Fire Safety Models for High-Rise Residential Buildings in Malaysia

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ABSTRACT

This research investigated the effects of escape route design and specification, and time taken on evacuation process in high-rise residential buildings in Malaysia. The aim is to produce a fire safety model on how fire safety standards in high-rise residential buildings can be achieved by investigating the relationship between human behaviour and structural design, particularly escape route design and specification.

In Malaysia, research on fire safety is very new, particularly research on provision of fire safety in high-rise residential buildings. The number of fire cases involved residential buildings is significantly high compared to other building types. Thus, escape routes in high-rise residential buildings should be designed and constructed to enable the occupants to evacuate the building as soon as fire has been detected.

Mixed methodologies i.e. quantitative and qualitative methods were adopted in this research. There are three research methods adopted i.e. observation, simulation and questionnaire. Observations were carried out to identify any problems encountered and to develop the study models for further analysis. Investigations of the effects of escape route design and specification on evacuation process were carried out using specialist software, i.e. Simulex, which simulates the evacuation of people from the building. The aim is to study escape route specifications i.e. staircase, fire door and corridor. Questionnaire surveys were than carried out to investigate the occupant's characteristics, behaviours, perceptions and motivation factors to evacuate the building.

From this research, fire safety models proposed for high-rise residential buildings as follows, (1) Fire safety model to achieve fire safety standard in high-rise residential buildings, (2) Escape route designs and specifications, and, (3) Human behaviour model. There are five fire safety components that need to be enhanced i.e. (1) Fire Safety Awareness, (2) Fire Safety Design, (3) Fire Safety Equipments and Evacuation Skill, (4) Fire Safety Audit, and (5) Fire Safety Enforcement. Besides, there are four factors which highly influence the evacuation process, fire and casualty risk i.e.: (1) People behaviour – knowledge and experience, (2) building element and escape routes design, (3) active fire protection system, and (4) legislation and enforcement.

For my parents, beloved wife and children

(*Nur Adlina, Nur Alya, and Muhammad Adam*)

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GLOSSARY OF SYMBOLS

BR	Building Regulation
BRE	Building Research Establishment
BSi	British Standard Institution
Btu	British Thermal Units
CIBSE	the Charted Institute of Building Services Engineering
CWC	Canadian Wood Council
FPA	Fire Protection Association
FRP	Fire Resistance Period
FSCT	Fire Safety Concept Tree
FSE	Fire Safety Engineering
GDP	Gross Domestic Product
GDP	Gross Domestic Product
HMSO	Home Minister S Office
HRO	Home Research Office
JFRO	Joint Fire Research Organisation
LPC	Loss Prevention Council
NFPA	the National Fire Protection Association
NRC	National Research Council
ODPM	the Office of the Deputy Prime Minister
PPE	Personal Protection Equipment
UBBL ’84	Uniform Building By-Laws 1984

PUBLISHED PAPERS

The following papers have been published as a result of this research:

(1) Yatim, Y.M. and Harris, D.J., (2005), Fire safety Management: Evaluation of Means of Escape in High-Rise Residential Building, *ASIANPGS 2005 Seminar in Built Environment, Proceeding*, University Malaya, Malaysia.

(2) Yatim, Y.M. and Harris, D.J., (2007), *An Evaluation of the Provision of Escape Route in High-Rise Residential Buildings: Malaysian Experience*, presented in Heriot-Watt Annual Research Conference 2007, at Heriot-Watt University, 14 June 2007.

(3) Yatim, Y.M. and Harris, D.J., (2007), Human Behaviour Response Issues in High-Rise Residential Building in Malaysia, *The 2nd International Conference on Interdisciplinary Social Sciences,* presented at Granada University, Spain, on 10 - 13 July 2007.

(4) Yatim, Y.M. and Harris, D.J., (2007), An Evaluation of Provision of Escape Routes in High-Rise Residential Buildings – Malaysian Experience, *Jurnal Alam Bina*, Universiti Teknologi Malaysia, Jld, 09 No. 04, pp 67 – 81.

(5) Yatim, Y.M. and Harris, D.J., (2007), Human Behaviour Response Issues in High-Rise Residential Building in Malaysia, *The International Journal of Interdisciplinary Social Sciences*, Common Grounds Publisher, Australia, Vol.2, No. 3, pp 277 – 289. http://www.SocialSciences-Journal.com

CHAPTER 1

INTRODUCTION

1.1 Introduction

Fire safety in buildings is not a new topic but seriously being developed by many researchers over a period of time, especially fire safety in workplace. However, research in fire safety for high-rise residential buildings is not many have been done. The first research on occupants' behaviour in high-rise apartment buildings was done following the fire incident at the MGM Grand Hotel and two incidents in University residence halls involving jumping behaviour by occupants previously injured while using the means of egress system in evacuation attempts in the 1970s. The first seminar on human behaviour was conducted in 1977 at the University of Surrey and the seminar proceeding from then became the first complete book on human behaviour in fire ever published (Bryan, 2002). The second seminar was conducted in October 1978 at the National Bureau of Standards, US. Both seminars were primarily involved with the examination and development of the methods for investigation of the behaviour of the occupants in a fire situation. The emphasis of the study was to define the behavioural actions of occupants in fire situations, examination of the then popular concept i.e. *Panic Behaviour*, and study of the evacuation process in high-rise building (Bryan, 2002). However, study concerning fire safety in high-rise residential buildings in Malaysia is very new and very limited resources are available to review. Even in the United Kingdom, not many studies concerning fire safety in high-rise residential buildings have been done.

1.2 Fire safety issues in Malaysia and United Kingdom

Fires in buildings are always related to either the human error or human negligence. Even a small fire can cause devastation if it has involved the dwelling buildings. Ten years fire statistics in Malaysia (1990 to 1999) show that there are 154,987 fire cases in Malaysia. From that figures, 23,911 or 15.45% cases involved buildings. Average more than 2000 fire cases annually involved buildings are significantly high. Among the types of building, residential buildings are the highest i.e. 9,512 cases followed by shops 2,767 cases, plants 2,636 cases and stores 1,489 cases (Bomba, 2001). From this statistic, it shows that residential buildings are the highest risks of possibility of fire break out. It includes high-rise accommodation buildings i.e. flats buildings, apartment buildings and condominiums. At this moment the recent statistics for the next ten years of fire statistics is not available and due to be compiled in the year 2010.

According to Datuk Dr. Ting Chew Peh (Statement in Berita Mingguan 26 Oct., 1996) fire had claimed 840 victims annually with the average of 70 persons monthly. In one fire case, which took place at 3.30 am on 16 July 1998, 4 persons died and 18 others were wounded when a fire broke out at their double story link house. The four are believed to have died because they were trapped inside the house as a result of delay to open the iron grills fitted at the main door and all windows. It is a trend in Malaysian buildings that all doors and windows are fitted with iron grills as an extra safety precaution to restrict the intruder from entering their building. At the same time, besides of extras precaution, this practice as well has created a death trap to building occupants. Fitting an iron grill to all doors and windows has reduced the chance for the building occupants to exit the building if a fire breaks out.

There are hundreds of thousands of fires in buildings, about 400 people will lose their lives and 14,000 people will suffer injury most likely from burns or smoke inhalation in United Kingdom annually (Billington, *et. al*. 2002). Ramachandran (1999) says that every year fires in the UK kill about 800 people and cause non-fatal injuries to 15,000 people. On average per year, the direct material damage is about £1,200 million and the indirect loss is about £120 million. The direct and indirect losses in the UK represent about 0.21 per cent of the gross domestic product (GDP). The average number of people dying in fire in UK has dropped about 50% after three years but the numbers of casualty increased by about 7.14%.

The total number of fire in the United Kingdom involving dwellings is about 35,000 per year in 1966 (JFRO, 1968) and this statistic has shown the upward trends which increased at about 8% every year until 70's (JFRO, 1970). The upward trends continued where in 1994 the dwelling fires were 66,300. In 1997, there were 72,200 dwelling fires where around three-quarters of all fires and casualties occur in dwellings. Even though the number of people killed each year in fires in the UK was decreasing, which 1994 was the lowest for 30 years, but yet there were still 676 deaths, 475 of which were in their own homes (Home Office, 1996). The reduction in deaths in the years 1994 has been attributed to the fact that more households have installed smokes alarm (Home Office, 1995). However, a number of death in UK increases again that estimated 560 people died in fires in their home and about 14,900 other were injured i.e. 5% increased on 1996 (HRO, 1998). The death tolls seems to fluctuate after 1996 where the estimated a number of deaths in accidental dwelling fires in 2001 was 435, compared to 397 in 2000 (ODPM, 2003). Even though a number of deaths was relatively decreased compare in 90's, but still many people died and some things should be done to increase the fire safety aspects in dwellings, especially high-rise residential buildings because risks of fire in dwelling buildings are greater than other categories of buildings.

In Scotland there are many high-rise residential buildings. Fire statistics in Scotland have shown tremendous figures that should be caused concern and should open many people's eyes. In comparison to the other UK countries, Scotland reported both the highest number of fatal casualties per million populations and the highest rate of non-fatal casualties (to those not working for fire brigades) per million populations. However, the difference between Scotland and the rest of the UK has narrowed since 2001, when Scotland had nearly twice the fatal casualty rate of the other UK countries (Scottish Executive, 2004). A number of main points about the fire cases in Scotland that involving the buildings as published in Statistical Bulletin, Criminal Justice Series (Scottish Executive, 2004) are as follows:

- Over one-third of all fires were primary fires. Of those, almost two-thirds (63 per cent) of primary fires were in buildings, Since 2001, primary fires have fallen by 3 per cent, secondary fires by 15 per cent and chimney fires by 28 per cent in 2002.

- In Scotland there were a total of 77 fatal casualties in 2002 – a decrease of 19 fatal casualties, or 20 per cent, on the figures from 2001. Sixty-three fatal casualties (82%) occurred in dwelling fires and seven (9%) were in road vehicles. The number of non-fatal casualties in Scotland in 2002 was 2,045, a decrease of 2% compared with 2001.

- It is of note that the Scottish rate of fatal casualties per 1,000 dwelling fires in 2002 was similar to the rates in the other UK countries. This suggests that the reason for Scotland's higher overall fatality rate per million populations in 2002 reflected a higher risk of dwellings fires rather than a greater likelihood of a fatal casualty occurring in such fires.

- The principal cause of fatal casualties was being overcome by gas and smoke (46 fatal casualties). A further 13 fatal casualties were caused by burns alone, and 12 fatal casualties were caused by a combination of burns and being overcome by smoke.

- In the years since 1994, the majority of fatal casualties have occurred in dwellings fires where either the smoke detector was present but failed to operate or in dwellings fires where a smoke detector was absent.

We also can not rule out the fact that in the real world many combustible materials have been brought into the flats by residents after the building was completed. The intensity of fire, especially if highly flammable material stored in a flat catches fire, will cause devastation and would cause the building to collapse. It becomes critical to ensure that all occupants in an affected building are evacuated before its collapse.

A fire accident in a building will generally start at a single location within a room, or compartment. In the early stages, it will present a threat to the occupants of that particular room, but if allowed to grow unchecked, adjacent rooms and indeed the whole building will eventually be placed at risk (Bishop and Drysdale, 1998)

The biggest threats of fire to people are heat and smoke released. Canada Wood Council (2000) quoted their research studies on major causes of fatalities in residential buildings concluded that only 0.2% of the deaths were attributable to fires where a floor or wall collapsed but smoke and heat generated from the burning building contents cause about 90% of the deaths (Christain, 1974), (Harwood, *et. al*, 1989), (Miller and Alison, 1991), (Ahrens and Marty, 2000). It can be concluded that the most threat to people when fire breaks out in the buildings is smoke and heat. These elements are needed to be tackled prior the initial development of fire in order to minimise the risk of casualties to the people during the evacuation processes. This is because risks to the building occupants are increased because of decreased of time available to escape.

From opinion surveys, 40.9% occupants of high-rise residential buildings when asked what they are going to do first if fire alarm went off, said that they will immediately evacuate from the building and 59.1% said that they will do something else e.g. call 999, try to put out fire, save possessions, etc. (Yatim and Harris, 2007b). It seems like majority of the building's occupants are unaware about what the consequences would be if they were caught in uncontrollable of fire.

Even though, many measures have been taken to prevent ignition and spread of fire within the building particularly residential and high rise buildings, numbers of fires recorded never show a significant sign that they will be drastically reduced and this should alarm many people about the consequences of fire as according to Mehaffey (1987) in seminar paper presented in Canada that:

"*Despite efforts to restrict the use of combustible material in buildings and to prevent ignition, fires will continue to start. Whether this fire grows and how quickly, depends to a large extent on the basic flammability of building materials and contents, as well as on the building design. The more quickly a fire develops, the less time occupants of the building have to escape*".

Time factor is one of the attribute risks. In evacuation processes if evacuation time has increased, it will increase the risk to evacuees as well. It means that it will increase the tendency of casualties among the building occupants. Hence risk factors are another variable that are needed to be identified to ensure the high-rise residential buildings of the future are not being fire traps neither for the building occupiers nor the first time visitors. The questions are what are the actual problems encountered in high rise residential building in Malaysia? Do human factors or structural factors contribute more in delaying an evacuation process? Are the escape route design and specification sufficient enough to cater for the crowds during the evacuation process? What is the optimum and the effective dimension of escape routes? How can we ensure that escape routes are always in good condition and do not pose any difficulties during evacuation process?

1.3 Fire safety model analysis

Fire safety analysis is a generic phrase that covers many approaches to decision making about the uncertainties of losses from fire. Within this general structure are techniques for both qualitative and quantitative fire risk analysis, fire modelling techniques, fire safety evaluation, and active and passive fire safety measures, etc.

The purpose of having a fire safety model analysis is to provide a guideline to relevant authorities such as local authorities, consultants, professional bodies and others before any proposal to build a new building in the future can be granted. For instance, a risk analysis technique has been used to evaluate the safety of building e.g. Delphi Technique (Marchant, 1988). Delphi used two set of questionnaires i.e. one is for the building occupants response and another is purposely set for the discussion and judgement of the professionals. The results would lead to decision making on the components of fire safety to be selected within the available technology and technique for fire fighting. Even though the results are very important as it provides a rationale using a flexible approach, the level of safety is not very clear and needs to be enhanced.

Another technique is "The Fire Safety Evaluation Scheme" which had been developed for the patient area within hospitals. (Marchant, *et. al,* 1982) This approach uses the contribution values assigned as a point's scheme based on the checklist provided as an evaluation tool. Point's scheme is basically to form the basis for further judgement on the adequacy of fire safety components or the level of safety against the level of risk or hazard of fire that is available within the system in a particular area. The areas than can be summarised in terms of their acceptable or not acceptable level of fire safety based on a number of points score compared to the stated benchmark.

With the fire risk assessment modelling, the risk components would be identified at the earlier stage on the building design and it is hope that the building that is going to be constructed will not be a death trap to the occupants as mention by (Berndt and Richardson,1982) that:

"*What can be done to control a fire hazard? How can a building designer be sure that he is not creating a death trap for the occupants? These problems can be addressed by three basic methods for controlling fire hazards in buildings: prohibition, isolation and protection*".

A multiattribute Evaluation Model is the most convincing method in fire safety assessment because the nature of its circumstances, in that fire safety decisions often have to be made under conditions in which the data are sparse and uncertain. It is complex and involves a network of interacting components, factors, elements, attributes, parameters, variables and so forth. Interactions are normally nonlinear and multidimensional. Sparseness and complexity of data, however, do not make it impossible to happen. A complex circumstance needs a complex system to solve it. Therefore one applicable approach to fire safety evaluation is Multiattribute Evaluation (Rasbash *et at*, 2004).

