UNIVERSITI PUTRA MALAYSIA

MODELING OF FIRE IN SCHOOL BUILDING USING COMPUTATIONAL FLUID DYNAMICS AND DEVELOPMENT OF EVACUATION TIME EQUATION IN PUTRAJAYA, MALAYSIA

HAIRUL NAZMIN BIN NASRUDDIN

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

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Chair: Mohd Rafee Bin Baharudin, PhD
Faculty: Medicine and Health Sciences

School's building fire had claimed many injuries, death and damage properties. While experimental on large scale fire to analyse the fire behaviour is impossible, the unknown fire pattern in a building and the students' evacuation performance made the situation worst. In the first objective, the fire prediction and simulation in the school's building was done by using Computational Fluid Dynamic (CFD) approach through Fire Dynamic Simulator (FDS) program. The model inputs were generated by using the interface program called Pyrosim. The subsequent objective is to develop a validated knowledge, attitude and practice (KAP) questionnaire and to develop the numerical formula for individual evacuation time estimation based on KAP, human characteristics, and travel distances. In CFD, the school model was constructed following the actual building specifications as in building floor plans and direct measurement. The four fire effluents (oxygen, carbon monoxide, temperature, and visibility) were studied for $250kW/m^2$ and $2500kW/m^2$ fire started in the classroom and laboratory. Relevant literatures were used to develop the KAP questionnaire and the validation was done through Content Validity test involving 11 experts. The totals of 290 secondary students were involved in the study. Every student's evacuation time was obtained through direct calculation during the fire drill. The KAP questionnaires have been distributed among the students to obtain the personal details and to test their KAP level. The relationship between the calculated evacuation time and the respected three components are done by using Multiple Linear Regression (MLR) to generate estimation formula. The first objective was achieved through prediction of fire patterns in the school building in respect to four fire effluents. In the subsequent objective, a validated KAP questionnaire was constructed consists of 9 questions for knowledge assessment and 13 and seven questions for attitude and practice respectively. The development of formula estimating the individual evacuation time indicates the achievement of the last objective. The developed formula was integrated with the mobility factors to make it practicable in various circumstances. The study findings' has revealed the potential fire risks and the factors contributing to students' performance at school when dealing with fire. The predicted consequences of fire disaster are varied depending on the fire situation and students' criteria. It is recommended that the related stakeholders to consider the building and students' factors in decision making especially in the allocation of student's classrooms. In conclusion, the study has developed a model to predict the fire behaviour at school. Subsequently, a numerical model was established to predict the individual evacuation time.

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

PERMODELAN KEBAKARAN DI BANGUNAN SEKOLAH MELALUI KAEDAH PERKOMPUTERAN DINAMIK BENDALIR DAN PEMBANGUNAN PERSAMAAN MASA PENGUNGSIAN DI PUTRAJAYA, MALAYSIA

Oleh

HAIRUL NAZMIN BIN NASRUDDIN

Ogos 2019

Pengerusi: Mohd Rafee Bin Baharudin, PhD
Fakulti: Perubatan dan Sains Kesihatan

Kebakaran bangunan sekolah telah menyebabkan banyak kecederaaan, kematian dan kerosakan harta benda. Sementra itu, percubaan kebakaran berskala besar bagi menganalisis penyebaran kebakaran adalah mustahil, ketidaktentuan pola kebakaran di dalam bangunan berserta prestasi pengungsian setiap pelajar telah memburukkan lagi situasi sedia ada. Bagi objektif pertama, ramalan dan simulasi kebakaran bangunan sekolah telah dilaksanakan dengan mneggunakan kaedah perkomputeran dinamik bendalir (CFD) melalui program simulator dinamik kebakaran (FDS). Input kepada model telah dihasilkan dengan menggunakan program perantaraan *Pyrosim*. Objektif susulan adalah untuk membangunkan borang soal selidik berkenaan dengan pengetahuan, sikap dan amalan (KAP) yang telah disahkan serta membangunkan formula berangka bagi penganggaran masa pengungsian setiap individu berdasarkan KAP, ciri-ciri manusia, dan juga jarak perjalanan. Dalam CFD, model sekolah telah dibina mengikut spesifikasi sebenar seperti di dalam pelan lantai bangunan dan pengikuran secara langsung. Empat efluen kebakaran (oksigen, karbon monoksida, suhu dan penglihatan) telah dikaji bagi punca berlakunya kebakaran pada 250kW/m^2 and 2500kW/m^2 di dalam kelas serta makmal. Kajian literatur yang bersesuaian telah digunapakai untuk membangunkan borang soal selidik KAP dan proses pengesahan telah dijalankan melalui ujian pengesahan kandungan melibatkan 11 orang pakar. Sejumlah 290 orang pelajar sekolah menengah terlibat dalam kajian ini. Masa pengungsian setiap pelajar diperolehi melalui pengiraan secara langsung ketika latihan kebakaran. Borang soal selidik KAP telah diedarkan kepada para pelajar untuk mendapatkan maklumat peribadi dan juga menguji tahap KAP mereka. Hubungkait antara masa pengungsian yang telah dikira dan ketiga-tiga komponen yng berkaitan telah dilaksanakan dengan mnggunakan Regrasi Pelbagai Linear (MLR) untuk penghasilan formula penganggaran. Objektif pertama telah dicapai melalui ramalan pola kebakaran di bangunan sekolah yang merujuk kepada empat efluen kebakaran. Bagi objektif susulan, borang soal selidik KAP`telah dibina yang terdiri daripada 9 soalan menilai pengetahuan serta 13 dan tujuh soalan masing-masing merujuk kepada sifat dan amalan. Pembangunan formula anggaran masa pengungsian setiap individu menunjukkan pencapaian objektif terakhir. Pembangunan formula ini telah disepadukan dengan faktor *mobility* yang menjadikannya lebih praktikal dalam pelbagai keadaan. Hasil kajian mendedahkan bahawa risiko potensi kebakaran dan faktor-faktor penyumbang kepada prestasi para pelajar di sekolah apabila berhadapan dengan situasi kebakaran. Ramalan kesan bencana kebakaran adalah berbeza dan bergantung kepada situasi kebakaran dan pencirian para pelajar. Kajian ini mengesyorkan bahawa pihak berkepentingan perlu mempertimbang faktor-faktor seperti bangunan dan para pelajar dalam membuat keputusan terutamanya dalam isu penempatan kedudukan kelas. Secara keseluruhannya, kajian ini telah membina model untuk meramal penyebaran kebakaran di sekolah dan seterusnya model berangka telah dibina untuk meramal masa pengungsian setiap individu.

