UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A SMOKE PREDICTION MODEL FOR STAIRWAYS IN A MULTI-STOREY BUILDING

NURUD SURIA BINTI SUHAIMI

FK 2019 142

DEVELOPMENT OF A SMOKE PREDICTION MODEL FOR STAIRWAYS IN A MULTI-STOREY BUILDING

By

NURUD SURIA BINTI SUHAIMI

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

April 2019

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

DEVELOPMENT OF A SMOKE PREDICTION MODEL FOR STAIRWAYS IN A MULTI-STOREY BUILDING

By

NURUD SURIA BINTI SUHAIMI

April 2019

Chairman : Professor Nor Mariah Adam, PhD
Faculty : Engineering

Multi-storey building in Malaysia has rapid growth rate especially in urban area with high population. During emergency in building fire, smoke could disturb people's health and vision thus affects the evacuation time. Simple and transparent engineering methods can create opportunities to better understand a complex fire phenomenon and estimate the answer quickly before making decision. Existing methods of calculation can only predict smoke temperature in a single fire compartment and there was a lack of calculation method for multi-storey compartment. The main goal of this study is to develop a new and validated simplified mathematical model to predict the smoke conditions in a multi-storey building specifically in a stairway which used as the only route for rescue and evacuation when fire happens. In this thesis, an experimental setup consisting one fire room adjacent to the vertical shaft fire scenario were simulated using Fire Dynamic Simulator (FDS) version 6.1. Eight (8) independent variable parameters were tested including heat release rate (HRR), enclosure geometry as well as venting opening size to measure the smoke temperature which considered as dependent variable. Three hundred sixty (360) different simulations which study smoke conditions in a room adjacent to a vertical shaft were utilized in statistical analysis to find a constant in mathematical correlation. In order to predict the smoke temperature in a stairway, additional heat loss to the tread boards and landing were also included in developed correlation while calculating. The validity of the mathematical correlation was studied by comparing results from the correlation with numerical simulation and full-scale test data from previous published cases. The predictions with developed correlation were within 32% from the simulation and less than 23% for an experimental full-scale result. Error up to 35% in prediction of smoke temperatures by using developed correlation were accepted and considered good as reported in previous validated work conducted by Nuclear Research Centre (NRC). Sensitivity analysis was conducted to investigate the most affected variables from the correlation model that would impact the smoke temperature in the stairway of multi-storey buildings. From the analysis, it was discovered that vent opening is the most

sensitive variables that will affect the smoke temperature in a stairway beside other parameters such as stair and room area, heat release rate and door opening. In conclusion, the derived equation can be used to perform simple calculation for smoke layer temperature in stairway and it is a promising for a faster calculation especially when assessing multiple fire scenarios in a fire safety design. However, further validation studies of the developed model are recommended to be compare with other types of correlation developed from previous researchers.

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

PEMBANGUNAN MODEL RAMALAN ASAP UNTUK TANGGA DI BANGUNAN BERTINGKAT

Oleh

NURUD SURIA BINTI SUHAIMI

April 2019

Pengerusi : Profesor Nor Mariah Adam, PhD
Fakulti : Kejuruteraan

Bangunan bertingkat di Malaysia bertumbuh dengan pesat terutamanya di kawasan bandar yang mempunyai kepadatan penduduk tinggi. Ketika kecemasan dalam kebakaran bangunan, asap yang terhasil memberi kesan kepada kesihatan serta penglihatan dan seterusnya menjejaskan masa yang diperlukan ketika proses pengungsian bangunan. Kaedah kejuruteraan yang ringkas dan telus mewujudkan peluang untuk memahami fenomena api yang kompleks dan memberi jawapan secara ramalan dengan cepat sebelum keputusan dibuat. Kaedah pengiraan sedia ada hanya boleh meramalkan suhu asap di dalam ruangan kebakaran tunggal dan masih agak kurang kaedah pengiraan yang digunakan untuk ruangan bertingkat. Matlamat utama kajian ini adalah untuk membangunkan model matematik yang diringkaskan dan kemudian divalidasi bagi meramal keadaan asap di bangunan bertingkat khususnya di bahagian tangga yang digunakan sebagai satu-satunya laluan menyelamat dan pengungsian apabila berlaku kebakaran. Korelasi matematik yang boleh meramalkan suhu dalam arah menegak seperti aci menegak yang digunakan sebagai tangga akan berguna dalam reka bentuk bangunan berasaskan prestasi, sebagai contoh untuk menilai situasi terbaik bagi mangsa dan anggota bomba yang terlibat dalam operasi menyelamat dan memadam kebakaran. Dalam tesis ini, eksperimen yang terdiri daripada satu ruangan terbakar bersebelahan dengan ruangan menegak telah disimulasikan menggunakan versi *Fire Dynamic Simulator* (FDS) 6.1 yang mana lapan parameter pembolehubah bebas telah diuji termasuklah kadar pembebasan haba, geometri ruangan serta saiz bukaan pengudaraan untuk mengukur suhu asap yang dianggap sebagai pemboleh ubah bersandar. Tiga ratus enam puluh simulasi berbeza yang mengkaji keadaan asap di dalam bilik bersebelahan dengan ruangan menegak digunakan dalam analisis statistik untuk mencari perselingkuhan dalam matematik. Untuk meramalkan suhu asap di tangga, kehilangan haba tambahan kepada anak tangga dan borders juga dimasukkan ke dalam model yang telah dibangunkan semasa proses pengiraan. Kesahihan korelasi matematik yang dibangunkan dikaji dengan membandingkan hasil daripada korelasi dengan simulasi komputer dan ujian

kebakaran skala penuh. Ramalan dengan model yang dibangunkan berada dalam lingkungan kesalahan ramalan sebanyak 32% berbanding simulasi dan kurang dari 23% berbanding hasil eksperimen kebakaran. Kesalahan ramalan suhu asap menggunakan model yang dibangunkan sehingga 35% dianggap baik dan diterima seperti yang telah dilapor dan disahkan dalam kajian lepas oleh Pusat Penyelidikan Nuklear (PPN). Analisis sensitiviti telah dijalankan untuk mangkaji pemboleh ubah yang paling sensitif daripada korelasi matematik yang akan mempengaruhi suhu asap di tangga bangunan bertingkat. Dari analisis, didapati bahawa bukaan lubang udara adalah pembolehubah yang paling sensitif yang akan mempengaruhi suhu asap di tangga di samping parameter lain seperti luas tangga, kadar pelepasan haba dan bukaan pintu. Sebagai kesimpulan, model matematik yang dibangunkan dalam kajian ini boleh digunakan untuk melakukan pengiraan mudah untuk meramal suhu asap di tangga terutama apabila melibatkan penilaian pelbagai senario kebakaran dalam rekabentuk keselamatan kebakaran. Walau bagaimanapun, kajian pengesahan lanjut mengenai model yang telah dibangunkan adalah disyorkan melalui perbandingan di antara korelasi-korelasi yang telah dibangunkan oleh penyelidik lain.

ACKNOWLEDGEMENTS

I wish to express my special sincere thanks and gratitude to my latter supervisor, Prof Ir Dr Nor Mariah Adam for her guidance, prayers, advice, support, help and encouragement throughout my critical situation while completing this journey. Not to forget my former supervisor; Prof Dr Sa'ari bin Mustapha for his advice and support. The warmest gratitude also dedicated to other co-supervisors; Prof Dr Abdullah bin Ibrahim as well as Dr Rafee bin Baharudin for their valuable comments and suggestions when I just started my role as a PhD student in UPM.

I wish to thank the University Malaysia Pahang (UMP) and the Government of Malaysia that is Ministry of High Education for awarded me scholarship to enable me to carry out this research.

Many thanks go to the staffs at School of Graduate, Faculty of Engineering; Kak Nor, Kak Faz, Kak Zai and their colleagues for providing assistance, advice and technical support during my research period.

I would also like to thank my parents (Suhaimi Hassan and Rasidah Zakaria) and in laws (Shafie Harun and Rahimah Muhammad), not to forget my wonderful husband (Shukri) and children (Sharif, Shasha, Sharah and Shakir) for their dua's, understanding, unconditional love, support and patient throughout the years of my study.

Last but not least, one of the foremost, thank you **Almighty Allah s.w.t** for all the favours and lessons given.

