1									
Items	Dimensions (cm)			Material Composition			Fraction		Number of items
	Width (cm)	Depth (cm)	Height (cm)						
Bed	100	205	40						1
Study Table	117	64	77						1
Chair	46	42	89						2
Curtain	160	1	200						2
Wardrobe	180	70	200						1
Floor Fire Load									
Solid Hardwood									

Extra Room 2									
Items	Dimensions (cm)			Material Composition			Fraction		Number of items
	Width (cm)	Depth (cm)	Height (cm)						
Bed	100	250	38						1
Study Table	117	64	75						1
Side table	58	40	40						1
Wardrobe	150	70	200						1
Chair	46	42	89						1
Curtain	160	1	200						1
Floor Fire Load									
Solid Hardwood									

Figure 4.23. Fire survey apartment B part 3.

4. Floor area of the rooms.

Room Names	Floor Area (m ²)
Living Room	30
Kitchen	15
Bedroom	20
Extra Room 1	17
Extra Room 2	12

Figure 4.24. Fire survey apartment B part 4.

The information given by the home resident was then inputted into the excel sheet created to calculate the energy and fire load density values for this apartment. Material compositions, fractions and void ratio of the items for each room is given in section A.3. Results of these calculations are given in Table 4.3.

It is seen that living room releases the most energy, followed by the bedroom, in a fire scenario; but it has a low fire load density while the kids room 2 and bedroom has higher density. Therefore, kids room 2 and bedroom should be investigated for a fire scenario.

Table 4.3. Apartment B Energy and fire load density values.

3+1 Apartment B			
Room Names	Total Energy(MJ)	Room Area(m2)	Fire Load(MJ/m2)
Living Room	12729	30,00	424,30
Kids Room 1	9398	17,00	552,84
Kids Room 2	7734	12,00	644,50
Bedroom	12234	20,00	611,69
Kitchen	3571	15,00	238,07
Apartment Total:	45666	94,00	485,81
Fixed Load			
Living Room	5309	30,00	176,98
Kids Room 1	3009	17,00	176,98
Kids Room 2	2124	12,00	176,98
Bedroom	3540	20,00	176,98
Kitchen	0	15,00	0,00
Apartment Total:	13981	94,00	148,74

In this apartment, living room has 8 chairs, 2 love seats, 2 sofas, 1 TV set, 1 cabinet and 4 curtains. Inputting these data into the matlab application, unscaled energy release is found as 3823 MJ. Living room releases 12729 MJ energy, so the scale factor is calculated as 3,34. After vertically scaling the graph with 3,34 hrr curve for the living room is obtained and shown in Figure 4.25.

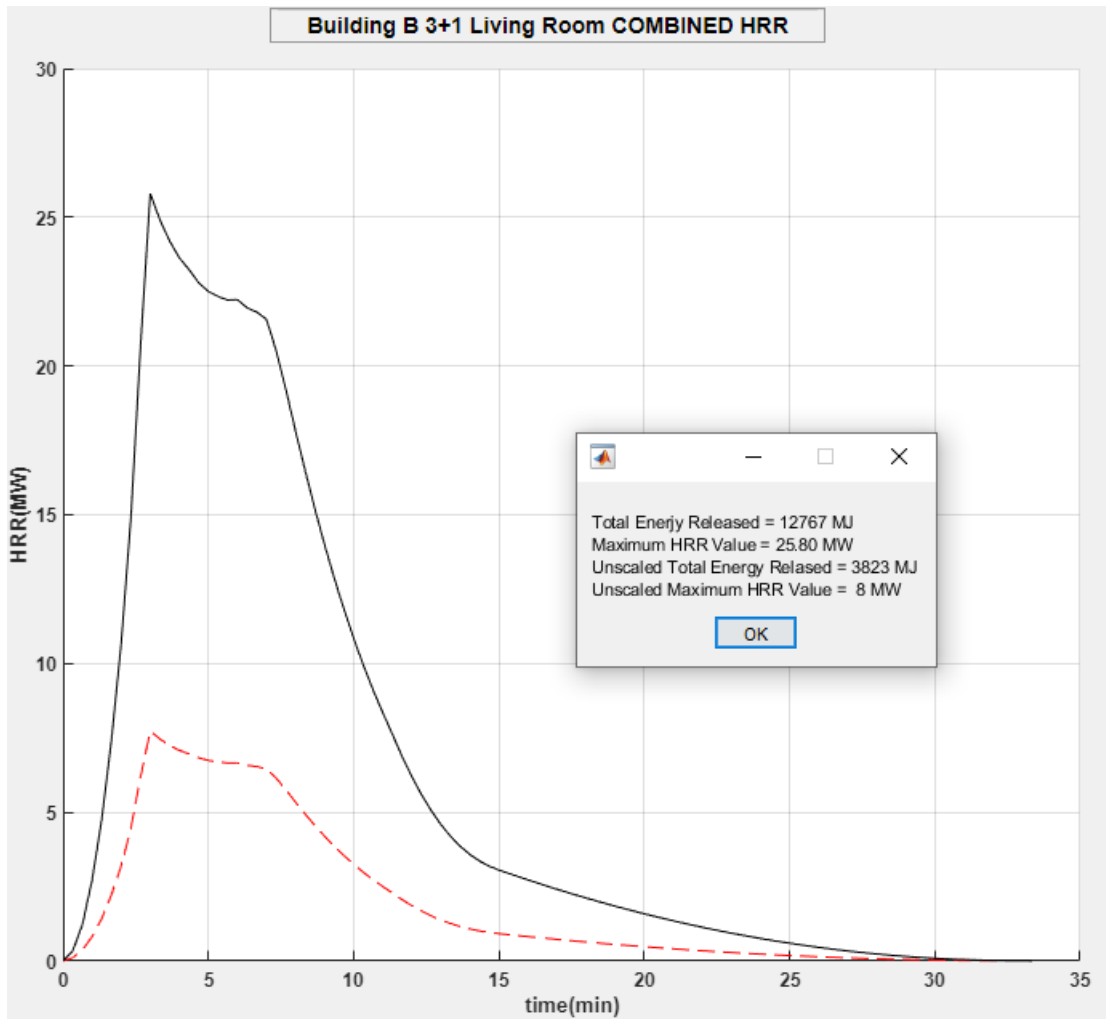


Figure 4.25. Apartment B living room hrr curve.

4.1.2.3. 3+1 Apartment C. Apartment C is the final low-rise apartment that was surveyed and it was physically surveyed by the author of this thesis. It is also the newest apartment, with the building age of 0, in this thesis. This apartment had the most wardrobes compared to the other dwellings. Fire load survey filled by the author is shown in Figure 4.26, Figure 4.27 and Figure 4.28.

1. What is the type of apartment that is being surveyed?

1+1	2+1	3+1	4+1	5+1
<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2. Total floor area of the surveyed apartment (m²).

133.52

Figure 4.26. Fire survey apartment C part 1.

Tables:

Living Room										
Items	Dimensions (cm)			Material Composition			Fraction			Number of items
	Width (cm)	Depth (cm)	Height (cm)							
Chair	45	45	90	P.Foam	Fabric		.5	.3		7
Table				Marble						1
Carpet	150	290	0.5							1
Pouf	40	60	7	P.foam	Fabric		.7	.3		2
L sofa	252	190	80							1
Sofa 1	90	80	75							1
Sofa 2	55	80	100							2
Cabinet 1	170	40	80	wood						1
Curtain										
Tv unit	120	45	30	Plyw.						1
Tv	108	3	68							1
Floor Fire Load										
Laminate										

Kitchen										
Items	Dimensions (cm)			Material Composition			Fraction			Number of items
	Width (cm)	Depth (cm)	Height (cm)							
Cupboard	50	35	70	Plyw.						10
Oven	60	2	60	Glass						2
Floor Fire Load										
Marble										

Bedroom										
Items	Dimensions (cm)			Material Composition			Fraction			Number of items
	Width (cm)	Depth (cm)	Height (cm)							
Ward. 1	90	50	185	Plyw.						2
Ward. 2	210	60	210	Plyw						1
Bed	200	160	70							1
Side table	50	45	50	Plyw						2
Tv	70	5	55							1
Ward 3.	100	45	140	Plyw						1
Ward 4.	130	40	200	Plyw						1
Carpet	210	145	0.5							1
Curtain										
Floor Fire Load										
Laminate										

Figure 4.27. Fire survey apartment C part 2.

Extra Room 1									
Items	Dimensions (cm)			Material Composition	Fraction	Number of items			
	Width (cm)	Depth (cm)	Height (cm)						
Ward 1.	185	60	225	Plyw.		1			
Bed	125	190	65			1			
Side table	57	45	53	Plyw.		1			
Small dre.	90	50	90	Plyw.		1			
Ward 2.	70	50	200	Plyw.		1			
Study Desk	130	60	200	Plyw.		1			
Carpet	215	140	0.5			1			
Curtain									
Floor Fire Load									
Laminate									

Extra Room 2									
Items	Dimensions (cm)			Material Composition	Fraction	Number of items			
	Width (cm)	Depth (cm)	Height (cm)						
Loveseat	190	80	80			1			
Small dre.	70	45	80			1			
Side table	55	45	80			1			
Wardrobe	220	65	280			1			
Study	135	70	75			1			
Carpet	145	145	0.5			1			
Curtain	150	1	280			4			
Bed	90	190	60			1			
Floor Fire Load									
Laminate									

4. Floor area of the rooms.

Room Names	Floor Area (m ²)
Living Room	30,42
Kitchen	12,72
Bedroom	19,62
Extra Room 1	14,69
Extra Room 2	15,04

Figure 4.28. Fire survey apartment C part 3.

Looking at the information provided by the survey, bedroom and extra room 1 have a lot of heavy furniture such as wardrobes and beds. It is expected that these rooms will have a high fire load density. This data is inputted into the excel sheet to calculate the energy and fire load density values which are given in Table 4.4. Excel sheet used to calculate these values are given in section A.4.

Table 4.4. Apartment C Energy and fire load density values.

3+1 Apartment C			
Room Names	Total Energy(MJ)	Room Area(m2)	Fire Load(MJ/m2)
Living Room	12507	30,42	411,14
Kids Room 1	11962	14,69	814,30
Kids Room 2	15102	15,04	1004,13
Bedroom	16912	19,62	861,97
Kitchen	3225	12,72	253,52
Apartment Total:	59708	92,49	645,56
Fixed Load			
Living Room	2990	30,42	98,30
Kids Room 1	1444	14,69	98,30
Kids Room 2	1478	15,04	98,30
Bedroom	1929	19,62	98,30
Kitchen	1250	12,72	98,30
Apartment Total:	9092	92,49	98,30

Living room releases 12507 MJ energy which is lower than most of the other rooms. Generally, living room has the highest energy release due to the floor area being larger than the other rooms. It is also interesting to note that all of the low-rise apartment living rooms have similar fire load density value. Fire load density value for living room is also similar with the studies performed in USA [43]. As expected, kids room and bedroom had the highest fire load density. Although, a fire analysis should be performed for bedroom and kids room 2 or even kids room 1, living room hrr curve is given as an example. Living room has 7 chairs, 1 L sofa, 3 armchairs, 4 curtains, 1 cabinet and a TV set. These items release 4255 MJ energy, multiplying with the scale factor 2,94 living room hrr curve is obtained and shown in Figure 4.29.

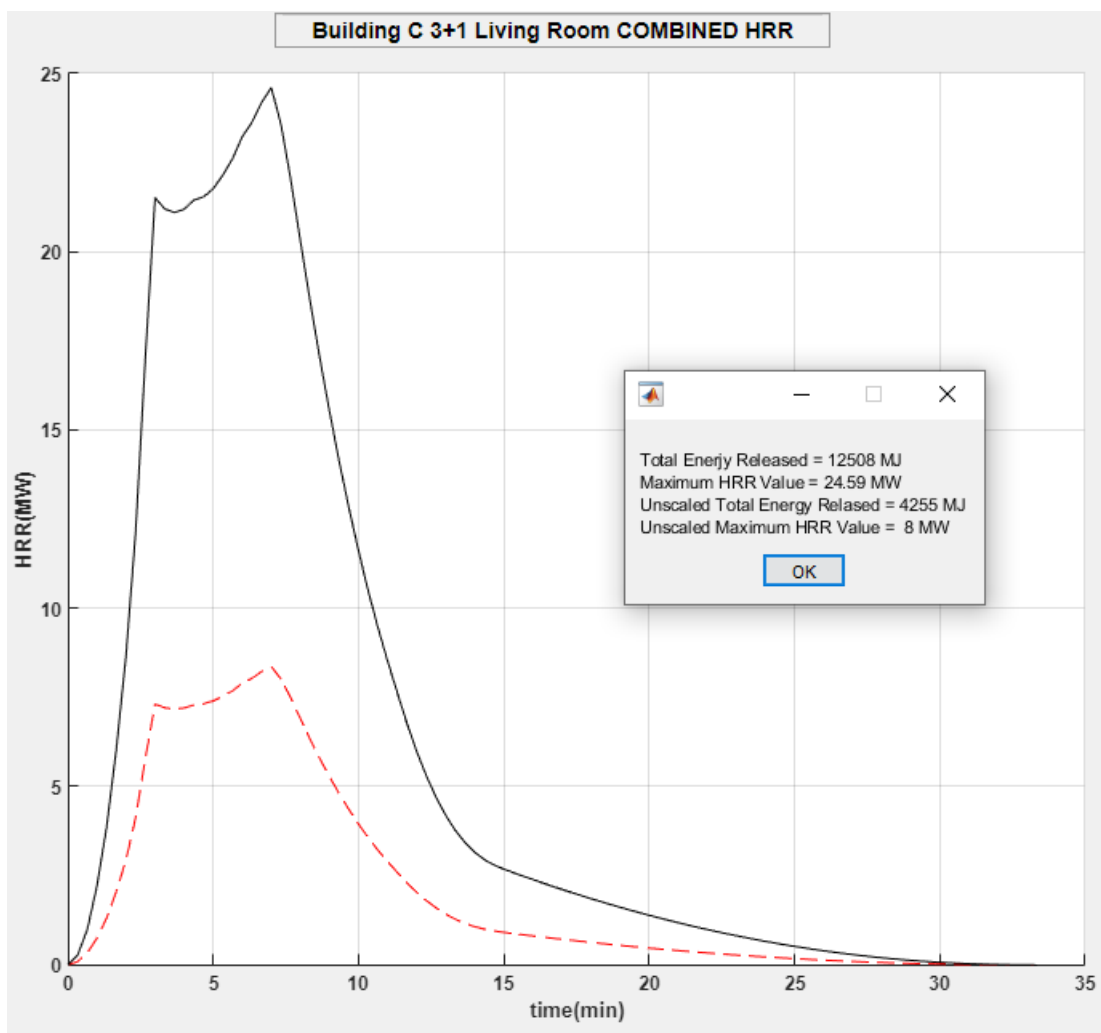


Figure 4.29. Apartment C living room hrr curve.

