UNIVERSITI PUTRA MALAYSIA

DETERMINATION OF ADDITIONAL ACCESS DOOR LOCATION FOR A TRADITIONAL HOUSE IN LIBYA TO REDUCE EVACUATION TIME

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By

MUFIDA IBRAHIM MKHAREM

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

July 2019

DEDICATION

I would like to dedicate this thesis to my beloved husband, family and all my supervisors and lecturers in the Department of Mechanical and Manufacturing engineering. Their guidance and relentless support have been a great inspiration to the realization of this project.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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Chairman : Professor Nor Mariah Adam, PhD PE
Faculty : Engineering

Fire incidents involving traditional houses in Libya between the years 2011 to 2015 accounted for 3,562 cases, claimed 436 lives and 614 injuries. These are linked to the types of roofing materials used in the building of the traditional Libya houses. Estimated losses of USD 2,217,500 were associated with the types of roofing materials used in such houses which are mainly from the date Palm Tree (DPT) parts, the harsh adverse weather impact, high fire load of consumables, poor fire-safety awareness and knowledge amongst the occupants. In order to minimize these negative impact on the house occupants based on some structural limitation of the existing emergency doors access and inadequate corridor width of 1 meter. This research study focuses on the determination of additional new door location on the existing traditional Libya house for the reduction of safe egress evacuation time in case of house fire eruption. This research study focused first on four-laboratory thermal characterization test on applied DPT building materials samples. Secondly, the mimic fire simulation modelling of a prototype traditional Libya house with the adoption of appropriate validated experimental data as inputs for the fire eruption study using Pyrosim Fire Simulator (PFS) Software. This mimic fire eruption model was produced close to reality with varying fire source Heat Release Rate per Unit Area (HRRPUA), and control air ventilation impact. Thirdly, egress safe evacuation analysis studies of 5, 10 and 15 occupants at different location of the same Pyrosim building fire model executed in Pathfinder Software (PS) with the new determined door location for improved egress evacuation time reduction. The roofing material characterization result produced the highest fire load calorific value contribution of 4,107.2 cal/g, thermal conductivity value of 0.189 W/m ^{0}C and heat diffusivity rate value of 0.128 mm/s as adopted input parameters for the mimic Pyrosim simulation. The fire simulation sources from children bedroom indicated that the room temperature increases with increase in the HRRPUA from available fire load contents, with highest measured values of 896 ^{0}C for winter and 859 ^{0}C for summer season open door fire, based on the external air support for enhanced rate of fire growth, and heat spread. The negative impact of

occupant density variation (10 – 15 persons) is eliminated with the same improved egress evacuation time of 7.6 s and 14.4 s for running and walking speed respective across all house densities above 5 persons with the additional new door location. Hence, produced an improved saved evacuation time margin of 1.6 s and 2.6 s for walking and running speed respectively. This is due to the reduction in the traveling distance covered with the new additional door location during egress safe evacuation. The analyzed questionnaire result indicated that larger numbers of Libyan house occupant have poor awareness of fire safety activities and limited knowledge on safe egress evacuation in case of unwanted fire eruption, despite good knowledge of fire hazards and consequences. This study has divulged detail insight into the fire accident in traditional Libya houses as a base for future in-depth study, and eliminate the negative impact of long evacuation time due to inadequate access provision for egress safe evacuation. The needed training requirement is also provided from the analyzed questionnaire for adequate training of all occupant appropriately.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENETAPAN LOKASI PINTU TAMBAHAN UNTUK RUMAH TRADISIONAL DI LIBYA UNTUK MENGURANGKAN MASA PEMINDAHAN

