



**MINIMALLY INVASIVE ACTIVE FIRE PROTECTION
SYSTEMS IN HERITAGE TIMBER BUILDINGS**

BY

MUHAMMAD ALIF WAJDI BIN MOHTAR

**A thesis submitted in fulfilment of the requirement for the
degree of Master of Science (Built Environment)**

**Kulliyyah of Architecture and Environmental Design
International Islamic University Malaysia**

APRIL 2019

ABSTRACT

The implementation of timber construction differs in most countries often symbolizes the country architectural style and represents the historical identity of the local community and its surrounding context. These heritage timber buildings have withstood the test of time and are still standing strong to this day. However, they are highly exposed to the threat of fire due to the combustible nature of the timber material itself. In order to prevent further loss to the heritage timber buildings, many new systems were developed to serve as the active fire protection system for the buildings. The main purpose of this research is to identify the appropriate types of active fire protection systems and their ideal methods of installation in the context of heritage timber buildings. The study begins by understanding the criteria of selection for implementing active fire protection systems and identifying the existing active fire protection systems which are commonly used in heritage buildings. In comparison to the newer buildings, the installation of these systems in heritage timber buildings require minimally invasive method to prevent any further damage to the original building's structure and should blend in well with the building's design aesthetic. Several international and local heritage buildings were also documented to determine the active fire protection system implemented in each of the respective buildings and the comparison between each building were evaluated. A variety of methods of implementation and installation were identified and compared. The findings of the research indicate that the selection of active fire protection system was determined based on key factors such as aesthetic, cost, and impact towards the original building structure. The outcome of these research findings would be useful for architects, conservators, and building owners as guidelines for future conservation projects towards heritage timber buildings.

Keywords: heritage buildings, timber buildings, building conservation, fire safety, active fire protection system

خلاصة البحث

إن تنفيذ العمارة الخشبية التي تختلف في معظم البلدان غالباً ما يرمز إلى الطراز المعماري للبلاد وتمثل الهوية التاريخية للسكان المحليين والمناطق المحيطة بها. هذه المباني الخشبية القديمة لها عمر طويل ولا تزال قوية حتى يومنا هذا، ولكنها معرضة الآن لتهديدات الحريق من استخدام مواد الخشب القابلة للاشتعال. لمنع فقدان المزيد من المباني الخشبية القديمة، لقد تم إدخال أنظمة جديدة مختلفة الذي يخدم نشط نظام الحماية من الحرائق لهذه المباني. يتمثل الهدف الرئيسي من هذا البحث في تحديد نوع نظام الحماية من الحريق النشط المناسب وطريقة التثبيت المتوافقة مع مبنى الخشب القديم. تبدأ هذه الدراسة بفهم معايير اختيار نظام الحماية من الحريق النشط للمباني القديمة وتحديد أنظمة الحماية النشطة من الحريق التي يتم استخدامها غالباً في المباني القديمة. مقارنةً بالمباني الجديدة، ويتطلب تركيب هذه الأنظمة في المباني القديمة طريقة تؤدي إلى الحد الأدنى من التأثير أو الضرر في بنية المبنى الأصلي، ويجب أن تتماشى مع بنية المبنى. وقد تم اختيار العديد من المباني من كل من الدول الأجنبية والمحلية لتحديد نظام الحماية من الحريق النشط المستخدم في كل مبنى وكذلك تحديد الاختلافات بين كل مبنى. تم تحديد طرق مختلفة للتنفيذ والتركيب، وتم اختيار كل من هذه الطرق لمعالجة القضايا المختلفة التي تنشأ خلال عملية الحفاظ على المباني التراثية. يعتمد اختيار نظام الحماية النشطة من الحريق على عدة عوامل مختلفة مثل الجمال والتكلفة والأثر على هيكل المبنى الأصلي. من المتوقع أن تكون نتائج هذا الاكتشاف مثلاً عاماً أو إرشادات موجزة لمشروعات الحفاظ المستقبلية على المباني القديمة الأخرى.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Built Environment).

.....
Nurul Hamiruddin Salleh
Main Supervisor

.....
Norwina Mohd Nawawi
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science Built Environment.

.....
Srazali Aripin
Internal Examiner

.....
Muna Hanim Abdul Samad
External Examiner

This thesis was submitted to the Department of Architecture and is accepted as a fulfilment of the requirement for the degree of Master of Science Built Environment.