***"Allah* knows what is the best for you and when it's best for you to have it"**

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Nor Mariah binti Adam, PhD
Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Rafee bin Baharudin, PhD
Senior Lecturer
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Member)

Abdulllah bin Ibrahim, PhD
Professor
Faculty of Engineering Technology
University Malaysia Pahang
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: ________________________ Date: ________________

Name and Matric No: Nurud Suria Binti Suhami, GS39838

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature:	
Name of Chairman of Supervisory Committee:	Professor Ir, Dr. Nor Mariah binti Adam

Signature:	
Name of Member of Supervisory Committee:	Dr. Rafee bin Baharudin

Signature:	
Name of Member of Supervisory Committee:	Professor Dr. Abdulllah bin Ibrahim

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

A_0	Area of the opening, m^2
A_T	Total surface area, m^2
$A_{T,1}$	Total enclosure surface area, m^2
c_p	Specific heat, kJ/(kgK)
D_f	Fire diameter
f	Full scale parameters
h_k	Effective heat conduction coefficient
H_D	Hot gas layer interface height, m
H_N	Neutral plane
H_0	Height of the opening, m
L	Model size/length
L_m/L_f	Similarity ratio (-)
m	Model scale parameters
$\dot{m}_g$	Mass flow rate of hot gases, kg/s
$\dot{m}_{g,2-out}$	Mass flow rate of hot gases from adjacent room to the outside, kg/s
M_p	Mass flow rate of plume,
Q	Heat release rate (HRR), kW
$\dot{Q}_B$	Rate of heat stored in the hot gas
$\dot{Q}_L$	Rate of heat leaving the room with the combustion gases through openings
$\dot{Q}_R$	Rate of heat loss due to radiation through openings to the outside,
$\dot{Q}_w$	Rate of heat loss to the interior surfaces of the room
q_{loss}	Rate of heat loss to compartment boundaries

T	Temperature, ^{o}C
T_a	Ambient temperature, K;
T_g	Smoke layer temperature, K
$T_{g,2}$	Smoke layer temperature in adjacent room, K
ΔT	Temperature gradient
V	Velocity, m/s
VF_{1-2}	Ventilation factor between fire room and adjacent room, $m^{5/2}$
VF_{2-out}	Ventilation factor between adjacent room and outside, $m^{5/2}$
Z	Smoke layer height, m

CHAPTER 1

INTRODUCTION

Fire safety in building is a set of measures designed to reduce the fire risk from its origin and risk of injury for building occupants as well as firefighters. Beside fire code regulations and standards, fire risk management is one of the measures for fire safety in building. In general, if a building design is constructed based on corresponding prescriptive codes, the level of fire risk is considered in acceptable risk range that is tolerable (Chu & Sun, 2008; and Ramachandran & Charters, 2011). Life safety is ultimate in building design and as prescribed by Uniform Building By-Law (1984), life safety can be achieved by minimum fire protection with basic aspects in means of evacuation and means of fire detection and extinguishment. In recent years, urban population and urbanization level have increased rapidly in Malaysia. Thus, with an increasing number of people as well as complex building construction, occurrence of fire could lead to many casualties and property loss. Fire statistics in Malaysia indicate increase from 21,524 fire cases in 2008 to 46,882 fire cases in 2017 with total cost damage of nearly RM1 billion and RM5 billion, respectively (Table 1.1). Nevertheless, in 2015, there were less number of fire cases reported (40,865) than previous year (2014) but with total cost damage of more than RM4.4 billion. This statistic shows the potential of huge increment in property loss that may incur in future due to increasing cost of construction and buildings' furnishing nowadays although fire statistic is lower.

Table 1.1 : Fire statistic in Malaysia for 2005 – 2017

Year	Fire call	Effect of fire		Estimated loss (MYR)
		Death	Injured	
2005	31,138	70	115	794 Mil.
2006	18,913	71	86	760 Mil.
2007	20,225	80	67	865 Mil.
2008	21,524	88	79	1,049 Mil.
2009	29,417	76	71	1,057 Mil.
2010	29,052	89	82	757 Mil.
2011	28,741	80	81	928 Mil.
2012	29,848	98	152	1,116 Mil.
2013	33,640	72	165	1,990 Mil
2014	54,540	139	389	2,787 Mil
2015	40,865	153	589	4,400 Mil
2016	49,875	107	477	2,866 Mil
2017	46,822	165	null	5,200 Mil
TOTAL	**434,600**	**1,105**	**1,805**	**20,646 Mil**

(Source : KPKT, 2017)

Beside property losses, the number of injuries and fatality cases in relation to fire has also been increasing. As reported by the Fire and Rescue Department Malaysia (FRDM), from the total of fire deaths reported since 2005 to 2017, one over third of fatality have been caused by burns while the rest died to inhaling harmful gases of smoke or suffocation (FRDM, 2017). Surprisingly, death caused by smoke in fire event is not a local issue. From fire statistic reported in United Kingdom, 48 percentage of death for fire victims in 2008 caused by gas or smoke while according to statistic in Japan, smoke suffocation can reach to 79 percentage of fire death (Qian-li & Ting-lin, 2011). Overall, there seems to be some evidence to indicate that most of fatality in fire cases have been caused by smoke inhalation than burns. Fire and Rescue Department Malaysia has reported that building fire is the highest type of fire breakouts after plantation fire and the number keep increasing between 2000 to 2016 as shown in Figure 1.1

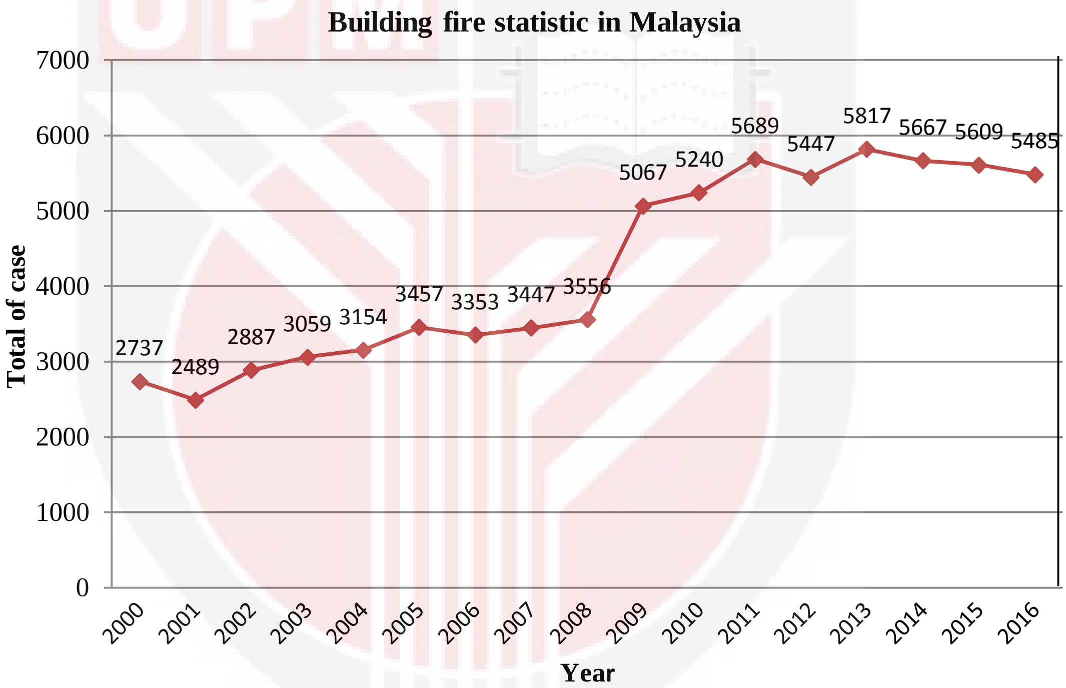

Figure 1.1 : Buildings fire statistics in Malaysia from 2000 – 2016
(Source : FRDM, 2017)

Multi-storey building in Malaysia has rapid growth rate especially in urban area with high population. Moreover, from January until March 2015, there were 46 cases of fire death and four of it was from shop-houses fire incident (KPKT, 2015). This type of building has rapid growth rate especially in urban area of high consumables with high population. Due to poor fire safety performance and awareness, the likelihood of fire to occur with high severity will be increased. Based on the fire investigation reports by the fire authority, it has been found that most of the fires happened at night and originated from the lowest floor which used for business purposes (FRDM, 2015). Fire occurred during sleep time could increase the likelihood of fatality since carbon monoxide is a silent killer as it could lead to a deep sleep and eventually death. Figure

1.2 shows some of multi-storey buildings fire cases and fatalities occurred in Malaysia recently. With regard to this news, fire in multi-storey building has caused a number of fatality in various occupancies such as commercial building, residential, shops, warehouse, and others in recent years.

(a) (b) (c)

Figure 1.2 : Fire cases in multi-storey building in Malaysia (a) Four family members died in shophouse fire while sleeping – 2010 (Metro, 2010), (b) Woman died due to smoke suffocated while trapped with daughter – 2015 (UtusanOnline, 2015), (c) A woman rental a top floor of shophouse trapped in a fire from grocery's shop in ground floor" – 2017 (AstroAwani, 2017)

Returning briefly to the issue of rapid growth of shop-house, fire occurred in this type of building has become a new concern as the owner of this type of building used lower floor for business purpose while the upper floor used for rental or occupied by owners or workers. In addition, this type of building has limited exit route and majority of deaths in fire building resulted from smoke inhalation during evacuation or trapped in the building (Bennetts & Poh, 2006; Tharmarajan, 2007; Cebela, 2012; and Luo, Li, Gao, Tian, & Hu, 2014). A heartfelt incident was reported previously where a couple suffocated to death in stairway of level 31st while escaping from level 38th when their high-rise apartment caught to fire (New York Daily News, 2014). This case is similar with building fire happened previously in 1998 at Upper West Side Apartment Tower, New York city which killed four people due to smoke inhalation in stairway during escape (The New York Times, 1998). The fire originated from the lower floor produced smoke which moved upwards to other level via stairway. During emergency, smoke in a stairway can affect vision and eventually suffocation to smoke thus affects the evacuation time. One major issue of fire research in multi-storey building is smoke propagated along stairway could poses a threat to occupants whom try to evacuate where there are cases of death (suffocate) reported due to victims trapped in the building. Fire management within the building is important to reduce the severity of risk from fire incidents and it generally begins with fire risk assessment. As stairway is the only measure for egress path in multi storey building, it is important to ensure the stairway is free access and is very well protected from smoke thus makes it worthwhile to study the fire and smoke behaviour in this area (LaFalam, Moseley, & Thomann, 2008; Yang, Rao, Zhu, Liu, & Zhan, 2012; Lambert & Merci, 2014; and Ji, Wan, Li, Li, & Sun, 2015). The findings could assist the determination and installation of effective smoke detection and control system which is technically dependent on the properties of hot gases or smoke. Beside evacuation, a stairway is also important as an entrance route for firefighters for rescue and fire extinguishment purposes.