Oleh

MUFIDA IBRAHIM MKHAREM

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Insiden kebakaran melibatkan rumah-rumah tradisional di Libya di antara tahun 2011 dan 2015 yang berjumlah 3,562 kes, telah meragut 436 nyawa dan menyebabkan 614 orang lagi tercedera. Ini dikaitkan dengan jenis bahan atap yang digunakan dalam bangunan rumah-rumah tradisional di Libya. Anggaran kerugian berjumlah USD 2,217,500 dikaitkan dengan beberapa faktor seperti jenis atap yang digunakan di rumah-rumah tersebut iaitu biasanya dari bahagian kelapa sawit, impak cuaca yang melampau, kehadiran bahan mudah terbakar, kurangnya kesedaran kepada pencegahan kebakaran dan kurangnya pengetahuan dalam kalangan penduduk. Ini bertujuan mengurangkan impak negatif ke atas penduduk rumah berdasarkan beberapa batasan struktur akses pintu kecemasan sedia ada dan lebar koridor yang tidak mencukupi, iaitu berukuran 1 meter. Kajian ini memfokus kepada penetapan lokasi pintu tambahan yang baru kepada rumah tradisional Libya sedia ada dalam mengurangkan msa pemindahan keluar yang selamat sekiranya berlaku letupan atau kebakaran di rumah. Pertama, kajian ini menjurus kepada ujian empat pencirian haba makmal ke atas sampel bahan bangunan DPT yang digunakan. Kedua, pemodelan simulasi kebakaran prototaip rumah tradisional Libya dengan penggunaan data eksperimen yang sah dan sesuai sebagai input kajian letupan kebakaran menggunakan Perisian Pyrosim Fire Simulator (PFS). Model letupan kebakaran ini dihasilkan hampir menyamai keadaan sebenar dengan pelbagai sumber api Kadar Pembebasan Haba untuk setiap kawasan (HRRPUA), dan impak kitaran udara kawalan. Ketiga, kajian analisa pemindahan keluar yang selamat ke atas 5, 10 dan 15 orang penduduk di lokasi berbeza model kebakaran bangunan Pyrosim yang dijalankan menggunakan Perisian Pathfinder (PS) dengan lokasi pintu yang baru ditetapkan untuk memperbaiki pengurangan masa pemindahan jalan keluar (egress). Keputusan pencirian bahan atap menghasilkan nilai kalori beban kebakaran tertinggi yang menyumbang 4,107.2 cal/g, nilai konduktiviti haba 0.189 W/m 0C dan nilai penyebaran haba 0.128 mm/s sebagai parameter input yang digunakan dalam menyamai simulasi Pyrosim. Sumber simulasi

kebakaran dari bilik tidur kanak-kanak menunjukkan bahawa suhu bilik meningkat dengan peningkatan HRRPUA dari isi kandungan beban kebakaran yang sedia ada, dengan nilai tertinggi 896 0C untuk musim sejuk dan 859 0C untuk musim panas di kawasan terbuka, berdasarkan sokongan udara luar untuk meningkatkan kadar penyebaran kebakaran, dan penyebaran haba. Impak negatif variasi kepadatan penduduk (10 – 15 orang) dibuang dengan masa pemindahan egress yang semakin baik iaitu 7.6 s dan 14.4 s untuk kelajuan berlari dan berjalan dalam kalangan semua kepadatan rumah dengan isi lebih 5 orang dengan lokasi pintu tambahan yang baru. Oleh itu, ini menghasilkan masa pemindahan yang semakin baik dan menjimatkan iaitu 1.6 s dan 2.6 s untuk berjalan dan berlari. Ini disebabkan oleh pengurangan jarak perjalanan yang dilakukan dengan lokasi pintu tambahan yang baru semasa pemindahan keselamatan dibuat. Keputusan soalselidik yang dikaji menunjukkan bahawa ramai penduduk rumah tradisional Libya kurang mempunyai kesedaran tentang aktiviti-aktiviti menyelamatkan diri dari kebakaran dan pengetahuan yang terbatas tentang pemindahan egres keselamatan sekiranya berlaku kejadian tidak diingini seperti letupan kebakaran, walaupun ada pengetahuan yang baik tentang bahaya kebakaran dan akibat-akibatnya. Kajian ini membuat kajian terperinci tentang insiden kebakaran di rumah-rumah tradisional di Libya sebagai asas kajian akan datang yang lebih terperinci, dan menyahkan impak negatif masa pemindahan yang panjang yang disebabkan oleh bekalan akses yang tidak mencukupi untuk tujuan pemindahan jalan keluar yang selamat. Semua penduduk perlu diberi latihan yang mencukupi mengikut keputusan analisa soalselidik yang telah dijalankan.