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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:

Mohd Rafee Baharudin, PhD
Associate Professor
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Chairman)

Muhammad Razif Mahadi, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Samsul Bahari Mohd Noor, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Anita Abd. Rahman, PhD
Associate Professor
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Member)

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

Date:

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Signature: ____________________ Date: ____________________

Name and Matric No.: Hairul Nazmin bin Nasruddin, GS35736

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Signature ______________________________

Name of Chairman of Supervisory Committee: Associate Professor Dr. Mohd Rafee Baharudin

Signature ______________________________

Name of Member of Supervisory Committee: Dr. Muhammad Razif Mahadi

Signature ______________________________

Name of Member of Supervisory Committee: Associate Professor Dr. Samsul Bahari Mohd Noor

Signature ______________________________

Name of Member of Supervisory Committee: Associate Professor Dr. Anita Abd. Rahman

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASET	Available Safe Evacuation Time
Ave	Average
BMI	Body Mass Index
CDC	Centers for Disease Control and Prevention
CFAST	Consolidated Model of Fire and Smoke Transport
CFD	Computational Fluid Dynamic
CFPA	Confederation of Fire Protection Associations
CLC	chemical looping combustion
CO	Carbon monoxide
CO_2	Carbon dioxide
CVI	Content Validity Index
CVR	Content Validity Ratio
DNS	Direct Numerical Simulation
DV	Dependent Variable
EEGL	Emergency Exposure Guidance Level
FD	Flat distance
FDM	Finite Difference Method
FDS	Fire Dynamic Simulator
FEM	Finite Element Method
FFT	Fast Fourier Transform
FVM	Finite Volume Method
HRR	Heat release rate
HRRPUA	Heat release rate per unit area
ICU	Intensive Care Unit
ICU	Intensive Care Unit
I-CV	Itemize-Content Validity
I-CVI	Itemize-Content Validity Index
IET	Individual Evacuation Time
IV	Independent Variable
K	Knowledge
KAP	Knowledge, Attitude, Practice
LES	Large Eddy Simulation
LgW	Log of Weight
MG	Geometric Mean Bias
MLR	Multiple Linear Regression
MOE	Ministry of Education
NFPA	National Fire Protection Association
NIST	National Institute of Science and Technology
NMSE	Normalized Mean Square Error
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Act
ppm	part per million
RANS	Reynolds Averaged Navier-Stokes
RSET	Required Safe Evacuation Time
S-CV	Scale-Content Validity
S-CVI	Scale-Content Validity Index

SD	Stair distance
SD	Standard deviation
SPSS	Social Packages for Social Sciences
UA	Universal Agreement
UBBL	Uniform Building By-Laws
US	United States of America
USD	United States Dollar
VIF	Variance Inflation Factor
WHO	World Health Organization
WS	Walking speed

CHAPTER 1

INTRODUCTION

1.1 Background of Study

In the way of discussing the occupational safety and health matters, the word 'hazard' and 'risk' usually being arise to describe the potential threat to workers. In occupational safety and health matter, there are many hazards in workplace either categorized under physical, chemical, biological, psychosocial, or any other hazards. Some of the danger situation may affect individually or maybe the whole organization. Some of them are easily identified before any accidents or incidents occur while the others may be difficult to be detected at early stage.

One of the main issues in occupational safety and health is fire. As fire may affect either individual or large population, the problem is critical for everyone to take into further consideration at workplaces. However, in certain cases, the risk of fire is not observable. This is frequently occurred when the heat source is not directly identified such as electrical overload. The presence of all elements in fire tetrahedron in building increases the risk of fire occurrence. This is the main reason why the fire safety management at schools requires full commitment from multi-level organizations from local government and school authorities to each individual personal (M. A. Hassanain, 2006b; Nadzim & Taib, 2014).

There are various types of building structure starting from simple to complex design. As fire hazard may occur anywhere, the process of controlling and preventing the fire become harder for latter design. Fire behaviour in buildings' floor plan may differ due to several factors such as space area, building materials, and the indoor air movement and circulation. A proper understand on the relationship between the complexity of structure with the fire hazard need to be developed to ensure safety and health of people especially among building occupants.

Buildings are constructed from many types of materials, which some of them are ignitable. The presence of these building materials which acted as fuel, altogether with chemical reaction with oxygen from surrounding and heat from any source such as hot electrical equipments may complete the fire tetrahedron. This circumstance usually similar with other building, or in other point, they are having the same risk of fire.

Most of the public building are required to be provided with the means of escape including the suggested evacuation route for emergency as required in Uniform Building By-law 1984 (Samad, Taib, & Ying, 2017; Uniform Building By-Laws, 1984) However, the evacuation time available for specific building remain unclear and not properly noticed. The combination of sufficient time and proper route of evacuation during fire emergency is crucial to avoid from any accident. This research tends to consider both factors to identify the best for safety and health.

1.1.1 Fire accident statistics in Malaysia

Statistics related to building fire disaster in Malaysia represents the distribution of the occurred fire accident for specific time and locations. In this subsection, the fire statistics in Malaysia were explained based on temporal and spatial to overview the distribution to determine the fluctuation in the data.

Table 1.1: Statistics of reported fire cases based on different types of building structure from 2014 to 2016

No	Premise	2014		2015		2016	
1	Residential	4,551	63.8%	4,642	67.4%	4,262	69.9%
2	Hotel	44	0.6%	41	0.6%	44	0.7%
3	Hostel	59	0.8%	75	1.1%	58	1.0%
4	School	122	1.7%	119	1.7%	101	1.7%
5	Higher institution	25	0.4%	19	0.3%	20	0.3%
6	Hospital / clinic	44	0.6%	34	0.5%	49	0.8%
7	Office	297	4.2%	224	3.3%	175	2.9%
8	Shop	734	10.3%	699	10.1%	547	9.0%
9	Shopping mall	35	0.5%	41	0.6%	34	0.6%
10	Assembly hall	39	0.5%	60	0.9%	38	0.6%
11	Store	269	3.8%	268	3.9%	214	3.5%
12	Factory	398	5.6%	392	5.7%	359	5.9%
13	Petrol station	15	0.2%	6	0.1%	7	0.1%
14	Special structure	30	0.4%	34	0.5%	46	0.8%
15	Others	472	6.0%	236	3.4%	139	2.3%
	TOTAL	7,134		6,890		6,093	

(Source: Fire and Rescue Department of Malaysia, 2016)

The total number of fire cases based on the type of building structure was obtained from the Fire and Rescue Department of Malaysia for year 2014 to 2016. The retrieved statistics as displayed in Table 1.1 clearly showed that most of the reported fire disasters were occurred involving the residential building followed by shop premises for the respected three consecutive years. In respect to school building, the data showed that the similar percentage of cases from 2014 to 2016 which is 1.7%.