We should have a mechanism to enable the selection of the most effective method for controlling a particular hazard. The prohibition, isolation and protection methods, taken individually, may be inadequate; consequently, most designs specify a combination of methods to achieve the desired result. It is often extremely difficult for a designer to choose the most appropriate method since this requires an awareness of the many situations which could lead to an uncontrolled fire in a building. Frequently, the control of these hazards is the last consideration in the design process and, as a matter of convenience, there is a tendency to rely on the letter-of-the-law requirements set down in various provincial or municipal codes. In the process, designers may neglect to consider the objective of these requirements and thus overlook the alternatives available to them (Thompson and Marchant (a), 1995)

One method of risk assessment is the assignment of points or scores to answers to questions in forms / questionnaires / worksheets, e.g., points scheme system, Gretener method, risk ranking, risk assessment schedules, points scheme for assessment of fire safety in hospitals, UK; Dow's fire and explosion index, merits and demerits of points and ranking schemes.

In view of the complexity of modern buildings, it is difficult to determine the escape pattern of occupants by simple calculations. With the advancement of digital computers, many computer-based evacuation models have recently been developed. According to Gwynne *et al*. (1999) they found that about 22 evacuation models have been developed or are under development. Most of them are designed using computational fluid dynamic (CFD) programme.

When evacuating through fire environments, the presence of smoke may not only have a physiological impact on the evacuees but may also lead occupants to adapt their evacuation strategy through the adoption of another exit. By simply considering physical or geometrical factors, the most important variable is omitted; namely occupant behaviour. For a more accurate depiction of events, the occupant's decision-making process should, even in a rudimentary form, be represented and should be able to influence the actions of the simulated occupants. (Gwynne (b) *et al*, 2001)

According to Proulx (1995), elderly people and people with disabilities did not impede the evacuation since occupants who were mobility impaired waited in their unit to be rescued. The problem is if the building is not provided with a fire lift, firemen have to use the routes used by evacuees to rescue the mobility impaired persons. This will delay the evacuation process and increase the evacuation time.

This research is attends to investigate the effects of escape routes design and specifications on the evacuation process and the time taken to evacuate in high-rise residential buildings in Malaysia. This study attends to investigate the integration between the human behaviour and structural design particularly the escape route design and specification. The aim is to produce a fire safety conceptual model on how fire safety standard in high-rise residential buildings can be achieved. Figure 1.1 below shows the outline investigation proposal, types of analysis and the aim of the research.

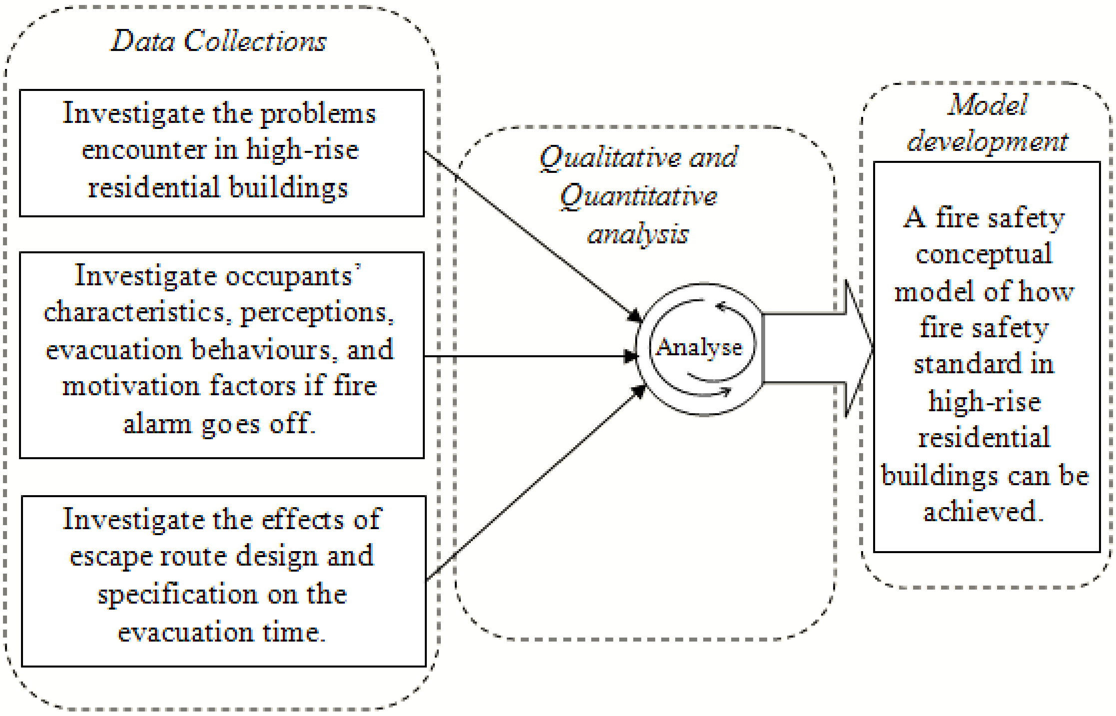

Figure 1.1: The investigation, analysis and modelling of research framework model to achieve research objective.

1.4 Rationale for research and development of fire safety model

The provision for active fire fighting systems and improvements in the technology used in manufacturing of fire safety products such as fire detector devices, sprinkler systems, portable fire extinguishers etc. is actively being developed but there is still room for research in this topic. Furthermore, research concerning the provision of escape routes in high-rise residential buildings has not yet been carried out comprehensively, thus, a study in this particular topic is viable and essential. In Malaysia research regarding fire safety in buildings is very new, particularly research regarding the provision of fire safety in high-rise residential buildings. Even in the United Kingdom, there has not been a great deal of research on fire safety in high-rise residential buildings.

Statistics show that the risk of fire in residential buildings is high. Therefore escape routes in high-rise residential building should be designed and constructed to enable all occupants to evacuate the building in the shortest time possible.

From the groundwork done by the researcher in Malaysia, it was found that the difficulty in escaping from a building fire is largely due to several factors such as:

- Unnecessary fitted 'safety precautions' which can create obstacles,
- The design and construction of escape stairs which do not comply with the rules and regulations,
- The number of people occupying the building at one particular time exceeding the design factor,
- Difficulty in finding the exact location of escape stairs due to unclear or no exit signage,
- Smoke entering the escape route and escape stair,
- Poor illumination system, etc.

Other factors of equal importance are:

- Lack of facilities for disabled people to evacuate from the building,
- No alternative escape route provided in the building,
- No fire-fighting lift being provided,
- Difficulties in identifying the location of egress due to unfamiliarity of the building environment. This is applicable to new tenants and visitors,
- The condition of fire doors,
- The size and shape of escape routes, and
- Traffic congestion during evacuation processes.

These factors have a potential to increase the risk of casualty to the building occupants. Therefore, research on a fire safety model for the high-rise residential building becomes essential.

The purpose of this fire safety model is to provide decision makers, professional bodies, local authorities, building owners and building occupants a sound indicator of fire safety level for high-rise residential buildings. The indicator meant here is a fire safety audit form for auditing the fire safety level regarding the provision of escape routes in high-rise residential building. This will be part of the model developed by analysing all data gathered from the research on existing high-rise residential buildings in Malaysia. The benchmarks for creating this model are Building Regulations approved documents part B (England and Wales), Building Regulation Part 2 (Scotland) and Uniform Building By-Laws 1984 (Malaysia).

If fire breaks out in high-rise residential buildings, it is expected that the occupants will evacuate the building using normal escape routes provided in the building unless they have caught fire. If fire and smoke conditions in the affected building are worse and threaten the occupants, then they may have no choice but to return to their respective apartments or seek refuge in other apartments and wait to be rescued by the fire fighter (Yung, *et. al*., 2001).

Therefore, escape routes in high-rise residential buildings are supposed to provide a safe egress for the building occupants to reach at the safe designated area. Elements of escape route such as steps, handrail, balustrade and staircase slope should have been designed and installed in such a way that they are safe to use. Are the designs of those elements safe to use? Moreover, most of the time taken to evacuate from the building during a building fire is to open the fire doors, pass through many corner and U-Turn, horizontal and vertical exits. Are these hypothetical statements true, or there are other human factors perceived being the major factors contributing to the casualties?

Any high-rise residential buildings in the future should have clear fire safety policies, objectives, tactics, components and elements, and a comprehensive fire evacuation plan and fire evacuation procedure. Those factors need to be identified and among the outcomes of this research is expected to suggest fire safety expectation i.e. fire safety components and elements, escape routes specifications, human behaviour factors regarding the evacuation process and how risk of fire and casualty can be reduced. Therefore, the main objective of my research is to produce a fire safety model for high-rise residential buildings, mainly dealing with the safety attributes of escape routes and safe egress for the building occupants.

1.5 Research Questions

(i). What are the actual problems with the escape routes in high rise residential building in Malaysia?

(ii). What are the factors that cause the evacuation to delay, human or structural?

(iii). Is the current escape route design and specification sufficient to cater for the crowds during evacuation process?

(iv). What are the optimum dimensions of escape routes?

(v). How can we be sure that escape routes are always in good condition and do not pose any difficulty during evacuation process?

(vi). Are the escape routes elements safe to use?

(vii). What factors most motivated people to evacuate the building once the alarm sounded?

1.6 Research Objectives

(i). To study the compliance of escape route design and construction in high-rise residential buildings to the specification given in Uniform Building By-Laws 1984 (Malaysia).

(ii) To formulate a fire safety model using qualitative and quantitative analysis techniques to improve fire safety standards in high-rise residential buildings.

1.7 Research scope and limitations

The scope of this research is:

(i). Only escape routes components i.e. staircase, corridor, fire door and intermediate floor are considered in analysis.

(ii). The study is focused on high-rise residential buildings with minimum of five storeys height.

(iii). Risk factors in building will be analysed according to the personal and damage hazards of fire as ruled out by Jabatan Bomba dan Penyelamat Malaysia.

(iv). Analysis of evacuation processes will be done using SIMULEX simulation software for the selected high-rise residential buildings.

1.8 Thesis organisation structure

There are nine chapters in this thesis with reference and appendixes.

Chapter 1

Chapter one is a brief introduction to the overall thesis

Chapter 2

Chapter two reviews the background studies or related literature that directly influences our general understanding of the area of concern. Understanding the principle of fire technology, provision for escape route in building regulation and Uniform Building By-Laws, fire safety evacuation model, human behaviour, escape route design and specifications, and fire plan and evacuation procedure.

Chapter 3

Chapter three outlines the methodology used for this thesis. Mixed methodologies adopted in this thesis i.e. qualitative and quantitative technique used to develop fire safety model proposed. Mixed research methods used include analysing observations, questionnaires and computer simulation data.

Chapter 4

Chapter four concerns observation of escape routes in high-rise residential buildings and formulation of study models for further analysis. In these observation exercises, 462 staircases, 1536 staircase steps, i.e. 33.29%, have been investigated in six high-rise residential buildings. Also, another six buildings have been visited to study their internal layout and circulation patterns.

Chapter 5

Chapter five is an evaluation of the condition of escape routes in high-rise residential buildings, based on the observation of twelve buildings in Kuala Lumpur and Penang.

Chapter 6

Chapter six is a study of human behaviour response issues in high rise residential buildings in Malaysia. A questionnaire survey was used to collect research data by distributing them to all residential units in selected high-rise residential buildings in Kuala Lumpur.

Chapter 7

Chapter seven is an evaluation of the provision of escape routes in high-rise residential buildings in Malaysia by analysing the escape route design and specification using special computer simulation. Based on the study models developed in chapter four, i.e. 225

models tested using speciality software call SIMULEX, specification for corridor, staircase, fire door, and intermediate and landing floor widths can be suggested.

Chapter 8

Chapter eight discusses the development and content of a fire safety model in high-rise residential buildings.

Chapter 9

Chapter nine contains conclusion and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter definitions of high-rise building from various references will be given followed by a brief description of Malaysian populations and the need for the housing. The current Malaysian population is estimated at 27.49 million with an annual growth rate of 2.6%. With huge numbers of foreign workers i.e. estimated about more that 7 million currently working in Malaysia, especially in the construction industry, manufacturing, housemaid, etc, high demand for housing has driven private and government-linked companies to build more high-rise residential buildings.

To understand the effects if fire breaks out in enclosed spaces, the science of fire and fire characteristics are also discussed. A literature review for escape route provision in Malaysia and United Kingdom building codes will also be presented followed by literature on the evacuation simulation package and fire safety management, fire risk assessment, and human behaviour studied by other researchers.

2.2 Definition of high-rise buildings

Most building codes define the high-rise building in terms of height and/or storeys. The fire department tend to thinks of high-rise buildings as being beyond the reach of the ground equipment available to them (Klaena, and Sanders 2000). The National Fire Protection Association (NFPA, 2000) defined a high-rise building as a building taller than 75 ft (23 meters) in height measured from the lowest level of fire department vehicle access to the floor of the highest occupiable storey. Another opinion says a high-rise structure is one that extends higher than the maximum reach of available fire-fighting equipment and it is between 75 ft and 100 ft. A particular building is deemed a high-rise specified by the fire and building codes in the area in which the building is located (Craighead, 2003).

Terpak, (2003) says the definition of high-rise building is any building exceeded 75 ft where fire department operation cannot be considered ground based. Meanwhile, Avillo, (2002) mentioned that a definition for the categorisation of a high-rise building is any building over 75 ft in height and equipped with a standpipe and/or sprinkler system. This definition of a high-rise is not totally accurate from a strategic and logistical point of view. Many departments have limited or non-existent aerial capability.

Building codes vary in their definition of high-rise buildings, but the intent is to define buildings in which fires cannot be fought successfully by ground-based equipment and personnel. Thus, ordinarily, high-rise means buildings 100 ft or more high (Merritt and Ricketts, 2000). Encyclopaedia Britannica gives a definition of a high-rise building as a multi-story building tall enough to require the use of a system of mechanical vertical transportation such as elevators (Britannica online). From the building construction article; the high-rise building is generally defined as one that is taller than the maximum height which people are willing to walk up; it thus requires mechanical vertical transportation (Britannica online).

A building is defined by the Uniform Building Codes as a high-rise building when it has floors for human occupancy which are more than 75 ft above the lowest level of fire department access. Second definition as stated in Uniform Building Codes is the buildings meet the definition to be equipped with an automatic fire sprinkle system designed in accordance with requirements in Uniform Building Codes (Patterson, 1993).

Therefore, for the purpose of this research, high-rise residential buildings to be selected for study are those buildings taller than 75 ft or roughly buildings taller than five storeys in height are categorised as a high-rise building.

2.3 Population and Housing in Malaysia

Malaysia became independent from Britain on 31st August 1957 with the name of Federation of Malaya or *Persekutuan Tanah Melayu* which consists of nine Malay States or *Negeri-Negeri Melayu* i.e. states that governed by the Malay Kings in the peninsular of Malaya. In 1963, all Malay States, including of Melaka, Penang, Sabah, Sarawak and Singapore were joined together to form Malaysia. Singapore then separated from Malaysia in 1965 to become Republic of Singapore.

Since the formation of Malaysia in 1963, there are four censuses on the Malaysian population i.e. in the year 1970, 1980, 1991 and 2000. It is expected that the next census exercise will take place around the year of 2010 i.e. every ten years. In the year 2000 census, the total population of Malaysia was 23.27 million with the majority ethnic Malay 58%, followed by Chinese 24%, Indian 8% and other 10%, and average annual growth rate of 2.6% over the period of ten years (1991 – 2000). This growth rate was similar to the previous census i.e. 2.6% for the period of 1980 – 1991 (Malaysia Statistics, 2000). The estimated current population of Malaysia is 27.49 million according to Malaysia statistics' website www.statistics.gov.my. Besides that there are more than 7 million foreign workers from varies countries i.e. Indonesia, Thailand, Philippine, Bangladesh, Burma, India, China, etc to work in various sectors. The most popular sectors that have employed substantial numbers of workers from foreign countries are the construction industry, housemaid, manufacturing and estates. These populations need buildings to house them. High-rise flat buildings seem to be the best solution to provide shelter in highly populated areas such as Kuala Lumpur, the capital of Malaysia. Therefore the number of high-rise accommodation buildings in Kuala Lumpur and nearby townships has drastically increased in the past few decades. It is expected that many more high-rise residential buildings will be built in the near future because of the high price of land in the town area, high demand from the first time purchaser and from the people who wants to buy a second house near to their workplaces.