.....
Srazali Aripin
Head, Department of Architecture

This thesis was submitted to the Kulliyyah of Architecture and Environmental Design and is accepted as a fulfilment of the requirement for the degree of Master of Science Built Environment.

.....
Abdul Razak Sopian
Dean, Kulliyyah of Architecture
and Environmental Design

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Muhammad Alif Wajdi bin Mohtar

Signature

Date

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF
FAIR USE OF UNPUBLISHED RESEARCH**

**MINIMALLY ACTIVE FIRE PROTECTION SYSTEMS
IN HERITAGE TIMBER BUILDINGS**

I declare that the copyright holders of this thesis are jointly owned by the student and IIUM.

Copyright © 2019 Muhammad Alif Wajdi bin Mohtar and International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.
1. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.
2. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Muhammad Alif Wajdi bin Mohtar.

.....
Signature

.....
Date

ACKNOWLEDGEMENTS

All praise to Allah, the Almighty, for granting me the guidance and knowledge to proceed with the research. He is truly an inspiration, and also the source of strength in completing this study.

I would like to express my most sincere and deepest gratitude to my main supervisor, Asst. Prof. Dr. Nurul Hamiruddin Salleh for providing me with valuable information, supervision, comments, and motivation during the course of completing this study. I would also like to express my appreciation to my co-supervisor, Assoc. Prof. Ar. Datin Dr. Norwina Mohd Nawawi for providing helpful information and guidance throughout the entire study. In addition, a special thanks to Prof. Ar. Dr. Abdul Razak Sapien for all of his beneficial advice. May Allah (SWT) bless them with success and happiness in this world and the hereafter.

I am also thankful to the staffs of Lembaga Muzium Negeri Sembilan, Muzium Matang, and Muzium Kota Kuala Kedah for assisting and cooperating with me during the research process, and also for providing me with the much needed information. I would also like to express my sincere gratitude to Encik Mohd Zaid bin Ab Ghani (Jabatan Bomba dan Penyelamat Malaysia), Ar. Chong Lee Siong, and Ar. Steven Thang Boon Ann for agreeing to be interviewed during the research process. I would also like to thank my fellow colleagues of Master of Science for Built Environments, friends, and fellow students of Kuliyyah of Architecture and Environmental Design who had contributed towards this study.

Finally, I would like to express my greatest appreciation towards my loving parents, Mohtar bin Mahmud and Wan Soraiya binti Wan Yahaya who had provided me with their unconditional love, encouragement, and moral support throughout the entire period of this study.

Thank you.

TABLE OF CONTENTS

Abstract	ii
Abstract in Arabic	iii
Approval Page	iv
Declaration	v
Copyright Page	vi
Acknowledgements	vii
List of Tables	xi
List of Figures	xiii
List of Abbreviations	xvii
CHAPTER ONE: INTRODUCTION	1
1.1 Background	1
1.2 Research Problem	4
1.3 Problem Statement	4
1.4 Aim of Research	8
1.5 Research Question	8
1.6 Research Objectives	9
1.7 Scope and Limitation of Research	9
1.8 Significant of Research	10
1.9 Flow of Thesis	11
CHAPTER TWO: LITERATURE REVIEW	12
2.0 Introduction	12
2.1 Heritage Building in Malaysia	12
2.2 Fire Safety Approach in Heritage Building	15
2.2.1 Essential	16
2.2.2 Appropriate to Risk	17
2.2.3 Compliance with Legislation	18
2.2.4 Minimally Invasive	19
2.2.5 Sensitively Integrated	20
2.2.6 Reversible	21
2.3 Passive and Active Fire Protection System	22
2.3.1 Fire Detection System	23
2.3.2 Alarm and Evacuation System	26
2.3.3 Fire Suppression System	27
2.3.3.1 Automatic Fire Suppression System	29
2.4 Building Materials Reaction to Fire	32
2.4.1 Timber Reaction to Fire	34
2.5 Existing Codes and Guidelines for Fire Safety in Malaysia	36
2.6 Selection of Active Fire Protection System for Heritage Timber Buildings	39
2.6.1 Fire Detection System	39
2.6.2 Fire Suppression System	41
2.7 Research on Fire Protection System for Heritage Buildings	44
2.8 Summary	46