In general, to reduce the severity of smoke hazards, preventing the fire occurrence and increase the fire safety of the building with the aim to improve the chance of successful fire evacuation, it is essential to conduct appropriate fire risk management. Risk assessment is part of risk management which is used as a basis to measure the risk when it can be managed. The process of risk analysis which quantify the probability and determination of physical process in building fire events is called full quantitative fire risk assessment (QRA). Full QRA is used to quantify level of risk to life safety, business, property, or environment for any individual building either during phase of design or occupancy in terms of:

i) Demonstrate equivalent life safety according to a building code compliance or satisfaction of fire risk criteria;
ii) Cost benefit analysis for property protection or business continuity; and
iii) Environmental impact assessment especially from large fires.

Even though this method requires a high degree of technical input and reliant on fire statistics and appropriate models available, the advantage of full QRA is they have a sound of theoretical basis and provide a numerical prediction of risk (Ramachandran & Charters, 2011). Basically, QRA adopts four main tasks: i) hazard identification, ii) frequency analysis, iii) consequence analysis and, iv) risk evaluation. Fire hazard can be defined as something with the potential to cause harm while risk defined as the combination of the frequency of an unwanted event and its consequences e.g. how often it might occur and how bad the outcome might be (Ramachandran and Charters, 2011). After the risk had been identified and assessed, the risk is evaluated to decide the level of fire risk for the risk treatment. The risk treatment application also known as risk reduction or risk control which based on hierarchy; i) elimination ii) prevention iii) mitigation and iv) control.

Risk assessment of fire and smoke movement in stairway is complicated according to its geometry, slope, opening and others. However, the analysis plays an important role in planning life-safety systems to protect occupants as stairway used as an escape route during evacuation. The severity of risks e.g. smoke layer height and temperature as an outcome of fire events are quantified in consequences analysis to assist the fire-safety engineer to explore different method in reducing the exposure of risks above. There are a number of ways which are reasonable to assess event consequences (Ramachandran and Charters, 2011) as follows;

i) historical data;
ii) disasters and near misses;
iii) experiments and fire tests; and
iv) modelling.

Consequences analysis based on historical and near misses data is not recommended due to lacks of information. To date there are several fire experiments were conducted to study smoke conditions in the single compartment of fire origin as well as in multi-compartment as event consequences. The room of fire origin usually referred as a fire in a single room and for the past of 50-years a number of researchers have produced various related findings and conclusion (Heselden, 1961; Mccaffrey, Quintiere, & Harkleroad, 1981; Kerber, 2012; Seo, Kim, Kim, & Kwon, 2013; De Sanctis, Fischer, Kohler, Faber, & Fontana, 2014).

Yang, Tan, & Xin, (2011) conducted a full-scale experiment in a multi-compartment storehouse to study the ignition manner, the fire spread and the combustion characteristics. Nevertheless, there are more examples of experimental studies conducted for multi-compartments (Wang, 2008; Olsthoorn, 2012, and Yi, Gao, Niu, & Yang, 2013). Moreover, apart from the study of smoke behaviour in a room, a multi-compartment configuration was also used to study the heat and smoke spread through the doors opening, ventilation ducts as well as leakage in nuclear industry (Audouin, Rigollet, Prétrel, Le Saux, & Röwekamp, 2013). Full-scale fire test is the best risk assessment method to obtain valuable information for the purpose of fire prevention and safety protection installation accordingly. However, fire experiments method is more expensive, unrepeatable and difficult to control. Modelling is an approach for predicting the various consequences of fires in buildings and there are three main approaches used which are simple calculation, zone, and field models.

Development of computer technology and tendency to replace prescriptive fire and building codes with performance-based codes has promoted the development of computer fire models to simulate fire and smoke movement such as FLUENT, FDS and PHOHENICS. Anyway, these models are complex and the user needs to have a fundamental understanding about the underlying fire dynamics calculation process to run the simulation. Furthermore, setting-up and running the computer simulation can be very time-consuming as it can take several days or weeks to obtain a result. Simple and transparent engineering methods can create opportunities to better understand a complex fire phenomenon and estimate the answer quickly before making decision (Xu, Xing, Jiang, & Li, 2019).

Simple and transparent engineering methods can create possibilities to better understand a complex fire phenomenon and estimate the answer quickly. In addition, simple calculations using mathematical models are good complement to the advanced computer models even though it has lower accuracy but offer simplified procedure (Johansson, 2015). It is useful to determine whether more detailed analysis is needed especially for different set of fire scenarios. The use of simple mathematical model also supported by another reason where it gives a possibility for engineers to make estimated calculations for a design related to fire safety. A mathematical model referred as McCaffrey, Quintiere and Harkleroad (MQH) correlation is one of the most well-known and widely used model to predict temperatures and smoke layer height for a single compartment. This correlation based on simple expression of energy balance where convective and conductive losses to enclosure are equivalent to the heat release rate (HRR) from the fire. Previous researchers had also developed a new mathematical method to predict smoke temperature and smoke layer height in a multi-compartment building. As described by Harada (2007), a method was used to calculate temperatures in fully developed multi-compartment fire also based on an energy balance. However, this method requires sub-models for smoke transport and conduction which make it complicated to be used in hand-calculation.

Another example was presented by Kim & Lilley (2000) which based on assumptions that the fire spread to the next room when flashover occurs. It has been discovered that both models reported on fully developed fire and there is less study on pre-flashover condition that used hand-calculation method. Thus, Johansson, (2015) had developed a new and simple expression for the relationship between the mass flow and the hot-gas-layer height in a pre-flashover fire in a multi-room with the help of existing plume models. With the help of qualitative best-fit analysis, two approximate expressions for the mass flow were established. Based on the result of those studies, it could create possibilities to propose a recommendation or guideline regarding compartment or building design for the reduction of fire consequences as well as severity. However, there is still lack of simple engineering methods which can be used to describe the smoke conditions in multi-storey building which become an interest because of many deaths reported while trapped mainly in the stairway due to suffocation during evacuation.

1.1 Problem statement

Fire safety engineering had address three objectives of fire system or strategy which are life safety, property loss prevention/business continuity and environmental protection. At the initial stage of fire growth, as a result of rising temperature and harmful gases emission, the main concern scientifically is life safety. After flashover, during fully developed fire, the concern shift from life safety to structural integrity, safety of fire fighters and soot generation release to environment. These circumstances need a quantitative fire risk assessment to select design fire scenario for deterministic analysis and/or quantify level of fire risk since the building fire could affect life safety, property loss/business continuity and environment. The most fundamental of fire safety goals in a building design is to ensure the life safety of occupants. The application of scientific and engineering principles to the fire protection in fire safety engineering to support building regulations (UBBL 1984) as the fire fighting guidance in “Guide to Fire Protection in Malaysia” may not adequately address the information on fire scenarios regarding to huge fire load in multi-storey building (Mustapha, 2018)(Ghani & Aripin, 2018). As was mentioned earlier, in the investigation of fire incident, smoke has been identified as a major cause of fatality in building fire. Locally in Malaysia, most of entertainment centre used multi-storey buildings as their premise and this place consist high intensity of people especially youth and tourist who are not aware and lacking of information on surroundings. It might create a problem when emergency happened at night as they do not know how to ask for help as happened in Ipoh recently. Six people died including two Vietnamese after an entertainment centre on the fourth floor caught on fire early morning where the cause of death was smoke inhalation (Kaur, 2019). Considering the stairway is the only route for evacuation and rescue when this type of building is on fire, with high intensity of people while evacuate it is important to ensure the stairway is free from smoke logging by installing fire protection measures. Essentially, the activation and effectiveness of smoke detection and control system is heavily dependent on hot gases or smoke, thus it is important to study the smoke conditions for the purpose of life safety and devices performance. By conducting a real experiment of fire, beside expensive it is hard to control and due to high humidity (>80%) of climate weather in this country, it might increase the corrosively of some equipment. Modelling with computer simulation (zone and field zone) can be used to predict some of the important factors such as smoke height layer and temperature for fire safety in new or existing building. However, a major problem with this kind of application is the complexity and the users need to have fundamental understanding on the underlying fire dynamics calculation process to run the simulation (Johansson, Svensson, & Hees, 2015). Furthermore, coding and running the computer simulation can be very time-consuming as it can take several days or weeks to obtain a result.

This study was conducted to develop a simple mathematical model used for smoke temperature prediction in stairway. Smoke spread from fire source to the stairway or upper level driven by buoyancy force that is the temperature difference which induced the air flow as demonstrated by previous field studies and experiment (Zohrabian, Mokhtarzadeh-Dehghan, Reynolds & Marriott, 1989; Feustel et al., 1985). Even though the calculation method might have lower accuracy than the computer simulation models, this method can provide an estimated value which is satisfactorily for the issues being studied. The gross estimation can also be used to decide whether a more detailed calculation using computer simulation is needed. Moreover, a simple mathematical model can be executed quickly while computer model may require hours or days to complete the simulation and provide the result (Kodur, Yu, & Dwaikat, 2013). This is very helpful when need to conduct a fire risk analysis for a multiple fire scenario cases. Finally, simple mathematical model can be used in parametric studies to improve knowledge of the factors that influence the conditions in compartment fire. Despite there are many consequences analysis methods available to predict smoke conditions which vary from point source models to highly complicated computational fluid dynamic models, only a few which have been validated for the use in s stairway of multi-storeys buildings (Chen et al., 2016)(Xia, 2014). The main goal of this study is to develop a new and validate simplified mathematical model to predict the smoke conditions in a multi-storey building specifically in a stairway which used as the only route for rescue and evacuation when fire happens. The findings could assist the determination of design related to fire safety and installation of effective smoke detection as well as control system in stairway which is technically dependent on the properties of hot gases or smoke.