4.2. Apartment Type 2+1

4.2.1. Building A

Building A was described in the beginning of section 4.1.1. This apartment was not surveyed by a home resident or the author; but the floor plan with the furniture inside it was available. Therefore, this apartments fire load and fire load density values are calculated over the floor plan. Floor plan is shown in Figure 4.30. Each items' dimension was individually measured from the floor plan and their material composition was taken as suggested in the survey template. For the shapes, chairs were assumed to be same as the chairs inside the Building A 3+1 apartment.



Figure 4.30. Building A 2+1 floor plan.

Fire load and fire load density values are calculated with the excel. Excel tables that are used in the calculations are given in section A.5. Table 4.5 shows the energy and fire load density values for each room.

Table 4.5. Apartment 2+1 of Building A fire load and energy values.

2+1			
Room Names	Total Energy(MJ)	Room Area(m2)	Fire Load(MJ/m2)
Living Room	22449	34,60	648,83
Kids Room 1	8530	12,07	706,71
Bedroom	19039	17,61	1081,17
Kitchen	4104	11,90	344,90
Apartment Total:	54123	76,18	710,47
Fixed Load			
Living Room	3401	34,60	98,30
Kids Room 1	1186	12,07	98,30
Bedroom	1731	17,61	98,30
Kitchen	0	11,90	0,00
Apartment Total:	6319	76,18	82,94

From the table it can be seen that living room releases the most energy and bedroom has the highest fire load density. Also living room has above average fire load density value compared with the previous apartments and studies. Hrr curve for the living room is calculated with the items that are present in the room. These are; 1 wardrobe, 3 sofa, 1 TV set, 6 curtain, 1 cabinet, 3 coffee table and 8 chair. Unscaled energy release is 4885 MJ compared to the 22449. Scaling the energy value with 4,6 hrr curve for the living room is obtained and shown in Figure 4.31.

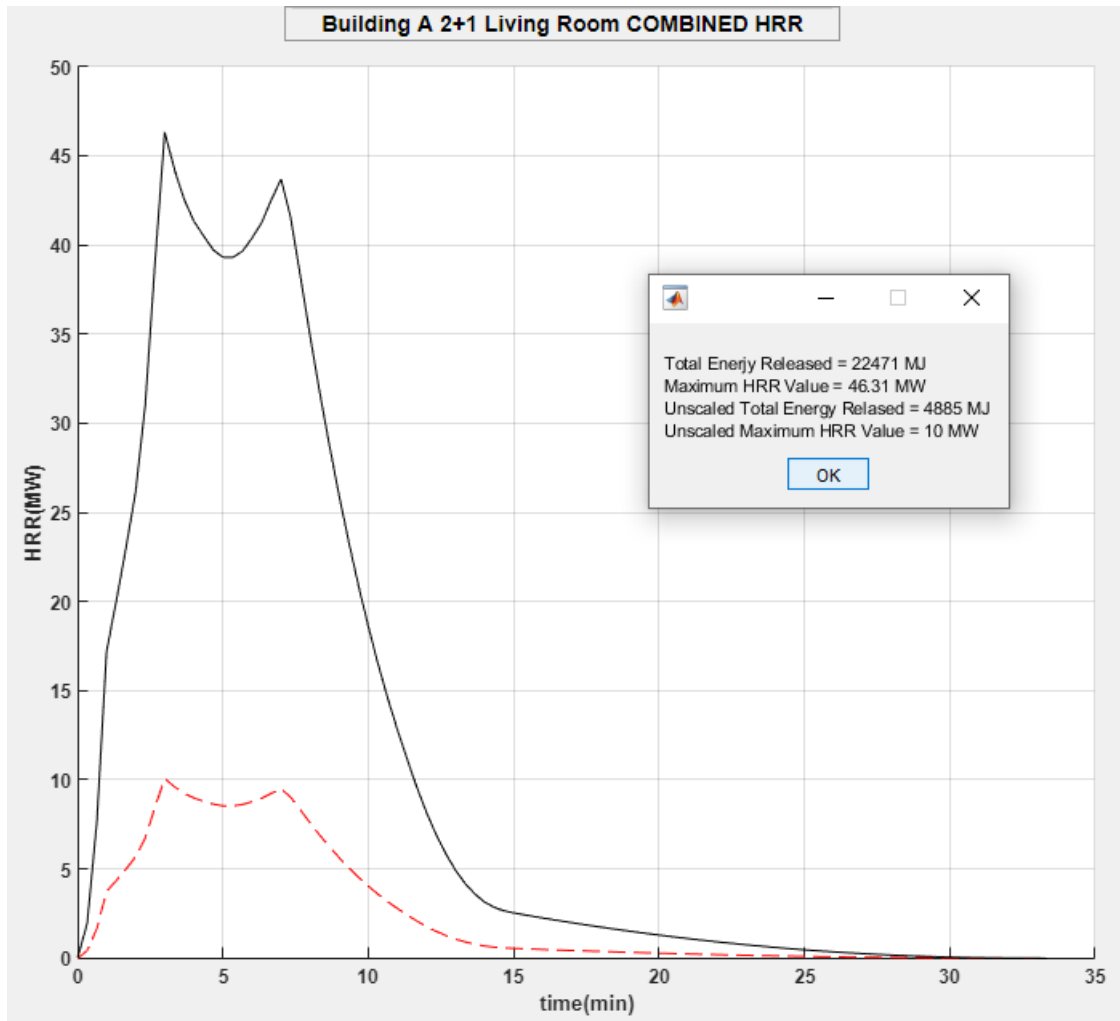


Figure 4.31. Building A 2+1 living room hrr curve.

4.2.2. Building B

Building B is a high rise building with 44 floors. It has 4 different apartment types ranging between 1+1 to 4+1. There is only information regarding a single 2+1 apartment inside the building. The apartment was not surveyed; but information about the furniture was gathered through the floor plan and photographs of the furniture. Figure 4.32 shows the floor plan for the apartment. Apart from the photographs list of items and their material compositions were also available which made the fire load survey easier. Excel tables that are used for the calculation of the fire load and fire load density values are given in section A.6. Fire load density and energy values are given in Table 4.6.

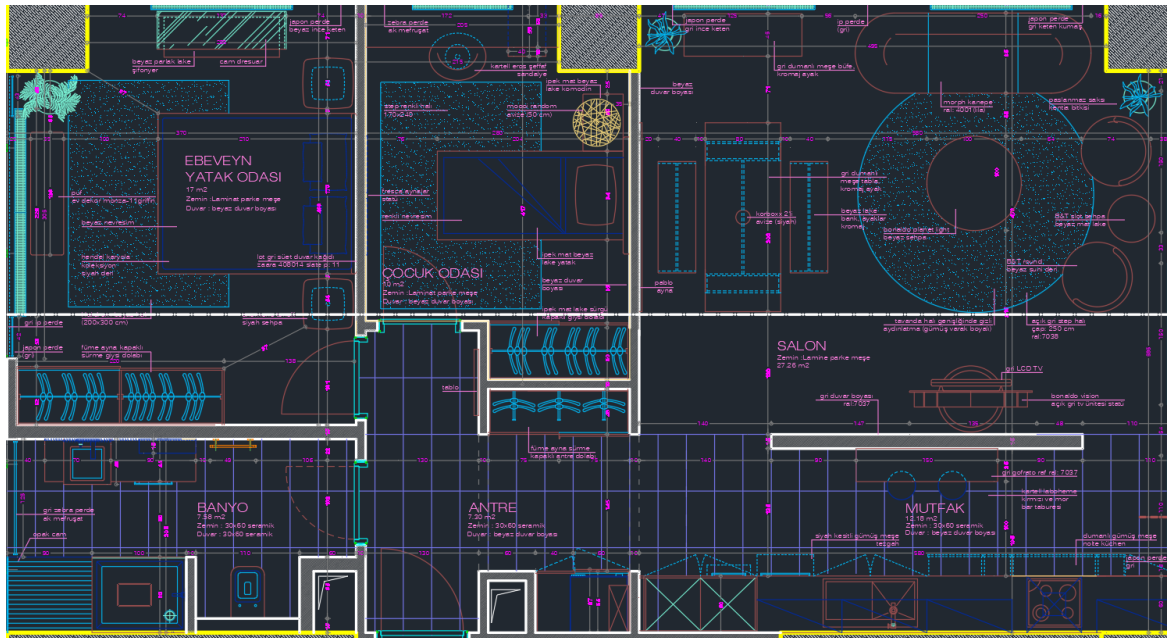


Figure 4.32. Building B 2+1 floor plan.

Table 4.6. Apartment 2+1 of Building B fire load and energy values.

2+1			
Room Names	Total Energy(MJ)	Room Area(m2)	Fire Load(MJ/m2)
Living Room	11737	27,26	430,56
Kids Room 1	4997	10	499,73
Bedroom	16280	17	957,62
Kitchen	3632	12,18	298,21
Apartment Total:	36646	66,44	551,57
Fixed Load			
Living Room	2680	27,26	98,30
Kids Room 1	983	10	98,26
Bedroom	1671	17	98,30
Kitchen	0	12,18	0,00
Apartment Total:	5333	66,44	80,27

Table 4.6 shows that bedroom has the highest fire load density with high energy release. It is expected that bedroom would have the highest FLD value as most studies show that this is the case and previous survey results also back this data up. Even though in some apartments bedroom was not the highest, it was very close to the highest FLD value. Living room fire load density value for this 2+1 apartment is similar to the previous 3+1 apartments; but with less total energy release. The data gathered about the furniture is used to create the hrr curve for the living room. The initial items release an unscaled energy of 4621 MJ which is lower than the actual energy release for this living room. Vertically scaling this value with 2.54, hrr curve for the living room is found and shown in Figure 4.33.