CHAPTER THREE: METHODOLOGY.....	47
3.0 Introduction	47
3.1 Research Instruments.....	47
3.1.1 Literature Based Discovery	48
3.1.2 Comparative Study	49
3.1.3 Case Study	50
3.1.2 Interview	50
3.2 Selection of Buildings	51
3.3 Methods of Active Fire Protection System in the Selected Heritage Timber Buildings.....	58
3.4 Summary.....	58
 CHAPTER FOUR: COMPARATIVE STUDY	 60
4.1 Background.....	60
4.2 Existing Active Fire Protection System in the Selected Heritage Timber Buildings.....	60
4.2.1 Frödinge Church, Sweden	61
4.2.1.1 Background of Building.....	61
4.2.1.2 Active Fire Protection System	64
4.2.2 Himeji Castle, Japan	68
4.2.2.1 Background of Building.....	68
4.2.2.2 Active Fire Protection System	73
4.2.3 Shirakawa-Go, Japan	81
4.2.3.1 Background of Building.....	81
4.2.3.2 Active Fire Protection System	87
4.3 Summary.....	93
 CHAPTER FIVE: CASE STUDY	 94
5.1 Background.....	94
5.2 Existing Active Fire Protection System in the Selected Heritage Timber Buildings.....	94
5.2.1 Istana Ampang Tinggi, Negeri Sembilan	95
5.2.1.1 Background of Building.....	95
5.2.1.2 Active Fire Protection System	98
5.2.2 Rumah Tradisional Negeri Sembilan, Negeri Sembilan	102
5.2.2.1 Background of Building.....	102
5.2.2.2 Active Fire Protection System	104
5.2.3 Muzium Matang / Kota Ngah Ibrahim, Perak	108
5.2.3.1 Background of Building.....	108
5.2.3.2 Active Fire Protection System	112
5.2.4 Muzium Kota Kuala Kedah, Kedah	118
5.2.4.1 Active Background of Building.....	118
5.2.4.2 Active Fire Protection System	121
5.4 Summary.....	125
 CHAPTER SIX: DATA ANALYSIS	 126
6.1 Background.....	126

6.2 Active Fire Protection System in the Selected International Heritage Timber Buildings.....	126
6.2.1 Fire Detection System	127
6.2.2 Fire Suppression System	129
6.3 Active Fire Protection System in the Selected Malaysian Heritage Timber Buildings.....	132
6.3.1 Fire Detection System	133
6.3.2 Fire Suppression System	134
6.3.3 Alarm and Evacuation System	135
6.4 Summary of Existing Active Fire Protection System in Heritage Timber Buildings.....	135
6.5 Installation Method in the Selected Heritage Timber Building.....	137
6.5.1 Minimally Invasive Installation Method	137
6.5.2 Sensitively Integrated Installation Method.....	144
6.6 Summary.....	148
CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS.....	149
7.1 Background.....	149
7.2 Discussion.....	149
7.2.1 Selection of Active Fire Protection System.....	150
7.2.2 Least Invasive Method of Installation for Active Fire Protection System	151
7.2.3 Recommendation for Active Fire Protection System in Heritage Timber Buildings	153
7.3 Conclusion.....	162
7.4 Recommendation for Future Studies	162
REFERENCES.....	164
APPENDICES	169

LIST OF TABLES

Table 1.1	List of Heritage Timber Buildings in Malaysia	3
Table 1.2	Fire Statistics for Heritage Timber Buildings in Malaysia from 2003-2016	5
Table 2.1	List of Gazetted National Heritage Buildings	14
Table 2.2	Types of Fire Detection System	24
Table 2.3	Types of Manual Fire Suppression System	28
Table 2.4	Types of Automatic Fire Suppression System	30
Table 2.5	Temperature Ranges of Strength Loss According to Type of Steel	34
Table 2.6	Notional Rate of Charring for the Calculation of Residual Section	36
Table 2.7	Comparison of Malaysia Codes and Guidelines for Fire Safety	37
Table 2.8	Comparison of Malaysia Heritage Building Guidelines in Regards to Fire Protection	38
Table 3.1	Selection of Research Methodologies According to Research Objectives	48
Table 3.2	Age of Selected Heritage Timber Buildings	53
Table 3.3	Selected Heritage Timber Buildings Function and Accessibility	54
Table 3.4	Probability Levels of Building Fire	55
Table 3.5	Severity Categories of Building Fire	55
Table 3.6	Fire Risk Matrix of Selected Heritage Timber Building	56
Table 3.7	Selected Heritage Timber Buildings Fire Risk Level	56
Table 4.1	Types of Active Fire Protection System Installed in Frodinge Church	67
Table 4.2	Types of Active Fire Protection System Installed in Himeji Castle	78
Table 4.3	Types of Active Fire Protection System Installed in Shirakawa-Go	92
Table 5.1	General Overview of Istana Ampang Tinggi	98