1.2 Research Objective

The aim of this research is to develop a mathematical model to predict smoke temperature in a stairway of multi-storey building. From a problem statement explain above, three (3) objectives were created for this research:

i) To investigate the risk parameters in the stairway of multi-storey building according to life safety when fire occur;
ii) To develop a simplified mathematical model for stairway in multi-storey building where a sensitivity analysis also been conducted to determine how independent variables (stairway enclosure) will impact the smoke temperature as dependent variable.
iii) To determine the degree of verification of developed mathematical model by comparing with numerical simulation and previous experimental full-scale result

The developed model is used to investigate the smoke behaviour for smoke control design and rescue operation plan involving multiple fire scenarios in multi-storey building in Malaysia. Moreover, when evacuating through fire environment the presence of smoke not only affected the physiological of occupants but may also lead the occupants to adapt their evacuation strategy by adopting another exit. Thus, a proper evacuation strategy with alternative exit is required.

1.3 Scope and limitation

The scope of this research mainly focused on the smoke temperature in stairway of multi-storey building. The scope of this study is limited to:

i) Smoke movement analysis only considered in vertical shaft of the building as an escape route;
ii) The study is focused on a multi-storey building with a maximum of 3-storeys or 18 meters height, used for business purpose on the lowest floor and for occupancy on the upper floors;
iii) This study works on the well ventilated pre-flashover fire paradigm which focuses on the smoke layer temperature as this parameter is important criteria in life safety as well as for property protection analysis. The derived model is developed for constant heat release rate, so temporary conditions are not considered in the methods.

1.4 Significance of study

This study will provide several significant contributions for fire safety practitioners as well as researchers in the field of fire science that are considered valuable. The major contributions from this study are listed below:

i) A discussion of both complex and simple methods used to calculate the condition in spaces adjacent to fire originated room for fire risk analysis which have been valuable in fire science for several decades;
ii) The new model development was extended from existing smoke prediction model that is MQH correlation which previously widely applied in single- or multi-compartments;
iii) From this study, a new mathematical model is developed to predict smoke movement in vertical shaft adjacent to a fire originated compartment which is valuable contribution to fire engineers. It could be considered as a toolbox for quick estimated calculation in fire protection design evaluation as well as for fire risk analysis without specific training on the usage; and
iv) Based on experimental works done previously by other scholar, additional heat loss to the tread boards and landing were also included in developed mathematical correlation while calculating which influenced the smoke temperature.

Previous correlation developed based on numerical and experimental result are applied for single and multi-room purpose. Thus for this study, the correlation developed using numerical simulation for a stairway of multi-storey building is the novelty of this research.

REFERENCES

AG, C. (1964). *Fire Tests: Research into Fire Phenomena in a Four-Storey Building Carried Out in the Building Wiesental*. Mannedorf, Switzerland,.

Al-janabi, M. M. (2013). *The impact of sustainability on fire safety*. Victoria University of Wellington.

Alarifi, A. A., Dave, J., Phylaktou, H. N., Aljumaiah, O. A., & Andrews, G. E. (2014). Effects of fire-fighting on a fully developed compartment fire: Temperatures and emissions. *Fire Safety Journal*, *68*, 71–80. https://doi.org/10.1016/j.firesaf.2014.05.014

Albrecht, C. (2014). Quantifying life safety Part II: Quantification of fire protection systems. *Fire Safety Journal*, *64*, 81–86. https://doi.org/10.1016/j.firesaf.2014.01.002

Andersson, O. (2012). *Experiment! Chichester, United Kingdom.* https://doi.org/10.1002/ 9781118311059.

Andreozzi, A., Bianco, N., Musto, M., & Rotondo, G. (2014). Adiabatic surface temperature as thermal/structural parameter in fire modeling: Thermal analysis for different wall conductivities. *Applied Thermal Engineering*, *65*(1–2), 422–432. https://doi.org/10.1016/j.applthermaleng.2014.01.036

AstroAwani. (2017). Wanita maut dalam kebaran rumah kedai.

Audebert, M., Dhima, D., Taazount, M., & Bouchaïr, A. (2013). Thermo-mechanical behaviour of timber-to-timber connections exposed to fire. *Fire Safety Journal*, *56*, 52–64. https://doi.org/10.1016/j.firesaf.2013.01.007

Audouin, L., Rigollet, L., Prétrel, H., Le Saux, W., & Röwekamp, M. (2013). OECD PRISME project: Fires in confined and ventilated nuclear-type multi-compartments - Overview and main experimental results. *Fire Safety Journal*, *62*, 80–101. https://doi.org/10.1016/j.firesaf.2013.07.008

Babrauskas, V., & Peacock, R. D. (1992). Heat release rate: the single most important variable in fire hazard. *Fire Safety Journal*, *18*, 255–272.

Badreddine, A., & Amor, N. Ben. (2013). A Bayesian approach to construct bow tie diagrams for risk evaluation. *Process Safety and Environmental Protection*, *91*(3), 159–171. https://doi.org/10.1016/j.psep.2012.03.005

Barnett, C. R. (1984). *Pilot Fire Load Survey Carried Out for the New Zealand Fire Protection Association.* Auckland.

Baroudi, D. (2007). *Thermal models for fire safety – calculation of flame spread on surfaces and heating of structures*. Helsinki University of Technology.

Bengtsson, L.-G. (2001). *Enclosure fires*. (A.-L. Goransson & B. Svensson, Eds.). Sweden: Swedish Rescue Services Agency.

Bennetts, I. D., & Poh, K. W. (2006). Design of Sprinklered Shopping Centre Buildings for Fire Safety. Newcastle, Australia: OneSteel-Market Mills.

Best, R. (1982). *Investigation report on the MGM Grand Hotel Fire*. Quincy, MA.

Bittern, A. (2004). *Analysis of FDS Predicted Sprinkler Activation Times with Experiments*. University of Canterbury.

Bjelland, H. (2013). *Engineering Safety with application to fire safety design of buildigns and road tunnels*. University of Stavanger.

Buchanan, A. H., & Abu, A. K. (2017). *Structural Design for Fire Safety* (2nd Editio). United Kingdom: John Wiley & Sons.

Cebela, A. (2012). *Fire safety education for staff members - case study*. Lund University Sweden.

Chen, C.-J., Hsieh, W.-D., Hu, W.-C., Lai, C., & Lin, T.-H. (2010). Experimental investigation and numerical simulation of a furnished office fire. *Building and Environment*, *45*(12), 2735–2742. https://doi.org/10.1016/j.buildenv.2010.06.003

Chen, J., Fang, Z., & Yuan, J. (2013). Numerical Simulation about Smoke Vent Arrangement Influence on Smoke Control in Double-decked Tunnel. *Procedia Engineering*, *52*, 48–55. https://doi.org/10.1016/j.proeng.2013.02.104

Chen, K. M. G. (2010). *Analysis of Semi-Rigid Connections Subject to Fire Loads in a Steel Framework*. University of Waterloo.

Chen, K., Mackie, J. C., Kennedy, E. M., & Dlugogorski, B. Z. (2012). Determination of toxic products released in combustion of pesticides. *Progress in Energy and Combustion Science*, *38*(3), 400–418. https://doi.org/10.1016/j.pecs.2012.01.002

Chen, Y., Zhou, X., Fu, Z., Zhang, T., Cao, B., & Yang, L. (2016). Vertical temperature distributions in ventilation shafts during a fire. *Experimental Thermal and Fluid Science*, *79*, 118–125. https://doi.org/10.1016/j.expthermflusci.2016.07.007

Cheng, H. (2010). *Modelling of Fire Spread in Buildings ad Modelling of Fire Spread from the Fire Building to Adjacent Buildings*. Carleton University.

Cheng, L., Li, S., Ma, L., Li, M., & Ma, X. (2015). Fire spread simulation using GIS: Aiming at urban natural gas pipeline. *Safety Science*, *75*, 23–35. https://doi.org/10.1016/j.ssci.2015.01.002

Chou, H.-C., Yeh, C.-T., & Shu, C.-M. (2015). Fire accident investigation of an explosion caused by static electricity in a propylene plant. *Process Safety and Environmental Protection*. https://doi.org/10.1016/j.psep.2015.02.007

Chow, C. L., & Chow, W. K. (2010). Heat release rate of accidental fire in a supertall building residential flat. *Building and Environment*, *45*(7), 1632–1640. https://doi.org/10.1016/j.buildenv.2010.01.010

Chow, W. K. (2014). Fire Safety Concern for Supertall Buildings. In *ASHRAE Winter Conference* (pp. 1–12). New York: ASHRAE Transaction.

Chow, W. K., Han, S. S., & Kong, H. (2006). REPORT ON A RECENT FIRE IN A NEW CURTAIN-WALLED BUILDING, *8*(3), 84–87.

Chow, W. K., & Meng, L. (2007). Application of symbolic mathematics in modelling fire for providing a safe environment. *Building and Environment*, *42*(5), 1936–1948. https://doi.org/10.1016/j.buildenv.2006.04.009

Chu, G., & Sun, J. (2008). Decision analysis on fire safety design based on evaluating building fire risk to life. *Safety Science*, *46*(7), 1125–1136. https://doi.org/10.1016/j.ssci.2007.06.011

Cohan, B. D. (2010). *Verification and Validation of a Candidate Soot Deposition Model in Fire Dynamic Simulator*. University of Maryland.

Cooper, L. Y., & Stroup, D. W. (1985). ASET-A computer program for calculating available safe egress time. *Fire Safety Journal*, *9*(1), 29–45. https://doi.org/10.1016/0379-7112(85)90028-1

Cutonilli, J., Associates, H., Ferreira, M. J., Associates, H., Ferreira, M. J., & Cutonilli, J. (2008). Protecting the Stair Enclosure in Tall Buildings Impacted by Stack Effect. Unpublished conference paper Magazine .