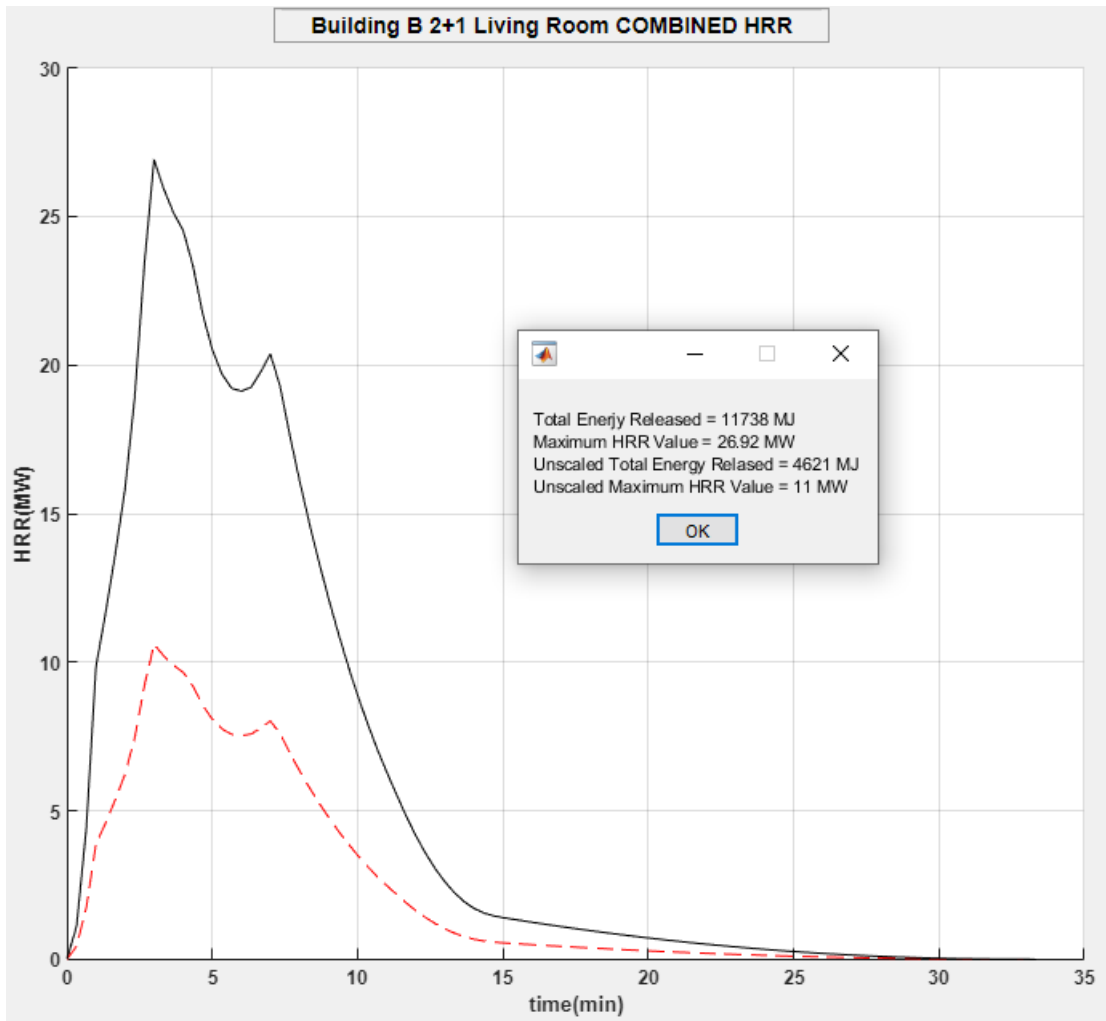


Figure 4.33. Building B 2+1 living room hrr curve.

4.3. Apartment Type 1+1 and 4+1

4.3.1. Building A

A 1+1 and a 4+1 apartment type was surveyed over the floor plan explained in section 4.2.1. Items were measured over the floor plan with AutoCAD, and assumed to have the same material composition with the items surveyed in the Building A 3+1 apartment. Floor plan for 1+1 and 4+1 apartment types are given in Figure 4.34 and Figure 4.35, respectively.



Figure 4.34. Building A 1+1 floor plan.

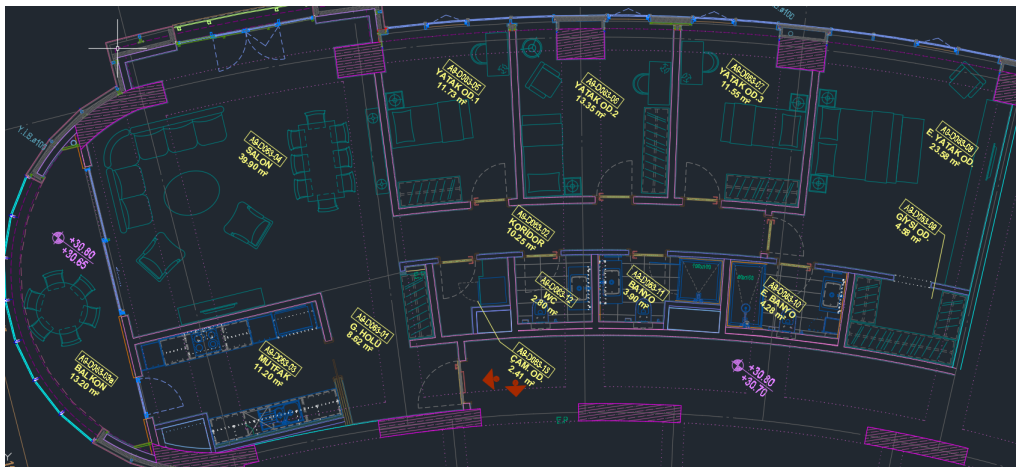


Figure 4.35. Building B 4+1 floor plan.

The 1+1 apartments kitchen and living room is merged. This causes a huge increase in the fire load for the living room. 2 different excel files are created to calculate the energy and fire load density values of each apartment. Table 4.7 and Table 4.8 shows the fire load density values for 1+1 and 4+1 apartments, respectively.

Table 4.7. Apartment 1+1 of Building A fire load and energy values.

1+1			
Room Names	Total Energy(MJ)	Room Area(m2)	Fire Load(MJ/m2)
Living Room + Kitchen	25140	30,87	814,37
Bedroom	18954	16,25	1166,42
Apartment Total:	44094	47,12	935,78
Fixed Load			
Living Room + Kitchen	3035	30,87	98,30
Bedroom	1597	16,25	98,30
Apartment Total:	4632	47,12	98,30

Table 4.8. Apartment 4+1 of Building A fire load and energy values.

4+1			
Room Names	Total Energy(MJ)	Room Area(m2)	Fire Load(MJ/m2)
Living Room	22282	48,50	459,43
Kids Room 1	8212	11,73	700,04
Kids Room 2	9754	13,35	730,61
Kids Room3	8212	11,55	710,95
Bedroom	24153	28	862,62
Kitchen	4104	11,2	366,46
Apartment Total:	76717	124,33	617,04
Fixed Load			
Living Room	4768	48,50	98,30
Kids Room 1	1153	11,73	98,30
Kids Room 2	1312	13,35	98,30
Kids Room3	1135	11,55	98,30
Bedroom	2752	28	98,30
Kitchen	0	11,2	0,00
Apartment Total:	11121	124,33	89,45

Tables show that both apartments bedroom has the highest FLD compared to the other rooms. 4+1 apartments living room has an average fire load density value while the 1+1 apartments living room is double this amount.

4.4. Summary

In total 8 apartments were surveyed in the scope of this thesis. From the gathered data, an average, minimum and maximum values for each type of room can be made. Table 4.9 provides fire load density values for living room depending on their floor area. It is seen that as the floor area of the room increases fire load density values decrease. It is also important to observe that the difference between the minimum and maximum values are smaller for the rooms that have a floor area larger than 35 m^2 .

Table 4.9. Living room FLD values summarized.

Moving Fire Load Density				Total Fire Load Density			
Fire Load Density(MJ/m ²) Living Room <35 m ²				Fire Load Density(MJ/m ²) Living Room <35 m ²			
Min	Mean	Max	Standard Dev.	Min	Mean	Max	Standard Dev.
411,14	545,84	814,37	179,53	509,44	659,88	912,67	169,37
Fire Load Density(MJ/m ²) Living Room >35 m ²				Fire Load Density(MJ/m ²) Living Room >35 m ²			
Min	Mean	Max	Standard Dev.	Min	Mean	Max	Standard Dev.
355,78	447,81	528,21	86,80	454,08	546,11	626,51	86,80

Table 4.10 summarizes the bedroom data provided in this thesis and shows the minimum, maximum and average fire load density values of the bedrooms depending on the rooms floor area. Same outcome is observed here as well, where the floor area increases FLD values decrease. Also compared to the living room FLD values bedroom has approximately 1.5 to 2 times bigger values.

Table 4.10. Bedroom FLD values summarized.

Moving Fire Load Density				Total Fire Load Density			
Fire Load Density(MJ/m ²) Bedroom <20 m ²				Fire Load Density(MJ/m ²) Bedroom <20 m ²			
Min	Mean	Max	Standard Dev.	Min	Mean	Max	Standard Dev.
861,97	1035,58	1166,42	123,56	960,27	1133,88	1264,72	123,56
Fire Load Density(MJ/m ²) Bedroom >20 m ²				Fire Load Density(MJ/m ²) Bedroom >20 m ²			
Min	Mean	Max	Standard Dev.	Min	Mean	Max	Standard Dev.
473,08	649,13	862,62	197,45	571,38	773,66	960,92	195,20

Table 4.11 and Table 4.12 shows the FLD values for the extra rooms and kitchens that are surveyed in this thesis, respectively. Extra rooms and kitchens that are surveyed in this thesis either have under 15 m^2 or slightly higher floor area which resulted in a decision of not classifying these 2 rooms with their floor area. Extra rooms have a difference of 700 MJ/m^2 between the minimum and maximum value which is caused by the usage of this room. Some of the families chose to use the room as a second living room with less density. On the other hand some people used it as a kids room with high density of furniture which resulted in a higher fire load. In this study it was observed that kitchens have a very low FLD value. This might be the result of not taking refrigerator into consideration while calculating the fire load. Refrigerators have a very complex material composition which makes the calculation very difficult and making a simplified assumption very hard regarding their composition. Recently a study performed by NIST [44] also did not account for a refrigerator inside the kitchen.

Table 4.11. Extra room FLD values summarized.

Moving Fire Load Density				Total Fire Load Density			
Fire Load Density(MJ/m ²) Extra Room				Fire Load Density(MJ/m ²) Extra Room			
Min	Mean	Max	Standard Dev.	Min	Mean	Max	Standard Dev.
307,76	676,41	1004,13	180,00	406,06	800,70	1102,43	163,97

Table 4.12. Kitchen FLD values summarized.

Moving Fire Load Density				Total Fire Load Density			
Fire Load Density(MJ/m ²) Kitchen				Fire Load Density(MJ/m ²) Kitchen			
Min	Mean	Max	Standard Dev.	Min	Mean	Max	Standard Dev.
238,07	305,53	366,46	52,59	238,07	305,53	366,46	52,59

Finally, Table 4.13 summarizes the fire load density value of the apartment, in order to make an appropriate comparison between the Eurocode's suggested dwelling fire load density value. It is seen that the difference between the mean value and the Eurocode's suggested value is very small and the standard deviation found in this study is also very close to the Eurocode's standard deviation (180 MJ) [33]. Therefore, Eurocode's suggested value can be adapted for the fire analyses made on the dwellings in Turkey.

Although, the dwelling value suggested is suitable; the more accurate way of performing the analysis would be to create a room fire based on the rooms' FLD instead of the apartments total FLD due to the most of the fires not reaching flashover. Figure 4.36 shows a Gumbel distribution graph made with the results collected in this thesis.

Table 4.13. Summarized apartment total fire load density values.

FIRE LOAD DENSITY OF APARTMENT				
Min	Mean	Max	Standard Dev.	Eurocode Dwelling
526,06	728,15	1034,08	150,32	780

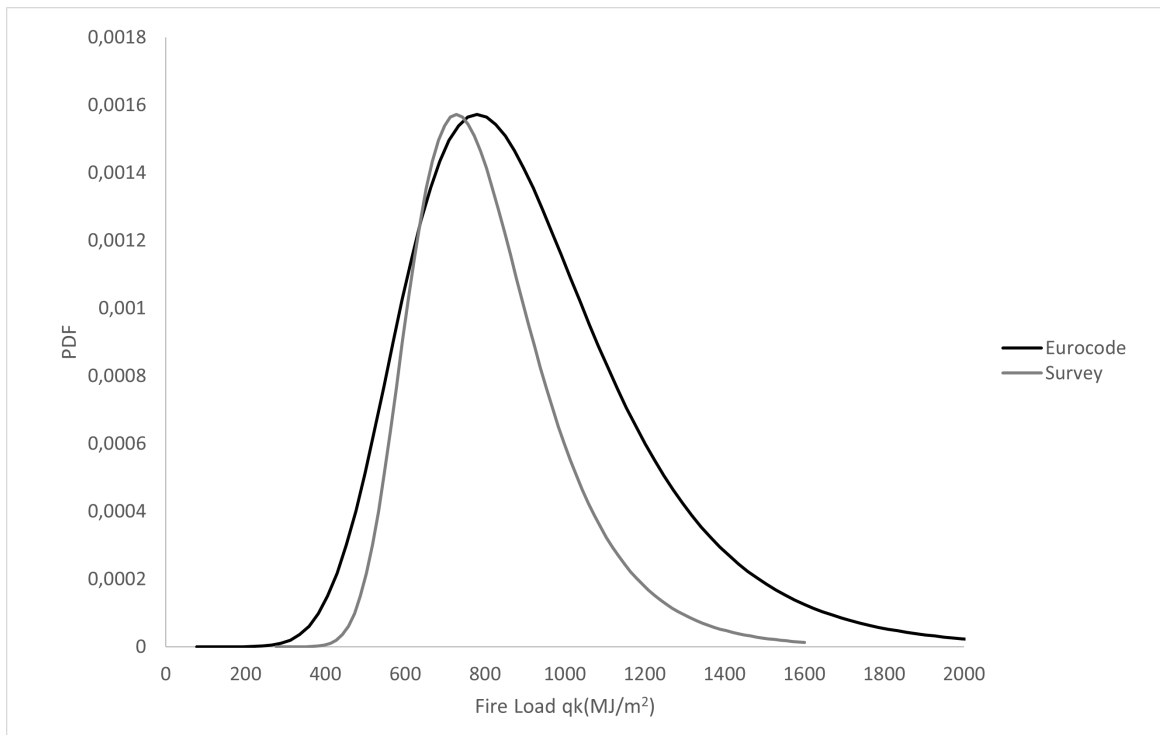


Figure 4.36. The probability density function of dwelling fire load as Gumbel distribution.