The construction of new high-rise residential buildings should not only be viewed from the prospective of economics and construction technology but equally important is that they are viewed from the perspective of fire safety as well. Research on effective design and specification of escape routes in high-rise residential buildings becomes essential to ensure building occupants are able to evacuate the building safely in the event of fire.

2.4 The science of fire and fire spreading in building

In the event of fire, deaths are mostly caused by smoke or smoke inhalation related causes, instead of direct burning. Smoke and heat become a major threat in building fire, therefore understanding the characteristic of smoke and heat are crucially important in building fire for the sake of life safety. With the knowledge and understanding of the behaviour of smoke and heat, one can be expected to be able to make a wise decision once in a critical situation i.e. dealing with the building fires. Life safety would be increased if occupants of the high-rise residential buildings know at what limit that the risk can safely to be taken. By understanding the science of fire and fire spreading in the building, evacuation process would be eased because occupants in high-rise buildings know what to do in the event of fire.

The size of a fire is related to the heat release rate. To determine a design fire, a database on heat release rate should thus be developed (Peacock *et al,* 1994). The size of the fire and its heat release rate is the first and most important element among the parameters commonly used to characterize an unwanted fire (FPEH, 2002, Huggett, 1980). However, the threat to the occupants may be minimized and the damage to the fabric and structure of the building could be reduced to an acceptable level by increasing knowledge of fire science and the principles of fire safety engineering (Bishop & Drysdale, 1998).

A fire tragedy will not only involve damage to property but also issues of life. Therefore we must be very careful when dealing with the elements having a high risk of fire ignition. Another important factor that needs to be considered is the *fire load*[1] stored in the building. According to Clark (1988), even buildings constructed of non-combustible materials will almost without exception contain materials that burn under certain circumstances. On the other hand, materials that are designated as a combustible material, according to tests, may be of negligible significance in fires. Wood is a good example of a common material for which fire performance is difficult to predict. It ignites if its surface reaches about 300°C in the presence of a flame or perhaps 400-500°C in its absence. It may also ignite, however, at much lower temperatures if the time of exposure to heat is longer. Charring, a process related to ignition, has been recorded when the temperature was not much above 100°C. Before we go further about science of fire, let us look at the definition of fire and fire safety related attributes.

2.4.1 Definition found in various references.

The definitions of fire and fire safety attributes given in this chapter are gathered from various sources.

i. Combustion:

Oxford Dictionary (OD) and International Encyclopaedia (IE) gave the definition of combustion as follows:

> *"A state of combustion in which the substances combine chemically with oxygen from the air and usually give out bright light and heat" (OD)*

> *"A rapid combustion characterized by high temperatures and flame. In order to produce fire, a combustible material and oxygen must be present and in contact at sufficiently high temperatures to initiate combustion" (IE)*

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[1] Fire Load – Every thing inside the building which is form a part or not a part of the building structure such as people, furniture, finishing etc….

Meanwhile, the American Heritage Dictionary of the English Language (AHDEL, 2004), gives the definition of combustion as the process of burning or a chemical changes, especially oxidation, accompanied by the production of heat and light. The word combustion was believed originated from the late Latin that *combustiō, combustiōn* or from Latin *combustus* that the past participle of *combūrere* which is giving a meaning of to burn up or blend of combustion or to burn around.

The Columbia Electronic Encyclopaedia (CEE, 2003) defines combustion as a rapid chemical reaction of two or more substances with a characteristic liberation of heat and light; it is commonly called burning. The burning of a fuel (e.g., wood, coal, oil, or natural gas) in air is a familiar example of combustion. Combustion reactions involve oxidation and reduction. Before a substance will burn, it must be heated to its ignition point, or kindling temperature. Although the ignition point of a substance is essentially constant, the time needed for burning to begin depends on factors such as the form of the substance and the amount of oxygen in the air (CEE, 2003). However, combustion sometime may not involve oxygen to the process for the ignition to start e.g. hydrogen burns in chlorine to form hydrogen chloride with the discharge of heat and light that a characteristic of combustion too.

Combustion or burning is an *exothermic reaction* between substances and gases to release heat. In chemistry, an *exothermic reaction* is one that releases heat. It is the opposite of an endothermic reaction which can be expressed in a chemical equation i.e. Reactants → Products + Energy. When using a calorimeter, the change in heat of the calorimeter is equal to the opposite of the change in heat of the system. This means that when the solution in which the reaction is taking place gains heat, the reaction is exothermic. In an exothermic reaction the total energy absorbed in bond breaking is less than the total energy released in bond making. Combustion normally occurs in oxygen (often in the form of gaseous O_2) to form oxides, However, combustion can also take place in other gases like chlorine. The products of such reaction usually include water (H_2O) as well as carbon monoxide (CO) or carbon dioxide (CO_2), or both which is high in toxicity. Other by products, such as partially reacted fuel and elemental carbon (C), may generate visible smoke and soot. Generally, the chemical equation for combusting a hydrocarbon, e.g. octane, in oxygen is as follow: $C_xH_y + (x + y/4)O_2 \rightarrow xCO_2 + (y/2)H_2O$. For example, the burning of Propane is: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$.

ii. Rapid Combustion

Rapid combustion is a form of combustion in which large amounts of heat and light energy are released. An example of rapid combustion is burning of fuel i.e. petrol or diesel in internal combustion engine, burning of highly combustible material in open burning, etc.

iii. Slow Combustion

Slow combustion is a form of combustion which taken place at a low temperature. Examples of slow combustion are what we see in everyday life e.g. gas cooker used to cook food, burning of candle, etc.

iv. Fire

According to Jerome (1994), fire is the manifestation of a chemical reaction called combustion. This reaction takes place between a fuel and oxygen but requires heat to initiate the reaction. When the reaction has started it generates its own heat and this reaction will continue until all available fuel finished. This reaction is called *chain reaction*[2] which means that fire spreads by it owns heat. In general terms, fire is defined as a rapid, persistent chemical change that releases heat and light and is accompanied by flame, especially the exothermic oxidation of a combustible substance. The word fire is used to refer to the combination of the brilliant glow and large amount of heat released during a rapid, self-sustaining exothermic oxidation process of combustible gases ejected from a fuel. The fire itself is a body of gas that releases heat and light. It starts by subjecting the fuel to heat or another energy source, e.g. a match or lighter, and is sustained by the further release of heat energy i.e. change reaction. Most commonly the word fire refers to uncontrolled fires than controlled fires.

v. Transfer of Heat

Heat may be transferred from one substance to another by three means that of conduction, convection, and radiation. Conduction involves the transfer of energy from one molecule

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[2] According to the Encyclopedia Britannica **Chain reaction** is a series of reactions in which the product of each step is a reagent for the next. Many polymerization reactions are chain reactions. A simpler example, however, is found in the synthesis of hydrogen bromide. The overall synthesis equation is $H_2 + Br_2$ ® 2HBr.

to adjacent molecules without the substance as a whole moving. Convection involves the movement of warmer parts of a substance away from the source of heat and takes place only in fluids, i.e., liquids and gases. Radiation is the transfer of heat energy in the form of electromagnetic radiation, principally in the infrared radiation portion of the spectrum.

vi. Smoke

Smoke is a visible gaseous product of incomplete combustion made up of small particles of carbonaceous matter in the air, usually comprises hot gas and suspended particles of carbon and tarry substances, fine solid or liquid particles in a gaseous medium, or soot and forming a cloud of fine particles resulting mainly from the burning of organic material, such as wood or coal. Smoke varies with its source, but it wood gives little smoke if burned when dry and if the fire is given a good supply of air.

vii. Fire Safety

Fire safety is a generic term normally used as a component of building fire safety which includes some elements as follows:

- Maximum occupancy or occupancy load, that is, the number of people permitted to occupy any building at one particular time. This is to ensure that they all can evacuate the building as quickly as possible in an emergency situation.

- There are sufficient fire exits and proper signage which is workable even if power failure occurs. The exit signage should be able to direct the occupants to the designated safe assembly area.

- Fire extinguishers or fire suppression system and fire alarms are placed in an easily accessible location. The system should be regularly inspected and maintained.

- All flammable materials are banned from being stored in building in large amounts unless permission has been given by the relevant authority. The place to store that material should be built with fire retardant materials and has passed the fire test.

- Regular inspecting of public buildings should be carried out to check for violations of fire safety policy or fire precaution act, and if necessary a closing order issued until the violation is corrected, or in extreme cases the building is condoned.

viii. Fire Exit

Fire exit is a fire escape route forming a part of the building component which is used by the people to evacuate from the building in a case of an emergency such as a fire. It is usually a strategically located (e.g. in a stairwell, hallway, or other likely place) outward opening door with a crash bar on it and with exit signage leading to it. A fire exit can also be a main doorway in or out. A fire escape is a special kind of fire exit, mounted to the outside of a building.

2.4.2 Classes of fire

Fire is categorised according to the types of fuel it consumes and named various classes of fires i.e. A to F or E (for United State) are detailed. In Europe and Australia, classes of fire are grouped into six groups as follows:

- Class A: Fires that involve flammable solids such as wood, cloth, rubber, paper, and some types of plastics.
- Class B: Fires that involve flammable liquids or liquefiable solids such as petrol/gasoline, oil, paint, some waxes & plastics, but NOT cooking fats or oils.
- Class C: Fires that involve flammable gases, such as natural gas, hydrogen, propane, butane.
- Class D: Fires that involve combustible metals, such as sodium, magnesium, and potassium.
- Shock Risk Fire (formerly known as Class E): Fires that involve any of the materials found in Class A and B fires, but with the introduction of an electrical appliances, wiring, or other electrically energized objects in the vicinity of the fire, with a resultant electrical shock risk if a conductive agent is used.
- Class F: Fires involving cooking fats and oils. The high temperature of the oils when on fire far exceeds that of other flammable liquids making normal extinguishing agents ineffective

In the U.S., fires are generally classified into five groups: A, B, C, D and E.

- Class A: Fires that involve wood, cloth, rubber, paper, and some types of plastics.

- Class B: Fires that involve gasoline, oil, paint, natural and propane gases, and flammable liquids, gases, and greases.
- Class C: Fires that involve any of the materials found in Class A and B fires, but with the introduction of an electrical appliances, wiring, or other electrically energized objects in the vicinity of the fire.
- Class D: Fires that involve combustible metals, such as sodium, magnesium, and potassium.
- Class E: Fires involving cooking fats and oils. The high temperature of the oils when on fire far exceeds that of other flammable liquids making normal extinguishing agents ineffective

2.4.3 Understanding the basic of chemical and physical nature of fire

In spite of knowing the definition of fire and fire related terms, the basic chemical and physical nature of fire needs to be studied for better understanding of fire and how it can be controlled during initial growth and development. In fire science, the well known theory of fire is 'Triangle of Fire' model. Figure 2.1 illustrates the triangle of fire which having three components links together to form a triangle. Those components are fuel, oxygen and heat which chemically bond together to form fire characteristics that is flame, smoke and heat.

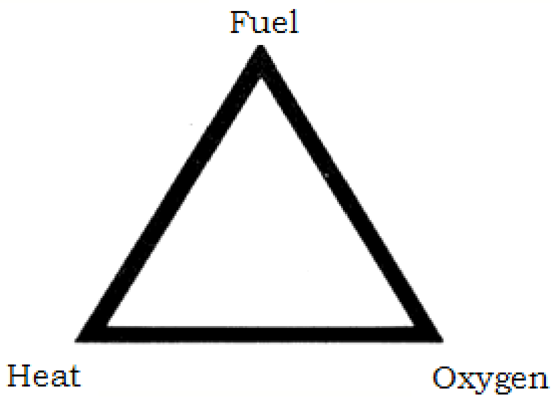


Figure 2.1: The triangle of fire concept model (Mehaffey (a), 1987)

This triangle of fire can be used to explain that if we want to extinguish the fire, it can be done by isolating one of the three components from the combination. Fire can be suppressed by removing either heat, which commonly means using water spray to cool the heat, or by removing the fuel, which normally means limiting or turning off the flow of gas in a gas stove or by removing the oxygen by smothering the fire with a fire blanket for example. However, we should not forget about the fact that ‘Chemical Reactions’ are also needed to keep the fire spreading. This reaction is known as the ‘Chain Reaction’ which is heated molecules freely and rapidly moving in all directions. These molecules are very active moving around and hitting the other molecules to set fire on other molecules. Fire will continue due to the chain reaction process in which the heated molecules will touch the others until the temperature reaches the state of auto combustion where hydrogen gas and oxygen gas from the air actively take part in the burning process. Figure 2.2 illustrates the process of chain reaction in burning materials.

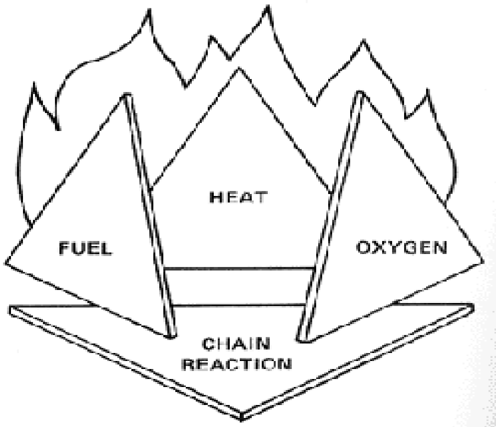


Figure 2.2: The chain reaction process in burning material, (Mehaffey (a), 1987)

How rapidly the chain reaction will take place depends on how fast the pyrolysis process occurs on the fuel. For example, polymer products of building materials e.g. synthetic polymers or plastic products have a very rapid chain reaction compared to organic carbonise construction materials e.g. woods. By breaking the chain reaction, fire can be suppressed and this allows for the possibility of a fourth extinguishment technique, that is, building components coated with fire retardant chemicals to react while being heated to break the chain reaction. Gypsum is one material which acts in this fashion. It is a mineral composed of calcium sulfate (calcium, sulfur, and oxygen) with two molecules of water. When it is heated approximately 150°C (302°F) partially dehydrates the mineral by driving off exactly 75% of the water contained in its chemical structure rather than increasing the temperature of the mineral. The temperature will rise slowly until the water is released as steam and delaying the burning process by slowing the chain reaction. The chemical formula for this process as follow: $CaSO_4 \cdot 2H_2O$ + heat → $CaSO_4 \cdot \frac{1}{2}H_2O$ + $1\frac{1}{2}H_2O$ (steam).

Products of combustion rising above the flame are in the form of smoke and heat. Smoke consists of airborne solids (soot), liquid droplets, and gases, some of which may be toxic. Among the toxic gases produced, carbon monoxide is certainly the most lethal gas. However, Carbon Dioxide, Hydrogen Cyanide, Hydrogen Chloride, Nitrogen Dioxide and may others also be produced when the relevant material set on fire. Carbon monoxide is the main toxic gas produced from the combustion of polyethylene and other organic materials that are made up of carbon and hydrogen atoms. It is produced as a result of incomplete combustion when the oxygen supply is limited. When it is inhaled, it causes asphyxiation by combining with haemoglobin in a reversible reaction to form *carboxyhaemoglobin*. Its formation at the expense of *oxyhaemoglobin* reduces the availability of oxygen for the cellular systems of the body (Sumi & Tsuchiya, 1971).