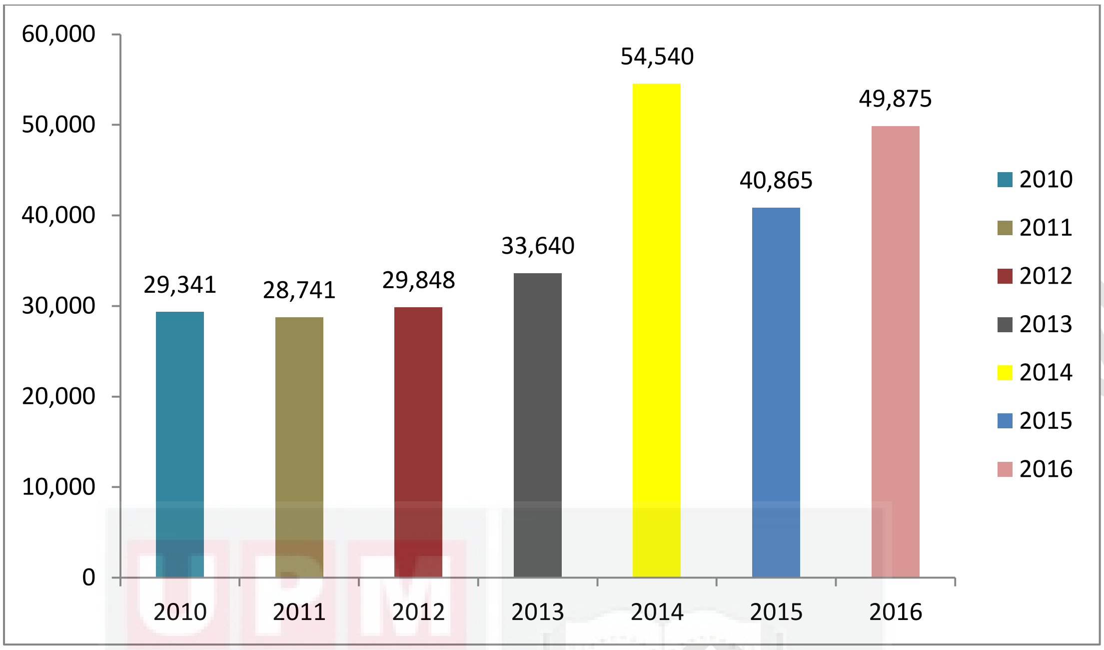

Figure 1.1: The trend of fire accident cases within 7 years from 2010 to 2016
(Source: Fire and Rescue Department of Malaysia, 2016)

Thousands of fire cases were being reported every year based on statistic by Fire and Rescue Department of Malaysia. The increasing trend of fire accident cases are displayed in Figure 1.1. The total numbers of fire accident cases are not significantly change between the first three years from 2010 to 2012. There are increasing in the figure for the subsequent years from 2012 to 2014 and decrease from 2014 to 2015 before increasing back in 2016. The highest number of fire accident cases was recorded at 54,540 in 2014.

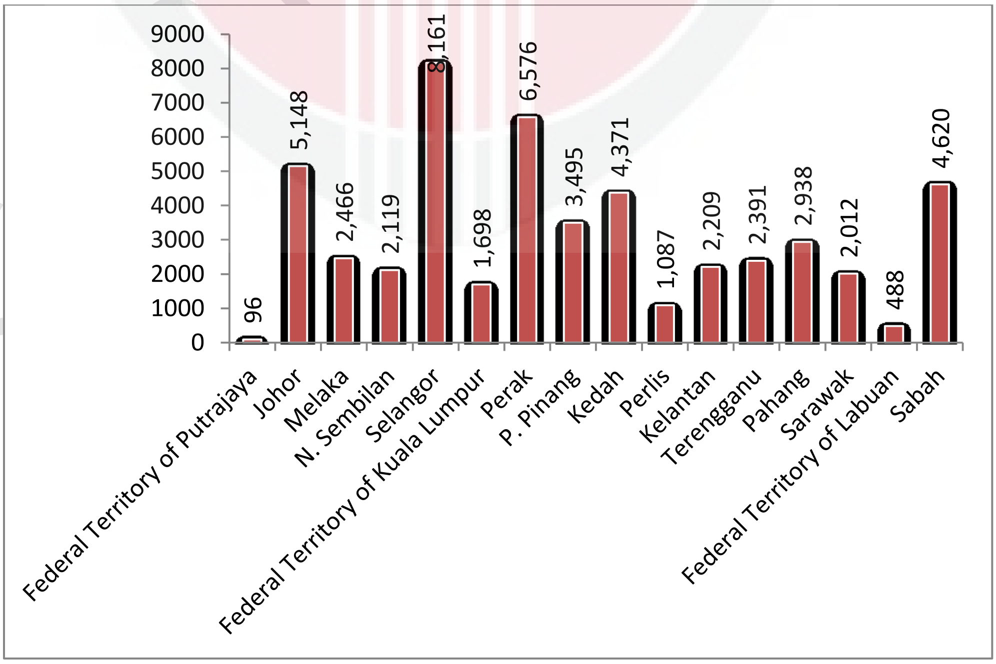

Figure 1.2: The number of fire accident cases by states in Malaysia for 2016
(Source: Fire and Rescue Department of Malaysia, 2016)

The statistic for the total fire accident cases in Malaysia for 2016 is illustrated in Figure 1.2. The highest number of fire accident cases reported in Selangor with 8,161 cases followed by Perak (6,576 cases). Based on the data distribution, both Federal Territory of Putrajaya and Labuan recorded the lowest number of fire accident which is 96 and 488 cases respectively.

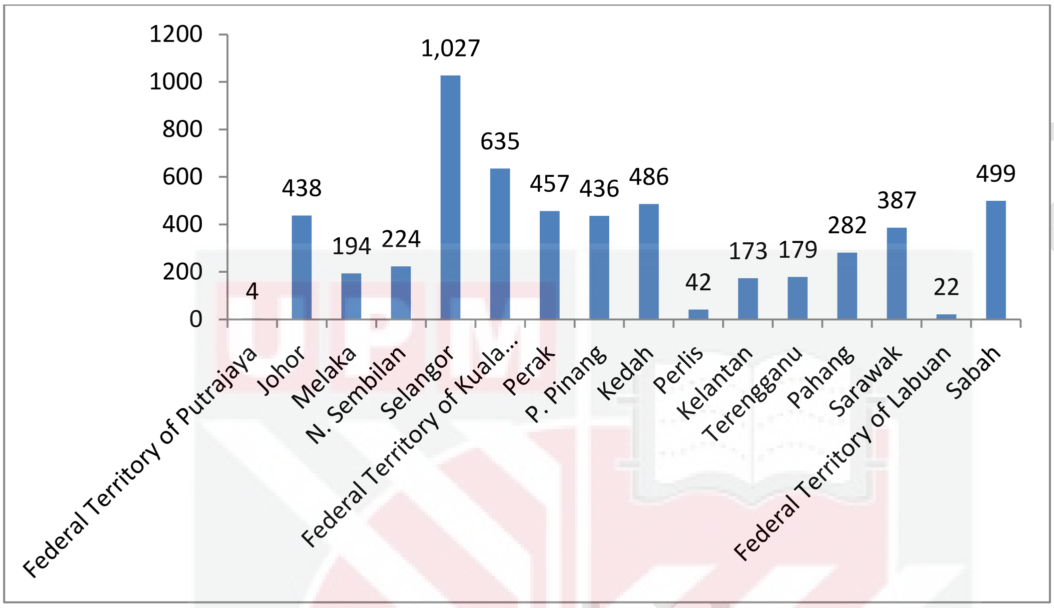

Figure 1.3: The total number of building-related fire accident cases by states in Malaysia in 2016
(Source: Fire and Rescue Department of Malaysia, 2016)

Among 18 types of fire, the building-related fire is the third highest reported cases (Fire and Rescue Department of Malaysia, 2014). According to 2016 statistics retrieved from local authority, it was noted that Selangor shows the highest building-related fire accident (1,027 cases) followed by Federal Territory of Kuala Lumpur (635 cases) while the lowest is 4 cases at Federal Territory of Putrajaya.