4.4.1. Fire Spread Analysis

HRR application creates a curve, but this curve is only accurate for the worst case scenario where all of the items inside the compartment is ignited at the same time. Therefore, to make the curve more accurate, Pyrosim, a CFD software based on large eddy simulation, has been used to track the fire spread times between the items.

Fire spread inside the living room and bedroom was studied. 1 analysis was made for the living room and 1 analysis was made for the bedroom. In this study, kitchen was neglected for the fire spread analysis due to the fact that kitchen's fire load is mainly fixed. Therefore, a fire inside the kitchen will quickly spread between the cupboards and grow. Bedrooms and living rooms have mainly moving fire load, and their geometry also changes from apartment to apartment which affects the distance between the items. Living room and bedroom models created for this study is given in Figure 4.37 and Figure 4.38, respectively. In Figure 4.37 living room has 2 windows which are assumed to be closed at the beginning and they will open at $400^{\circ}C$. Pyrosim manual suggests that the mesh boundaries should be placed at least 1 m away from the openings. Otherwise the smoke movement will not be properly observed, so in this study mesh boundaries were placed 1 m away from the exterior walls. This way a more realistic approach was achieved. In all of the scenarios, analyses lasted until the fire spread to at least 2 items. Meshes are chosen as 0.1 m in the fire compartment and 0.2 for the outside of the fire compartment which is fine meshing for fire compartment and coarse meshing for the outside of the fire compartment. Mesh size is calculated with the equation (4.1) [45] and here, \dot{Q} represents the total heat release rate of the fire, p_{∞} is the air density kg/m^3 , c_p is the air specific heat kJ/kgK , g is the gravitational constant m/s^2 and T_{∞} is the ambient temperature (K)

$$D^* = \left(\frac{\dot{Q}}{p_{\infty} c_p T_{\infty} \sqrt{g}} \right)^{\frac{2}{5}}. \quad (4.1)$$

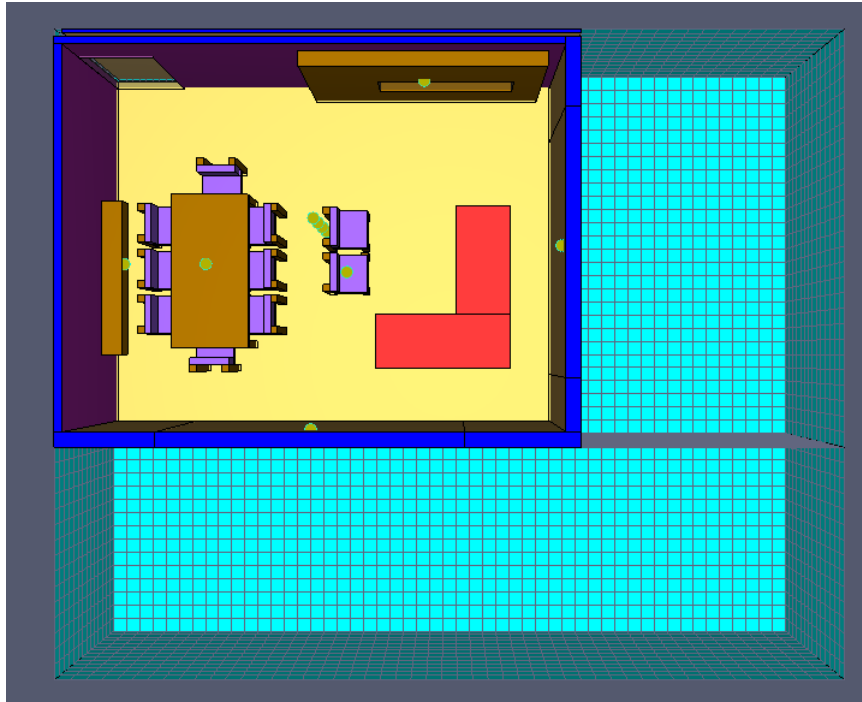


Figure 4.37. Living room fire spread model.

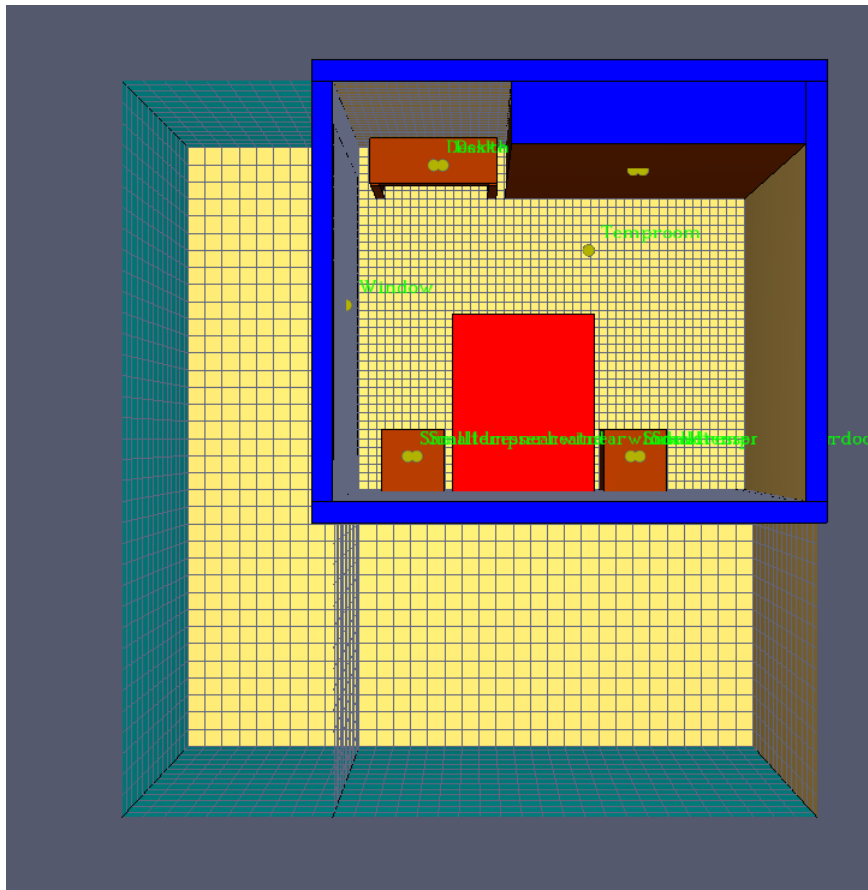


Figure 4.38. Bedroom fire spread model.

4.4.1.1. Living Room Analysis. Living room has 10 chairs, 2 sofa, 1 TV unit, 1 dinner table and a cabinet. Carpet, curtains and fixed fire load were not included in the fire spread analysis. The HRR curve applied to the sofa was taken from the Matlab application and given in Figure 4.39. It was assumed that the sofa was burning at the start, this is shown in Figure 4.40, to fasten up the analysis process. The analysis was stopped after 250 seconds and at this point all of the items inside the living room were burning which is given in Figure 4.41. After 129 seconds from ignition of the sofa; fire spread to the chair leg and caused an ignition, which had an ignition temperature of 250°C (triggers an automatic ignition when the surface reaches this value). The chair was 1.30 meters away from the sofa and at the time of ignition, the chair had a 11.9 kW/m^2 incident heat flux. This value coincides with the data provided by Babrauskas [46], according to his findings an item which is 1.3 meters away from the fire source will ignite over 10 kW/m^2 heat flux. Second item ignited after the chair was the TV unit which ignited after 145 seconds of the couch fire ignition. Remaining items were ignited 30 seconds after the TV unit ignition. Heat flux values of the items are given in Figure 4.42. After ignition, heat flux devices follow the HRR curve assigned for the items.

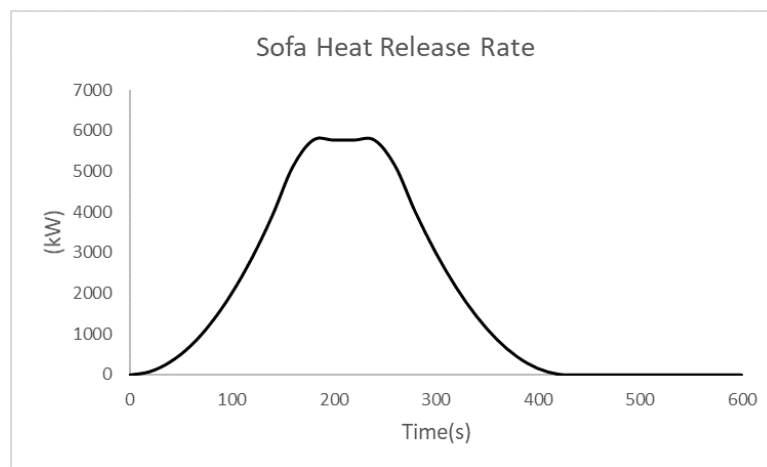


Figure 4.39. Living room sofa HRR curve.

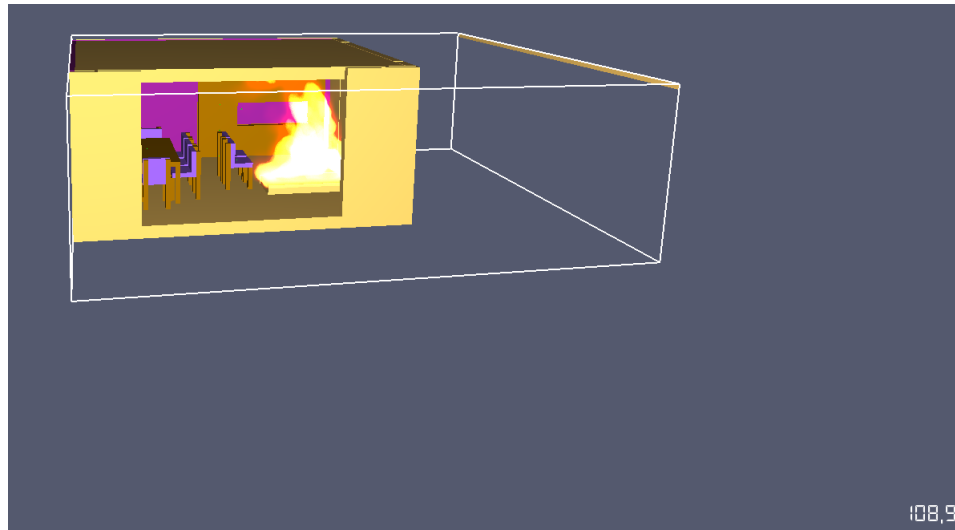


Figure 4.40. Living room FDS analysis at 109 seconds.

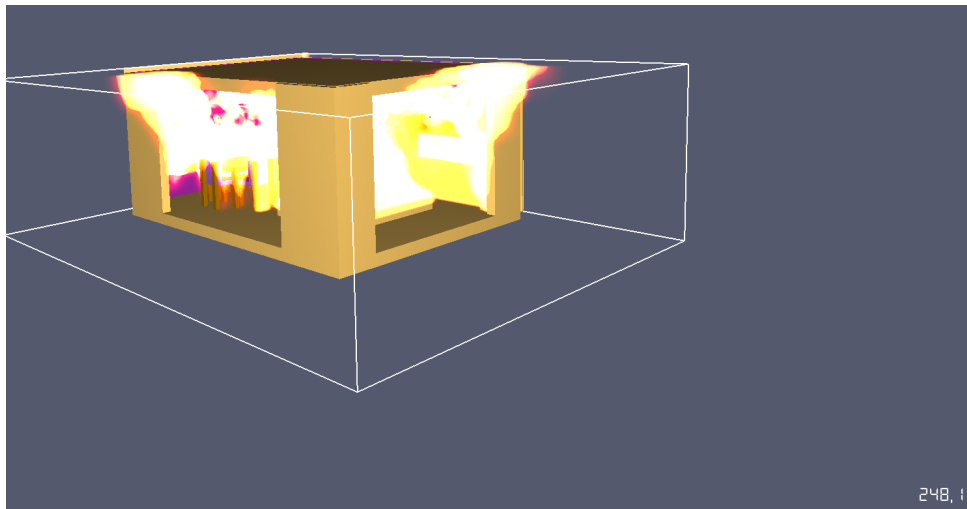


Figure 4.41. Living room FDS analysis at 248 seconds.

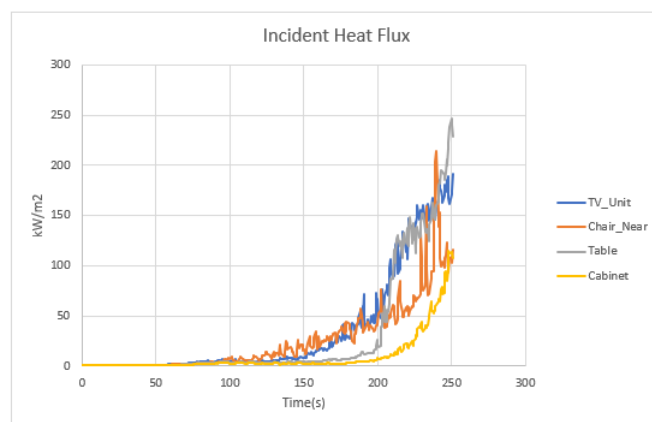


Figure 4.42. Living room furniture heat flux graphs.