Table 5.2	Types of Active Fire Protection System in Istana Ampang Tinggi	101
Table 5.3	General Overview of Rumah Tradisional Negeri Sembilan	103
Table 5.4	Types of Active Fire Protection System in Rumah Tradisional Negeri Sembilan	107
Table 5.5	General Overview of Muzium Matang	111
Table 5.6	Types of Active Fire Protection System in Muzium Matang	116
Table 5.7	General Overview of Muzium Kota Kuala Kedah	121
Table 5.8	Types of Active Fire Protection System in Muzium Kota Kuala Kedah	124
Table 6.1	List of Active Fire Protection System in International Heritage Timber Buildings	127
Table 6.2	List of Active Fire Protection System in Malaysian Heritage Timber Buildings	132
Table 6.3	Summary of Existing Active Fire Protection System Commonly Found in Heritage Timber Buildings	136
Table 7.1	Recommendation Fire Detection System in Heritage Timber Buildings	154
Table 7.2	Recommendation Fire Suppression System in Heritage Timber Found in Heritage Timber Buildings	158

LIST OF FIGURES

Figure 1.1	Aftermath of Fire in Ho Ann Kiong Temple (left) and Punan Bah Longhouse (right)	5
Figure 1.2	Exposed sprinkler piping and smoke detector	7
Figure 1.3	Installation of services which damages the building fabric	8
Figure 1.4	Flow of Thesis	11
Figure 2.1	Organisation of Fire Protection Measures	18
Figure 2.2	Integration of smoke detector with existing architectural features	20
Figure 2.3	Minimally sized fittings can be hidden amongst the building elements.	21
Figure 2.4	Water Sprinkler System Activation	31
Figure 2.5	Water Mist System Activation	32
Figure 2.6	Fire Tetrahedron	33
Figure 2.7	Charred Timber Condition	35
Figure 2.8	Reflected Smoke Beam Detector System	40
Figure 2.9	Aspirating Smoke Detector System	41
Figure 2.10	Fire Extinguisher Cabinet	42
Figure 2.11	Different Types of Sprinkler Head for Different Purposes	43
Figure 3.1	Research Design Framework	49
Figure 4.1	Exterior view of Frödinge Church	61
Figure 4.2	The church bell tower	62
Figure 4.3	The church's facade and one of the entrance doors	63
Figure 4.4	The interior view of Frodinge Church	64
Figure 4.5	The equipments are well hidden within the painting on the ceiling	65
Figure 4.6	Stainless steel main pipe which connects to the copper piping used for the facades sprinkler system	66

Figure 4.7	Exterior view of Himeji-jo	68
Figure 4.8	Site Plan of Himeji-jo	69
Figure 4.9	Elevation of Dai-Tenshu, Ko-Tenshu, and Watariyagura (Donjon Compound)	70
Figure 4.10	Exterior wall of Himeji-jo	71
Figure 4.11	Interior view of Himeji-jo	72
Figure 4.12	Plan of the Fire Detection Systems in Himeji-jo	73
Figure 4.13	Himeji-jo Disaster Management Centre	74
Figure 4.14	Fire extinguisher within the castle ground	75
Figure 4.15	Indoor fire hydrant box located inside the castle	76
Figure 4.16	Plan of the water fire extinguishing system	77
Figure 4.17	Water jet fire drill at Himeji-jo	77
Figure 4.18	View of Shirakawa-Go	81
Figure 4.19	Plan indicating the buildings for which conservation work has been done since the time of designation	82
Figure 4.20	Distant view of Shirakawa-Go from the South	83
Figure 4.21	South elevation of Gassho-Style House	84
Figure 4.22	East elevation of Gassho-Style House	85
Figure 4.23	Transverse section of Gassho-Style House	85
Figure 4.24	Longitudinal section of Gassho-Style House	85
Figure 4.25	Rethatching work of Mizuno House	86
Figure 4.26	Interior view of Myozen-Ji living room	88
Figure 4.27	Irrigation canal in Shirakawa-Go	89
Figure 4.28	The water cannon prior to activation	90
Figure 4.29	Annual fire drill simulation in Shirakawa-Go	90
Figure 4.30	Plan indicating locations of fire extinguishing systems	91
Figure 5.1	Front view of Istana Ampang Tinggi	95