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Declaration by graduate student

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LIST OF ABBREVIATIONS

CFD	Computational fluid dynamic
CO	Carbon monoxide
CO_2	Carbon dioxide
DPT	Date palm tree
DSC	Differential scanning calorimetry
DTG	Derivative thermogrametric
FDS	Fire dynamic simulator
H_2O	Water
HRRPUA	Heat release rate per unit area
LFA	Laser flash apparatus
N_2	Nitrogen
NIST	National institute of standard and technology
PFS	Pyrosim fire simulator
PVA	Poly vinyl alcohol
PS	Pathfinder software
SFPE	Society of fire protection engineers
TGA	Thermos gravimetric analysis

CHAPTER 1

INTRODUCTION

1.1 Background

The lives and properties of residential house occupants are often affected by fire accidents, which could occur because of inadequate fire safety considerations in residential buildings. In order to reduce the risk to life, injuries and property damages, the science of preventing and mitigating undesirable fire outbreak, also known as fire safety must be integrated into residential buildings design (Kobes et al., 2010; Lo et al., 2000; Ming Lo, 1998). Generally, fire accidents occurred in residential buildings due to poor electrical wiring, overloads of electrical equipment, and types of building materials used in the building structure with high combustibles according to (Leung & Chow, 2016). Other risks associated to the fire accident may be due to lack of appropriate optimal location of proper evacuation paths and exit routes provision. These problems are associated with most residential houses fire accident around the world and constitute a significant threat to living and properties, with more than 300,000 people killed by fire in the world annually (Jonsson, et al., 2017). In fact, research publication stated that residential fires constituted about 39.7% of all building fires causing direct damage to properties worth about USD 48,936,330, about 347 and 853 civilian deaths annually in China as published (Xin & Huang, 2013). Therefore, research on fire safety in residential houses is germane across the globe and indispensable, with several solutions been employed to mitigate the fire eruption threat lives and properties. Some of the palliatives measure introduced includes the review of the formulated building constructions regulations, fire hazard education, and building material standardization (Xin & Huang, 2013).

Libya is located in the northern part of Africa with a population of 6.5 million, and the majority of her population living in the cities like the Tripoli, Benghazi, Misrata, Bayada, Zawiya, and Zliten, Ajdabiya as illustrated by the (Worldometers, 2018). Nonetheless, the current population growth rate of 1.58 % with expected population projections of about 50 % increment of the urban population for the next three decades in the studies published (CIA world fact, 2018), (Osama, et al., 2008). These administrative areas have total coverage of 308,512 sq. /km as created in 1969 of the various administrative districts as display in Figure 1.1. The Libya capital (Tripoli) falls within the coastal area in the north-western part of the country, sharing the coastal area with Mediterranean sea coordinate of 32º 52` N, 13º 10` E, and altitude of 9 m above the sea level. Tripoli has relatively pleasant weather, and climates resulting from the favourable location as a coastal city especially in summertime, with an average daily temperature of about 40°C, and high humidity around July – August annually. Winter season is often associated with rainfalls, and cold nights, with an average temperature ranging between 15°C to 20°C (Department of climate, 2017).

Figure 1.1 : The Libya administrative areas in Tripoli (https://greenwichmeantime.com/time-zone/africa/libya/tripoli/map-tripoli/)

Finally, spring occurs at the earlier part of the summer season and offers an unpleasant experience with high-temperature increment because of extremely hot sandy-wind blowing from the desert. Figure 1.1 displays the geographical setting of the area under study, containing the typical traditional houses around different administration locations of the Libyan civil defense district in Tripoli.