4.4.1.2. Bedroom Analysis. Bedroom has 1 queen-size bed, 1 wardrobe, 1 desk and 2 small dressers near the bed. In bedroom analysis the queen size bed was ignited. Heat release rate curve of the bed, innerspring mattress and the box spring is included, is given in Figure 4.43. It has a peak heat release of 1.98 MW and total fire duration is 900s. After 65 seconds of the ignition, small dresser near the bed which was close to the door ignited. The small dresser had an incident heat flux of 11,96 kW/m². There were 2 small dressers near the bed where one of them was close to the door and the other one was close to the window. It was observed that the dresser near the window ignited after the wardrobe which was closer to the fire source compared to the wardrobe. Wardrobe had an incident heat flux of 9,65 kW/m² and the small dresser near the window had an incident heat flux of 11,35 kW/m². Heat flux values of the items are shown in Figure 4.44. Although the peak heat release rate and total energy release of the fire was lower compared to the living room fire, flashover was observed 100 seconds after the bed's ignition.

It is seen from these analyses that fire spread relies on; peak HRR value, fire area, distance between the items and ventilation factor. Second item's ignition time is mainly affected by the peak HRR value and fire area. Distance between the fire source and the items have a lesser impact on fire spread compared to the peak HRR value. There is a limit heat flux value on materials found by experiments [46] and without sufficient HRR value fire spread will not be observed. Fire analyses also show that when the item has an incident heat flux greater than 10 kW/m² ignition occurs. Ventilation affects the flashover occurrence inside the compartment. Babrauskas suggested a flashover factor which is calculated with the equation (4.2)

$$\dot{Q} = 750A_o\sqrt{H_o}(kW). \quad (4.2)$$

Table 4.14. Summarized fire spread times for living room and bedroom analyses after.

Fire Spread Times(s)					
Living Room			Bedroom		
First Item Spread	Second Item Spread	All Items Ignited	First Item Spread	Second Item Spread	All Items Ignited
129	145	250	65	80	130

Table 4.14 shows the fire spread times for the first, second and all items after the ignition of the fuel. Although Table 4.14 provides fire spread times for both rooms, how heat flux is affected from the ventilation and distance is not known. Therefore, 3 extra analysis were made to find the effects of ventilation factor and distance on heat flux values.

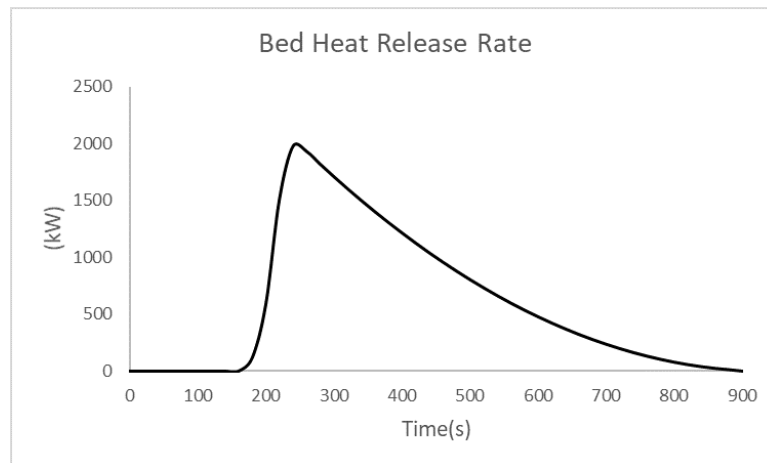


Figure 4.43. Bedroom bed HRR curve.

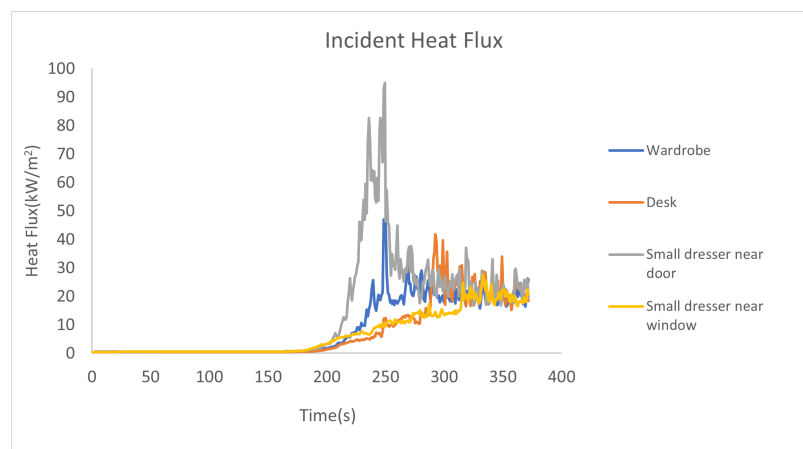


Figure 4.44. Bedroom furniture heat flux graphs.

4.4.1.3. Heat Flux Analyses. 3 different scenarios, scenario A, scenario B and scenario C were examined in heat flux analyses. In all scenarios the HRR curve was same, fire area was same and the width of the corridor was same. In scenario A, there was a 12 m long 4 m width corridor with a single opening which has 2 m width with 2 m height and it is 4.5 m behind the fire source. Fire area is a 2 m x 2 m square which has 5.5 m distance between the closed side of the corridor and 4.5 m distance between the opening. The nearest heat flux device is placed at 0.1 m away from the fire source on the closed side of the corridor and every other heat flux device is placed at 0.5 m spacings. This corridor is given in Figure 4.45. Heat flux values for each distance is shown in Figure 4.46.

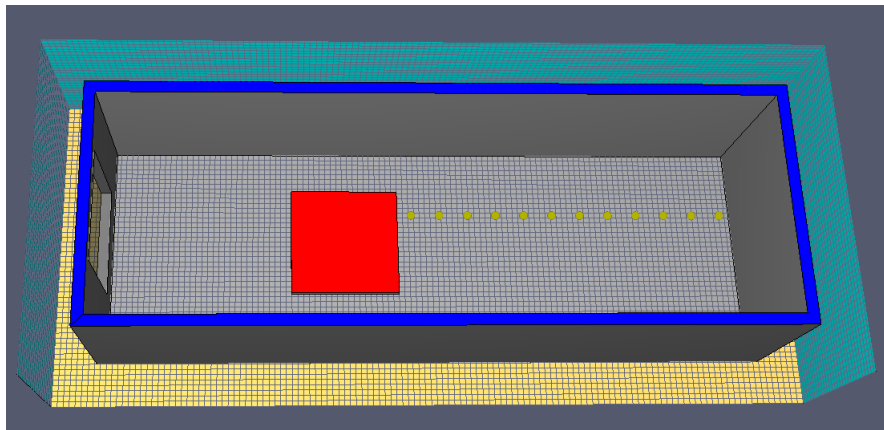


Figure 4.45. Scenario A corridor with one opening.

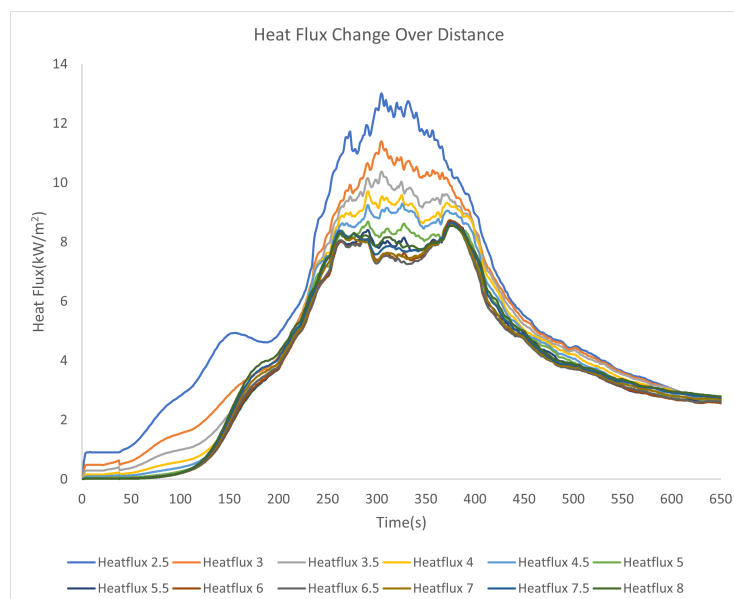


Figure 4.46. Scenario A corridor with one opening heat flux graphs.

In scenario B the same corridor was used in the analysis with 1 opening on both ends this time that has the same width and height and it is shown in Figure 4.47. Heat flux devices are also placed in the same places of scenario A. Heat flux values for each distance is given in Figure 4.48.

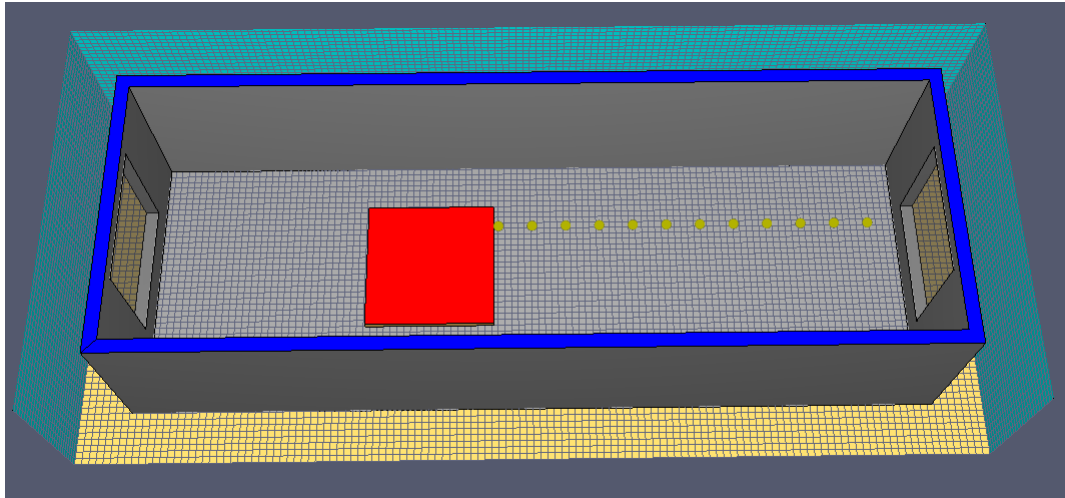


Figure 4.47. Scenario B corridor with two opening.

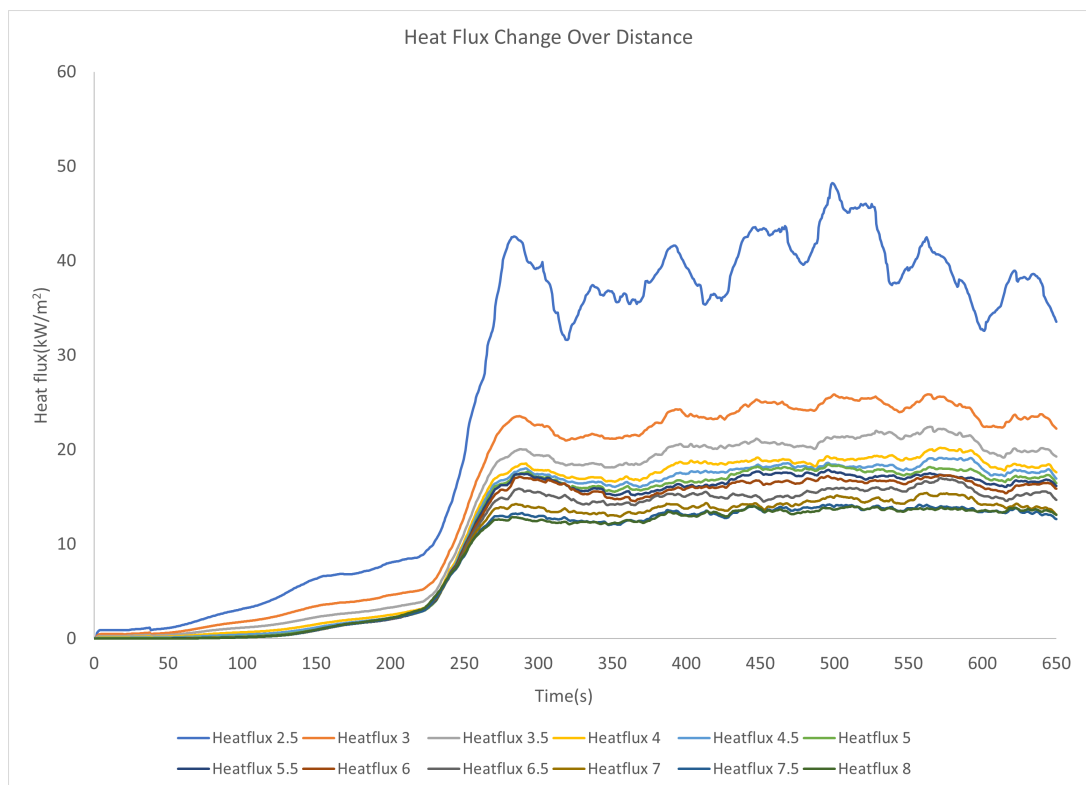


Figure 4.48. Scenario B corridor with two opening heat flux graphs.