Figure 5.2	Traditional carvings on the internal wall of Istana Ampang Tinggi	96
Figure 5.3	Interior view of Istana Ampang Tinggi	97
Figure 5.4	Site Plan of Negeri Sembilan Cultural Complex	99
Figure 5.5	Location of Active Fire Protection System in Istana Ampang Tinggi	100
Figure 5.6	Front view of Rumah Tradisional Negeri Sembilan	102
Figure 5.7	Interior view of Rumah Tradisional Negeri Sembilan	103
Figure 5.8	Site plan of Negeri Sembilan Cultural Complex	105
Figure 5.9	Location of Active Fire Protection System in Rumah Tradisional Negeri Sembilan	106
Figure 5.10	Front view of Muzium Matang	108
Figure 5.11	Interior view of the Ground Floor of Muzium Matang	109
Figure 5.12	Interior view of the 1st Floor of Muzium Matang	110
Figure 5.13	View of one of the rooms on the 1st Floor of Muzium Matang	111
Figure 5.14	Location of Active Fire Protection System on the Ground Floor of Muzium Matang	114
Figure 5.15	Location of Active Fire Protection System on the 1st Floor of Muzium Matang	115
Figure 5.16	Front view of Muzium Kota Kuala Kedah	118
Figure 5.17	Interior view of Muzium Kota Kuala Kedah	119
Figure 5.18	Exhibit items on display in Muzium Kota Kuala Kedah	120
Figure 5.19	Previous building condition in 1987 (left) & existing building condition in 2017 (right)	120
Figure 5.20	Location of Active Fire Protection System in Muzium Kota Kuala Kedah	123
Figure 6.1	Water mist nozzle hidden within the ceiling of Frodinge Church	138
Figure 6.2	Chrome piping for the facade's deluge sprinkler system at Frodinge Church	139
Figure 6.3	Water sprinkler piping was painted to match the building's colour in Himeji-jo	139

Figure 6.4	The piping for the electrical wiring was painted to match the building's colour in Istana Ampang Tinggi	140
Figure 6.5	CCTV Camera installed in a wooden box at Himeji-jo	140
Figure 6.6	Indoor fire hydrant box is hidden under the staircase at Himeji-jo	141
Figure 6.7	The water cannon system before (left) and	142
Figure 6.8	The fire hose storage box at Himeji-jo	142
Figure 6.9	Fire hydrant cover (left) & water cannon (right) at Himeji-jo	143
Figure 6.10	Water mist system installation at the ceiling in Frodinge Church	145
Figure 6.11	Water mist system installation at the attic in Frodinge Church	146
Figure 6.12	Water sprinkler system installation on the external wall of Frodinge Church	147
Figure 6.13	Internal piping arrangement in Himeji Castle	148

LIST OF ABBREVIATIONS

BOMBA	Jabatan Bomba dan Penyelamat Malaysia
BSI	British Standard Index
CCTV	Closed-circuit television
CFPA	Confederation of Fire Protection Associations Europe
COST	European Cooperation in Science & Technology
HUD	United States Department of Housing and Urban Development
ICOMOS	International Council on Monuments and Sites
JMM	Jabatan Muzium Malaysia / Department of Museum Malaysia
JPBD	Jabatan Perancangan Bandar dan Desa
JWN	Jabatan Warisan Negara / Department of National Heritage
LMNK	Lembaga Muzium Negeri Kedah
LMNS	Lembaga Muzium Negeri Sembilan
NFPA	National Fire Protection Association
PAM	Pertubuhan Arkitek Malaysia
SIRIM	Standard and Industrial Research Institute of Malaysia
UBBL	Uniform Building By-law
UNESCO	United Nations Education, Scientific and Cultural Organization

CHAPTER ONE

INTRODUCTION

1.1 Background

One of the most valuable historical assets of any civilization or country is the existence of its heritage buildings. Heritage buildings can be easily described as buildings that were constructed in the past and may contain a certain historical value within its design. According to Siemens Switzerland Ltd. (2015), heritage building helps to provide a general glimpse of the past of a particular community or civilization through its craftsmanship and technology used in the building's design and construction. Aside from the workmanship, heritage building also represents the living condition and way of life of its previous occupants. These buildings of the past designed and constructed have withstood the test of time and may play an important role towards the development of its surrounding civilization. This is further supported by the Malaysian National Heritage Act 2005 that defines heritage building as a building or groups of separated or connected building that stands out amongst the rest due to their architectural essence, their cultural homogeneity, or even their placement within the surrounding landscape from the perspective of history, arts, and science.