1.2 Traditional House in Libya

Traditional houses are mostly found in the rural areas settings, as the unique settlement for ethnic people of any particular geographical settings, where the largest cluster of the typical traditional houses are located in the "Old historic cities" (Azlitni, 2009). Traditional houses are mostly roofed and furnished with wooden materials obtained from Date Palm Tree (DPT) due to the ease of availability and low cost. The houses are closely linked together with only one entrance / exit door for female and another entrance / exit door for male. There are windows ventilation access to the court yard but not external to the outside, with party walls with neighbours as in Figure 1.2. The structural element used in the building constructions depends on the adoption of DPT leaves twigs for ceiling and trunk as roofing beams in order to regulate the ease of air movement within the house as display as in Figure 1.3 (a) – (d), which illustrates the plan layout of traditional houses with the main front entrance / exit door. Although, the low thermal resistivity and high flammability of such building materials is a major challenge that enhances ease fire eruption in such building, together with inadequate fire safety evacuation scheme been reported to impact negatively on the houses occupants during unexpected fire eruption in such traditional Libyan residential houses (El may, et al., 2012)(Agoudjil, et al., 2011)(Istre & Mallonee, 2000; Shai, 2006).

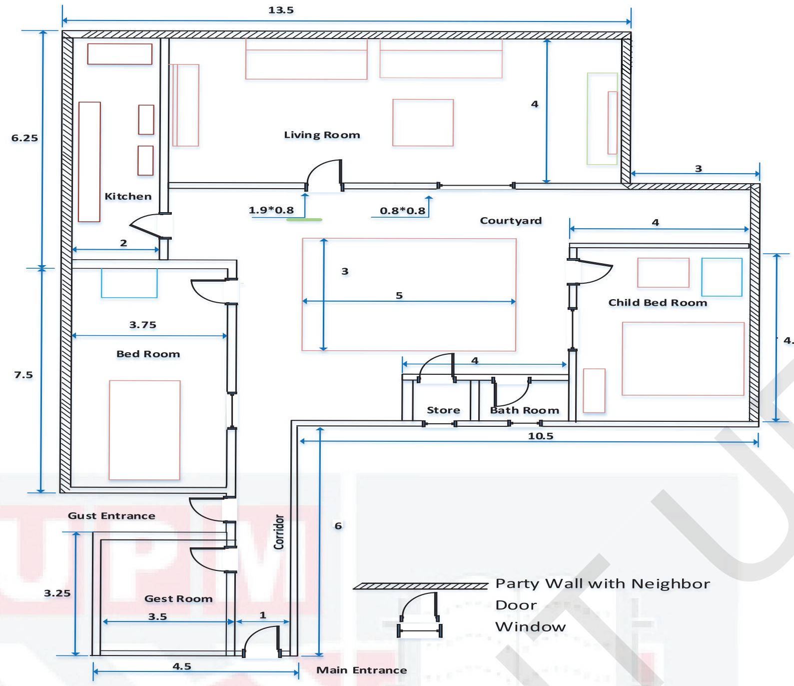

Figure 1.2 : Typical traditional Libya house architectural view

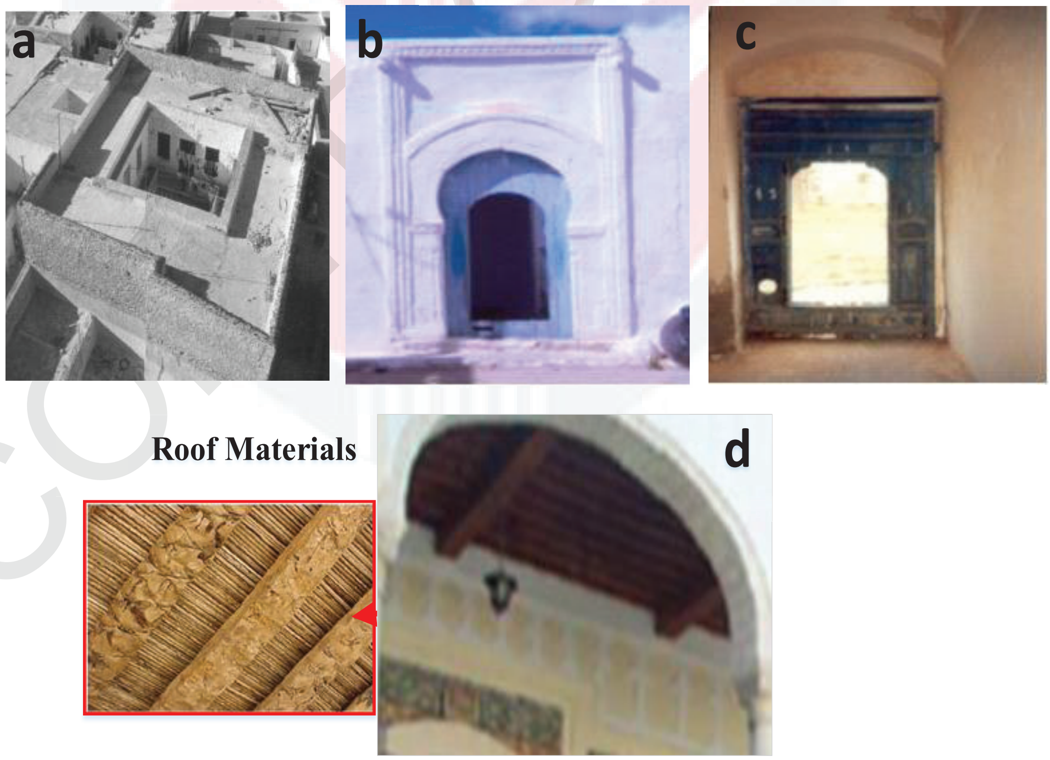

Figure 1.3 : Typical traditional building from the old city of Tripoli; a: houses plan layout, b: exit door from outside, c: exit door from inside, d: roof materials (Elwefati, 2007)

The house roof structural dimensions depend on the trunk length, which is a function of the DPT age (Racchi et al., 2014) (Keramat Jahromi, Jafari, Rafiee, & Mohtasebi, 2007). The trunk length and material strength are evaluated in accordance to the tree age with most DPT trunk best suitable for usage at maturity (roofing and furnishing) from an average age of 40 – 82 years old trees as shown in Figure 1.4.