In scenario C the corridor length was changed from 12 m to 20 m. In this analysis there was only 1 opening which had same dimensions of the previous scenarios, but this time the fire source had 5.5 m distance between the opening and 12.5 m distance between the closed end of the corridor. Heat flux devices are placed with the same distance integers. This time there are more heat flux devices compared to the first two scenarios due to the corridor being longer. The corridor and heat flux values are given in figure 4.49 and Figure 4.50, respectively.

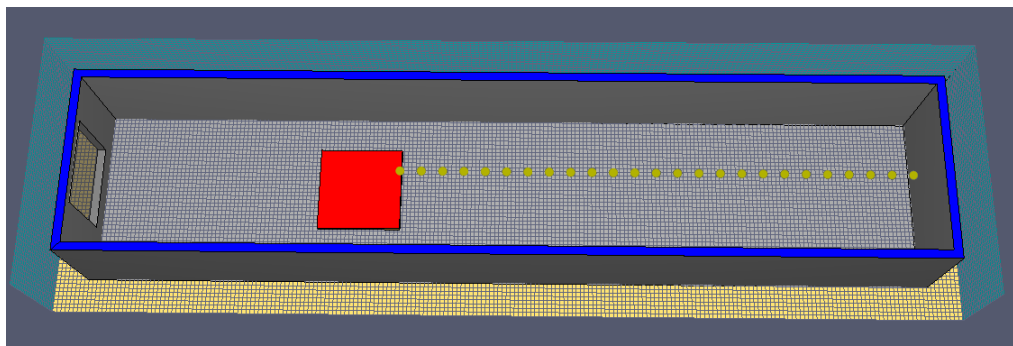


Figure 4.49. Scenario C corridor with longer corridor and one opening.

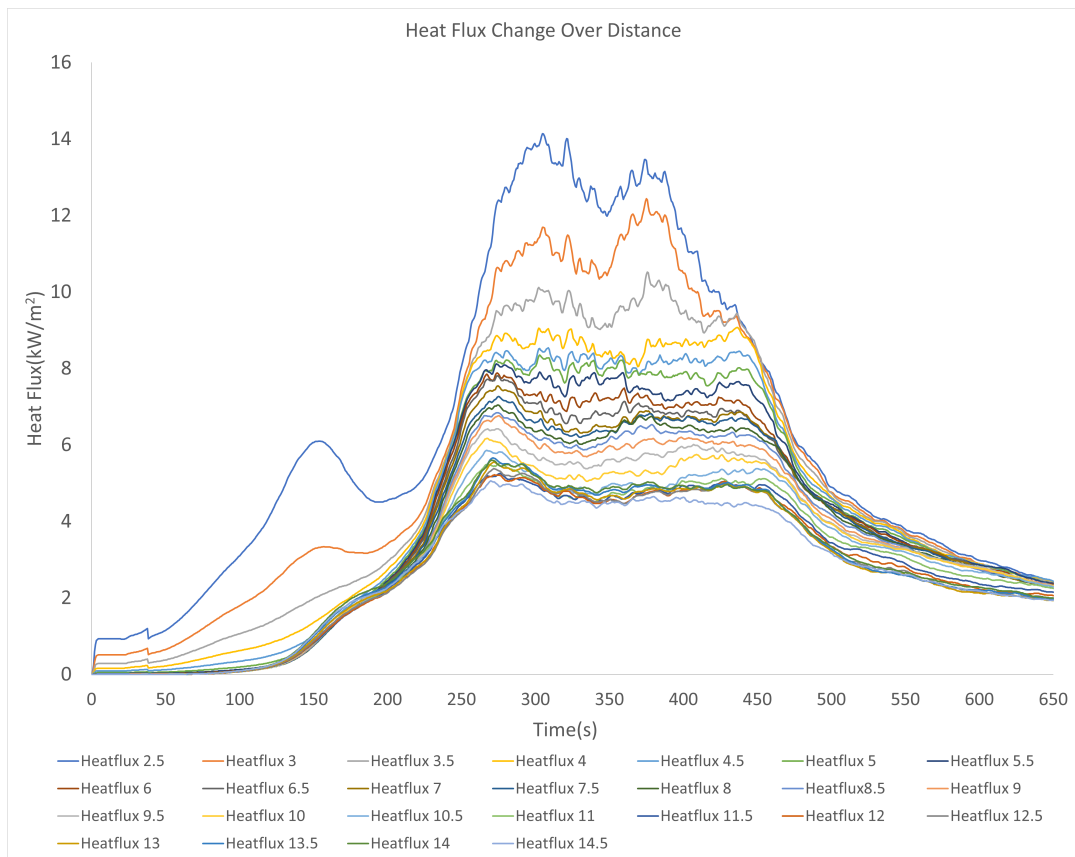


Figure 4.50. Scenario C corridor heat flux graphs.

From the heat flux graphs of these 3 scenarios, it is seen that ventilation factor affects the heat flux value the most. This can be seen from the scenario B where the peak heat flux value read is approximately 50 kW/m^2 , for scenario A peak value is 13 kW/m^2 and for scenario C peak value is 14 kW/m^2 . Table 4.15 shows the ventilation factor for scenario A and scenario B. Table 4.16 shows mean ventilation factors for living room and bedroom. Figure 4.51 shows that as the ventilation factor gets closer to 0.1 maximum room temperature increases and in scenario A and scenario B the only difference is the amount of openings. Ventilation factor is 100% higher in Scenario B which leads to a 400% difference in peak heat flux value. This difference in heat flux is caused by the maximum temperature. Radiation is the main source of heat transfer in compartment fires and when temperature increases, T_g , radiation heat flux increases in T_g^4 .

Table 4.15. Ventilation factors.

Ventilation Factor	
Scenario A	Scenario B
0.0295	0.0589

Table 4.16. Ventilation factors for rooms.

Ventilation Factor	
Living Room <35 m2	Living Room >35 m2
0,084	0,230
Bedroom <20 m2	Bedroom >20 m2
0,105	0,053

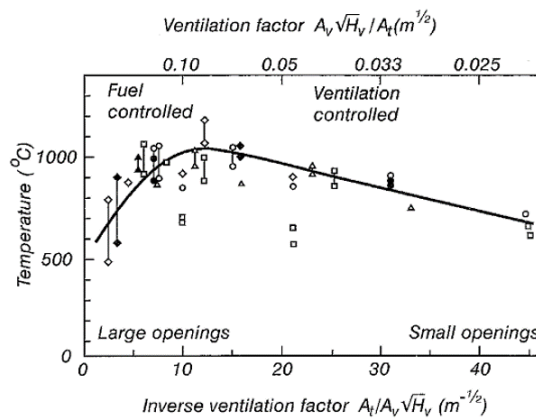


Figure 4.51. Ventilation factor vs temperature.

There is a 30% difference between the nearest two heat flux devices for scenario A and C. The change between the values read from the consecutive heat flux devices go lower after 1.5 m. In scenario A and scenario C, the heat flux devices placed on the end of the corridor has a slightly higher heat flux value compared to the devices that are placed right before them. In all of the 3 scenarios peak heat flux value read from the device drops around 30 – 40% between the 0.1 m and 0.6 m and between the 0.1 m and 1.1 m this change increases to 45 – 50%. This occurs due to the smoke gathering at the end of the corridor which increases the heat flux from the radiation effect. In conclusion; scenario A and scenario B shows that peak heat flux value is exponentially affected by the ventilation factor as ventilation factor gets closer to 0.1. Scenario A and scenario C shows that distance loses its effect after 1 m. Babrauskas' study shows that wood can ignite around 4.3 kW/m^2 [47] in 5 hours. The surveys performed in this study shows that modern dwelling furniture is heavily composed of wood. Therefore, fire spread time estimations will be based around the ignition time of wood. Taking this assumption into consideration; for living room fires furniture should be placed at least 1.5 m away from each other to prevent fire spread as much as possible, but generally this is not possible. Therefore, 1 m distance should be maintained to slow down the fire spread as the peak heat flux value drops around 45%. Assuming that the items are placed with 1 m distance, fire will spread after 5-6 minutes (considering the time for the first items ignition and growth phase) to the second item and the entire room will be ignited after 8-9 minutes of initial ignition. In living room analysis a higher HRR curve was used compared to bedroom, but fire spread was observed 65 seconds later compared to the bedroom. The closest furniture to the fuel was chair with a distance of 1.3 m while the closest item in bedroom analysis was a dresser with a distance of 0.7 m. This also coincides with the findings of scenario A and scenario C analysis. It should also be noted that in these analyses the fuel was assumed to be burning at the beginning so in a real fire scenario there will be more time for the occupants to evacuate.

5. CONCLUSION AND RECOMMENDATIONS

In this thesis, 8 apartments were surveyed. Some of these apartments were physically surveyed and the remaining apartments were surveyed over the floor plan and photographs provided by the home owners. The goal of this thesis was to create an easy methodology to perform fire surveys and find the fire loads and heat release rate curves of the dwellings and rooms inside the dwellings. After the template was created, it was provided to 2 different non-fire engineer person who lived in different apartments to perform the fire load survey inside their houses by following the guide written on the template. It was an overall successful process and the survey was completed with minimal questions. After calculating the fire load density and energy values, matlab application was used to calculate the heat release rate curve. Heat release rate is the most important variable and it is needed by any analysis program to perform fire analysis. Therefore, using the data provided by Kim [37] an application was created. Application provides the HRR curves that are available in NIST website and linearly interpolates them to create the HRR curve for the room. Since the items are not exactly the same and the dimensions are different, energy values do not match and this problem is solved with the vertical scaling in order to find the HRR curve of the room. To understand fire spread speed and fire character, FDS simulations were conducted. Based on the work done in this thesis following conclusions are made.

- In Turkey, as the floor area of the room increases people tend to not increase the furniture proportionally which results in a lower fire load for bigger floor area. This also coincides with Kumar and Rao's findings [6].
- Survey results show that living room and bedroom releases the most energy in a fire scenario. Therefore, it is logical to create a design fire in one of these rooms as a fire engineer in Turkey. Past studies also show that the risk of a fire occurring in a dwelling is highest for the bedroom followed by the living room.
- Height of the building did not have an effect on the energy release or fire load density values. Therefore, fire load surveys performed on a dwelling should not need to be classified based on the buildings height.

- Rooms have a fire load density mean value between 305 MJ/m^2 - 1135 MJ/m^2 which has a high range and this shows that fire analysis should be performed in a compartment instead of using a fixed value for the entire dwelling.
- Volumetric approach was used in this study where the maximum furniture dimension in x, y and z axis are measured and created a rectangular prism. Then the missing part from the prism is deducted to estimate the volume of the furniture. Volumetric approach showed promising results when compared to the item weight, energy released values given by Bwalya [34].
- Distribution graph and the minimum, mean and maximum values provided in this thesis for dwellings show that Eurocodes [33] suggested dwelling fire load density value can be adapted in Turkey to create a design fire.
- Heat release rate application gives curves which have very high peak values due to the assumption of the worst case scenario, 63.55 MW found in living room analysis shown in Figure 4.16, but there is a huge gap in the literature to compare this value. Although this value is higher than the peak value allowed by Eurocode [33], it is quite close to the peak hrr value provided by Heitaniemi [43]. Therefore, HRR application can be used for post-flashover design fires and after modifying the application with ignition times, HRR application will result in accurate pre-flashover design fire curves.
- In a ventilation controlled fire, fire spread to a furniture that has a distance of 0.5 m to the fire source is affected by the ventilation factor more than the distance.
- Furniture should be placed at least 1.5 m away to prevent fire spread. To slow it down, the minimum spacing is 1 m.

For further studies, more fire load surveys should be performed in dwellings to increase the sample size. This way the minimum, mean and maximum values will be more accurate. Void ratio assumption can also be improved by finding an approximate void ratio for the most common items such as sofas, chairs, tables and desks. This can be done by finding the mass of the item and trying to match the mass with changing the void ratio.

There is a lot of room for improvement of the Hrr_calculator application. Adding an ignition time input will increase the accuracy of the application and this way the room fire can be investigated in different time intervals other than just post-flashover state. As the application uses combination method to find the heat release rate curve, sometimes the peak values stack and it results in an unrealistic peak value. More furniture items can also be added to the app such as table, desk, carpets which will also improve the accuracy of the application. With these improvements to the application, it is expected that vertical scaling will not create high peak values.

To find more accurate fire spread time and speed, more FDS analysis should be performed. During these analyses furniture can be placed in different distance intervals, opening factor can be changed or the initial ignition can be performed with a small burner to find the most accurate fire spread results.