Dadashzadeh, M., Khan, F., Hawboldt, K., & Amyotte, P. (2013). An integrated approach for fire and explosion consequence modelling. *Fire Safety Journal*, *61*, 324–337. https://doi.org/10.1016/j.firesaf.2013.09.015

Daisaki, N., Noe, T., Kazunori, H., Yoshifumi, O., Yamana, T., & Hagiwara, I. (2004). A model of smoke movement in stair shafts. *International Association for Fire Safety Science*, 12. Retrieved from http://www.iafss.org/publications/aofst/6/1b-1/view/aofst_6-1b-1.pdf

De Sanctis, G., Fischer, K., Kohler, J., Faber, M. H., & Fontana, M. (2014). Combining engineering and data-driven approaches: Development of a generic fire risk model facilitating calibration. *Fire Safety Journal*, *70*, 23–33. https://doi.org/10.1016/j.firesaf.2014.08.017

Debrouwere, B. (2012). *A study on initial fire behaviour in low-energy houses*. Ghen University.

Delichatsios, M. A., Lee, Y., & Tofilo, P. (2009). A new correlation for gas temperature inside a burning enclosure. *Fire Safety Journal*, *44*(8), 1003–1009. https://doi.org/10.1016/j.firesaf.2009.06.009

Department of Occupational Safety and Health (DOSH). (2014). *Guidelines for Hazard Identification, Risk Assessment and Risk Control*. Malaysia: Ministry of Human Resources.

Doheim, R. M., Yohanis, Y. G., Nadjai, A., & Elkadi, H. (2014). The impact of atrium shape on natural smoke ventilation. *Fire Safety Journal*, *63*, 9–16. https://doi.org/10.1016/j.firesaf.2013.11.005

Dong, W., & Liang, D. (2013). Simulation of the Atrium Fire Smoke Flow and Research about Control Studies. *Procedia Engineering*, *52*, 92–96. https://doi.org/10.1016/j.proeng.2013.02.111

Door, F., Piawaian, T., Of, M., The, D., Of, P., Door, C., & Devices, C. (2009). Senarai piawaian yang dirujuk oleh jabatan bomba dan penyelamat malaysia bagi pengeluaran sijil perakuan bahan.

Drysdale, D. (2001). Fire safety design requirements of flame-retarded materials. In A. Harrocks & D. Price (Eds.), *Fire retardant material* (3rd ed., p. 378). USA: Woodhead Publishing Ltd.

Eduful, J. (2012). *Correlation of fire load survey methodologies towards design fires for office buildings*. Carleton University.

Environmental Protection Agency (EPA). (2015). Retrieved from https://www.epa.gov/science-and-technology/substances-and-toxics-science

Ergin-Özkan, S., Mokhtarzadeh-Dehghan, M. R., & Reynolds, A. J. (1995). Experimental study of natural convection between two compartments of a stairwell. *International Journal of Heat and Mass Transfer*, *38*(12), 2159–2168. https://doi.org/10.1016/0017-9310(94)00350-5

Fang, J., Jie, J., Hong-Yong, Y., & Yong-Ming, Z. (2006). Early fire smoke movements and detection in high large volume spaces. *Building and Environment*, *41*, 1482–1493.

Fang, L., Nielsen, P. V, & Brohus, H. (2007). *Investigation on Smoke Movement and Smoke Control for Atrium in Green and Sustainable Buildings*. Denmark.

Farid Wajdi, A., Brit, A. K., & Nor Haniza, I. (2013). Quantitative Risk Assessment for Performance-Based Building Fire Regulation. In *The 3 rd International Building Control Conference* (p. 9). Kuala Lumpur, Malaysia.

Farouk, A., Gawad, A., & Ghulman, H. A. (2015). Prediction of Smoke Propagation in a Big Multi-Story Building Using Fire Dynamics Simulator (FDS). *American Journal of Energy Engineering*, *3*(4–1), 23–41. https://doi.org/10.11648/j.ajee.s.2015030401.12

Fernando, A. E. (2000). *Modelling of fire spread and the growth of fire in buildings using computational fluid dynamics*. Victoria University of Technology.

Feustel, H., Zuercher, C. H., Diamond, R., Dickinson, B., Grimsrud, D., & R. Lipschutz. (1985). Temperature- and wind-induced air flow patterns in a stairwell: computer modeling and experimental verification. *Energy and Buildings*, *8*, 105–122.

Floyd, J., Overholt, K., & Ezekoye, O. (2014). Soot Deposition and Gravitational Settling Modeling and the Impact of Particle Size and Agglomeration. In *International Association for Fire Safety Science*.

Fong, C. C. ., & Chow, W. . (2011). Fire Load Density Survey in Four Shopping Malls in Hong Kong. *International Journal on Engineering Performance Based Fire Codes*, *10*(1), 12–16.

Fowell, A. J. (1985). Assessing toxic hazard as it relates to overall fire hazard. *Fire Technology*, *21*(3), 199–212. https://doi.org/10.1007/BF01039974

FRDM. (2015). Fire Statistic in Malaysia 2008-2014.

Fullwood, R. R. (2000). *Probabilistic Safety Assessment in the Chemical and Nuclear Industries*. *Probabilistic Safety Assessment in the Chemical and Nuclear Industries*. Elsevier. https://doi.org/10.1016/B978-075067208-5/50013-5

Gao, Y., Liu, Q. K., Chow, W. K., & Wu, M. (2014). Analytical and experimental study on multiple fire sources in a kitchen. *Fire Safety Journal*, *63*, 101–112. https://doi.org/10.1016/j.firesaf.2013.12.001

Ghani, M. Z. A., & Aripin, S. (2018). A comparative review of design requirements for natural smoke ventilation in hospital buildings. *Planning Malaysia*, *16*(2), 334–344.

Giebułtowicz, J., Rużycka, M., Wroczyński, P., Purser, D. A., & Stec, A. A. (2017). Analysis of fire deaths in Poland and influence of smoke toxicity. *Forensic Science International*, *277*, 77–87. https://doi.org/https://doi.org/10.1016/j.forsciint.2017.05.018

Glasa, J., Valasek, L., Weisenpacher, P., & Halada, L. (2013). Cinema Fire Modelling by FDS. *Journal of Physics: Conference Series*, *410*, 5. https://doi.org/10.1088/1742-6596/410/1/012013

Gollner, M., Kimball, A., & Vecchiarelli, T. (2012). *Fire Safety Design and Sustainable buildings: Challenges and Opportunities*.

Gorbett, G. E., & Pharr, J. L. (2016). *Fire Dynamics 1st edition*.

Grimwood, P., & Sanderson, I. A. (2015). A performance based approach to defining and calculating adequate firefighting water using s.8.5 of the design guide BS PD 7974:5:2014 (fire service intervention). *Fire Safety Journal*, *78*, 155–167. https://doi.org/10.1016/j.firesaf.2015.08.007

Grunt, O., & Briš, R. (2015). SPN as a tool for risk modeling of fires in process industries. *Journal of Loss Prevention in the Process Industries*, *34*, 72–81. https://doi.org/10.1016/j.jlp.2015.01.024

Hadjisophocleous, G. V, & Fu, Z. (2004). LITERATURE REVIEW OF FIRE RISK ASSESSMENT METHODOLOGIES, *6*(1), 28–45.

Hamins, A., & McGrattan, K. (2007). *Verification and Validation of Selected, Volume 2: Experimental Uncertainty*.

Han, Z., Weng, W., & Huang, Q. (2013). Numerical Investigation on the Effects of Human Movements on Smoke Propagation in Building Fire. *Procedia Engineering*, *62*, 470–477. https://doi.org/10.1016/j.proeng.2013.08.089

Harada, K. A. (2007). Calculation method for fully developed fire temperature for multi-room fire spread scenarios. In *Proceedings of the Seventh Asia-Oceania Symposium on Fire Science and Technology*. Asian-Oceania Fire Science and Technology.

Hartzell, G. . (2001). Engineering analysis of hazards to life safety in fires: the fire effluent toxicity component. *Safety Science*, *38*(2), 147–155. https://doi.org/10.1016/S0925-7535(00)00065-5

He, Q., Ezekoye, O. A., Li, C., & Lu, S. (2015). Ventilation limited extinction of fires in ceiling vented compartments. *International Journal of Heat and Mass Transfer*, *91*, 570–583. https://doi.org/10.1016/j.ijheatmasstransfer.2015.07.080

He, Y. of, & Beck, V. (1997). Smoke in the Spread Experiment in A Multi-Story Building and Computer Modeling. *Fire Safety Journal*, *96*, 49–60. https://doi.org/139-16410.1016/S0379-7112(96)00081-1.

Heselden, A. (1961). *Some fires in a single compartment with independent variation of fuel surface area and thickness*. Boreham Wood, UK.

Horváth, I., van Beeck, J., & Merci, B. (2013). Full-scale and reduced-scale tests on smoke movement in case of car park fire. *Fire Safety Journal*, *57*, 35–43. https://doi.org/10.1016/j.firesaf.2012.10.009

Hu, X., Wang, Z., Jia, F., Galea, E. R., & Patel, M. K. (2011). Simulating Smoke Transport in Large Scale Enclosure Fires Using a Multi-Particle-Size Model. In *International Association for Fire Safety Science* (pp. 445–458). https://doi.org/10.3801/IAF

Ji, J., Wan, H., Li, Y., Li, K., & Sun, J. (2015). Influence of relative location of two openings on fire and smoke behaviors in stairwell with a compartment. *International Journal of Thermal Sciences*, *89*, 23–33. https://doi.org/10.1016/j.ijthermalsci.2014.10.008

Johansson, N. (2013). *Numerical experiments-a research method in fire science*. Lund University.