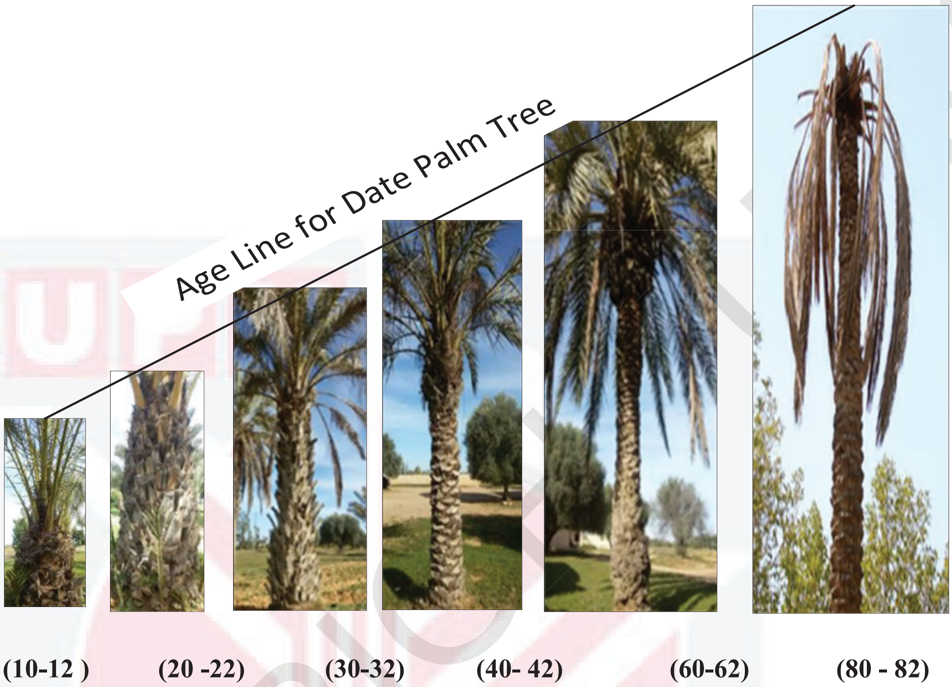

Figure 1.4 : Date palm tree different ages (Keramat Jahromi et al., 2007)

1.3 Problem Statements

The lack of adequate fire safety awareness, prevention and evacuation knowledge amongst the occupants is one of the factors that contributes to constant fire accident outbreaks in most traditional houses in Libya as observed from the conduct of the occupants in the handling of alternative light sources like candle closer to highly inflammable materials in the rooms due to epileptic power supply, which have claimed several lives and destroyed properties (Shai, 2006) (Department of planning, 2015). However, there have been speculations that the major causes of most unwanted fire eruptions in traditional houses in Libya are associated with the types of materials used in the construction and lack of adequate escape evacuations access during an emergency. The DPT adoption as roofing and furnishing material has very low heat and fire resistance characteristic, which enables heat conductions and fire propagation as established from the previous studies (Azhakesan, et al., 2012). The limitations of the earlier studies are subject to further investigation of the material behaviour under different seasonal eruptions for winter and summer for different seasons of the year based on the material properties support for fire ignition when in contact with any fire sources. In addition, the lack of adequate fire safety standard compliance and incorporation in traditional house building like effective fire safety measures and fire extinguishers for the prevention and control of ignited fire spread that may impact negatively on the lives of occupants (Horasan 2013).

A typical traditional Libya house has an average density of between 5 – 8 occupants for a medium family size, but could also increase to between 10 – 16 persons in larger family size density (Radhakrishnan, El- Mangoush, & Gerryo, 1987). The high density nature of the traditional houses structures at every location with just two set of entrance / exit access doors for both main house occupants (both men and women) and guest is one major challenge with reference to the proximity of both doors from each other with one meter width door size not suitable enough for high density egress evacuation during house fire eruption. The corridor width of one meter is also not sufficient enough for effective evacuation of the house occupants during egress evacuation with reference to the density of the house occupant likewise as displayed in Figure 1.2. This could not be expanded as the partition walls are surrounded with other neighbours' houses. Another very important aspect challenging such traditional house fire eruption is in the improvement (reduction) on the safe evacuation time of the occupants during the full blown fire spread, which impacts negatively with the higher number of human deaths (casualties), injuries and damages of properties. Studies in UK shows reduced traveling distance because there is need to reduce the traveling distance by all occupants in case of any fire eruptions by the effective location of emergency safe evacuation access that should be optimally close to all occupants in addition to the existing ones (Jonsson et al., 2017). This will help in the reduction of the traveling distance and in turns improve on the egress evacuation time reduction of all house occupants to safe haven in any fire eruption scenarios.

1.4 Research Hypothesis

The means of egress ($\mathcal{M}_1$) is an issue for the crowed situations in traditional Libya house. The hypothesis is as follows therefore

H_0: $\mathcal{M}_1 - \mathcal{M}_0 = 0$

To add another exit door for egress in emergency situation does not reduce egress time for occupants.

H_1: $\mathcal{M}_1 - \mathcal{M}_0 \neq 0$

To add another exit door for egress in emergency situation can reduce egress time for occupants.