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APPENDIX A: ADDITIONAL INFORMATION FOR CALCULATIONS

A.1. Building A 3+1

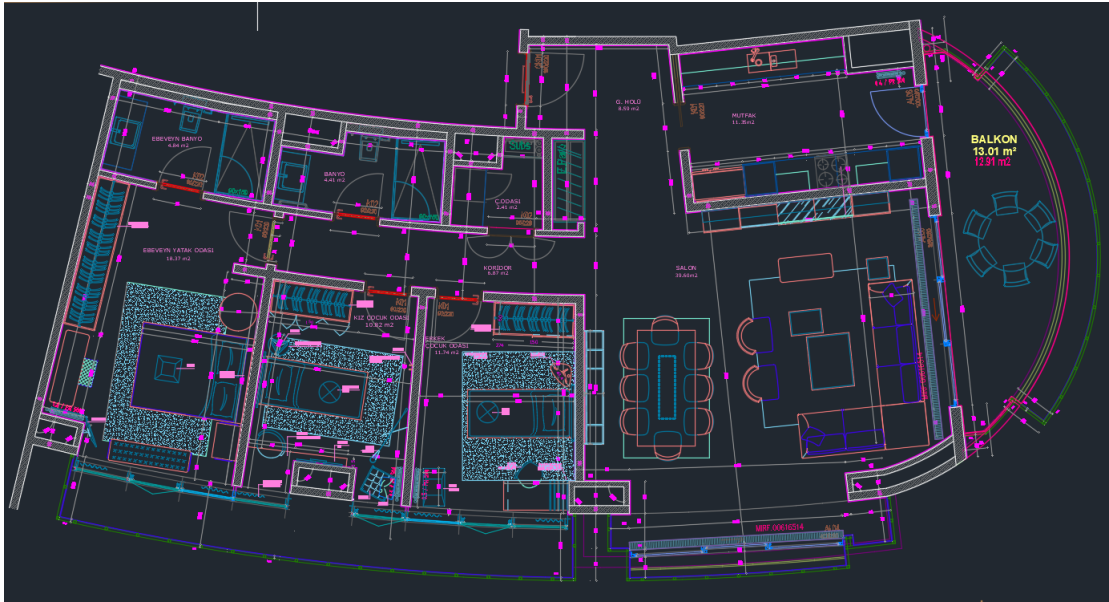


Figure A.1. Building A 3+1 floor plan.

TOTAL FIRE LOAD										
Living Room	DIMENSIONS(x,y,z)[cm]	VOID RATIO	VOLUME(m ³)	MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED	
Lsofa	240 250 70	0,8	0,84	Polyurethane foam	0,5	20,218	190	1	3226,79	
Carpet1	500 300 0,5	0	0,075	Acrylics	0,5	36,23	1112,5	1	3022,94	
Carpet2	400 250 0,5	0	0,05	Acrylics	0,5	36,23	1112,5	1	2015,29	
TV	140 5 40	0	0,028	Glass	0,7	15,45	4572	1	1977,85	
TV unit	350 40 150	0,7	0,63	Plywood	1	18,05	544,6	1	6192,92	
6xChair	50 40 100	0,8	0,04	Wood-Heavy Wood	0,3	21,477	242,8	8	1668,68	
6xCurtain	5 120 250	0,45	0,0957	Cotton	1	18	80	6	826,85	
Dining table	250 80 90	0,95	0,09	Wood-Heavy Wood	1	18,59	680	1	1137,71	
Cabinet	220 40 30	0,3	0,1848	Wood-Heavy Wood	1	18,59	680	1	2336,09	
Wardrobe	100 50 200	0,7	0,3	Plywood	1	18,05	544,6	1	2949,01	
FLOOR FIRE LOAD										
Laminate	2400 200 1	0	0,48	Plywood	1	18,05	544,6	1	4718,4144	
TOTAL FIRE LOAD										
Kids Room 1	DIMENSIONS(x,y,z)[cm]	VOID RATIO	VOLUME(m ³)	MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED	
Wardrobe	150 60 250	0,9	0,261	Plywood	1	18,05	544,6	1	2565,64	
Carpet	210 240 0,5	0	0,0252	Acrylics	0,5	36,23	1112,5	1	1015,71	
Bed	200 90 50	0	0,9	Latex Foam	0,6	31,619	140,6	1	4001,07	
Sidetable	40 40 65	0,8	0,0208	Plywood	1	18,05	544,6	1	204,46	
Desk	87 77 5	0	0,033495	Plywood	1	18,05	544,6	1	329,26	
Desk continued	99 15 5	0	0,007425	Plywood	1	18,05	544,6	1	72,99	
Floor Pouf	48 48 60	0	0,13824	Cotton	0,8	17,4	84	1	202,05	
FLOOR FIRE LOAD										
Laminate	577,5 200 1	0	0,1155	Plywood	1	18,05	544,6	1	1135,368465	

Figure A.2. 3+1 Living room and extra room 1.

TOTAL FIRE LOAD															
Kids Room 2	DIMENSIONS[k,y,z][cm]			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE			FRACTIONS			ENERGY RELEASED			
	150	60	290			0,9	0,261	Plywood	Fabric	LPG	1		0	0	DENSITY[kg/m ³]
Wardrobe	240	210	0,5	0	0,0252	Acrylics	Polystyrene	LPG	0,5	0,5	0	18,05	544,6	1	2565,63783
Carpet	200	90	55	0	0,99	Latex Foam	Cotton	Wood-Heavy Wood	0,6	0,3	0,1	36,23	1112,5	1	1015,70805
Desk	120	60	60	0,9	0,432	Plywood	LPG	LPG	1	0	0	18,05	544,6	1	4401,175086
Bookshelf	70	40	100	0,95	0,014	Plywood	Stainless Steel	LPG	1	0	0	18,05	544,6	1	424,657296
FLOOR FIRE LOAD															
Laminate	529,5	200	1	0	0,1059	Plywood	Glass	LPG	1	0	0	18,05	544,6	1	1041,000177
TOTAL FIRE LOAD															
Kitchen	DIMENSIONS[k,y,z][cm]			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE			FRACTIONS			ENERGY RELEASED			
	60	60	40			0,8	0,0288	Plywood	Fabric	LPG	1		0	0	DENSITY[kg/m ³]
Cupboards	90	61	50	0,9	0,02745	Stainless Steel	Glass	LPG	0	1	0	18,05	544,6	9	2547,943776
Oven	577,5	200	1	0	0,1155	Ceramic	Glass	LPG	1	0	0	21	2700	1	1556,415
FLOOR FIRE LOAD															
TOTAL FIRE LOAD															
Bedroom	DIMENSIONS[k,y,z][cm]			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE			FRACTIONS			ENERGY RELEASED			
	70	160	65			0,6	0,1176	Plywood	Fabric	LPG <td>1</td> <td>0</td> <td>0</td> <th>DENSITY[kg/m³]</th> <th>Number of Items</th>	1		0	0	DENSITY[kg/m ³]
Sidetable	210	160	65	0	2,184	Latex Foam	Cotton	Wood-Heavy Wood	0,6	0,3	0,1	18,05	544,6	2	2312,023056
Bed	300	195	0,5	0	0,02925	Acrylics	Polystyrene	LPG	0,5	0,5	0	31,619	140,6	1	9709,255878
Carpet	282	60	290	0,9	0,49068	Plywood	LPG	LPG	1	0	0	18,05	544,6	1	1178,946844
Wardrobe	50	40	45	0	0,09	Cotton	Fabric	LPG	0,7	0,3	0	17,1	86	1	4823,39912
Floor pouf	140	45	80	0,6	0,2016	Plywood	LPG	LPG	1	0	0	18,05	544,6	1	132,354
Desk	906,5	200	1	0	0,1813	Plywood	Glass	LPG	1	0	0	18,05	544,6	1	1981,734048
Laminate	906,5	200	1	0	0,1813	Plywood	Glass	LPG	1	0	0	18,05	544,6	1	1782,184439

Figure A.3. 3+1 Extra room 2, kitchen and bedroom.

TOTAL FIRE LOAD										
Living Room 2	DIMENSIONS(k,y,z)[cm]	VOID RATIO	VOLUME(m ³)	MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED	
L sofa	200 65 50	0,75	0,1625	Polyurethane foam	0,5	19,618	174,8	1	557,24929	
Desk	120 60 60	0,8	0,0864	Plywood	1	18,05	544,6	2	1698,629184	
Cabinet	150 25 210	0,8	0,1575	Plywood	1	18,05	544,6	2	3096,45945	
Carpet	300 150 1	0	0,045	Polyester	0,5	26,5	673,25	1	802,850625	
Laminate	1000 200 1,4	0	0,28	Plywood	1	18,05	544,6	1	2752,4084	
FLOOR FIRE LOAD										
TOTAL FIRE LOAD										
Bedroom	DIMENSIONS(k,y,z)[cm]	VOID RATIO	VOLUME(m ³)	MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED	
Bed	200 210 65	0	2,73	Latex Foam	0,6	31,619	140,6	1	12136,57372	
Wardrobe	280 55 210	0,9	0,3234	Plywood	1	18,05	544,6	1	3179,031702	
Side table	50 45 60	0,8	0,027	Plywood	1	18,05	544,6	3	796,23243	
Carpet	200 125 1	0	0,025	Polyester	0,5	26,5	673,25	1	446,028125	
			0	Cotton		0	0	0	0	
			0	Plywood		0	0	0	0	
Laminate	1750 200 1,4	0	0,49	Plywood	1	18,05	544,6	1	4816,7147	
FLOOR FIRE LOAD										
TOTAL FIRE LOAD										
Kitchen	DIMENSIONS(k,y,z)[cm]	VOID RATIO	VOLUME(m ³)	MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED	
Table	120 65 60	0,9	0,0468	Glass	1	21	2700	1	2653,56	
Cupboard	50 50 100	0,9	0,025	Plywood	1	18,05	544,6	8	1966,01	
Oven	90 5 60	0	0,027	Glass	1	21	2700	1	1530,90	
Carpet	150 100 1	0	0,015	Polyester	0,5	26,5	673,25	1	267,62	
Chair	42 45 65	0,75	0,0307125	Polyurethane foam	0,6	21,118	184,8	4	479,44	
Ceramic	1250 200 1	0	0,25	Ceramic	1	0	3000	1	0	

Figure A.5. 3+1 Extra room 2, kitchen and bedroom.

A.3. Apartment B 3+1

Living Room	DIMENSIONS(k,x,y,z)(cm)			VOID RATIO	VOLUME(m ³)	TOTAL FIRE LOAD		CALORIFIC VALUE[MJ/kg]	DENSITY(Kg/m ³)	Number of Items	ENERGY RELEASED
	MATERIAL TYPE	FRACTIONS	FLOOR FIRE LOAD								
Table	210	100	80	0.85	0.084	Fabric	1	18.59	680	1	1061.86
Sofa 1	150	80	85	0.55	0.351	Wood-Heavy Wood	0.5	20.218	190	1	1348.34
Sofa 2	200	80	85	0.55	0.468	Polyurethane foam	0.5	20.218	190	1	1797.78
Armchair	80	60	85	0.55	0.2052	Fabric	0.5	20.218	190	2	1576.52
Cabinet	105	90	200	0.9	0.189	Plywood	1	18.05	544.6	1	1857.88
Curtain	160	1	285	0	0.0472	Cotton	1	18	80	4	271.87
Carpet 1	300	300	1	0	0.09	Polyurethane foam	0.5	26.5	672.25	1	1605.70
Carpet 2	200	200	1	0	0.04	Wood	0.5	26.5	672.25	1	713.65
Tv unit	110	45	50	0.8	0.0495	Polyester	1	18.05	544.6	1	486.59
Chair	41	45	87	0.7	0.0481545	Plywood	0.6	21.477	242.8	8	2008.86
Solid Hardwood	1500	200	1.4	0	0.42	Wood-Heavy Wood	1	18.59	680	1	5309.304
Kids Room 1	DIMENSIONS(k,x,y,z)(cm)			VOID RATIO	VOLUME(m ³)	TOTAL FIRE LOAD		CALORIFIC VALUE[MJ/kg]	DENSITY(Kg/m ³)	Number of Items	ENERGY RELEASED
Bed	100	205	40			0.3	0.574				
Study Table	117	64	77	0.6	0.230504	Plywood	1	18.05	544.6	1	2257.10
Chair	46	42	89	0.8	0.0343896	Polyurethane foam	0.6	21.477	242.8	2	358.66
Curtain	160	1	200	0	0.032	Cotton	1	18	80	2	92.16
Wardrobe	180	70	200	0.9	0.252	Plywood	1	18.05	544.6	1	2477.17
Desk	100	60	70	0.6	0.168	Plywood	1	18.05	544.6	1	1651.45
Solid Hardwood	850	200	1.4	0	0.238	Wood-Heavy Wood	1	18.59	680	1	3006.6056

Figure A.6. 3+1 Living room and extra room 1.