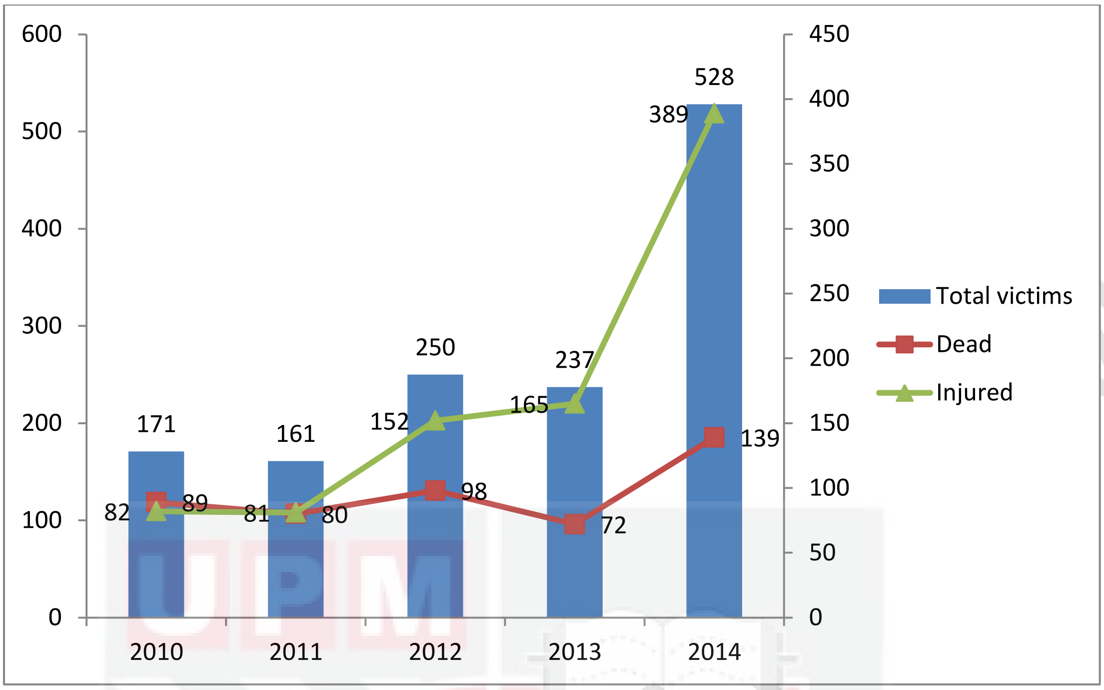

Figure 1.4: The number of victims caused by fire accidents together with the injury status within 5 years
(Source: Fire and Rescue Department of Malaysia, 2014)

The pattern of fire impacting human could be seen as in Figure 1.4. Even there are only slight changes in the number of victims within four year from 2010 onwards, the distribution is significantly change in 2014 with the increase over 100 percent compare to the previous year.

The statistics from Figure 1.4 is further specified into two categories of consequences on human caused by fire which are either injured or dead. For the first two years (2010 and 2011), the ratio between injured and dead victims are almost 1:1. However, the numbers are change for 2012 and 2013 with a ratio 1:2. There is drastic changes in 2014 where the number of death caused by fire are increase almost triple compared to the injured victims.

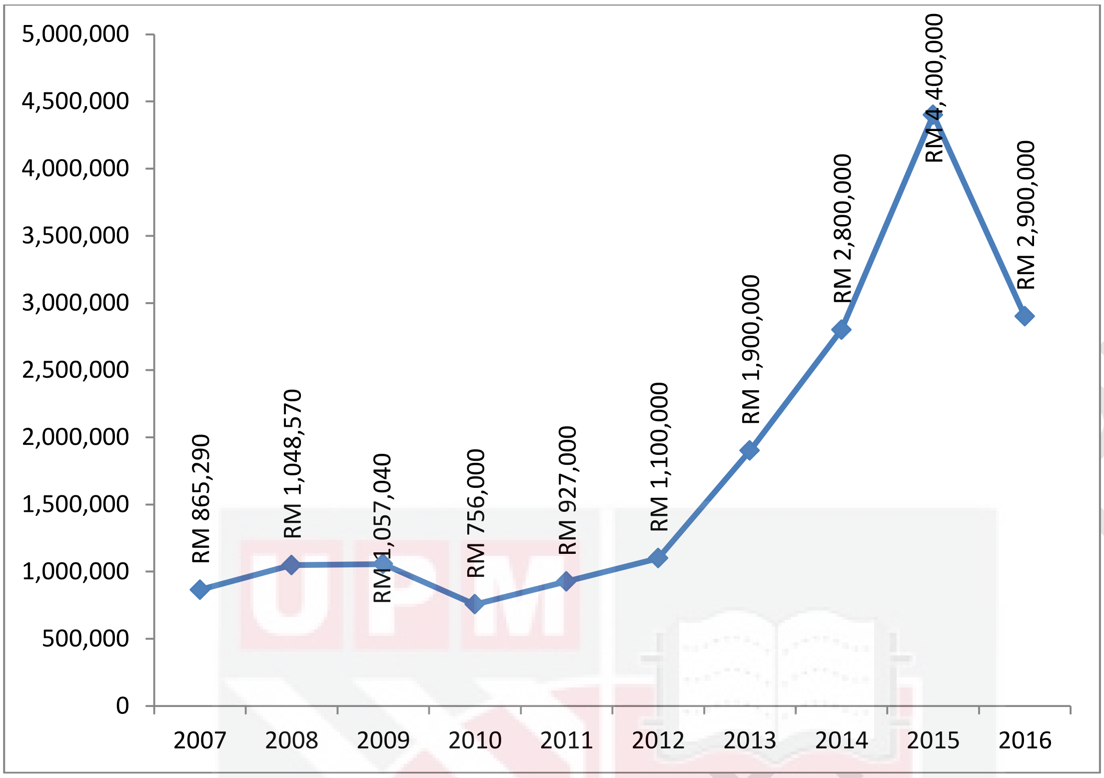

Figure 1.5: The estimated losses caused by fire from 2007 to 2016
(Source: Fire and Rescue Department of Malaysia, 2014; Rahim, 2015; Fire and Rescue Department of Malaysia, 2016)

From year to year, the fire causes massive losses especially in term of properties. The increase in estimated losses was showed in Figure 1.5. It is clearly observed that the trend is significantly increased along the years from 2007 to 2015. The estimated cost is slightly decreased about RM301,040.00 between 2009 and 2010 before continuously shows the upward losses trend for the subsequent 5 years. As the pattern continues, the losses were decreased about RM1.5 million from year 2015 to 2016.

The estimated losses were increased around RM800,000.00 every year after 2012 compared to RM183,280.00 from 2007 to 2008 and around RM170,000.00 per year between 2010 to 2012. There is small difference in losses between 2008 and 2009 which estimated about RM8,470.00.

1.1.2 Fire History at school building

1.1.2.1 Malaysia

Malaysia often shocked with the fire accidents that occurred even from a long time ago. The recent fire incident occurred at Sekolah Kebangsaan Sentosa in Tawau on April 23rd 2018 (Vanar, 2018). Eventhough the fire which destroyed two building blocks did not result any injuries or death, the disaster has caused panic among school building's occupants especially school children. In 2017 only, several fire cases occurred in Malaysia. The most unforgettable fire disaster at school which claimed lives was occurred on September 14th 2017 and had resulted 21 students and 2 teachers died (BBC, 2017; Jastin Ahmad Tarmizi, Yimie Yong, 2017; NST Online, 2017). This tragedy has become the worst fire case involving students after the fire incident at Pondok Pak Ya Religous School at Kedah on September 22nd 1989 which caused 27 female children lost their life (Bernama, 2017). Even though the investigation by police and fire department revealed that the source of fire is the arson, however, the recorded video explained that evacuation is important as several safe evacuees were injured during evacuation process.