1.5 Research Objectives

The aim of this research study is to determine the new evacuation access door location for the traditional houses in Libya as fire safety improvement strategy to reduce the traveling distance and reduction in the evacuation time as critical steps to reduce fire accident impacts on occupants and properties. The specific objectives are as follows:

i. To determine the thermal properties (calorimetric value, conductivity, diffusivity and TGA properties) of date palm trunk and leaves as they are not common building materials but common for traditional Libya house adoption.
ii. To simulate a typical traditional Libya house fire using commercial software (Pyrosim Fire Simulator software) to predict worst the impact of fire spread, heat propagation and room temperature measurements at different HRRPUA for winter and summer seasons fire eruptions in children bedroom under different under different windows and door arrangements using result from objective 1.
iii. To determine the location of the new access door for evacuation of occupants under (all doors open) worst scenarios from objective 2.
iv. To determine fire safety awareness, practice and knowledge level assessment among Libya residential houses occupants, through questionnaire so that they can be trained on safe evacuation.

1.6 Significance of Research

This research study will help in addressing the pending challenges on the traditional Libya house fire eruption that is impacting negatively on human lives and properties as stated in the problem statements. The following are significance deduced from the study:

i. Optimal location of additional access door for safe egress evacuation of the house occupant in case of fire eruption with limited impact on human lives and properties. This will help in reducing the traveling distance to be covered to the emergency exit.
ii. The insertion of additional safe exit door in the building corridors by the applied pathfinder egress safety analysis software (PFS) will reduce the evacuation time of any house fire eruption with minimum renovation to existing design.
iii. The study encourages building safety enforcement group to consider the modification of the traditional house building plan in compliance with the safety standard requirement as may be incorporated in the building plan to improve fire safety of traditional Libyan house.

1.7 Scope and Limitation of Research

This research study focuses mainly on the testing of the formulated hypothesis directed at achieving the stated objectives as an improvement on the safe egress evacuation in tradition house fire eruption in Libya as proposed for this study. The study does not cover the chemical composition and moisture analysis of DPT roofing material samples(41 and 81 years) as it impacts on house fire ignition, heat and smoke spread as used in the construction of traditional Libyan houses as earlier documented in (Ibrahim, et al., 2014; Nehdi, et al., 2010). In addition, the smoke analysis study of the modeling and gaseous hazardous effects were not considered in this work as earlier studies have taken care of this area (El, et al., 2013).

Only the children bedroom are considered as the location for the fire source (Department of planning, 2015). The kitchen cooking gas cylinder is located outside the house. The number of house occupants of 5, 10 and 15 with walking of (1.5 m/s) and running (3.5 m/s) speed followed the earlier study by (Jevtić, Engineering, & Tesla, 2016).

1.8 Thesis Layout

This research was formatted with five chapters in accordance with the guidelines for thesis preparation, March 2004, provided by the School of Graduate Studies, Universiti Putra Malaysia. Chapter 1 entails the introduction and overview of the research study, the background information on the impact of fire eruption on the occupant in traditional Libya house, formulated hypothesis, stated research objectives and the scope and limitations of the study.

Chapter 2 enumerate recent related works in the reviewed literature as it relates to the impact of fire eruption in house settings, several techniques applied in earlier studies to mitigate the negative impact of house fire accidents and the research gaps discovered as the novelty for additional safety access door provision and location for effective evacuation of the occupants with reduced egress time improvement.

Chapter 3 contained the methodology of the research procedures, starting proposed thermal properties determination of DPT building as input parameters for the mimic simulation of the actual fire simulations scenarios in winter and summer seasons of the country. The Pyrosim FDS modeling with the appropriate parameters was deployed for the determination of fire and heat spread of the typical model of a traditional Libya house fire. The determination of the room temperature to determine the impact assessment of heat on the occupant for optimal performance of the egress evacuation of the house occupants under winter and summer seasons under several rooms ventilation control with the application of the Pathfinder software to determine the optimal location of an additional new door.

Chapter 4 is the results and discussions and the implication divulged accordingly.

Chapter 5 present the conclusion of the research study by highlighting the novelty of the research study by considering the implication of the achieved result on the proposed objectives and recommend some potential future researches area.

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