Johansson, N. (2014). Numerical experiments and compartment fires. *Fire Science Reviews*, *3*(2), 1–12. https://doi.org/http://firesciencereviews.springeropen.com/articles/10.1186/s40038-014-0002-2

Johansson, N. (2015). *Fire Dynamics of Multi-Room Compartment Fires*. Lund University.

Johansson, N., & Hees, P. V. A. N. (2014a). A Simplified Relation Between Hot Layer Height and Opening Mass Flow, *60*(1), 432–443. https://doi.org/10.3801/IAFSS.FSS.11-432

Johansson, N., & Hees, P. Van. (2014b). A correlation for predicting smoke layer temperature in a room adjacent to a room involved in a pre- fl ashover fi re. *Fire and Material*, *38*(December 2012), 182–193. https://doi.org/10.1002/fam

Johansson, N., Svensson, S., & Hees, P. Van. (2015). An evaluation of two methods to predict temperatures in multi-room compartment fires. *Fire Safety Journal*, *77*, 46–58. https://doi.org/10.1016/j.firesaf.2015.07.006

Johansson, N., Wahlqvist, J., & Van Hees, P. (2013). SIMPLE CEILING JET CORRELATION DERIVED FROM NUMERICAL EXPERIMENTS. In *Proceedings of the 13th International Interflam Conference* (pp. 61–72). Interscience Communications.

Karlsson, B., & Quintiere, J. G. (1999). *Enclosure Fire Dynamics*. United States of America: CRC Press LLC.

Karlsson, B., & Quintiere, J. G. (2000). *Enclosure Fire Dynamics Fire Dynamics*. United States of America: CRC Press LLC.

Kaur, M. (2019, February 20). Ipoh karaoke fire: Six dead, including two Viet girls. *Star Online*.

Kawagoe, K. (1967). *Estimation of fire temperature-time curve in rooms. Research paper no. 29*. Tokyo, Japan.

Kawagoe, K., & Sekine, T. (1964). *Estimation of fire temperature-time curve in rooms. Second report. Occasional report no. 17*. Tokyo, Japan.

Keogh, C., & Lord, J. (2012). *Guidelines for Designing Fire Safety in Very Tall Buildings*.

Kerber, S. (2012). Analysis of One and Two-Story Single Family Home Fire Dynamics and the Impact of Firefighter Horizontal Ventilation. *Fire Technology*, *49*(4), 857–889. https://doi.org/10.1007/s10694-012-0294-5

Kim, H., & Lilley, D. G. (2000). Heat release rate of burning items in fires. In *38th Aerospace Sciences Meeting and Exhbit* (p. 27). Oklahoma, United State: American Institute of Aeronautics and Astronautics.

Klem, T. J. (1988). *Fire Investigation Report: First Interstate Bank Building of California Fire, Los Angeles, CA*. Quincy, MA.

Kodur, V. K. R., Yu, B., & Dwaikat, M. M. . (2013). A simplified approach for predicting temperature in reinforced concrete members exposed to standard fire. *Fire Safety Journal*, *56*, 39–51. https://doi.org/10.1016/j.firesaf.2012.12.004

KPKT. (2015). *Statistics 2015*. Putrajaya, Malaysia.

KPKT. (2017). *Kementerian Kesejahteraan Bandar, Perumahan dan Kerajaan Bandar Statistics 2017*. Putrajaya, Malaysia.

LaFalam, R., Moseley, J., & Thomann, R. (2008). *Analysis of Sprinkler use in a Library Stack Room Using Fire Dynamics Simulator*. Worcester Polytechnic Institute.

Lai, C., Chen, C.-J., Tsai, M.-J., Tsai, M.-H., & Lin, T.-H. (2013). Determinations of the fire smoke layer height in a naturally ventilated room. *Fire Safety Journal*, *58*, 1–14. https://doi.org/10.1016/j.firesaf.2013.01.015

Lai, C., Chen, K.-J., Chen, C.-J., Tzeng, C.-T., & Lin, T.-H. (2010). Influence of fire ignition locations on the actuation of smoke detectors and wet-type sprinklers in a furnished office. *Building and Environment*, *45*(6), 1448–1457. https://doi.org/10.1016/j.buildenv.2009.12.008

Lambert, K., & Merci, B. (2014). Experimental Study on the Use of Positive Pressure Ventilation for Fire Service Interventions in Buildings with Staircases. *Fire Technology*, *50*(6), 1517–1534. https://doi.org/10.1007/s10694-013-0359-0

Landucci, G., Argenti, F., Tugnoli, A., & Cozzani, V. (2015). Quantitative assessment of Safety Barrier Performance in the Prevention of Domino Scenarios Triggered by Fire. *Reliability Engineering & System Safety*. https://doi.org/10.1016/j.ress.2015.03.023

Lay, S. (2014). Pressurization systems do not work and present a risk to life safety. *Case Studies in Fire Safety*, *1*, 13–17. https://doi.org/10.1016/j.csfs.2013.12.001

Lee, J., Kim, J., & Kim, S. (2011). Formaldehyde emission and burning behaviors from wood- based panels according to various surface finishing methods. *5th International Symposium on Sustaianable Healthy Buildings*, (February), 327–334.

Lennon, T., & Moore, D. (2003). The natural fire safety concept—full-scale tests at Cardington. *Fire Safety Journal*, *38*(7), 623–643. https://doi.org/10.1016/S0379-7112(03)00028-6

Li, H., Fan, C., & Wang, J. (2014). Effects of Wind and Adjacent High Rise on Natural Smoke Extraction in an Atrium with Pitched Roof. *APCBEE Procedia*, *9*, 296–301. https://doi.org/10.1016/j.apcbee.2014.01.053

Li, K. Y., Hu, L. H., Huo, R., Li, Y. Z., Chen, Z. B., Li, S. C., & Sun, X. Q. (2009). A mathematical model on interaction of smoke layer with sprinkler spray. *Fire Safety Journal*, *44*(1), 96–105. https://doi.org/10.1016/j.firesaf.2008.04.003

Li, S. C., Chen, Y., & Li, K. Y. (2011). A mathematical model on adjacent smoke filling involved sprinkler cooling to a smoke layer. *Safety Science*, *49*(5), 670–678. https://doi.org/10.1016/j.ssci.2011.01.001

Li, X., Zhang, X., & Hadjisophocleous, G. (2013). Fire Risk Analysis of a 6-storey Residential Building Using CUrisk. *Procedia Engineering*, *62*, 609–617. https://doi.org/10.1016/j.proeng.2013.08.106

Lin, C.-H., Ferng, Y.-M., & Pei, B.-S. (2009). Development of CFD fire models for deterministic analyses of the cable issues in the nuclear power plant. *Nuclear Engineering and Design*, *239*(2), 338–345. https://doi.org/10.1016/j.nucengdes.2008.09.010

Lin, C. S., & Chen, T. C. (2013). Numerical Modeling of Fire Dynamic Behavior for a Five-Story Building. *Applied Mechanics and Materials*, *365–366*, 145–149. https://doi.org/10.4028/www.scientific.net/AMM.365-366.145

Liu, J., & Chow, W. K. (2014). Determination of Fire Load and Heat Release Rate for High-rise Residential Buildings. *Procedia Engineering*, *84*, 491–497. https://doi.org/10.1016/j.proeng.2014.10.460

Livkišs, K. (2012). *Fully developed fires in low energy and energy efficient ” buildings*. Lund University, Sweden.

Lönnermark, A., & Björklund, A. (2008). *Smoke Spread and Gas Temperatures during Fires in Retail Premises - Experiments and CFD Simulations*. Sweden.

Luo, N., Li, A., Gao, R., Song, T., Zhang, W., & Hu, Z. (2014). Performance of smoke elimination and confinement with modified hybrid ventilation for subway station. *Tunnelling and Underground Space Technology*, *43*, 140–147. https://doi.org/10.1016/j.tust.2014.05.001

Luo, N., Li, A., Gao, R., Tian, Z., & Hu, Z. (2014). Smoke confinement utilizing the USME ventilation mode for subway station fire. *Safety Science*, *70*, 202–210. https://doi.org/10.1016/j.ssci.2014.06.002

Luo, N., Li, A., Gao, R., Zhang, W., & Tian, Z. (2013). An experiment and simulation of smoke confinement utilizing an air curtain. *Safety Science*, *59*, 10–18. https://doi.org/10.1016/j.ssci.2013.04.009

M.O., S., Li, Z., Liang, D., Li, J., & Zhou, N. (2013a). Analysis of Smoke Hazard in Train Compartment Fire Accidents Base on FDS. *Procedia Engineering*, *52*, 284–289. https://doi.org/10.1016/j.proeng.2013.02.141

M.O., S., Li, Z., Liang, D., Li, J., & Zhou, N. (2013b). Analysis of Smoke Hazard in Train Compartment Fire Accidents Base on FDS. *Procedia Engineering*, *52*, 284–289. https://doi.org/10.1016/j.proeng.2013.02.141

Martin, D., Tomida, M., & Meacham, B. (2015). *The Environmental Impact of Fire: Final Report*. Worcester.

Mccaffrey, B. J., Quintiere, J. G., & Harkleroad, M. F. (1981). Estimating Room Temperatures and the Likelihood of Flashover Using Fire Test Data Correlations. *Fire Technology*, *17*(2), 22. https://doi.org/http://link.springer.com/article/10.1007%2FBF02479583

McGrattan, K. B., Hamins, A., & Stroup, D. W. (1998). *Sprinkler, Smoke and Heat Vent, Draft Curtain Interaction – Large Scale Experiments and Model Development*. Gaithersburg, MD.