2.4.4 The stages of a fire

Fires within an enclosed space behave differently and with a different rate of burning from those in the open (Stollard & Abrahams, 1999). The growth period lasts from the moment of ignition to the time when all combustible materials within the enclosure area are burned.

Figure 2.3 shows the standard fire curve in a compartment fire. The Time – Temperature curve in this figure 2.3 is not according to the scale and the time taken in each stage cannot be directly measured to get an empirical reading but rather a conceptual graph to show the behaviour of fire in building. There are four stages all together i.e. initial stage, growth, steady combustion and decay. In the initial stage, fire behaviour largely depends on the types of fuel available in the building. If the fuel is in gaseous form, the ignition will be very rapid and if the fuel is in a solid material like timber, it will be a slow combustion or smouldering fire. On the other hand, fire behaviour is largely influenced by how fast pyrolisis processes take place. At the initial stage only smoke and heat will be released. Once smoke has been detected, i.e. fire alarm goes off, people in the affected buildings should start to make their way out to the escape stairs as soon as possible. They should not wait until the fire has emerged and become serious or uncontrollable before beginning to evacuate. The chance of saving life is greater if immediate action is taken to evacuate the building soon after the fire has been detected.

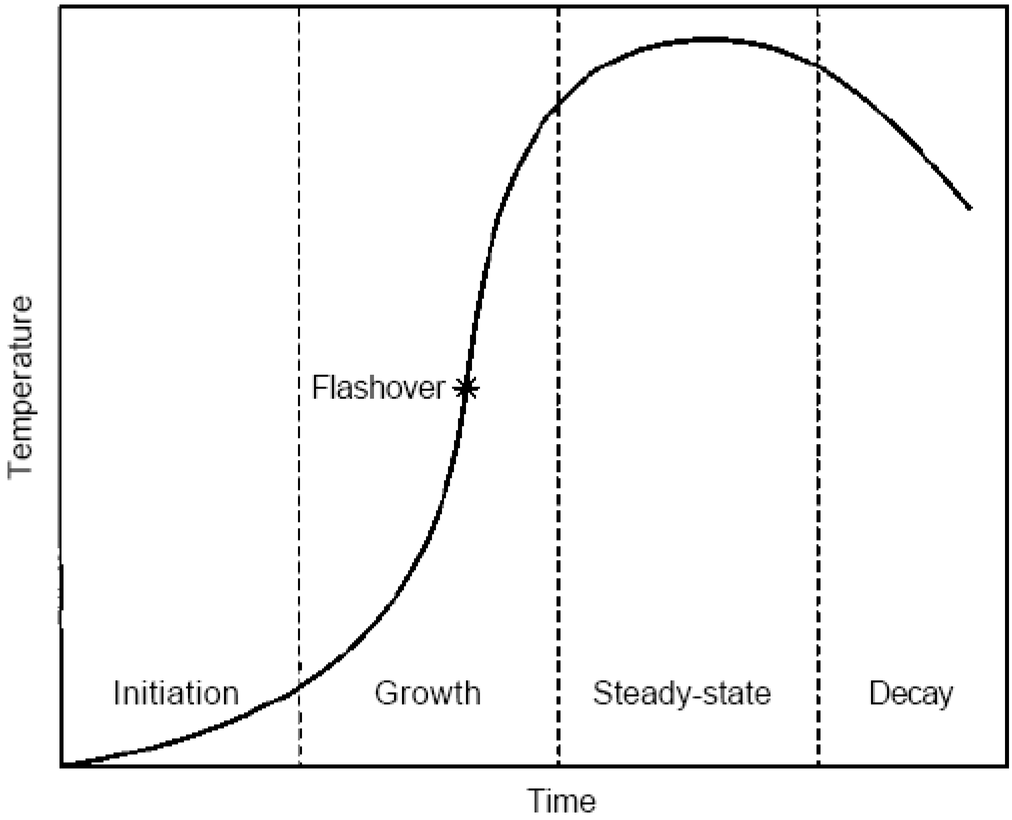


Figure: 2.3: A standard fire curve in enclosed spaces (CIBSE, 2003)

The rate of development of fire and it duration are influenced by the nature of the contents of the building and materials of the room surfaces (Marchant, 1972). The phase of fire growth is started when ignition has begun and continues until all combustible materials are lighted. At this point flashover begins and the fire begins to enter the steady state combustion phase where most of the combustible materials are burning and the heat releases is maximum. For building fires the temperature at this stage ranges from 900^{0} C – 1200 ^{0} C and the duration of the fire is determine by the amount of air supplied and the quantity of combustible material available. After all the material has been consumed, it then starts to enter the next stage, the decay phase.

In decay phase, the fire starts to decay until it stops completely if there are no more combustible materials available. The heat release will gradually reduce to leave charcoal and dust at the end of the combustion process. Even though fire is in a decaying process, it is still dangerous and still fatal if extremely exposed because there is still smoke in the fire vicinity which poses a danger to the people if they breathe this smoky air. It can possibly choke the respiration system and be lethal, since there are toxic gases produced during the combustion process. This can happen if the materials involved are classified as toxic materials such as materials containing high chlorinate or nitrite compounds.

2.4.5 Fire spreading in building

When fire starts to burn in a compartment, i.e. after ignition, it burns just like in open space. After a short period of time, smoke produced by the burning processes starts to form a hot layer below the ceiling, heating the ceiling and upper walls of the room. Thermal radiation from the hot layer, ceiling, and upper walls begins to heat all objects in the lower part of the room and may augment both the rate of burning of the original object and the rate of flame spread over its surface as illustrated in figure 2.3a.

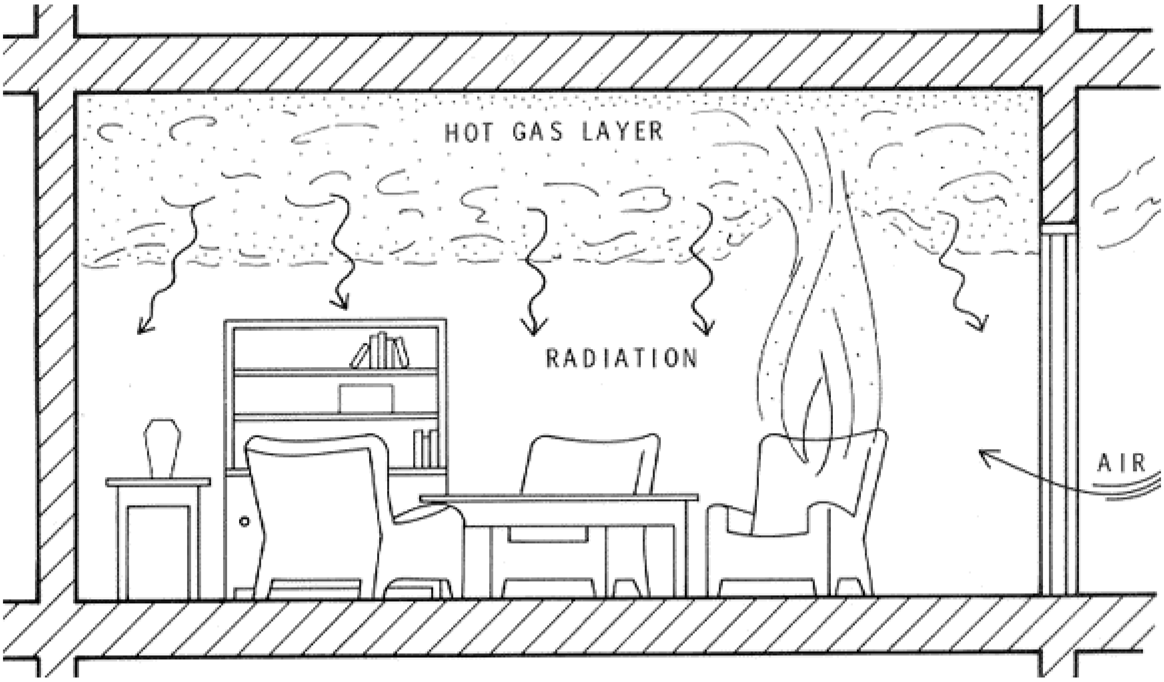


Figure 2.3a: Fire behaviour in compartment (Mehaffey (b), 1987)

To reduce the risk to persons if there is a fire, it is necessary to consider how to control or restrict the spread of fire and smoke in building because the majority of people who die in fires are overcome by the smoke and gases. Thick and black smoke can obscure vision, choke breathing, and block the escape routes. Fire can spread by three methods i.e.

- Convection,
- Conduction, and
- Radiation

Convection is the most dangerous and causes the majority of injuries and fatalities. Heat and smoke spreads by convection, once fire starts in an enclosed space, when heat and smokes rises from the burning material and is trapped by the ceiling and walls. Heat and smoke will pass through any holes or gaps in the ceiling, walls, or floor into other parts of the building. The heat from the fire trapped in the building will increase the temperature of other combustibles until they reach their ignition temperature and ignite more or less simultaneously to cause flashover.

Conduction occurs when heat absorb by metal and transmit it to other room where it can set fire to combustible materials that are in contact with the heated metal.

Radiation transfers heat in the air in the same way that electric bar heater heats the room. Any combustible materials close to a fire will absorb the heat until they reach their ignition temperature and start to burn.

2.5 Regulatory framework and escape routes provision in the Uniform Building By-Law 1984 in Malaysia.

In this section, provision of escape route in UBBL 84, Malaysia, which is currently in use, and the Building Regulation, UK, will be discussed. Definition of terms and references used in the Uniform Building By-Laws 1984 can be found in appendix 2.0.

2.5.1 Regulatory framework in Malaysia

Local authorities are a government agency. One of it function is to check all applications for a new building to be built in their territory. Any application for a new building will be approved if it has fulfilled all requirements by the by-law. The consideration to approve any building plans submitted to the local authority will only be given after the local authority has received a written recommendation by internal and external technical departments. The application for a new building needs to be made by the developer or by the developer's representative which is normally a registered architect.

The number of internal technical department depends on the size of the local authority. For example the Kuala Lumpur Municipal Council has 12 internal technical departments i.e. Economy Planning and development department, Town Planning Department, Building Department, Mechanical Engineering Department, Architect Department, etc. Meanwhile, the Penang Municipal Council only has five internal technical departments i.e. Building Department, Engineering Department, Town Planning and Development Department, Licensing Department, and Urban Services Department. Among the internal technical departments, Building Department is the one who is responsible for controlling, implementation and enforcement to ensure that all buildings in their area are safe for occupy.

Besides that there are a number of external technical departments that the local authority will have to refer for the technical comments before any building plans can be approved that:

i. Irrigation and Drainage Department,

ii. Fire Services and Rescue Department,

iii. Sewerage and Services Department,

iv. Public Works Department,

v. Water Supply Department,

vi. Electrical Energy Department (Tenaga National Berhad)

vii. Telecommunication Department (Syarikat Telekom Malaysia)

Fire Services and Rescue Department is responsible to comment on the design and specifications of escape routes, emergency exits, party wall, and / or fire doors, fire barrier, compartment floors etc. Reference for regulatory requirement regarding the fire safety aspects in the building is The Uniform Building By-Law 1984 which uses by both departments i.e. Building Department, and Fire Services and Rescue Department for statutory satisfaction.

2.5.2 Managing residential buildings

The authority of the high-rise residential building is similar to the other buildings i.e. private property which after the building has been completed and handover to the purchaser, after two years of handover, all liabilities on the building i.e. maintenance, to keep the building clean etc is the owner’s responsibility. The owner is all the purchaser of the flats in that building. Two years is a developer’s liability period i.e. all maintenance is under the developer’s responsibility. After the liability period ended, the owners will have to appoint a Management Corporation (MC) to manage the building. The MC can be among the purchasers which mean they can form a committee to manage the building or appointing a proper building management firm to manage the building. All maintenance fees and costs, if any, are the liability to the owners. A normal practice is the owners will pay a monthly “maintenance fees” to the MC. The MC will inform all owners about any maintenance cost involve if any part of the building or services in the building is needed for replacement.

The problem starts to arise when some of the owners reluctant to pay the maintenance fees which has caused the MC of having a financial difficulty. This has caused the maintenance on the building can not be effectively completed. To overcome this problem, Joint Management Corporation (JMC) has been formed where the developer will be part of the Management Corporation i.e. to head the JMC to manage the building. It means that they will be joint responsibility between the developer and the management corporation on the managing of the building. For example if a state government agencies, e.g. State Economics Development Corporation (SEDC), as a developer, SEDC will head the JMC to manage the high-rise residential buildings. JMC has an authority to implement any measures to improve the fire safety standard in the building they manage. They shall be responsible to ensure any legal aspects in the buildings under their management are complied.

2.5.3 Escape routes specification as in UBBL ‘84

Staircase riser and tread dimensions

The riser of any staircase shall be not more than 180 millimetres and the tread shall be not less than 255 millimetres and the dimensions of the riser and the tread of the staircase chosen shall be uniform and consistent throughout. Figure 2.4 shows the risers and the treads of the staircase form and dimension.

The widths of staircases shall be in accordance with by-law 168. Sub-clause 2 stated that “staircases shall be of *such width* that in the event of any one staircase not being available for escape purposes the remaining staircases shall accommodate the highest occupancy load of any one floor discharging into it, calculated in accordance with provisions in the Seventh Schedule to these By-laws”. In sub-clause 3 it is stated that “the required width of a staircase shall be the clear width between walls but handrails may be permitted to encroach on this width to a maximum of 75 millimetres” and sub-clause 4; “the required width of a staircase shall be maintained throughout its length including at landings”.

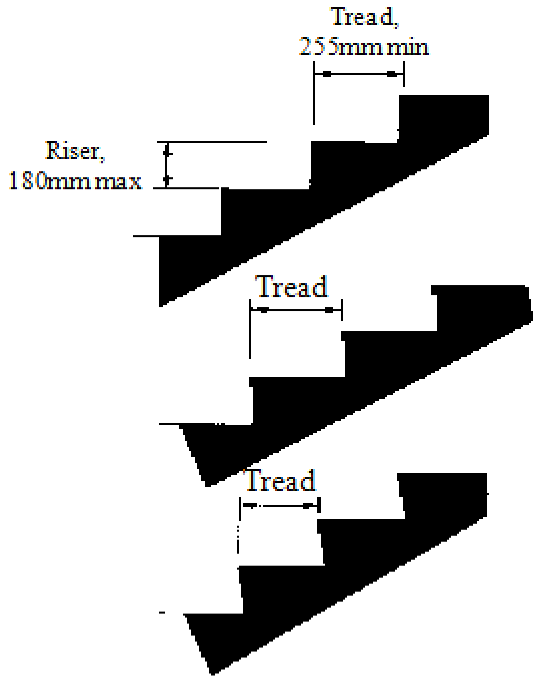
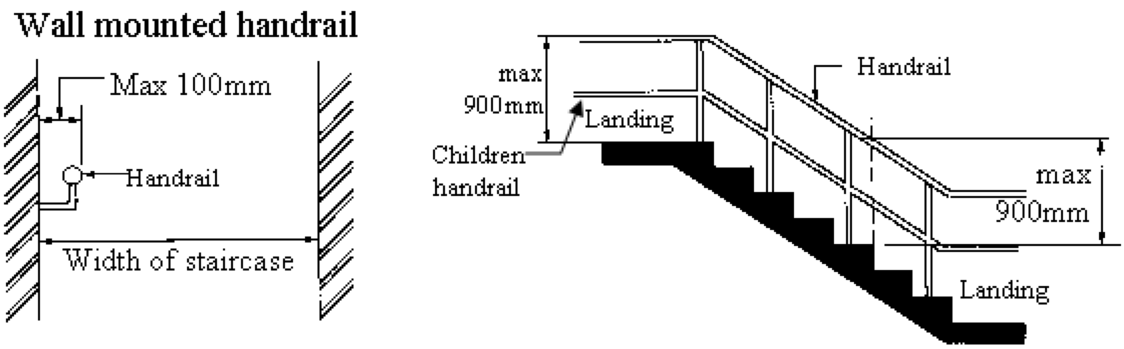


Figure 2.4: Specification for treads and risers for difference types of staircase design.