1.1.2.2 Another country

The neighbouring countries such as Singapore also experienced fire disasters at school. One of the reported cases was occurred at Raffles Girls' School on October 19th, 2016 ("Fire at Raffles Girls' School," 2016). Less than a year later on September 29th, 2017, a fire broke out at St Andrew's Junior School causing smoky environment at canteen area (Lam, 2017). Even though both tragedies did not result in any injury, the condition were enough to trigger panic among the occupants. In Thailand, a fire was started at around 1 a.m. at school building at Kanlayanawat School on October 21st, 2018 (Nathanri, 2018). In more serious cases, 17 schoolgirls were killed when a fire broke out at a Pithakkiart Witthaya school on May 22nd, 2016 ("Thailand school dormitory," 2016).

In US, there are several histories being recorded involving school fire tragedies causing 10 or more deaths. Based on the information retrieved from National Fire Protection Agency's record, the three major fire accidents occurred in 1908, 1937, and 1958 causing 175, 294, and 95 deaths respectively (Heath, Ryan, Dean, & Bingham, 2007; National Fire Protection Association, 2018). As Ohio was reported the largest number of students' death caused by school fire, one of the most unforgettable tragedies occurred on March 4th 1908 at Collinwood's Lake View Elementary School. The fire had caused 172 children together with 2 teachers and 1 rescuer have lost their lives (Heath et al., 2007). On December 1st 1958, the following fire accident occurred at Chicago's Our Lady of Angels School causing 92 children perished and 77 were seriously injured.

In East Africa region, a fire occurred in April 2008 at Budo junior boarding school in Uganda which have killed 19 girls and 2 adults (Ndetu & Kaluyu, 2016; Sekiwu & Kabanda, 2014; Shibutse & Omuterema, 2014). In Kenya, the two dreaded fire disasters occurred on March 25th 1998 and 26th 2001 at Bombolulu and Kyanguli Secondary School respectively. The former incident have claimed 27 girls' live while the latter cause 59 boys died (Shibutse & Omuterema, 2014). Nigeria which located at West Africa region also experiences the frightful fire tragedy involving school children. One of the unforgettable accident occurred in 2001 where 23 students have been lost when fire occurred at girls' dormitory as the building was locked with iron bars and a chain (Ndetu & Kaluyu, 2016).

In December 23rd 1995, majority from 425 people which are school children died after fire occurrence during a ceremony organized at school in Haryana, India (Ministry of Home Affairs, 2004). In other reported case, 93 school children died in a fire tragedy at Tamil Nadu, India due to explosion of the cooking gas cylinder (Bethou & Venkatesh, 2014; Tuladhar, Yatabe, Dahal, & Prakash, 2014; United Nations Office for Disaster Risk Reduction, 2012). Another fire history at Asia region occurred at Shinabad, Iran. Seven children were critically injured while two children have been lost when fire started followed with explosion at primary school (A, Mowafi, & Ardalan, 2013).

1.2 Problem Statement

Recently, articles in newspaper reported that around third of government buildings in Putrajaya do not certified for fire safety (Timbuong, 2019; Shahrul Annuar, 2019). It was added that the issues led to failure to obtained certification is because of the fire prevention tools problem. It is an alarming issue since Putrajaya considered the most developed area with modern building structures which supposed to be no toleration on major fire safety issue.

While fire could happen from multiple sources, literature specifically stated the causes of fire in the schools due to arsons, low attitudes, faulty electrical systems, poor housekeeping standards, smoking, and improper storage management (M. A. Hassanain, 2006a). Based on the case study, most of the fire at school are started intentionally while another two reported causes of fire are due to accidental ignition and electrical fault (Wade, et al. 2007).

Fire behaviour within a volume such as building needs further clarification as the fire widely affected by many factors including building geometries. For example, it was revealed that the building height greater than 6 metres and the area more than 1500 m^2, the variations in height and area of building not significantly affect the fire curve pattern, while fire powers may exerted significant impact on the shape coefficient (G. W. Zhang, Zhu, & Yin, 2014).

While the consequences of fire disaster not limited to building operational, it also could impact on human life. In United Kingdom, around 1400 to 1800 schools' fires were reported each year (Shibutse & Omuterema, 2014; Wade, Teeman, Golden, Wilson, & Woodley, 2007). In 2004, almost 96000 children below the age of 20 were lost due to fire-related burn (World Health Organisation, 2008). Based on the statistics from 2009 to 2011, it was estimated that U.S experiences around 4000 fire disaster involving school buildings each year (U.S. Fire Administration, 2014). Additional retrieved statistics showed that average of 190 children are lost or injured every year caused by fire (M. A. Hassanain, 2006). Annually, it is observed that 1,000 fire-related deaths and 100,000 fire incidents were reported in China (G. H. Li et al., 2016). Statistic shows that 500 children die and 40,000 children are injured caused by fire (V. Hwang, Duchossois, Garcia-Espana, & Durbin, 2006). From year 2000 to 2011, 13.7% of all injuries and 108.6 fire injuries per million were accounted by those with the age range between 15 and 24 years (Lambie, Best, Tran, Ioane, & Shepherd, 2015).

Other than affecting the safety and health of human being, one of the most obvious effects is on the property damage. Based on Malaysia statistics from 2012 to 2013, an increase in the loss of property is estimated around RM874.31 million due to fire breakouts (Rahim, 2015). In 2013, it was estimated around 11.5 billion USD damages on property in US (Lambie et al., 2015). In addition, it was reported that US experiences an average of 5500 structure fires at educational institutions each year (Shibutse & Omuterema, 2014). The fire has cost around 66.1 million US dollars in properties loss while 75 injuries were reported every year involving school building (U.S. Fire Administration, 2014). The subsequent 4 years (2011 to 2015) showed increment in educational building fire where the average of 4980 cases were reported annually. Even though the number of injuries have been reduced to 70 cases, the fire has caused the annual average of 1 death and 70 million US dollars of property damages per year (National Fire Protection Association, 2017). Compared to United Kingdom, over the ten years from 1995, the cost of fire at school has increased almost 18 million euro from 49 million euro in 1995 to 67 million euro in 2005 (Wade et al., 2007).

Fire study is not similar with other hazard analysis which able to be done through lab testing. Fire in small scale maybe only require basic assessment tool to be evaluated. However, in term of safety and health, the effect of fire on human being and building properties often being discussed in larger scale. The increase in fire size will directly jeopardize the effect to safety and health together with the damages to properties involved. The actual fire study in large scale would require a lot of funding, time consumption, manpower and also advanced tools or labs (Jia, F., Wang, Z. & Galea, 2010; Y. Z. Li, 2015; Lippiatt, 2002; Pedersen, 2012; Stokos, Vrahliotis, Pappou, & Tsangaris, 2015). The institution or countries which unable to provide such things would probably just rely on assumption of safe workplace rather than spending a lot in fire analysis which then risking the human life. The application of computational modelling together with the development of new formula for evacuation calculation would be a great alternative for any institutions to use.