Mcgrattan, K., Hostikka, S., McDermot, R., Floyd, J., Weinschenk, C., & Overholt, K. (2013). Fire Dynamics Simulator User ' s Guide. USA: National Institute of Standards and Technology.

Mcgrattan, K., Peacock, R., & Overholt, K. (2016). Validation of Fire Models Applied to Nuclear Power Plant Safety. *Fire Technology*, *52*, 5–24. https://doi.org/10.1007/s10694-014-0436-z

McGuire, J. H., & Tamura, G. T. (1977). Simple Analysis of Smoke-Flow Problems in High BuiMings. *Fire Technology*, 15–22.

Meacham, B., Poole, B., Echeverria, J., & Cheng, R. (2012). *Fire Safety Challenges of Green Buildings*. USA.

Mehaffey, J. R. (1987). *Combustibility of Building Material, Designing for Fire Safety: The Science and its Application to Building Codes*. Canada.

Metro, H. (2010). Empat sekeluargra terbunuh dalam kebakaran.

Miller, R. S., & Beasley, D. (2009). On stairwell and elevator shaft pressurization for smoke control in tall buildings. *Building and Environment*, *44*(6), 1306–1317. https://doi.org/10.1016/j.buildenv.2008.09.015

Mo, S., Li, Z., Liang, D., Li, J., & Zhou, N. (2013). Analysis of Smoke Hazard in Train Compartment Fire Accidents Base on FDS. *Procedia Engineering*, *52*, 284–289. https://doi.org/10.1016/j.proeng.2013.02.141

Mokhtarzadeh-Dehghan, M. R. (2011). Numerical simulation and comparison with experiment of natural convection between two floors of a building model via a stairwell. *International Journal of Heat and Mass Transfer*, *54*(1–3), 19–33. https://doi.org/10.1016/j.ijheatmasstransfer.2010.09.067

Mustapha, N. A. (2018). *Fire Safety on High Rise Residential Building in Shah Alam*. University Malaysia Pahang.

Mydin, M. A. O., Arminda, W., & Sani, N. M. (2014). Fire Risk Assessment of Adaptive Re-Use of Historic Shop Houses for Sleeping Accommodations in Malaysia. *MATEC Web of Conferences*, *17*, 01011. https://doi.org/10.1051/matecconf/20141701011

Nakaya, I., Tanaka, T., Yoshida, M., & Steckler, K. (1986). Doorway flow induced by propane fire. *Fire Safety Journal*, *10*, 185–195.

Nielsen, J. G. (2013). *Validation Study of Fire Dynamics Simulator*. Aalborg University.

Nur, S., Saruddin, A., & Mohamed, F. (2015). Fragility curves for low- and mid-rise buildings in Malaysia. *Procedia Engineering*, *125*, 873–878. https://doi.org/10.1016/j.proeng.2015.11.056

Ocran, N. (2012). *Fire loads and design fires for mid-rise buildings*. Carleton University.

Ocran, N. (2014). *Technical Note 4* (June 2014 No. Technical Note 4).

Odigie, D. (2000). *The Investigation of Fire Hazards in Buildings using Stochastic Modelling*. VIctori University, Melbourne.

Oladokun, V. O., & Ishola, F. A. (2010). A Risk Analysis Model for Fire Disasters in Commercial Complexes in Nigeria . *The Pacific Journal of Science and Technology*, *11*(2), 376–386.

Olenick, S. M. (2015). International Survey of Computer Models for Fire and Smoke. Retrieved from http://www.firemodelsurvey.com/

Olsthoorn, M. (2012). *FDS validation and grid resolution study for large atrium buildings*. University of Edinburgh.

Omidvari, M., Mansouri, N., & Nouri, J. (2015). A pattern of fire risk assessment and emergency management in educational center laboratories. *Safety Science*, *73*, 34–42. https://doi.org/10.1016/j.ssci.2014.11.003

Osborne, L. (2010). *THE EFFECTS OF FLOOR AREA AND OPENING AREA ON THE DEVELOPMENT OF FIRES IN RESIDENTIAL DWELLINGS*. Carleton University.

Overholt, K. J. (2014). *Verification and Validation of Commonly Used Empirical Correlations for Fire Scenarios*. *NIST Special Publication 1169*. United States of America. https://doi.org/http://dx.doi.org/10.6028/NIST.SP.1169

Peacock, R., Stanford, D., & Lee, B. (1988). *An experimental data set for the accuracy assessment of room fire models. National Bureau of Standards*.

Perangkaan Sosial Negeri-Daerah Malaysia. (2013). Jabatan Perangkaan Malaysia.

Pula, R., Khan, F. I., Veitch, B., & Amyotte, P. R. (2005). Revised fire consequence models for offshore quantitative risk assessment. *Journal of Loss Prevention in the Process Industries*, *18*(4–6), 443–454. https://doi.org/10.1016/j.jlp.2005.07.014

Qian-li, M., & Ting-lin, H. (2011). Analysis of and Study on the Difficulties in the Fire Protection Design of Large Commercial Complex. *Procedia Engineering*, *11*, 302–307. https://doi.org/10.1016/j.proeng.2011.04.661

Qu, L., & Chow, W. K. (2013). Common practices in fire hazard assessment for underground transport stations. *Tunnelling and Underground Space Technology*, *38*, 377–384. https://doi.org/10.1016/j.tust.2013.07.018

Quintiere, J. . (2002). Fire behavior in building compartments. *Proceedings of the Combustion Institute*, *29*(1), 181–193. https://doi.org/10.1016/S1540-7489(02)80027-X

Quintiere, J. G., & Wang, L. (2009). A general formula for the prediction of vent flows, *44*, 789–792. https://doi.org/10.1016/j.firesaf.2009.03.012

Ramachandran, G., & Charters, D. (2011). *Quantitative Risk Assessment in Fire Safety*. London, United Kingdom: Taylor & Francis LTD.

Rao, P. (2014). *Fire Risk Analysis of Combustible and Non-Combustible Mid-Rise Residential Building USing CuRisk*. Carleton University.

Riahi, S., & Beyler, C. (2011). Measurement and Prediction of Smoke Deposition from a Fire against a Wall. In *International Association for Fire Safety Science* (pp. 641–654). https://doi.org/10.3801/IAF

Rie, D.-H., Hwang, M.-W., Kim, S.-J., Yoon, S.-W., Ko, J.-W., & Kim, H.-Y. (2006). A study of optimal vent mode for the smoke control of subway station fire. *Tunnelling and Underground Space Technology*, *21*(3–4), 300–301. https://doi.org/10.1016/j.tust.2005.12.157

Rong, T. Y., Akashah, F., & Mahyuddin, N. (2014). Agent-Based Fire Evacuation Model as a Tool for Fire Safety Design Assessment in Malaysia. *International Journal of Property Sciences*, *4*(1), 1–13.

Rutherford, I. (2002). *Experimental Results for Pre-flashover Fire Experiments in Two Dajacent ISO Compartments*.

Salem, A. M. (2013). Parametric analysis of a cabin fire using a zone fire model. *Alexandria Engineering Journal*, *52*(4), 627–636. https://doi.org/10.1016/j.aej.2013.10.001

Shariff, A. M., & Wahab, N. A. (2013). Inherent fire consequence estimation tool (IFCET) for preliminary design of process plant. *Fire Safety Journal*, *59*, 47–54. https://doi.org/10.1016/j.firesaf.2013.03.015

Shen, T.-S., Huang, Y.-H., & Chien, S.-W. (2008). Using fire dynamic simulation (FDS) to reconstruct an arson fire scene. *Building and Environment*, *43*(6), 1036–1045. https://doi.org/10.1016/j.buildenv.2006.11.001

Shi, C. L., Li, Y. Z., Huo, R., Yao, B., Chow, W. K., & Fong, N. K. (2005). Mechanical smoke exhaust for small retail shop fires. *International Journal of Thermal Sciences*, *44*(5), 477–490. https://doi.org/10.1016/j.ijthermalsci.2004.10.002

Shi, L., & Chew, M. Y. L. (2013). Fire behaviors of polymers under autoignition conditions in a cone calorimeter. *Fire Safety Journal*, *61*, 243–253. https://doi.org/10.1016/j.firesaf.2013.09.021

Shrivastava, P. R., & Sawant, P. H. (2013). Estimation of Fire Loads for an Educational Building - A Case Study. *International Journal of Scientific Engineering and Technology*, *391*(2), 388–391.

Soja, E. (1995). *The use of the cone calorimter or determining the hazard of the building materials and contents in fire*. New Zealand. https://doi.org/ISSN:0113-3675

Stec, A., & Hull, R. (2010). *Fire Toxicity*. (A. Stec & R. Hull, Eds.), *Fire Toxicity* (1st editio). North America, USA: Woodhead Publishing Ltd. https://doi.org/10.1016/B978-1-84569-502-6.50025-7

Stroup, D. W. (2003). *Literature Review on Enclosure of Elevator Lobbies*. *Technology*. United State.