The depths of landings shall be not less than the width of the staircases. In residential buildings, a landing of not less than 1.80 metres in depth shall be provided in staircases at vertical intervals of not more than 4.25 metres and in staircases in all other buildings there shall be not more than sixteen risers between each such landing (UBBL, 108:1) and no part in any flight of any staircase shall have less than two risers (UBBL, 180:2). Figure 2.6 shows the landing depth and width of the staircase.

Handrail



(a) (b)

Figure 2.5: (a) Wall mounted handrail, (b) Handrail detail

In clause 107 (4) it is stated that all handrails shall project not more than 100 mm from the face of the finished wall surface and shall be located not less than 825 mm and not more than 900 mm measured from the nosing of the treads provided that handrails to landings shall not be less than 900 mm from the level of the landing. Figure 2.5 (a) and (b) show the specification for handrail mentioned. It means that it has to be 900 mm for adult handrails. Children's handrail can be provided between these ranges as an optional.

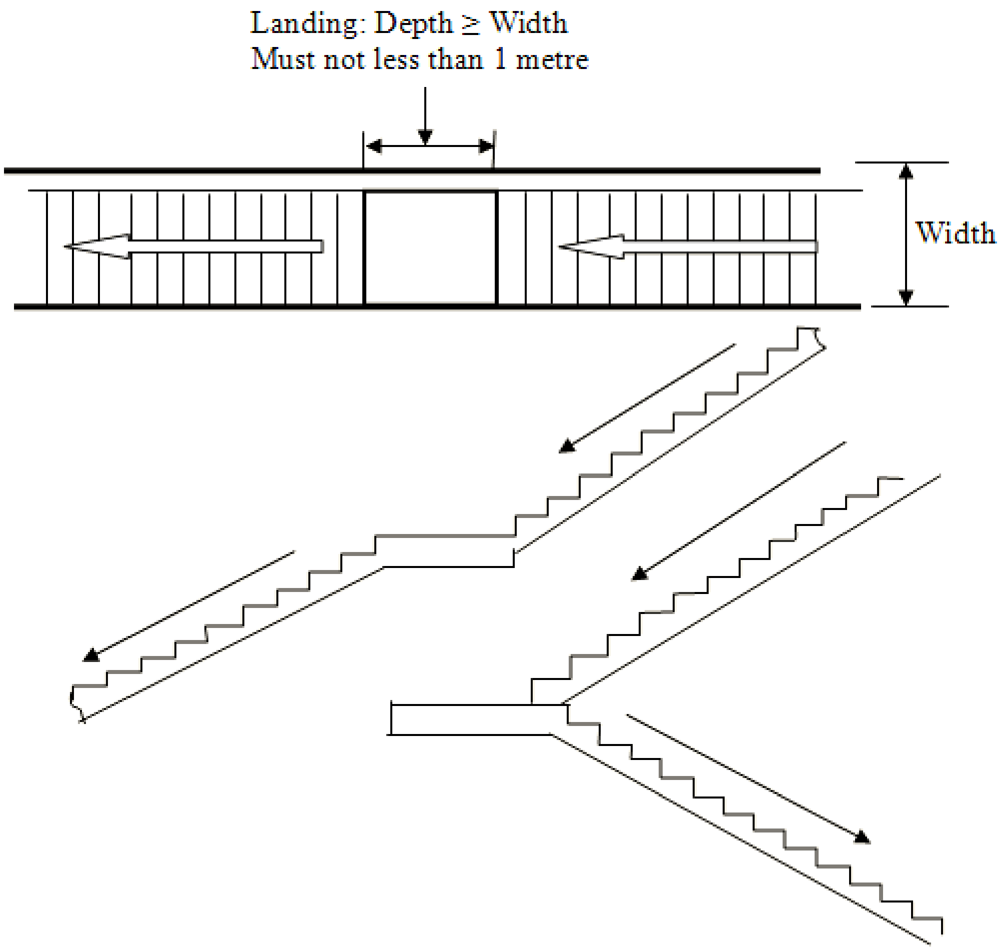


Figure 2.6: The landing depth and width of the staircase

Except for staircases of less than 4 risers, all staircases shall be provided with at least one handrail. Staircases exceeding 2225 millimetres in width shall be provided with an intermediate handrail for each 2225 millimetres of required width spaced approximately equally (see figure 2.7). In building other than residential buildings, a handrail shall be provided on each side of the staircase when the width of the staircase is 1100 millimetres or more. All handrails project not more than 100 millimetres from the face of the finished wall surface and shall be located not less than 825 millimetres and not more than 900 millimetres measured from the nosing of the treads provided that handrails to landings shall not less than 900 millimetres from the level of the landing (UBBL, 107:1,2,3,4)

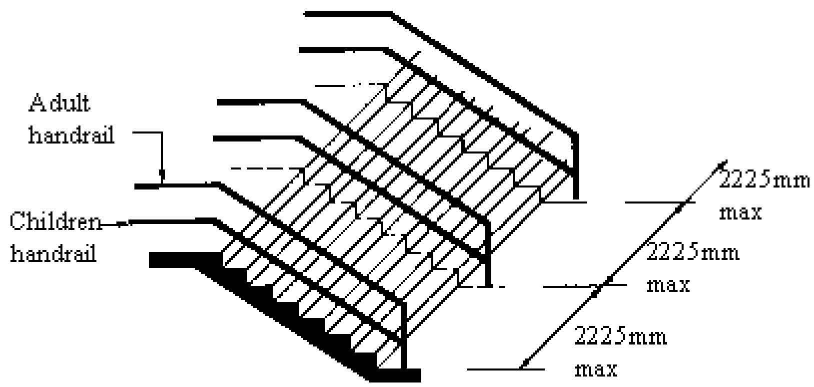


Figure 2.7: Provision of intermediate handrail if staircase exceeded 2225mm width

Spiral staircase

Subject to the provisions of part VII and VIII of these By-laws spiral staircases may be permitted as a secondary staircase in buildings where the topmost floor does not exceed 12.2 metres in height. Winding staircase may be permitted where they are not used as a required means of egress (UBBL, 109:1,2).

Obstruction and projection on staircase

There shall be no obstruction in any staircase between the topmost landing thereof and the exit discharge on the ground floor and there shall be no projection, other than handrails in staircases, in any corridor, passage or staircase at a level lower than 2 metres above the floor or above any stair (UBBL, 110:1, 2).

Computing the staircase width

There are some guidelines in computing the staircase width as stated in clause 177 the By-Laws i.e.:

i. In a multi-storeyed building the staircases need be only wide enough to serve each floor but not less than the minimum width allowed and in every case one of the protected staircases shall be assumed to be inaccessible and the remaining protected staircase shall be of sufficient width and number to accommodate the relevant occupancy. It means that staircase width is computed base on the maximum occupancy load of each floor. Calculation of occupancy load shall be accordance with the provision in the seventh schedule (see appendix 2.0). Underlying assumption is occupants at every floor evacuate at the same time and which the dynamic flows of occupants will allow the occupants at the lower floor to evacuate first.

ii. Depending on the occupancy, street floor exits have to be sized to handle not only the occupant load of the street floor but also a percentage of the load of the exits discharging to the street floor from floors above and below;

iii. Exits should never decrease in width along their length of travel and, if two or more exits converge into a common exit, the common exit should never be narrower than the sum of the width of the exits converging into it;

iv. At least one of the staircases should be a minimum of two units width **(**One unit equivalent to 550mm) except that 900 millimetres may be allowed where total occupancy of all floors served by staircases is less than 50; and

v. There should be no decrease in width along the path of travel of a staircase.

Clause 176 gives how to compute the required staircase width and the number of exits from individual floors of a building as follows:

i. Calculate the floor area net or gross in square meter whichever is applicable;

ii. Determine the allowance occupancy load factor from seventh schedule, i.e. at the second column. Occupant load residential flats are 24 per gross area.

iii. Divide the gross floor area by the occupant load to determine the number of occupants occupying for that floor.

iv. Determine from the seventh schedule the capacity of the type of exit to be use for the purpose group. For stairs, the capacity exit is 45.

v. To determine the staircase width in units, the number of occupants for that floor divided with the capacity exit.

vi. To determine the staircase width, units determined multiply by 550mm.

vii. To determine the number of staircase needed, staircase width divides by 1100mm i.e. a minimum width of staircase as in clause 177. Its must also consider the dead-end limit and maximum travel distance when calculating the number of staircase needed.

An example calculation of the number of staircase needed is:

If the gross floor area of one floor level of the flats building is 2.400 sq m. As specified in seventh schedule that the occupant loads for the residential flats is 24 (i.e. from seventh schedule, UBBL). Therefore the number of staircase needed is;

= 2,400/24
= 100 people
= 100/45 (i.e. 45 is the capacity exit for the stairs; from seventh schedule)
= 2.22 staircase width in unit

This unit needs to multiply by 550 to obtain the staircase width in mm. Therefore;

2.22 x 550 = 1221 mm.

To determine the number of staircase required if the minimum staircase width is chosen i.e. 1100mm. Therefore the number of staircase required for the 2400 sq m of the flats building is;

= 1221 / 1100
= 1.11

Therefore 2 staircases i.e. 1100 mm width each are needed for this building because 1.11 staircases needed but less than two staircases required. The rule of thumb is if the number of staircase needed is more than the round figure, the next round figure should be chosen. In this example the next round figure is 2, therefore 2 staircases are needed in this example.

In terms of the maximum number of people allowed to exit via the specific width of staircase is not clearly mention in UBBL. However, based on the above calculation, the maximum number of people can be calculated as follow:

For the staircase width 914 mm, the staircase width in unit can be calculated by dividing the staircase width 914 mm with 550 = 1.7. Multiplying 1.7 with the capacity exit for the stairs i.e. 45 for the high-rise residential building, we can get the number of people for the staircase width 914mm. Therefore 1.7 x 45 = 76.5 i.e. 77 people allow for the staircase 914mm width. Table 2.0 shows the staircases width correspondent with the maximum number of people allowed for one staircase width of individual floors.

Staircase (mm)	914	1067	1100	1220	1372	1524
No. of People	77	87	90	100	112	125

Table 2.0: Staircase width and the maximum number of people allowed

Measurement of travel distance to exits

The travel distance to an exit shall be measured on the floor or other walking surface along the centre line of the natural path of travel, starting 0.300 metre from the most remote point of occupancy, curving around any corners or obstructions with 0.300 metre clearance there from and ending at the storey exit. Where measurement includes stairs, it shall be taken in the plane of the trend nosing. In the case of open areas the distance to exits shall be measured from the most remote point of occupancy provided that the direct distance shall not exceed two-thirds the permitted travel distance. In the case of individual rooms which are subject to occupancy of not more than six persons, the travel distance shall be measured from the doors of such rooms, provided that the travel distance from any point in the room to the room door does not exceed 15 metres. The maximum travel distances to exits and dead end limits shall be as specified in the Seventh Schedule of these By-laws (UBBL, clause 165 sub-section 1, 2, 3, and 4).

Lighting and ventilation system in staircase

In By-Laws 111 it is stated that all staircases shall be properly lighted and ventilated according to the requirements of the local authority. This is a general statement which did not give any detail about the types or technical specifications about what lighting system should be installed in staircase. Local authorities may have their own specification about how lighting should be installed in staircase and how many lux of the minimum illumination should be.

Means of access and fire fighting in buildings over 18.3 metres high

Every building over than 18.3 meters high should be provided with means of gaining access and fighting fire from within the building consisting of fire fighting access lobbies, fire fighting staircases, fire lifts and dry or wet rising systems. Fire fighting access lobbies shall be provided at every floor level and shall be so located that the level distance from the furthermost point of the floor does not exceed 45.75 meters. This in inline with the By-Law 229 (3) that Fire fighting access lobbies may be omitted if the fire fighting staircase is pressurised to meet the requirements of by-law 200 and all fire fighting installations within the pressurised staircase enclosure do not intrude into the clear space required for means of egress and (4) that a fire fighting staircase shall be provided to give direct access to each fire fighting access lobby and shall be directly accessible from outside the building at fire appliance access level. This may be one of the staircases required as a means of egress from the building. Besides that a fire lift as well shall be provided to give access to each of fire fighting access lobby or fire fighting access staircase in the absent of fire fighting access lobby on each floor.

Provision for fire door

Fire doors of the appropriate FRP, i.e. 30 minutes, shall be provided at compartment walls and separating walls in accordance with the requirements for that wall specified in the Ninth Schedule to these By-laws. Openings in protecting structures shall be protected by fire doors having FRP of not less than half the requirement for the surrounding wall specified in the Ninth Schedule to the By-laws but in no case less than half hour. Openings in partitions enclosing a protected corridor or lobby shall be protected by fire doors having FRP of half-hour (Clause 162 By-Laws).

According to clause 164 all fire doors shall be fitted with automatic door closers of the hydraulically spring operated type in the case of swing doors and of wire rope and weight type in the case of sliding doors. If double doors with rabbeted meeting stiles shall be provided with co-ordinating device to ensure that leafs close in the proper sequence and fire doors may be held open, provided the hold open device incorporates a heat actuated device to release the door. Heat actuated devices shall not be permitted on fire doors protecting openings to protected corridors or protected staircases.

Clause 173 (1) states that all exit doors shall be openable from the inside without the use of a key or any special knowledge or effort and exit doors shall close automatically when released and all door devices including magnetic door holders, shall release the doors upon power failure or actuation of the fire alarm.

Doors giving access to staircases shall be so positioned that their swing shall at no point encroach on the required width of the staircase or landing as stated in By-Laws 168 (5).

Meanwhile clause 196 (1) states that access to a staircase smoke lobby shall be by means of fire doors opening in the direction of escape.

Horizontal exits

In accordance with clause 171, where appropriate, horizontal exits may be provided in lieu of other exits. Where horizontal exits are provided protected staircases and final exits need only be of a width to accommodate the occupancy load of the larger compartment or building discharging into it so long as the total number of exit widths provided is not reduced to less than half that would otherwise be required for the whole building. For institutional occupancies the total exit capacity other than horizontal exits shall not be reduced by more than one-third that would otherwise be required for the entire area of the building.

Emergency exit signs

In accordance with clause 172, storey exits and access to such exits shall be marked by readily visible signs and shall not be obscured by any decorations, furnishings or other equipment. A sign reading "KELUAR" which means “EXIT” with an arrow indicating the direction shall be placed in every location where the direction of travel to reach the nearest exit is not immediately apparent. Every exit sign shall have the word "KELUAR" in plainly legible letters not less than 150 millimetres high with the principal strokes of the letters not less than 18 millimetres wide. The lettering shall be in red against a black background. All exit signs shall be illuminated continuously during periods of occupancy. Illuminated signs shall be provided with two electric lamps of not less than fifteen watts each.