TOTAL FIRE LOAD														
Kids Room 2	DIMENSIONS(x,y,z)(cm)			VOID RATIO	VOLUME(m ³)	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED
Bed	100	250	38	0,3	0,665	Latex Foam	Wood-Heavy Wood	0,6	0,3	0,1	31,619	140,6	1	2956,344881
Study Table	117	64	75	0,6	0,22464	Plywood	Polystyrene	1	0	0	18,05	544,6	1	2208,217939
Sidetable	58	40	40	0,8	0,18956	Plywood	Wood-Heavy Wood	1	0	0	18,05	544,6	1	182,4453568
Wardrobe	150	70	200	0,9	0,21	Plywood	LPG	1	0	0	18,05	544,6	1	2064,3063
Curtain	46	42	89	0	0,171948	Cotton	LPG	1	0	0	18	80	1	247,60512
Chair	160	1	200	0,55	0,0144	Polyurethane foam	Wood-Heavy Wood	0,6	0,1	0,3	21,477	242,8	1	75,09046464
FLOOR FIRE LOAD														
Solid Hardwood	600	200	1,4	0	0,168	Wood-Heavy Wood	Glass	1	0	0	18,59	680	1	2123,7216

TOTAL FIRE LOAD														
Bedroom	DIMENSIONS(x,y,z)(cm)			VOID RATIO	VOLUME(m ³)	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED
Bed	210	205	40	0,2	1,3776	Latex Foam	Wood-Heavy Wood	0,6	0,3	0,1	31,619	140,6	1	6124,301817
Sidetable	58	40	44	0,8	0,020416	Plywood	Wood-Heavy Wood	1	0	0	18,05	544,6	2	401,379785
Wardrobe	360	80	200	0,9	0,576	Plywood	Polystyrene	1	0	0	18,05	544,6	1	5662,09728
Curtain	160	1	200	0	0,032	Cotton	LPG	1	0	0	18	80	1	46,08
					0	Cotton	Fabric				0	0		0
					0	Plywood	LPG				0	0		0
FLOOR FIRE LOAD														
Solid Hardwood	1000	200	1,4	0	0,28	Wood-Heavy Wood	Glass	1	0	0	18,59	680	1	3539,556

TOTAL FIRE LOAD														
Kitchen	DIMENSIONS(x,y,z)(cm)			VOID RATIO	VOLUME(m ³)	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED
Chair	41	45	87	0,55	0,0723175	Polyurethane foam	Wood-Heavy Wood	0,6	0,1	0,3	21,477	242,8	4	1506,643241
Dining Table	50	105	80	0,9	0,042	Plywood	LPG	1	0	0	18,05	544,6	1	412,86126
Cupboard	40	40	40	0,8	0,0128	Plywood	LPG	1	0	0	18,05	544,6	4	503,297536
Oven	90	5	45	0	0,02025	Stainless Steel	LPG	0	1	0	21	2700	1	1148,175
FLOOR FIRE LOAD														
Ceramic	750	200	1	0	0,15	Ceramic	Glass	1	0	0	0	3000	1	0

Figure A.7. 3+1 Extra room 2, kitchen and bedroom.

TOTAL FIRE LOAD														
Kids Room 2	DIMENSIONS(x,y,z)[cm]			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE[MJ/kg]	DENSITY[kg/m ³]	Number of Items	ENERGY RELEASED
	185	60	225			0.9	0.24975	Plywood	Fabric	1				
Wardrobe 1 Bed	125	190	65	0.3	1,080625	Latex Foam	Cotton	0,6	0,2	0,2	31,678	200,6	1	6866,95
Side Table	57	45	53	0.7	0,0407835	Plywood	Cotton	1	0	0	18,05	544,6	1	400,90
Small Dresser	90	50	90	0.7	0,1215	Plywood	LPG	1	0	0	18,05	544,6	1	1194,35
Study Desk	130	60	200	0.8	0,312	Plywood	LPG	1	0	0	18,05	544,6	1	3066,97
Curain	100	1	280	0	0,028	Cotton	LPG	1	0	0	18	80	4	161,28
Carpet	215	140	0,5	0	0,01505	Polyster	Wool	0,5	0,5	0	26,5	673,25	1	268,51
Wardrobe 2	70	50	200	0.9	0,07	Plywood	Stainless Steel	1	0	0	18,05	544,6	1	688,10
FLOOR FIRE LOAD														
Laminate	752	200	1	0	0,1504	Plywood	Glass	1	0	0	18,05	544,6	1	1478,44
TOTAL FIRE LOAD														
Kitchen	DIMENSIONS(x,y,z)[cm]			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE[MJ/kg]	DENSITY[kg/m ³]	Number of Items	ENERGY RELEASED
	50	35	70			0.8	0,0245	Plywood	Fabric	1				
Cupboard	60	2	60	0	0,0072	Stainless Steel	Glass	0	1	0	21	2700	2	816,48
FLOOR FIRE LOAD														
Ceramic	636	200	1	0	0,1272	Plywood	Glass	1	0	0	18,05	544,6	1	1250,38
TOTAL FIRE LOAD														
Bedroom	DIMENSIONS(x,y,z)[cm]			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE[MJ/kg]	DENSITY[kg/m ³]	Number of Items	ENERGY RELEASED
	90	50	185			0.9	0,08325	Plywood	Fabric	1				
Wardrobe 2	210	60	210	0.9	0,2646	Plywood	Cotton	1	0	0	18,05	544,6	1	2601,03
Wardrobe 3	100	45	140	0.9	0,063	Plywood	Polystyrene	1	0	0	18,05	544,6	1	619,29
Wardrobe 4	130	40	200	0.9	0,104	Plywood	LPG	1	0	0	18,05	544,6	1	1022,32
Bed	200	160	60	0.3	1,344	Latex Foam	Cotton	0,6	0,2	0,2	31,678	200,6	1	8540,59
TV	70	5	55	0	0,01925	Glass	Copper	0,8	0,2	0	17,3	3948	1	1314,78
Carpet	210	145	0,5	0	0,015225	Polyster	Wool	0,5	0,5	0	26,5	673,25	1	271,63
Curain	150	1	280	0	0,042	Cotton	LPG	1	0	0	18	80	4	241,92
Side table	50	45	50	0.7	0,03375	Plywood	LPG	1	0	0	18,05	544,6	2	663,53
FLOOR FIRE LOAD														
Laminate	654	300	1	0	0,1962	Plywood	Glass	1	0	0	18,05	544,6	1	1928,65

Figure A.9. 3+1 Extra room 2, kitchen and bedroom.

TOTAL FIRE LOAD														
Bedroom	DIMENSIONS(x,y,z)(cm)			VOID RATIO	VOLUME(m ³)	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE(MJ/kg)	DENSITY(kg/m ³)	Number of Items	ENERGY RELEASED
	40	40	60			Plywood	Fabric	1	0	0				
Sidetable	210	60	65	0	0,0384	Latex Foam	Cotton	0,6	0,3	0,1	18,05	544,6	2	754,946304
Bed	250	250	0,5	0	2,184	Acrylics	Polystyrene	0,5	0,5	0	31,619	140,6	1	9709,258978
Carpet	300	60	290	0,9	0,03125	Plywood	LPG	1	0	0	36,23	1112,5	1	1259,558594
Wardrobe	70	65	80	0,45	0,2002	Polyurethane foam	Fabric	0,5	0,3	0,2	18,05	544,6	1	5131,27566
Sofa	50	125	70	0,7	0,13125	Plywood	LPG	1	0	0	20,218	190	1	769,05
Desk	50	40	60	0,8	0,024	Wood-Heavy Wood	Polyurethane foam	0,3	0,6	0,1	18,05	544,6	1	1290,19
Chair	880,5	200	1	0	0,1761	Plywood	Glass	1	0	0	21,477	242,8	1	125,15
Laminate	60	60	40	0,8	0,0288	Plywood	Fabric	1	0	0	18,05	544,6	1	1731,068283
Cupboardx9	90	61	5	0	0,02745	Stainless Steel	Glass	0	1	0	21	2700	1	1556,415
Oven	595	200	1	0	0,119	Ceramic	Glass	1	0	0	0	3000	1	0
Ceramic	FLOOR FIRE LOAD													
TOTAL FIRE LOAD														
Kitchen	60	60	40	0,8	0,0288	Plywood	Fabric	1	0	0	18,05	544,6	9	2547,943776
Oven	90	61	5	0	0,02745	Stainless Steel	Glass	0	1	0	21	2700	1	1556,415
Ceramic	595	200	1	0	0,119	Ceramic	Glass	1	0	0	0	3000	1	0

Figure A.11. 2+1 Bedroom and kitchen.

A.6. Building B 2+1

TOTAL FIRE LOAD												
Room	DIMENSIONS (x,y,z)(cm)	VOID RATIO	VOLUME (m ³)	MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE (MJ/kg)	DENSITY (kg/m ³)	Number of Items	ENERGY RELEASED			
Living Room	250 85 70	0.4	0.823	Polyurethane foam	0.6	20,759	126.8	1	2348.28			
Sofa	100 100 40	0.6	0.18	Fabric	1	18.05	544.6	1	1575.80			
Coffee Table	125 45 70	0.5	0.136875	Plywood	1	18.05	544.6	1	1545.84			
TV unit	125 45 70	0.5	0.136875	Polyurethane foam	0.9	18.05	544.6	1	1575.80			
Chair	50 50 40	0	0.1	Wood-Heavy Wood	0.1	18.05	544.6	1	1545.84			
Dining Table	200 80 10	0	0.16	Wood-Heavy Wood	1	18.05	544.6	1	1575.80			
Bench	40 118 5	0	0.0238	Plywood	1	18.05	544.6	2	463.88			
Cabinet	125 45 70	0.6	0.07975	Wood-Heavy Wood	1	18.59	660	1	995.49			
Chair	74 74 70	0.65	0.134162	Polyurethane foam	0.6	20,759	126.8	2	706.29			
Carpet	280 280 0.5	0.3	0.02744	Acry/CI	0.5	36.23	1112.5	1	1105.99			
Curtain	380 1 280	0	0.1064	Cotton	1	18	80	1	133.22			
Curtain 2	300 1 280	0	0.084	Cotton	1	18	80	1	120.95			
			0	Polyurethane foam		0	0		0.00			
			0	Fabric		0	0		0.00			
			0	Wood-Heavy Wood		0	0		0.00			
			0	Plywood		0	0		0.00			
Laminar	580 470 1	0	0.2726	Plywood	1	18.05	544.6	1	2675.86178			
				Glass								
				EPS								
				Glass								
FLOOR FIRE LOAD												
Room	DIMENSIONS (x,y,z)(cm)	VOID RATIO	VOLUME (m ³)	MATERIAL TYPE	FRACTIONS	CALORIFIC VALUE (MJ/kg)	DENSITY (kg/m ³)	Number of Items	ENERGY RELEASED			
Kid Room 1	204 84 30	0.5	0.28764	Ureth Foam	0.6	31.678	200.6	1	1827.84			
Bed	60 42 20	0.8	0.01008	Plywood	1	18.05	544.6	1	99.09			
Side table	150 60 270	0.95	0.1213	Plywood	1	18.05	544.6	1	1184.13			
Wardrobe	85 60 40	0.6	0.0332	Plywood	1	18.05	544.6	1	245.02			
Small dresser	170 240 0.5	0	0.0204	Plywood	1	18.05	544.6	1	245.02			
Chair	50 50 40	0	0.01	Wood-Heavy Wood	0.1	18.05	544.6	1	1545.84			
Carpet	380 1 280	0	0.084	Acry/CI	0.5	36.23	1112.5	1	822.24			
Laminar	357 280 1	0	0.09996	Plywood	1	18.05	544.6	1	982.6077988			
				Glass								
				EPS								
				Glass								

Figure A.12. 2+1 Living room and extra room 1.

TOTAL FIRE LOAD														
Bedroom	DIMENSIONS[X,Y,Z](cm)			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE[MJ/kg]	DENSITY[kg/m ³]	Number of Items	ENERGY RELEASED
	210	170	50			0,4	Latex Foam	Cotton	0,6	0,2				
Bed	54	54	40	0,6	1,071	Plywood	Wood-Heavy Wood	1	0	0	31,678	200,6	1	6805,783883
Side tables	100	30	50	0,6	0,046656	Plywood	Wood-Heavy Wood	1	0	0	18,05	544,6	2	917,2597594
Small Dresser	137	40	60	0,98	0,006576	Glass	LPG	1	0	0	18,05	544,6	1	589,9018
Table	220	60	280	0,9	0,3696	Plywood	LPG	1	0	0	21	2700	1	372,8592
Wardrobe	100	30	20	0,3	0,042	Cotton	Fabric	0,8	0,2	0	18,05	544,6	2	7266,358176
Floor pouf	220	3	280	0	0,1848	Cotton	Polyurethane foam	1	0	0	17,4	84	1	61,39
Curtain	358	474,86	1	0	0,16999988	Plywood	Fabric	1	0	0	18	80	1	266,11
Laminate	358	474,86	1	0	0,16999988	Plywood	FLOOR FIRE LOAD	1	0	0	18,05	544,6	1	1671,10392
TOTAL FIRE LOAD														
Kitchen	DIMENSIONS[X,Y,Z](cm)			VOID RATIO	VOLUME[m ³]	MATERIAL TYPE		FRACTIONS			CALORIFIC VALUE[MJ/kg]	DENSITY[kg/m ³]	Number of Items	ENERGY RELEASED
	150	35	15			0	Fabric <th>Fabric <th>1</th> <th>0</th> <th>0</th> </th>	Fabric <th>1</th> <th>0</th> <th>0</th>	1	0				
Desk	90	60	60	0,88	0,00648	Glass	LPG	1	0	0	18,05	544,6	1	774,1148625
Oven	60	60	50	0,8	0,036	Plywood	Fabric	1	0	0	21	2700	2	734,832
Cupboard	609	200	1	0	0,1218	Ceramic	Glass	1	0	0	18,05	544,6	6	2123,28648
Ceramic	609	200	1	0	0,1218	Ceramic	FLOOR FIRE LOAD	1	0	0	0	3000	1	0

Figure A.13. 2+1 Bedroom and kitchen.