It is very hard to make a firm conclusion on the cause of fire, the exact pattern and its effects within a building through experimental fire study (F. Kang, Kennedy, Rabidou, & Savva, 2016). The fire will change depend on the multiple factors, for example the complexity of building design and also the internal environmental condition such as wind velocity and buildings' material. It is almost impossible to study fire within specific building structure through direct approach. It requires a more convenient way to analyse the fire which is though computational fluid dynamic approach.

In term of evacuation procedures, every building especially in Malaysia was required by law to be provided with the evacuation route plan placed at the specific locations. The plan was constructed based on the structure and design of the building. However, there is no proof that the suggested route is able to provide safe evacuation within the available time to evacuate the building safely. The best evacuation route is selected based on the minimum movement time of the last evacuee (Cepolina, 2005). The time obtained through computational modelling and the developed formula could be used to check whether the route provided is safe or not in term of available evacuation time.

Statistically, from 2010 to 2012, fire represent 33% of all common emergencies at schools and secondary school shows a greater fire cases compared to primary school (Tipler, Tarrant, Johnston, & Tuffin, 2017). Fire could be a major threat for these students who spent a long time at school. The students spend up to 12% of their time in the classroom which is longer than any other buildings excluding home (Yang Razali et al., 2015).

In Malaysia, the common practice used in every school to arrange students is based on the level of ingenuity. The arrangement of students was done without considering the safety in case of emergencies such as fire. It is not wrong for the school management to adopt the method, however, it cannot be applied independently without emphasizing the safety and health of students and other building occupants. The element of safety and health of student must be taken in further consideration together with the ingenuity level so that every student will be provided with safe environment. It was believed that the students who take longer time to evacuate from the building need to be placed near to safe evacuation area compare to students who take shorter time. However, it would become a great challenge to setup the optimum classrooms and seating arrangement while avoiding interruption on teaching and learning session quality.

Even though time plays a very important role during evacuation, there is no standard available which could be used as reference for any buildings. Rule of thumb often used as a reference which is 120 seconds is seemed inapplicable and unreasonable due to the variation in building structures and designs. For example, evacuation in two stories school building within 120 seconds may seemed possible but irrational for six stories building. There must be a standard set for each building instead of using single reference so that every occupant knows the time required for the building. By applying computational approach in this study, the recommended time to evacuate could be determined based on the fire simulation done.

The school's geometries are continuously developed to become more complex and sophisticated over time. The implemented fire safety management program at school which may be efficient at the moment but currently may not enough to cope with the increase in building complexity and number of students to protect the students' safety and health. The failure to implement an effective fire safety intervention program could increase the risk of injuries or in more serious cases would increase fatality rate due to fire hazards.

In addition, the prolong current fire problem without immediate intervention could impact in term of economic value. Even though the costs of fire accident are change over time, the annual costs after year 2011 were millions compared to the previous years. In the other hand, the estimated losses may not include the indirect costs of fire such as loss of work time and incapable of work due to permanent injuries. The actual cost could possibly greater than the estimation. The cost of the school's building and its properties (included the school and personal assets) are greater than before. Thus, the damages could be worst following the alarming trend of losses caused by fire. In conclusion, without active intervention in assessing the building and human performance to fire risk, the impact on human lives and economic could be a major issue in the future.

Despite of clear impact of fire on economic value, all the relevant stakeholders are also affected by fire consequences. In the management level (ministry, department and school level), the fire could cause disruption to the educational plans. The proposed activities and educational programs could not be done due to the emergency situation such as fire. In addition, the fire could increase the cost to repair and replace the damaged properties and assets. The budget for education purposes may need to be reduced and reallocated to all activities related to recovery processes. Other indirect impact of fire on the management level is the ruining of the educational sector's reputation. As school is a public institution, the reputation is depending on the perspective of surrounding community towards school management. A fire occurrence at school may indicate a failure of school management to provide a safe environment to students.

In respect to the parent, the fire at school could reduce thrust of the parents to the management level in protecting their children at school. The fire occurrence could cause a chaotic situation where parents are scare to send their children to school. As for students, the most obvious impact of fire is the possibility of getting injuries or fatality. The students' exposure to fire hazards such as toxic smoke inhalation could cause both short acute and chronic illnesses. Other than that, the learning session could be interrupted after the fire occurred. The damages of the educational properties and time taken to restore the damages cause the learning session cannot be done efficiently.

It is very important to fix the highlighted issue because the magnitude and severity of fire consequences are remained unknown and unclear until it really happens. By analysing the fire and human behaviour through prediction, such information could be obtained. The information could be provided to increase awareness on the building's and students' performance within the situation. Subsequently, if the building's performance and student's capability to evacuate is known, the data could be used in planning for intervention program to reduce the risk of injuries and fatality rate due to fire. Fixing the fire hazard is crucial to avoid any unwanted conditions that threaten live. Preventing fire accident could lead to no interruption in learning session thus indirectly provide safe and healthy environment that conducive for educational purposes. Other than that, fixing the fire problems is importance to ensure optimum budget for management if school's safety and health. Preventing fire and injuries at early stage could avoid from overspending cost to repair the after-fire damages.

1.3 Significance of the Study

Early determination of risks is important in occupational safety and health field to avoid any injuries or death at workplace. Small-scale fire probably possible to be study by using simple analysis method. However, the analysis of larger fire scale shall require more sophisticated approach. While the application of CFD in process safety is common, the use of CFD to assess the fire behavior in respect to occupational safety is new and a novelty in this study.

In this research, the CFD was applied to assess fire is because of the its ability to investigate the fluid flow that not easy to be measured by other available approach such as zone modeling. CFD's high performance that able to generate results faster than any other assessment methods, for example in-situ experiment, is one of the justifications for the method selection in this study. In addition, different multiple fire scenario and fire parameters could be analyzed in shorter time. The features in CFD make prediction in most of the complex fire circumstances become possible.

Other than CFD, the common approaches applied to study the fire consequences are through either simple models or hand calculations, and zone fire models (Tofilo & Wegrzynski, 2016). The example of the simplest and the most frequent equation to solve the respected problems are as follow:

$$\dot{m} = c_e P Y^{\frac{3}{2}} \qquad \text{(Eq. 1.1)}$$

Other comparable method was introduced by Morgan and Hansell to determine the heat release rate, Q for a design fire by using the following equation (Yuen & Chow, 2005).

$$Q = F(A_w, \mathrm{H}, \mathrm{x}) \qquad \text{(Eq. 1.2)}$$

Based on the above equation, the A_w is represents the area and H is height while x is the desired cumulative probability. A study done by Liu, Fu & Chow (2001), suggested another fire model other than CFD and zone models namely air flow network models. The model operates to analyze the smoke movement by creating the mass balance equation by taking the compartment's mass production rate equal to the sum of mass flow rate through all the compartment's openings (Liu & Fu, 2001). It is difficult to simply justify which of the available method is the most superior method since all of them have their own advantages and disadvantages in the performance. However, the most obvious benefit of using CFD than other two methods is the ability to study complex fire phenomena and able to model pyrolysis in larger and more complex building geometry.