Separate or alternative exits

Separate or alternative exit shall be provided. It means that not less than two escape staircases shall be provided and they shall be sited within the limits of travel distance as specified in the seventh schedule i.e. 30 meter for unsprinklered high-rise residential buildings and readily accessible at all times (By-Laws 166). Clause 168 (1) states that every upper floor shall have means of egress via at least two separate staircases. Exceptions is given to the buildings which do not exceed 12 meters in height provided each element of structure shall have a FRP of not less than one hour, no rooms or stories are used other than for domestic or office purposes except for the ground floor which may be used for shops or car park. In this case the staircase from the ground floor to the first floor shall be separated by a wall having a FRP of not less than two hours from the remainder of the ground floor utilities, the maximum travel distance shall be 12 meters, and in ground and first storeys which have windows containing opening lights sufficiently near the adjacent ground level as to make emergency escape by this means reasonable, a maximum travel distance up to 30 meters is permissible as stated in By-Laws 194.

Arrangement of storey exits.

According to clause 174 regarding the arrangement of storey exits, if two or more storey exits are required they be spaced at not less than 5 metres apart measured between the nearest edges of the openings. Each exit shall give direct access to: a final exit; a protected staircase leading to a final exit; or an external route leading to a final exit. Basements and roof structures used solely for services need not be provided with alternative means of egress.

2.5.4 Escape route specification as in Building Regulation 2006 (UK)

The Building Regulations 2006 came into effect on January 2007, based on the amended documents of Building Regulation 1984, then 2000 (England and Wales). Approved Document B1: Fire Safety became Approved Document B: Fire Safety Volume 1 (Dwellings) and will be used as a reference in this literature review. All information and figures in this section are reproduced from the Building Regulation 2006, Approved Document B: Fire Safety (Dwelling), England and Wales as part of a literature review.

Building Regulation paragraph 0.14, Fire Safety Engineering, mentions that fire safety engineering can provide an alternative approach to fire safety. It may be the only practical way to achieve a satisfactory standard of fire safety in some large and complex buildings, and in buildings containing different uses, e.g. airport terminals. Fire safety engineering may also be suitable for solving a problem in aspects of the building designs.

For buildings with a special architectural or historical interest, it would be appropriate to take into account a range of fire safety features and fire safety assessment suggested in the Building Regulation to deal with an assessment of the hazard and risk peculiar to the particular case, factors that should be taken into consideration are:

i. The anticipated probability of fire occurring,

ii. The anticipated fire severity,

iii. The ability of a structure to resist the spread of fire and smoke; and

iv. The consequential danger to people in and around the building.

A wide variety of measures which could be considered appropriate in these circumstances are:

i. The adequacy of means to prevent fire;

ii. Early fire warning by an automatic detection and warning system;

iii. The standard of means of escape;

iv. Provision of smoke control;

v. Control of the rate of fire growth;

vi. The adequacy of the structure to resist the effects of a fire;

vii. The degree of fire containment;

viii. Fire separation between buildings or parts of buildings;

ix. The standard of active measures for fire extinguishment or control;

x. Facilities to assist the fire service;

xi. Availability of power to require staff training in fire safety and fire routines;

xii. Consideration of the availability of any continuing control under other legislation that could ensure continued maintenance of such systems; and

xiii. Management.

Means of warning and escape

> "The building shall be designed and constructed so that there are appropriate provisions for the early warning of fire, and appropriate means of escape in case of fire from the building to a place of safety outside the building capable of being safety and effectively used at all material times"

This philosophical statement is deemed to have been met if the following measures have been put in placed i.e.

i. There are routes of sufficient number and capacity, which are suitably located to enable persons to escape to a place of safety in the event of fire;
ii. The routes are sufficiently protected from the effects of fire by enclosure where necessary;
iii. The routes are adequately lit;
iv. The routes are suitably signed;
v. There are appropriate facilities to either limit the ingress of smoke to the escape routes or to restrict the fire and remove smokes; and
vi. There is sufficient means of giving early warning of fire for persons in the building.

The basic principles for the design of means of escape are:

i. They should have an alternative means of escape from most situations.
ii. If direct escape to a place of safety is not possible, it should be possible to reach a place of relative safety e.g. a protected stairway, which is on a route to an exit, within a reasonable travel distance.
iii. The ultimate place of safety is the open air clear of the effects of the fire.
iv. A single direction of escape i.e. a dead end can be designed depending on the use of the building and its associated fire risk, the size and height of the building, the extent of the dead end, and the numbers of persons accommodated within the dead end.

Provision for Fire door

Fire door shall be either 20 minutes or 30 minutes minimum fire resistance. 20 minutes fire resistance is only applicable to the following conditions i.e. forming part of the enclosures of protected corridor except a protected lobby approach to a stairway, sub-dividing of corridor and dead-end portion of corridor, any door forming part of the enclosures to a protected stairway in a single family dwelling house, forming part of the enclosure to a protected entrance hall or protected landing in an apartment or within any other fire-resisting construction in a dwelling not described elsewhere in table B1 in appendix B of Building Regulation 2006. In any other compartment wall, protected stairway, protected lobby, and compartment floor, 30 minutes fire resistance is required.

The door should be readily openable and should not be fitted with a lock, latch or bolt fastening and should be opened in the direction of escape if the number of persons that might be expected to use the door at the time of fire is more than 60. It should be hung to open not less than 90^0 and with a swing that is clear of any change of floor level, other than threshold or single step on the line of the doorway as stated in clause 4.11 to 4.17. All doors giving access to the escape stairs should be fitted with a self-closing device and appropriately signed to be kept closed always except for fire doors for cupboards, service ducts, and fire doors within a dwelling and as mentioned in appendix B of the Building Regulation.

Provision for fire door in protected corridor

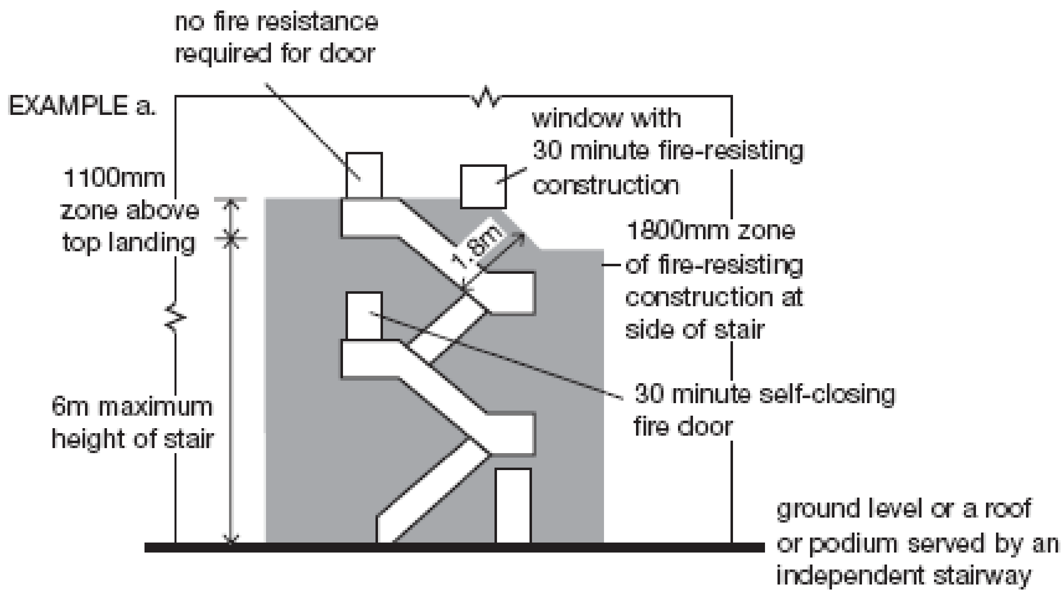


Figure 2.8: Fire resistant of areas adjacent to external stairs example A (BR, 2006: Approved Document B)

A self-closing fire door shall be installed to sub-divide any two or more storey exit connected to a common corridor. The door should be positioned so that smoke will not affect access to more than one stairway. It is applicable to the dead-end portion of a common corridor as well which should be sub-divided by a self-closing fire door as mentioned in clause 3.27 and 3.28 of the Building Regulation.

Provision for protected staircase

All common staircases should be sited in a protected enclosure in order to reduce the risk of smoke and heat ingress obstructing the evacuation process. The appropriate level of fire resistance can be referred to Table A1 and A2 of Building Regulation 2006. The provision of protected staircase is as stated in clause 3.35 and 3.36. It is mentioned in clause 4.2 that generally 30 minutes fire resistant is sufficient for the protection of means of escape.

Figure 2.8 shows an example of a staircase design for a two storey building in which the maximum height of the staircase is not more than 6m. 30 minutes self-closing fire doors are required in this construction to be the enclosure wall separates the occupancy areas and the staircases are required of fire resisting construction of not less than 30 minutes as a fire barrier.

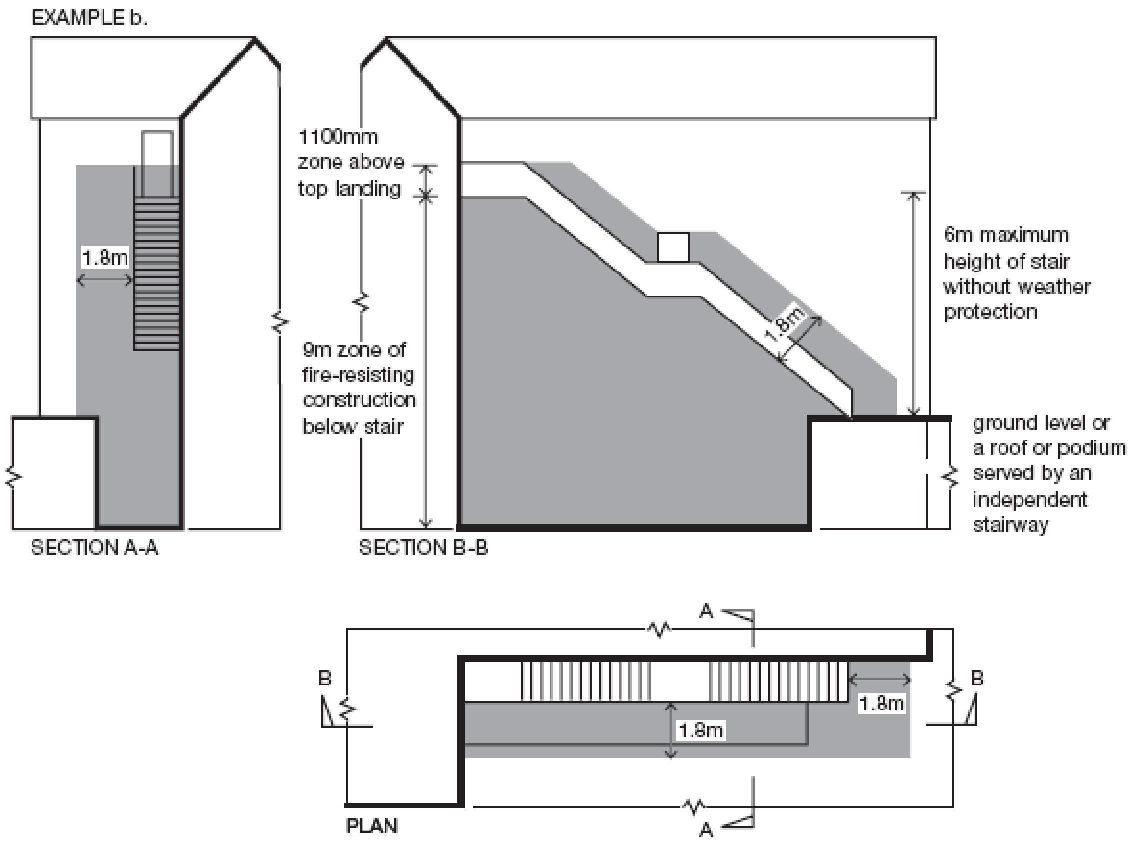


Figure 2.9: Fire resistant of areas adjacent to external stairs example B (BR, 2006: Approved Document B)

Figure 2.9 shows another example of external open-air staircase design for a building not more than two storeys in height. The Staircase has to be separated from occupancy area by fire barrier and fire door of 30 minutes fire resistant period. Those areas below the staircase should be constructed with fire resistant materials bearing no opening and smoke tight. It essential to have any opening, it should be fitted with fire doors of 30 minutes FRP.

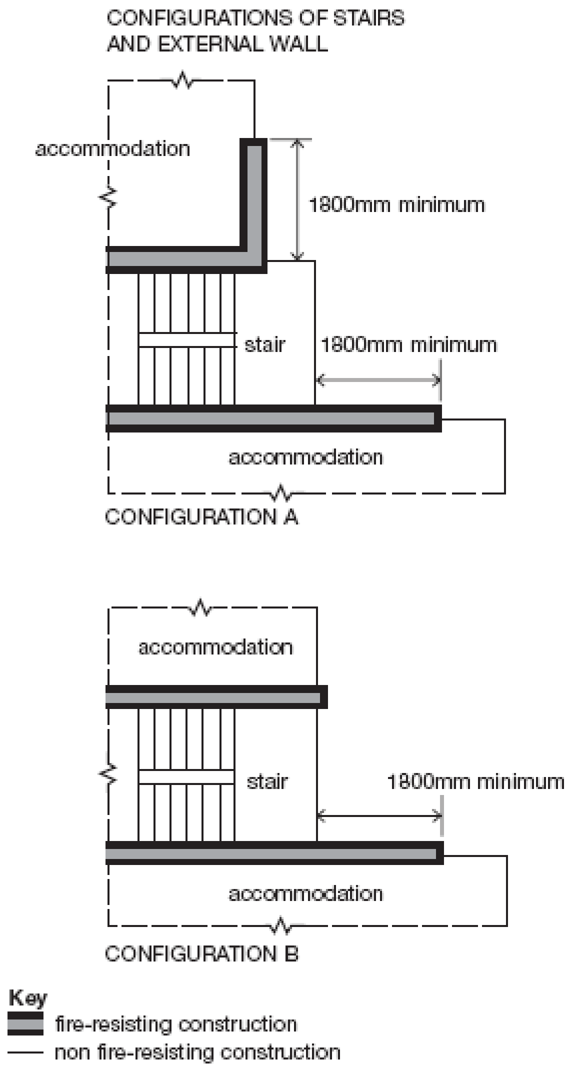


Figure 2.10: External protections to protected stairways (BR, 2006: Approved Document B)

Figure 2.10 shows configurations of external wall of the staircase if it is built in between the accommodations. 1800mm minimum projection wall of fire barrier bearing 30 minutes fire resistant period is necessary from any nearest opening e.g. windows or doors of the accommodation sharing the same separated wall of the staircase. However the staircase configurations remain the same as previously described.

Provision for common escape routes (Corridor)

There are limitations on the distance of travel in common areas of apartment buildings that is the maximum travel distance from dwelling entrance door to common stair, or stair lobby i.e. 7.5m if escape is only in one direction and 30m if escape is in more than one direction. In the case of the building provided with an indoor car park, the maximum travel distance to the storey exit is 25m if escape is only in one direction and 45m if escape is more than one direction as stated in clause 3.22. Escape stairs designed should be parted so that people do not have to pass through one stairway enclosure to reach another, but it is possible to move through the same protected lobby of one stairway in order to reach another.

There no limitation of width of common staircase for everyday use, but it should be sufficient for escape. If the same staircase is also use by the fire brigade, it should be at least 1100mm wide according to clause 3.32.