Fire is a constant risk that causes various types of destruction towards most buildings and its contents. In the case of heritage building, fire is considered as the most significant threat towards the historic essence of the building and its context especially with the increasing age of most of the heritage building materials and insufficient safety provision. According to Historic Scotland (2005), fire usually

occurs due to the presence of three main elements which includes heat, oxygen, and fuel. Additionally, fire can also easily spread when its movement is unhindered from any types of separation. This is a main threat to heritage buildings since most of them were constructed using traditional methods and tend to contain numerous paths that fire can easily pass through. Aside from the threat towards the building occupants, the spread of fire also creates several negative impacts towards the building and its surrounding context.

During the historical period of Malaysia, timber was considered as the main choice of material for construction purposes. According to Zainab (2005), brick was eventually introduced in Malaysia since 350 years ago but it was rarely accessible to everyone and was usually limited to government-related buildings. Thus, timber was regarded as the easiest available material and can easily be constructed. Table 1.1 shows the list of some of the heritage timber buildings that had been registered under the National Heritage Act 2005 and acknowledged by Department of National Heritage (JWN) in their website. The list showcases only a small fraction of the number of heritage timber buildings that can be found throughout Malaysia.

Table 1.1: List of heritage timber buildings in Malaysia

Types of Buildings	List of Buildings
Places of worship	<ol style="list-style-type: none"> 1. Masjid Insaniah Iskandariah, Kg Kuala Dal, Perak 2. Masjid Mulong, Kota Bharu, Kelantan 3. Balai adat Kampung Putera Jelebu, Negeri Sembilan 4. Masjid Kampung Laut, Kelantan 5. Gereja All Saints, Taiping, Perak* 6. Surau Kampung Tuan, Kemaman, Terengganu
Private property	<ol style="list-style-type: none"> 1. Rumah Tiang Kembar & Rumah Tiang Limas, Terengganu 2. Rumah Penghulu Mat Nattar, Jasin, Melaka
Government administration	<ol style="list-style-type: none"> 1. Bangunan Sanitary Road, Taiping, Perak 2. Muzium Islam, Kota Bharu, Kelantan 3. Kota Ngah Ibrahim, Taiping, Perak
Palace	<ol style="list-style-type: none"> 1. Istana Lama Ampang Tinggi, Negeri Sembilan 2. Istana Jahar (Muzium Adat Istiadat Diraja), Kota Bharu, Kelantan* 3. Istana Kenangan (Muzium Diraja Perak), Kuala Kangsar* 4. Istana Seri Menanti, Kuala Pilah, Negeri Sembilan*
Commercial	<ol style="list-style-type: none"> 1. Gedung Raja Abdullah, Klang, Selangor*

* Buildings gazetted under National Heritage Act 2005

(Source: heritage.gov.my)

When a heritage building changes its function and is opened to the public, the building is required to conform to the various building regulations and by-laws in particular to the fire protection system. In most cases, after a certain period of time, most of these heritage timber buildings were later converted to suit a different purpose. As mentioned by Kidd (2001), the building faces potential risk of arson or wilfully set fires by allowing public access. He also added that since the number of visitors or occupants had increased, great consideration should also be made towards the improvement risk assessment programme. According to Jabatan Bomba dan Penyelamat Malaysia (2017), 1,438 cases involving incendiary fire were reported from the year 2013 to 2016. Thus, the installation of appropriate fire protection system into the heritage building to conform to the fire regulations is important and would reduce the potential risk of fire exposure towards the occupant. In addition, the risk of damages towards the heritage building iconic construction elements can also be greatly reduced by having fire protection system available throughout the whole

building. As emphasized by The Confederation of Fire Protection Associations Europe (2013), awareness towards the risk of fire and the possibility of its occurrences is vital towards the protection of the heritage building and its content.