School has been selected as a study location rather than industry. The quality of fire safety at school is less known and need further study. In the other hand, the industry was assumed to have a better safety system than school. The school in Putrajaya was selected because of the study inclusive criteria which is the multiple story academic building (higher or equal to the three-story building). The selection of school in Putrajaya rather than any school in urban area was to reduce bias in data due to the assumption that school in more developed area such as Putrajaya has better fire management plan. It was assumed that the fire severity and consequences in school with less management plan would be worst compared to the school with proper management plan.

When discussing about occupational safety, the term occupational often misled to refer merely on workers at industry. School is viewed as a workplace and the responsibility to ensure safety and health of students at school is clearly described in Occupational Safety and Health Act (OSHA) 1994. However, fire safety studies are mostly covered the industrial sector and less focused at school. Thus, this study has considered the school for the study location and students as a target population.

The most common method to estimate the evacuation time is through direct measurement. The results are often obtainable during fire drill activity which rarely organized. In school, the number of students is change over time and the estimation of individual evacuation time requires more practicable approach. The gap has led to the development of formula specifically to calculate student's fitness to evacuate efficiently in term of time. The time assessment on each student was done considering the element of knowledge, attitude, practice and the students' characteristics to determine the risk level. The estimated time for each student could be used as a baseline data in managing the classrooms and students' locations which traditionally based on the level of ingenuity.

The findings of this study will redound to the benefit of society and local authority either at ministry, department or school level. The education managements that apply the recommended approaches derived from the study will be able to pre-determine the possible hazards and risk related to fire, thus assist them to improve the quality of safety and health among students.

1.4 Objectives of Study

The general objective of this research is to comprehensively study the situation during building fire emergency in term of cradle to grave of the fire, meant from generation until the part of fire prevention and building occupants' evacuation especially in school building.

1.4.1 Specific Objectives

Based on the general objective set, the research listed two objectives to achieve the specific target which are listed and explained below:

1) To establish the modelling of the fire generation and spread and smoke transport at multi-storeys school building by using Computational Fluid Dynamics (CFD) technique based on multiple fire scenario.
2) To develop an instrument for KAP analysis among students specifically on fire evacuation assessment.
3) To develop a numerical method to calculate the total evacuation time for each student based on knowledge, attitude and practice (KAP) level, human characteristics and travel distances.

1.5 Research Hypothesis

The following research hypotheses are drawn based on the study objectives.

1) All seven human characteristics, KAP factors, and both flat and stair travel distances are significantly correlate and capable to determine the individual evacuation time.
2) All the three models would show a high predictive capability in determining the individual evacuation time.
3) The combination of variables in human characteristics, KAP, and travel distances would show greater prediction on individual evacuation time.

1.6 Research Questions

Considering the research goals, several pertinent questions were designed and listed as follow:

1) How the CFD technique predict the pattern of fire occurrence and the behavior of the fire effluents?

2) How CFD technique applied in fire modeling can contribute to improve building occupants' safety and health?
3) What set of questions need to be emphasized in constructing an instrument mainly for KAP assessment in relation to individual evacuation time?
4) What are the factors on human, travel distances and KAP that significantly influence the time taken to evacuate?

1.7 Scope of study

In this study, the research was conducted through several steps which explained through diagram as displayed in Figure 1.6. The subsequent diagram (Figure 1.7) showed the overview of the study idea.