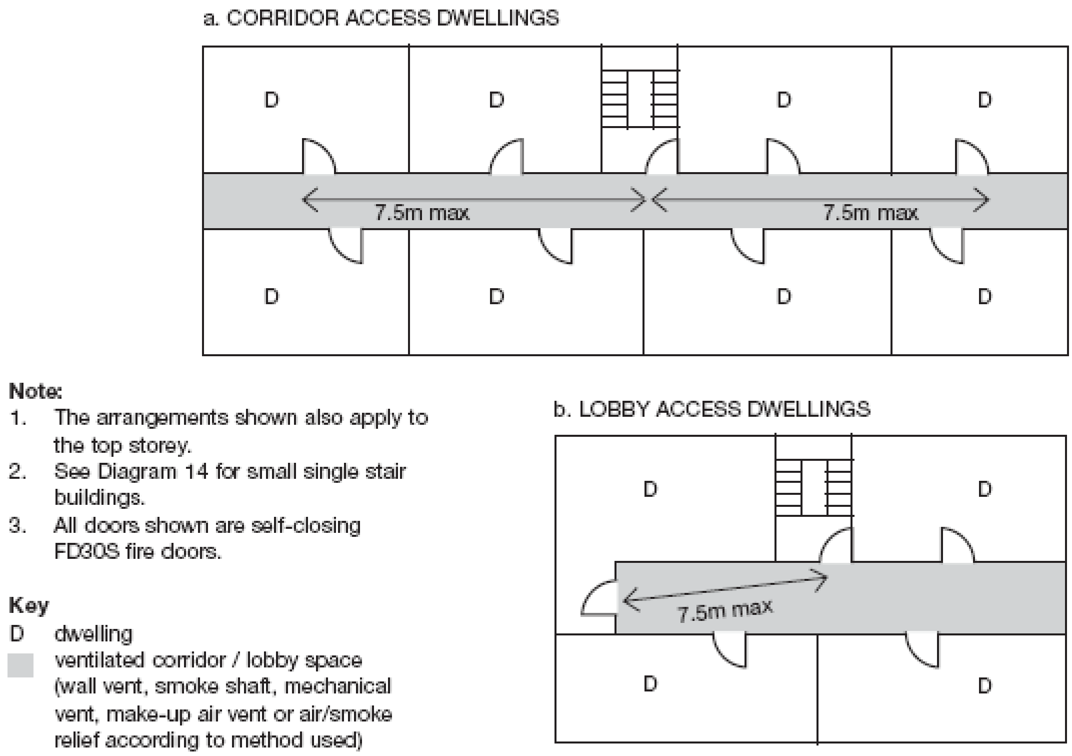


Figure 2.11: Apartment served by one common stair (BR, 2006: Approved Document B)

There is provision for a protected corridor in order to reduce the risk of a fire in a dwelling affecting the means of escape. The common corridor should be design with a compartment floor and the wall between each apartment and the corridor should be a compartment wall. It means that the wall should be constructed with materials having a fire resistance of not less than 30 minutes. In order to restrict the ingress of smoke from any apartment fire to the common corridor, installation of means of ventilation is essential either by natural or mechanical ventilation as requested in clause 3.24.

Common corridors and common stairs

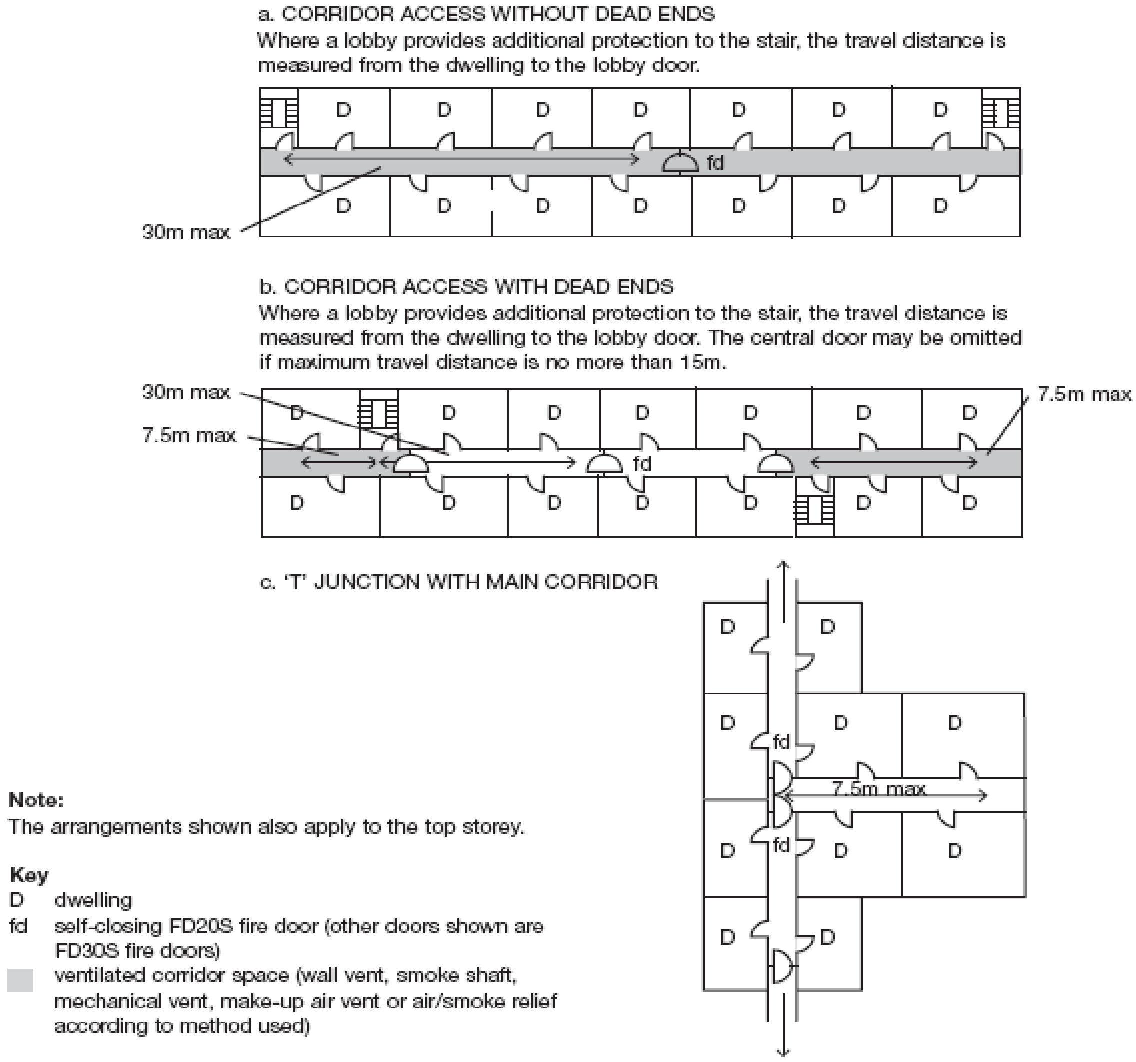


Figure 2.12: Apartment served by more than one common stairs (BR, 2006: Approved Document B)

Figure 2.11 shows the orientation of a common corridor and common stair with the location of any dwelling i.e. within a minimum limit of travel distance i.e. 7.5m if only one escape staircase provided. If lobby access is provided (see figure 2.11 b), the minimum limit of travel distance from the most remote area i.e. dwelling entrance door must be not more than 7.5m.

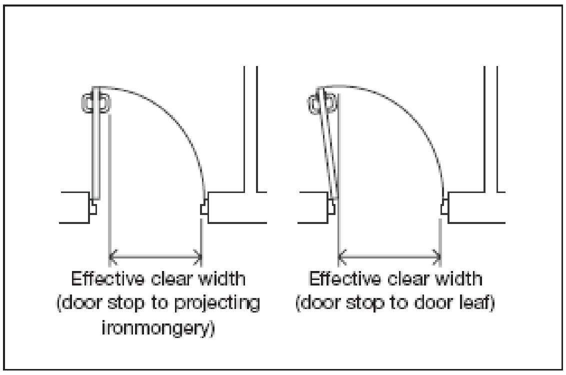


Figure 2.13: Measurement of door width (BR, 2006: Approved Document B)

If there is an alternative escape stair provided for the common corridor and the design has not got any dead-ends, those escape stairs must be separated with a 20 minutes FRP fire door. The limit travel of distance from the separated fire door is 30m. If the corridor access is designed with dead-ends, the specification and location of fire doors should be provided as in figure 2.12b. If the common corridor is designed having a 'T' junction with other main corridors, the design specification and provision for fire doors are as in figure 2.12c.

Number of escape routes

Every dwelling should have access to alternative escape routes so that a person confronted by the effects of an outbreak of fire in another dwelling can turn away from it and make a safe escape. However a single escape route from the dwelling entrance door is acceptable if either:

(a) the dwelling is situated in a story served by a single common stair and:

i. every dwelling is separated from the common stair by a protected lobby or common corridor (see figure 2.11) and

ii. the travel distance limitations in table 1 (i.e. in table 1 Building Regulation Part B – Fire Safety England and Wales) on escape in one direction only, are observed; or

(b) alternatively the dwelling is situated in a dead end part of a common corridor served by two (or more) common stairs, and the travel distance complies with the limitations in table 1 (i.e. in table 1 Building Regulation Part B – Fire Safety England and Wales) on escape in one direction only (see figure 2.12).

Measurement of width of doors, escape routes and stairs.

- A door is the clear width when the door is open see figure 2.13.
- An escape route is the width at 1500mm above floor level when defined by walls or, elsewhere, the minimum width of passage available between any fixed obstructions.
- A stair is the clear width between the walls or balustrades.

2.6 Building evacuation simulation package

In view of the complexity of modern buildings, it is difficult to determine the escape pattern of occupants by simple calculations. With the advancement of digital computers, many computer-based evacuation models have recently been developed. According to Gwynne *et al* (1999) more than 22 evacuation models have been developed or are under development. Some of the models can describe and visualise the individual's patterns of movement, such as EXODUS. EXODUS is a prototype egress model designed to simulate the evacuation of large numbers of individuals from an enclosure. The model tracks the trajectory of individuals as they make their way out of the enclosure, or are overcome by fire hazards such as heat and toxic gases. The software is expert based system, the progressive motion and behaviour of each individual being determined by a set of heuristics or rules. EXODUS is intended, primarily, for use in mass-transport vehicles such as aircraft, but it also has application to cinema, theatres and lecture halls (Galea and Galparsoro, 1994, Owen *et al*, 1996).

The EGRESS evacuation model is designed to evaluate the hazards of fire growing in a building to the people by using integrated assessment tools with the description of the building elements or the structures and the ways of fire and smoke spread as an input. Generally the building design and provision of escape routes in the building will influence the movement of people evacuating. EGRESS uses a simple calculation to estimate the time taken by evacuees to egress from the building to the safe place (Ketchell *et al.,* 1993 & 1995). Sim, (1995) developed the VEGAS programme to evaluate information for fire specialists in performing fire safety engineering studies. Another evacuation model called spatial-grid evacuation model (SGEM), includes a pre-processing engine to assist in the transformation of the spatial information from computer-aided design (CAD) based architectural plans and performs a simulation to generate the escape patterns in many complex buildings. This model resolves the setting of a building into a network with a series of nodes (Lo *et al*, 2004)

Fahy presented EXIT89 model to study the evacuation process in high-rise buildings which tracks the travel paths of each individual occupant to predict the effects of fire spread on evacuation. EXIT89 also requires a network description of the building in the form of nodes and arcs (Fahy, 1994). Kisko and Francis presented a computer programme EVACNET+, in a user-friendly interactive mode to model evacuation plans for user defined buildings. EVACNET+ uses a network of nodes and arcs to represent a building and utilises a capacitated network flow transshipment algorithm (Kisko & Francis, 1985). Stahl, presented a dynamic stochastic computer model to simulate the emergency egress behaviours of building occupants during fires. The model, BFIRES, as it is known, is based upon the perceptual and behavioural responses of the building occupants involved in fire emergencies and suggests that the occupants act in accordance with their perceptions of a constantly changing environment (Stahl, 1982).

Berlin *et al* presented a methodology for estimating the evacuation time from a building. Network descriptions of the building together with a simulation model of occupant movement are used to simulate alternative egress and rescue plans from group houses. A technique for calculating the available number of direct routes from any room to any location of safety also has been suggested (Berlin *et al*., 1982). Gupta *et al* presented a mathematical model called SAFE-R to analyse the building evacuation problem. SAFE-R uses a graphical theoretical approach to identify various routes that are available to the occupants for movement. Travel time of each route is determined on the basis of the travel distance as well as the walking speed. This has been done to make sure that the escaping-time is minimal (Gupta & Yadaz, 2004).

Thompson and Marchant developed SIMULEX to evaluate the potential evacuation process of a complex building with a high degree of accuracy. In the development of SIMULEX, the authors have attempted to minimise user inputs while increasing the complexity of the algorithm in the program. The program incorporates route-finding techniques so that travel distance can be calculated automatically (Thompson *et al*, 1995a,b,c,). I have chosen SIMULEX to be used in my experimentation of people evacuation the building in selected high-rise residential buildings. This programme as well will be used to further analyse the effects of staircase, corridor and fire door changing specifications on the time taken to evacuate pre-developed study models.

SIMULEX is a software package that has capabilities to models occupant evacuation from any building structure. The user is able to view real-time playback of people overtaking, side-stepping, shuffling and queuing during the evacuation. Furthermore, different floors and staircases can all be viewed simultaneously, for an in-depth analysis of the total building evacuation. It also is able to calibrate the longest distance within the building design from the most remote location to the nearest escape stair available in building.

Simulex validation

Simulex was originally developed at Edinburgh University. According to the information gathered from *www.crowddynamics.com*, simulex has been validated through validation test carried out by staffs at Edinburgh University, Lund University, Ove Arup (Australia) and University of Ulster. Tests have been carried out on a number of different types of building such as department stores, office buildings, lecture theatres, sports stadium egress areas, university buildings, mock-up building geometries for student tests, etc. The test results conformed that simulex is able to accurately models individual movement and produce a realistic result when the performance of group tests are analysed.

2.7 Fire safety in building background study

Fire safety in buildings is an important issue but it has not been addressed sufficiently. People are only talking about the fire safety in the buildings, particularly in dwellings, when a fire tragedy occurs and it has caused devastation. Kendik (1986) mentioned that over a decade ago there was considerable activity in research of modelling egress from buildings. The behavioural models developed are mainly divided into two types, i.e. conceptual models which attempted to include the observation, empirical and reported actions from collective interview or questionnaire studies, and computer models that simulated the behaviour of individual in the fire incident. The conceptual models attempt to model the theoretical design or heuristic which try to provide some logical explanation for the decision making process, and alternative choice of process of the individual involved with the fire.

2.7.1 Defining fire safety

Defining fire safety is difficult and often results in a listing of factors that together comprise the intent. These factors tend to be of different sorts. Fire safety may be defined as goals and aims such as fire prevention, fire control, occupant protection, and so forth which normally can be found in the introductory sections of building codes and other fire safety legislation (Rasbash, *et. al.* 2004). According to Howarth, (1999), quoted by Derek & Chakib. (1999) fire safety management can be defined as the application by a manager of policy, standards, tools, information and practices to the task of analyzing, evaluating and controlling fire safety.

The National Building Code of Canada (NRC, 1995) defines fire safety as “an objective to reduce the probability that a person in or adjacent to a building will be exposed to an unacceptable fire hazard as a result of the design and construction of the building.” According to Ramachandran (1999), safety is the complement or antithesis of risk. Safety will be increased if the risk is reduced. There is no such thing as absolute safety. Some level of risk is virtually unavoidable. A building may be considered to be ‘very safe’ from fire if a sufficiently ‘low fire risk’ is associated with its structure, contents and occupants’. Occupants play a vital role in lowering the fire risk if their behaviour during evacuation exactly follows the theoretical frame work. But people’s behaviour is sometime unpredictable and very complex.

CWC, (2000), stated that fire safety is the reduction of potential for harm to life as a result of fire in buildings. Although the potential for being killed or injured in a fire cannot be completely eliminated, fire safety in a building can be achieved through proven building design features intended to minimise the risk of harm to people from fire to the greatest extent possible. According to Canadian experience, the number of deaths in building fires has significantly dropped for the last two decades mainly due to:

- Increased used of smoke detectors,
- Improvements in electrical and heating systems,
- Changing in life-style habits of habitants i.e. non-smoking, reduced alcohol consumption and dining out,
- Public awareness i.e. education programs.