1.2 Research Problem

When it comes to fire-related issues, timber has always been an immediate concern on its resistance to fire and many considered timber buildings to be prone to fire spread. In addition, heritage timber buildings rely heavily towards the application of fire protection system in order to prevent any further damage caused by fire from spreading. However, detailed consideration and assessment should be made regarding the choice of methods to be used since it may instead cause irreplaceable damage towards the building itself and may stand out differently compared to the building's fabric.

1.3 Problem Statement

1.3.1 Heritage Timber Building Risks to Fire

One of the main concerns when it comes to the application of fire protection system in a heritage building is the choice of methods available particular to the condition of the building materials and design. Different material may cause a different reaction compared to others when it comes to interaction with fire. In the case of heritage timber building, the combustible nature of timber material proves to be a significant challenge in implementing adequate fire protection system. This has

always been a main concern since most the heritage buildings in Malaysia are constructed using timber as its main material. Table 2 highlights the list of heritage timber buildings which had been severely damaged or destroyed by fire in Malaysia. Unfortunately, no official statistic was able to be obtained from Jabatan Bomba dan Penyelamat Malaysia (BOMBA).

Table 1.2: Fire statistic for heritage timber buildings in Malaysia from 2003-2016

Date	Building	Estimated Loss (MYR)
2 May 2003	8 Double-storey wooden shop houses (1950), Batu Kawa Bazaar, Kuching	
25 July 2003	138-years old semi-wooden girls dormitory, St Joseph Home, Penang	100,000
20 Oct. 2003	Rumah Pak Ali (1876), Gombak, Kuala Lumpur	>1 mil.
5 May 2008	38 units of Punan Bah longhouse, Belaga, Sarawak	>500,000
5 Feb 2009	5 Heritage houses, Chew Jetty, Penang (In World Heritage Site Zone)	
24 Feb 2010	Ho Ann Kiong Temple, Kampung Cina, Kuala Terengganu	

(Source: thestar.com.my)



Figure 1.1: Aftermath of fire in Ho Ann Kiong Temple (left) and Punan Bah Longhouse (right)
(Source: thestar.com.my)

Most of the heritage timber buildings in Malaysia are designed to allow the timber material to be exposed. According to Gerard & Barber (2013), the presence of exposed timber material will contribute to the combustible fuel load as well as the room fire behaviour and structural fire resistance. From this statement, it can be understood that the material used in the heritage building construction plays a significant role towards the fire safety performance. Hill (2004) stated that the interaction between timber and fire would result to smouldering fire. Smouldering fire tends to burn slower than flaming fire; thus, it may initially release less smoke particles. As a result, certain detectors may have a slower reaction time before the fire start to spread.

1.3.2 Aesthetical Integration of Fire Protection System with Building Fabric

Another main issue that occurs during the installation of fire protection system in heritage timber building is the appearance of the equipments stands out differently compared to the building fabric, as shown in Figure 1.2. The installation of the fire protection system should not contradict with the design elements of the building since it will most likely lose the purpose of historical preservation. As mentioned by Allwinkle, Bell et al. (1997), changes should only be made where it is deemed absolutely essential for the building's safety. This is further supported by Siemens Switzerland Ltd. (2015), in which they stated that the procedures involved should be done with the least amount physical impact towards the fabric and decor of the building. In the context of heritage timber buildings, the installation of the fire protection system should be carried out with minimally invasive methods.



Figure 1.2: Exposed sprinkler piping and smoke detector
(Source: Arvidson [2006])

1.3.3 Damages Caused to the Building Fabric During Installation

The third concern of this research is on the installation process of the selected fire protection system that would damage the highly valuable and irreplaceable building elements or structure as evidently shown in Figure 1.3. During the installation process, drilling or alterations may take place to the existing building elements in order to allow the implementation of the fire protection system equipments for compliance to fire regulations. Without proper established methods, guidelines and assessment, this outcome may lead to a devastating result since most of the building elements in a heritage timber building play an important role towards its structural integrity. According to United States National Fire Protection Association (2015), one of the main objectives of historical preservation is to fully utilize the level of protection of the heritage buildings against damage and loss to fire. Thus, it is important to note that the choice of choosing the ideal fire protection system to be implemented in a heritage timber building is important towards the preservation of its authenticity and safety.