Sun, X. Q., Hu, L. H., Chow, W. K., Xu, Y., & Li, F. (2011). A theoretical model to predict plume rise in shaft generated by growing compartment fire. *International Journal of Heat and Mass Transfer*, *54*, 910–920. https://doi.org/10.1016/j.ijheatmasstransfer.2010.10.012

Sun, X. Q., Hu, L. H., Li, Y. Z., Huo, R., Chow, W. K., Fong, N. K., … Li, K. Y. (2009). Studies on smoke movement in stairwell induced by an adjacent compartment fire. *Applied Thermal Engineering*, *29*(13), 2757–2765. https://doi.org/10.1016/j.applthermaleng.2009.01.009

Sun, X. Q., Li, Y. Z., Zhang, J. Y., & Tu, R. (2007). NUMERICAL STUDIES ON STAIRWELL SMOKE MOVEMENT INDUCED BY AN ADJOINING COMPARTMENT FIRE. *International Association for Fire Safety Science*, 1–11. Retrieved from http://www.iafss.org/publications/aofst/7/124/view/aofst_7-124.pdf

SyedFadzil, S. F., & AL-Absi, Z. A. (2016). No Title. In S. S. Zubir, C. A. Brebbia, & A. S. Hassan (Eds.), *Sustainable Development and Planning VIII* (p. 809). Malaysia: WIT Press.

Tharmarajan, P. (2007). *The Essential Aspects of Fire Safety Management in High-Rise Buildings*. Universiti Teknology Malaysia.

Thauvoye, C., Zhao, B., Klein, J., & Fontana, M. (2008). Fire Load Survey and Statistical Analysis. In *Fire Safety Science Proceedings of the Ninth International Symposium* (Vol. 9, pp. 991–1002). International Association for Fire Safety Sience. https://doi.org/10.3801/IAFSS.FSS.9-991

Thomas, P. (1967). *Theoretical Considerations of the Growth to Flashover of Compartment Fires. Fire Research Note 663.* Boreham Wood, UK.

Tilley, N., Deckers, X., & Merci, B. (2012). CFD study of relation between velocity and smoke backlayering distances in large closed carpark. *Fire Safety Journal*, *48*, 11–20.

Tilley, N., Deckers, X., & Merci, B. (2012). CFD study of relation between ventilation velocity and smoke backlayering distance in large closed car parks. *Fire Safety Journal*, *48*, 11–20. https://doi.org/10.1016/j.firesaf.2011.12.005

UtusanOnline. (2015). Wanita maut dalam kebakaran rumah kedai.

UtusanOnline. (2017, August). Pendawaian punca utama kebakaran. *Utusan Online*.

Valbuena, G., & Modarres, M. (2009). Development of probabilistic models to estimate fire-induced cable damage at nuclear power plants. *Nuclear Engineering and Design*, *239*(6), 1113–1127. https://doi.org/10.1016/j.nucengdes.2009.01.003

Walton, W. D., & Thomas, P. H. (2008). “Estimating Temperatures in Compartment Fires.” In P. J. DiNenno (Ed.), *SFPE Handbook of Fire Protection Engineering.* (4th ed., pp. 204–222). Bethesda, MD, USA,: The Society of Fire Protection Engineers.

Wang, P., Ban, Q., Liu, J., & Zhao, C. (2013). Impacts of Staircase Windows on Pressurized Ventilation System. *Procedia Engineering*, *52*, 363–370. https://doi.org/10.1016/j.proeng.2013.02.154

Wang, Y. (2008). *A study of smoke movement in multi-storey buildings using experiments and computer modelling*. Carleton University. https://doi.org/10.1017/CBO9781107415324.004

Wang, Y. (2011). An Experimental Study of Smoke Movement in Multi-Storey Buildings. *Fire Technology*, *47*, 1141–1169. https://doi.org/10.1007/s10694-009-0132-6

Weyenberge, B. Van, & Deckers, X. (2014). DEVELOPMENT OF A RISK ASSESSMENT METHOD FOR FIRE IN RAIL TUNNELS. In *7th International Conference Tunnel Safety and Ventilation 2014* (Vol. 2, pp. 180–189).

Willi, J. M., Horn, G. P., & Madrzykowski, D. (2016). Characterizing a Firefighter ’ s Immediate Thermal Environment in Live-Fire Training. *Fire Technology*, 30. https://doi.org/10.1007/s10694-015-0555-1

Xia, Y. (2014). Simulation on spread of fire smoke in the elevator shaft for a high-rise building. *Theoretical and Applied Mechanics Letters*, *4*(3), 34007. https://doi.org/10.1063/2.1403407

Xin, J., & Huang, C. F. (2013). Fire Risk Assessment of Residential Buildings Based on Fire Statistics from China. *Fire Technology*, *50*(5), 1147–1161. https://doi.org/10.1007/s10694-013-0327-8

Xu, P., Xing, R. J., Jiang, S. P., & Li, L. J. (2019). Theoretical prediction model and full-scale experimental study of central smoke extraction with a uniform smoke rate in a tunnel fi re. *Tunneling and Underground Space TEchnology*, *86*(66), 63–74. https://doi.org/10.1016/j.tust.2019.01.014

Xu, X. Y., Li, Y. Z., & Mao, S. H. (2011). Model for neutral-plane location in shaft in fire. *Journal of Combustion Science and Technology.*, *17*, 375–381.

Xu, Z., Tang, F., & Ren, A. (2010). Smoke assessment of building fire based on FDS and GIS. In W. Tizani (Ed.), *Proceedings of the International COnference on Computing in Civil and Building Engineering* (pp. 1–6). China: Nottingham University Press.

Yan, H. W. (2005). *Fire Safety Concerns for New Architectural Features*. THe Hong Kong Polytechnic University.

Yang, L., Rao, P., Zhu, K., Liu, S., & Zhan, X. (2012). Observation study of pedestrian flow on staircases with different dimensions under normal and emergency conditions. *Safety Science*, *50*(5), 1173–1179. https://doi.org/10.1016/j.ssci.2011.12.026

Yang, P., Tan, X., & Xin, W. (2011). Experimental study and numerical simulation for a storehouse fire accident. *Building and Environment*, *46*(7), 1445–1459. https://doi.org/10.1016/j.buildenv.2011.01.012

Yatim, Y. M. (2009). *Fire Safety Models for High-Rise Residential Buildings in Malaysia*. Heroit-Watt University.

Yi, L., Gao, Y., Niu, J. L., & Yang, S. J. (2013). Study on effect of wind on natural smoke exhaust of enclosure fire with a two-layer zone model. *Journal of Wind Engineering and Industrial Aerodynamics*, *119*, 28–38. https://doi.org/10.1016/j.jweia.2013.05.005

Yii, H. W. (2000). *Effect of Surface Area and Thickness on Fire Loads*. New Zealand. https://doi.org/ISSN 1173-5996

Yu, Y., Chu, Y., & Liang, D. (2014). Study on Smoke Control Strategy in a High-rise Building Fire. *Procedia Engineering*, *71*, 145–152. https://doi.org/10.1016/j.proeng.2014.04.021

Zalok, E. (2011). *Simple Design Tools for the Assessment of Upholstered Furniture Burning in Home Fires*. Ottawa, Canada.

Zhang, X., Wang, S., Wang, J., & Giacomo, R. (2014). A simplified model to predict smoke movement in vertical shafts during a high-rise structural fire. *Journal of Engineering Science and Technology Review*, *7*(2), 29–38.

Zohrabian, A. S., Mokhtarzadeh-Dehghan, M. R., Reynolds, A. J., & Marriott, B. S. T. (1989). An experimental study of Buoyancy-driven flow in a half-scale stairwell model. *Building and Environment*, *24*(2), 141–148. https://doi.org/10.1016/0360-1323(89)90003-6

BIODATA OF STUDENT

Nurud Suria binti Suhaimi is an academic staff in University Malaysia Pahang (UMP), Gambang branch. She got her first degree in Environmental Technology from University Malaysia Terengganu which is formerly known as Kolej Universiti Sains and Teknologi Malaysia (KUSTEM) in 2004. In addition, her master in Environmental Engineering also been awarded by the same university in 2009. She started her career in 2008 as a lecturer in private paramedic college before continued her career in UMP a year later. Her area of research is more on safety and environment and she has been involved with a number of research encountered those areas previously. She is now pursuing her study in Doctoral of Philosophy majoring in safety, health and environment focusing on fire safety.

LIST OF PUBLICATIONS

Suhaimi, N.S. and Mustapha, S. A review of fire risk assessment tools in compartment. ARPN Journal of Engineering and Applied Sciences. Vol. 11, No.11, June 2016. ISSN 1819-6608.

Nurud, M, Saari, M, Abdullah, I, Nor, M.A. and Mohd, R.B. Fire load survey in multi-storey wholesale premise – a case study. International Journal of Engineering Technology and Science (IJEST). Vol. 5, No. 1, June 2018. 52-58. ISSN 2289-697X.

Nurud, M, Saari, M, Abdullah, I, Nor, M.A. and Mohd, R.B. Development of smoke prediction model using numerical simulation. International Journal of Computer Aided Engineering and Technology. 2019. (Accepted for publication)

Nurud, M, Saari, M, Abdullah, I, Nor, M.A. and Mohd, R.B. Influence of natural smoke vent opening in stairway of multi-storey building. Journal of Mechanical and Engineering Science (JMEAS) (Submitted on Feb 2018; under review by reviewer)

Nurud, M, Saari, M, Abdullah, I, Nor, M.A. and Mohd, R.B. A review of smoke prediction methods for consequences analysis in Quantitative Risk Assessment (QRA). International Journal of Risk Assessment and Management. (Submitted on Jan 2018; under review by reviewer)

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : First Semester 2019/2020

TITLE OF THESIS / PROJECT REPORT :

DEVELOPMENT OF A SMOKE PREDICTION MODEL FOR STAIRWAYS IN A MULTI-STOREY BUILDING

NAME OF STUDENT: NURUD SURIA BINTI SUHAIMI

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from__________ (date) until __________ (date)

Approved by:

____
(Signature of Student)
New IC No/ Passport No.:

Date :

____
(Signature of Chairman of Supervisory Committee)
Name:

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]