1.7.1 Study flowchart

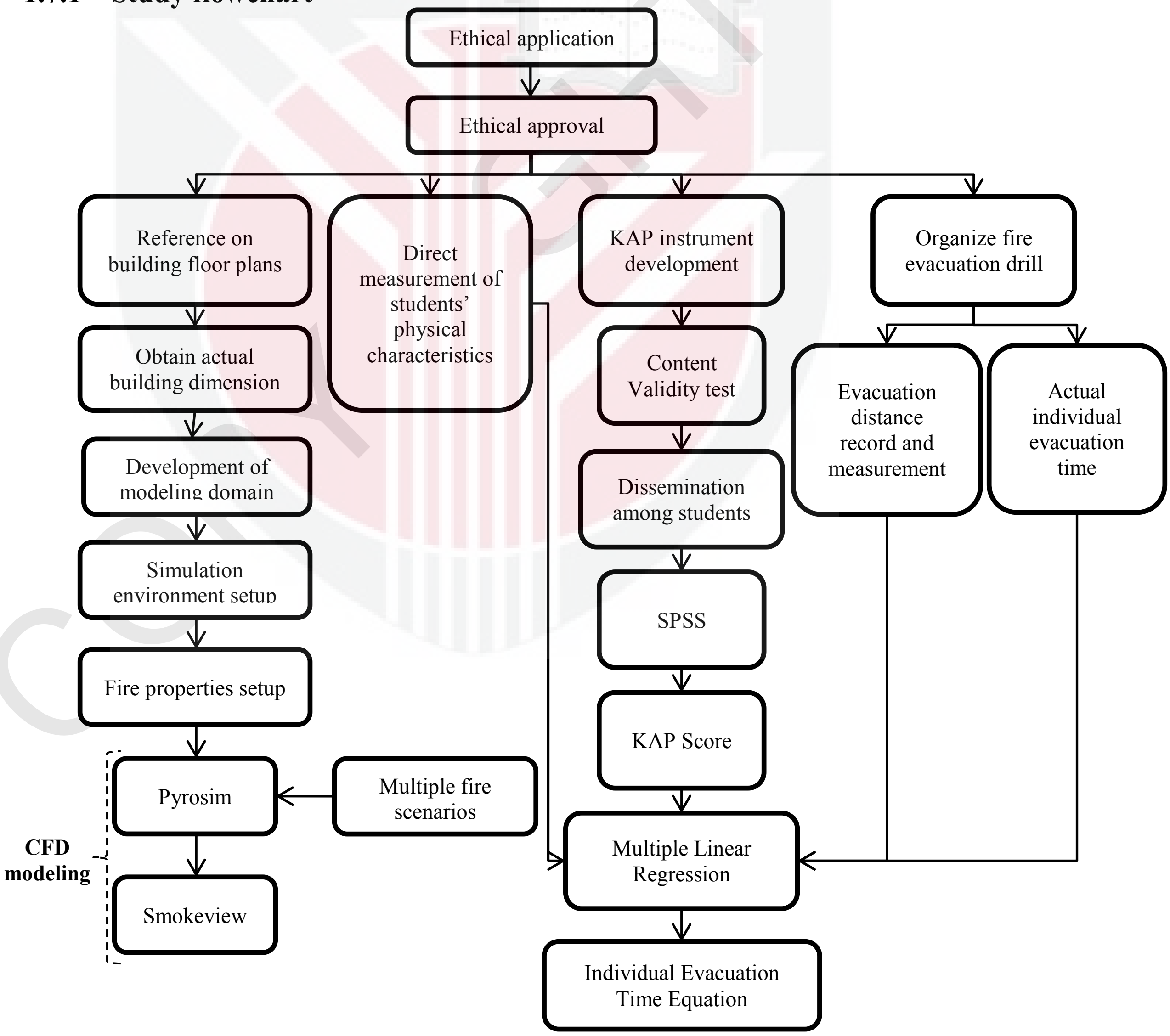

Figure 1.6: The overview of steps and flow of the study

1.7.2 Conceptual framework

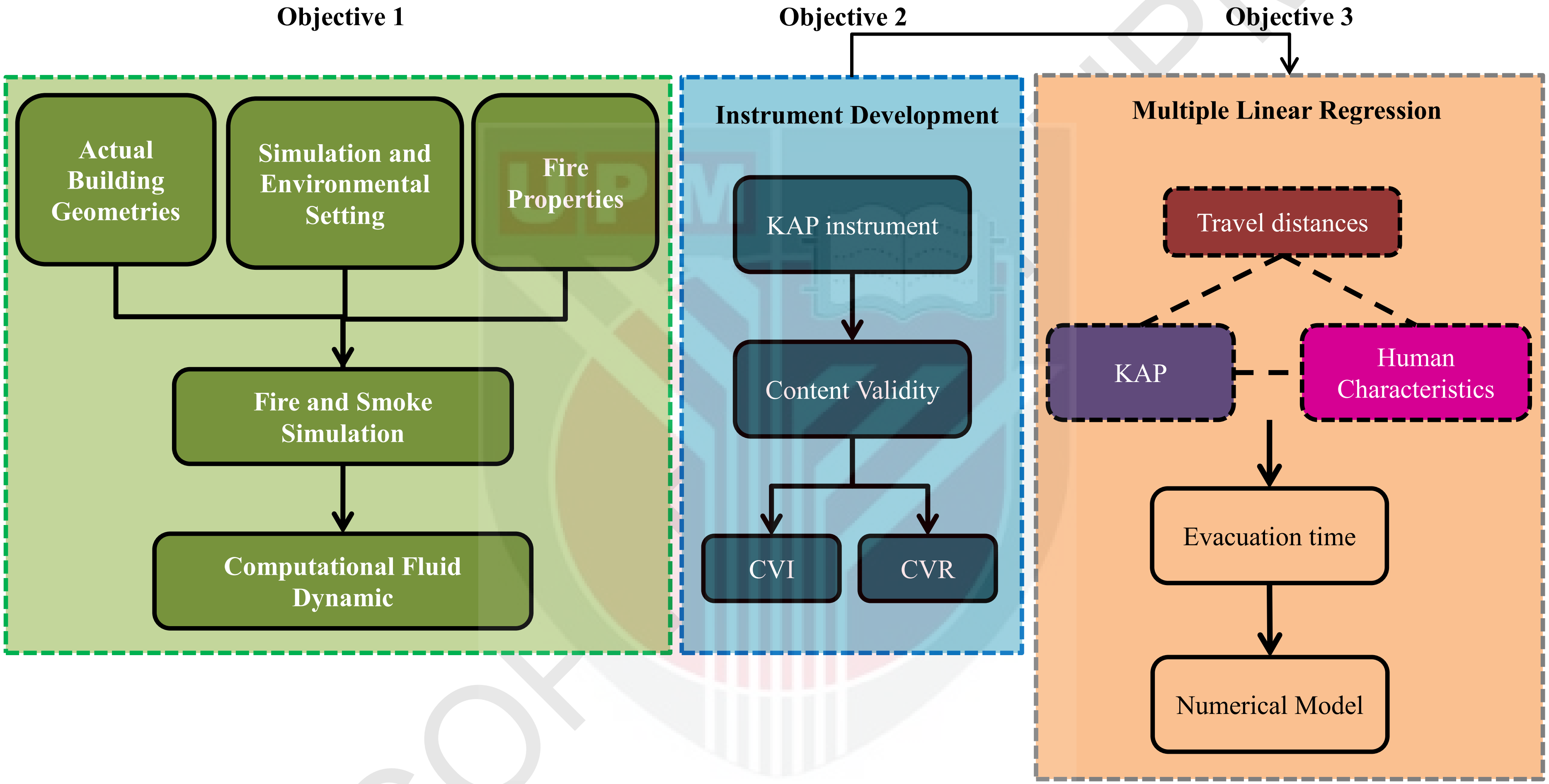

Figure 1.7: The conceptual idea designed for the whole study

1.8 Ethical application and considerations

As one of the rules set by the University and a good practice in research, ethical permission must be obtained, especially in research involving human intervention. Ethical application was done to ensure compliance of this study with the ethical rules and regulations and also to avoid the violation on the critical matters especially in term of medical and political perspectives. The application was made before conducting the data collection process. All these documents were sent to the Committee for evaluation in order to secure an approval: the application form, the proposal and permission letters from Ministry of Education Malaysia, Putrajaya Federal Territory Education Department and school management level; and the instrument used such as the developed questionnaire. The approval to conduct the research was granted by the Universiti Putra Malaysia Ethical Research Committee with the reference number FPSK(EXP16)p167.

1.9 Organization of the Thesis

The chapters in the thesis were organized by using the conventional style 2 format. The thesis is composed of nine chapters, each of them are dealing with different aspects. Chapter 1 is the introduction for the whole study matters. The chapter describe on the study background includes the objectives for the study together with the several statistics retrieved from the literature. Chapter 2 concentrates on the review of literatures from various sources related to the study objectives. Chapter 3 to Chapter 8 are specifically describing each of the study objectives. Chapter 3 emphasizes on the completing objective 1 which is on CFD modelling. Chapter 4 highlights on the validation of the constructed KAP questionnaire while Chapter 5 to Chapter 7 focus on the influence of evacuation travel distance, KAP, and human characteristics on individual evacuation time respectively. Chapter 8 concentrates on the development of numerical model to estimate individual evacuation time through the combination of the three elements. The conclusions are drawn in Chapter 9.

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BIODATA OF STUDENT

The student, Hairul Nazmin bin Nasruddin was born May 10, 1987 in Federal Territory of Kuala Lumpur. Academically, he received his primary education in Sekolah Menengah Sri Adika Raja at Gerik, Perak (1994-1999). He completed his secondary level education at Sekolah Menengah Kebangsaan Tun Abang Haji Openg at Kuching, Sarawak on 2004. He obtained his Degree in Environmental Health and Safety at Universiti Teknologi MARA (UiTM) in 2010 and then graduated in Master of Environment at UPM in 2012. He is currently doing his PhD. in Occupational Health and Safety at Universiti Putra Malaysia (UPM) under the supervision of Dr Mohd Rafee Baharudin mainly of fire safety through modelling approach. Along his studies, he worked as Research Assistant under the same supervisor and involved in many researches on academic purposes and even granted by Government and Government-link Company such as Department of Occupational Safety and Health (DOSH), National Institute of Occupational Safety and Health (NIOSH), and Social Security Organization (SOCSO) especially in the matter of occupational accident cost estimation. Some of the researches are "Estimating Accident Costs in Small Medium Manufacturing Industries in Malaysia", "Estimating Accident Costs in Public Service Sectors in Malaysia", "The Cost of Commuting Accidents among SOCSO Contributors in Malaysia", "Evaluation on The Effectiveness of SOCSO Accident Prevention Programs", and many more. He involved in the publication of book entitled "*Practical guide to OSH risk management: Understanding, evaluating and implementing HIRARC at workplac*e" which helps OSH practitioners to properly assess their workplace risks. He also contributed to the development of OSH Accident Calculator (OSHACC) at the national level.

PUBLICATION

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