Failure to manage safety adequately is often results in death or injury, chronic ill health and damage to property and/or the environment. Such results have a significant impact on the physical and economic well-being of society (Furness and Muckett, 2007).

2.7.2 Assessing the adequacy of escape routes

At present there is no quantitative method of assessing the adequacy of any escape route provided in a building other than by empirical means. The current method of providing means of escape from buildings is by specification and rules, i.e. rules that have evolved through time and are deemed to provide a satisfactory escape route (Shields & Silcock, 1989). In Malaysia Uniform Building By-Laws 1984 (LRB, 1993) is currently in use by the relevant authority to provide a satisfactory specification and guideline to building designers for their duty of work.

In United Kingdom, the legal requirement for means of escape can be found in Building Regulation 2005, England and welsh. In Building Regulation 2005, document B1: Means of warning and escape, it is stated that 'The building shall be designed and constructed so that there are appropriate provisions for the early warning of fire, and appropriate means of escape in case of fire from the building to a place of safety outside the building capable of being safely and effectively used at all material times' (ODPM, 2005). This is a philosophical statements of requirement of needs, i.e. appropriate provisions, appropriate means of escape, capable of being safely and effectively, without giving any detail of how its can be achieved. This functional requirement needs to be read together with the other parts, i.e. B2 – B5 of schedule 1 of the Building Regulations. B2 is about the fire spread over the internal linings of buildings, B3 is to ensure the stability of buildings in the event of fire; to ensure that there is a sufficient degree of fire separation within buildings and between adjoining buildings; and to inhibit the unseen spread of fire and smoke in concealed spaces in buildings, B4 is the external walls and roofs should have adequate resistance to the spread of fire over the external envelope, and that spread from one building to another is restricted, and B5 is to ensure satisfactory access for fire appliances to buildings and the provision of facilities in buildings to assist firefighters in the saving of life of people in and around buildings.

Daimantes, (2003), stressed that accessible means of egress meant the exit access, exit, and exit discharge that can be entered and used by a person with severe disability using a wheelchair and also safe and useable for people with other disabilities. The installation of those elements from the building code, are the responsibility of the building authorities and responsibility for the maintenance of all means of egress, accessible or non-accessible, are under the fire authorities. These requirements are new to some of fire authorities and introduce some totally new concepts in occupant protection. It means that the enforcement of the maintenance as stated in the building code is a liability to the fire authorities.

There are numbers of issues raised by Meacham, (2004), regarding the building codes and how have things changed. Among the issues raised are the efficacy of passive and active fire protection systems in extreme event conditions, the effectiveness of emergency egress systems, the impact on life safety and structural response if these systems are unavailable when needed, and who understanding of human behaviour and risk perception and risk tolerance have remained weak. He says that better understanding the performance of materials, systems, buildings and people will undoubtedly lead to better performing buildings. However, the question of who should set the performance objectives, how should performance objectives and criteria be set, and how should performance be defined, measured, calculated, assured and monitored after buildings are occupied remain unanswered in many cases.

Bukowski, (2004), defined extreme event condition as any event or load that exceeds the design event which is usually the worst likely over the life of the building. An extreme condition should not be a limitation for further improvement of a safety in building designs to achieve the main and widely accepted fire safety objectives in buildings i.e. life safety and structural protection.

2.7.3 Research on evacuation from the building

Jones and Hewitt (1986) studied a group formation and leadership during evacuation of a high-rise office building due to fire. They focus on the social context and organisation characteristics of occupancy within which were decisions about evacuation strategy, group formation and questions of leadership. Horiuchi *et al* (1986) studied the effects of fire and evacuation from a multi-purpose office building in Osaka, Japan. Sekizawa *et al* (2001) studied the feasibility of evacuation by elevators in high-rise building.

Benthorn and Frantzich (1998) studied how people evaluate the information and choose the evacuation exit when fire alarm goes off in a public building. Kagawa *et al* (1986) studied the movement of people on stairs in high-rise office building in Japan. Shields and Boyce (2000), studied the evacuation from a large retail store and among the findings that 50.1% choose the nearest exit to evacuate from the building and 19.5% choose a familiar exit to evacuate from the building. Shields *et al* (1998) studied behaviour and characteristics of people on unannounced fire drill on large retail stores.

Purser (1986) studied the effect of fire products on escape capability using primates and human fire victims. Beller and Watts, (1998), studied human behaviour approach to occupancy classification. They suggested that there are four categories of occupants' data that are necessary to implement a performance approach to life safety i.e. location of occupants with regards the allowable minimum travel distance, occupants response to fire, number of occupants, and staff training. Galina and Mutani (1998) studied fire safety aspects in historical buildings reused as libraries on people evacuation in Italy.

Proulx (2001) studied the possibility of adopting stay-in-place procedure during high-rise building fire. She suggested that stay-in-place is appropriate for high rise residential, hotel, and dormitory building based on the analysis of evacuation behaviour in high-rise apartment building fire at Ambleside, Ottawa and Forest Laneway, North York. She proposed the stay-in-place is only appropriate if the building was constructed of non-combustible material, equipped with self-closers on all main doors, has a central alarm system to warn occupants and voice communication system to inform occupants of the evolution of the incident and the protect-in-place activities should be applied.

Sekizawa *et al* (1998) studies the occupant's behaviour in response to high-rise apartment's fire occurred in October 1996 in Hiroshima City where 20 storey apartments building built in 1972 was caught with fire. Fire first started at the 9th floor and quickly spread up to 20th floor through balconies. His concluded that (1) many respondents who start their evacuation are not motivated by the fire cues but others. (2) In terms of exit choices, the possibility of occupants to use elevator for the evacuation is dependent on which level they stay and not an age of the occupants. (3) Occupants are likely to choose the route that they are familiar with or they think is safe instead of the route closer to them. (4) It is very common in every high-rise apartment buildings provided with horizontal route for evacuation on its floor. It is hard to say whether occupants have used this route, therefore education or directive to the occupants are necessary to make them understand and appreciate the advantages of the existence of horizontal route for evacuation in building fire.

Proulx (1998) studied the impact of voice communication messages during a residential high-rise fire in a 25-storey apartment building located in Ottawa, Ontario Canada. This building was mainly occupied by senior citizens the majority of whom were over the age of 65. She used two methodologies to gather the data i.e. face-to-face interviews with the occupants of the floor where fire started and the floor above, and a questionnaire survey to the rest of the occupants in that building. The intention of the study was to gather the information on the behaviour of occupants who were in the building at the time of the fire incident. The study concluded that most occupants treat the sounding of a fire alarm as a warning and wait for further information over the voice communication system, or other sources, before starting to evacuate. It is consider a very risky approach where occupants delay to start their evacuation unless the exit routes are very well protected from smoke entry and no one opens doors on the fire floor that could allow smoke into other location such as the stairwell.

2.8 Fire safety management background study

There are very limited resources concerning fire safety management in high-rise residential buildings. However there are a number of publications regarding the fire safety management in a workplace. Furness and Muckett, (2007), gave definitions of the terminology which is normally used in the fire safety discipline, for example:

- *Safety* i.e. the freedom from unacceptable risk from harm;
- *Hazard* i.e. a source or situation with the potential to cause harm (death, injury, ill health, damage to property or environment). A source or situation that could cause harm such as chemicals, electricity, working at height, hot work processes and in case of emergency an inability to respond and escape to a place of safety;
- *Harm* i.e. includes the effects relation to human injury and ill health, damage to the environment or loss to an organisation;
- *Risk* i.e. the combination of the likelihood and severity (consequence) of a specified event occurring and should it to do so, the severity of the outcome;
- *Risk assessment* i.e. the process of identifying hazards and evaluating the level of risk (including to whom and how many are affected) arising from the hazards, taking into account and existing risk control measures; and
- *Risk controls* i.e. workplace precautions, for example a guard on a dangerous part of machinery, sprinkler systems within a building, safe systems of work (procedure), personal protected equipment (PPE), safety signs.

The law regarding fire safety in the United Kingdom has changed i.e. on the 1st October 2006 fire certificates will no longer be issued and replaced with the need for a fire risk assessment for all workplaces or premises which employ more than five people. All existing fire legislation is repealed including The Fire Precautions Act 1971, Fire Precautions (Workplace) Regulations Act 1997/99, Management of Health and Safety in the Workplace Regulation 1999 and so on with the introduction of the Regulatory Reform

(Fire Safety) Order (FRS, 3/2008). However this order is not applicable to domestic buildings. In Malaysia fire risk assessment is totally new and appropriate measures should be taken to introduce this into current legislation. The application should be extended not only to the workplaces but the high-rise residential buildings managed by private or public sectors. It may not practical to apply to low rise building, but high-rise residential buildings i.e. apartments, condominiums, and etc, which are fully or partly owned by the state governments or private sectors who are responsible to manage and maintain the building should be accountable as well to ensure fire safety in the buildings are adequately installed.

2.8.1 Fire safety design framework

FPA, (2003) gives a basic fire safety design framework as in figure 2.14. A fire safe building should be consider as one that provides adequate means of escape, adequate facilities for fighting fire i.e. including adequate water supplies and access for fire fighting and brigade vehicles, and adequate property and business protection.

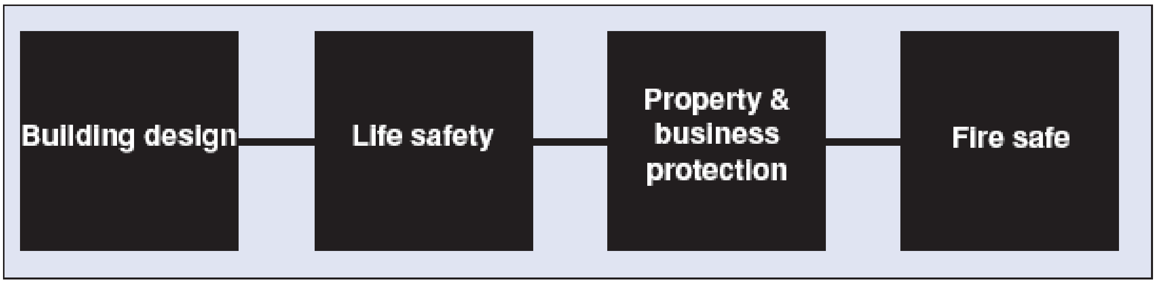


Figure 2.14: Basic fire safety design framework (FPA, 2003)

FPA, (2003) also proposed guidance framework for designing buildings for life safety and property protection as in figure 2.15. Designing a building for life safety should follow the statutory requirements and fire safety engineering approach and for property protection should following fire safety engineering and Loss Prevention Council (LPC) design guide for fire protection of buildings. It should be noted that both the life safety and property-and-business starting point allow for a fire safety engineering (FSE) approach as an alternative approach (perhaps to deal with a specific issue) to the appropriate guidance document. It is the responsibility of the designer or his fire safety consultant to justify that the FSE approach provides as adequate level of safety in respect to the protection of business. There are twelve designs principle proposed by FPA (2003) to achieve fire safety objective i.e. life safety and property protection as in appendix 2.1.

2.8.2 Fire safety risk analysis

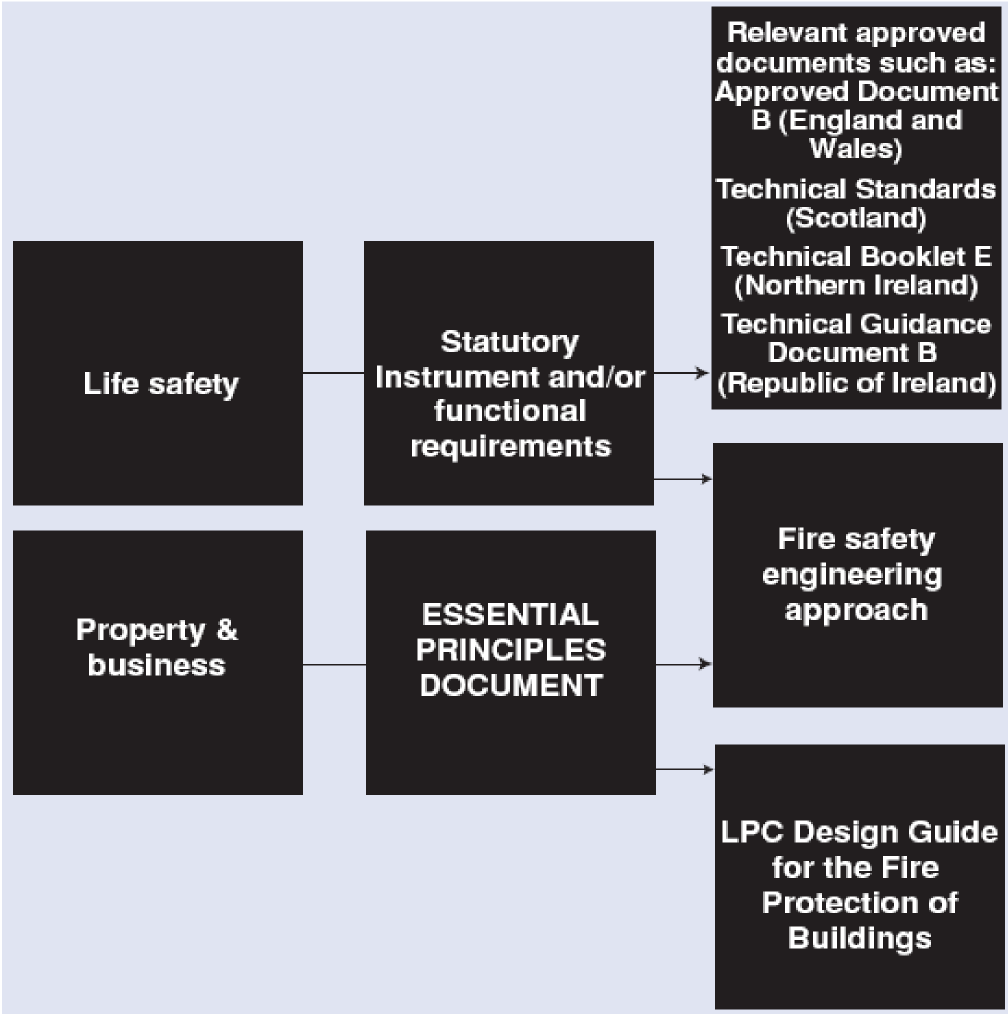


Figure 2.15: Life safety and property protection guidance framework (FPA, 2003)

There are a number of methods for evaluating risk. The method applied for any particular risk will depend on a number of factors, such as the complexity of the activities carried out and type and nature of the workplace. That are three common methods usually used i.e. Qualitative analysis – describes the quality of risk using words, quantitative analysis – quantifies the risk with numerical data and Semi-Quantitative analysis – uses numbers to quantify qualitative data (Furness and Muckett, 2007).

Qualitative analysis describes a quality of the risk. Typical of the qualities most often described is that of quantum, i.e. size or magnitude. For example, when assessing the means of escape in the event of a fire, fire risk has historically been rated as high, normal or low. Example of a simple risk matrix using the two aspects of risk to determine the magnitude of risk is as in figure 2.16 (Furness and Muckett, 2007).

Quantitative analysis evaluates factors not by subjective judgement, but by numerical data. Quantitative evaluation of risk is more demanding than qualitative approach but provides a more rigorous evaluation.

	Major injuries may occur	Serous injury may occur	Slight injury may occur
High chance of an event	High Risk	Medium Risk	Low Risk
Medium chance of an event	Medium Risk	Medium Risk	Low Risk
Low chance of an event	Low Risk	Low Risk	Insignificant Risk

Figure 2.16: Qualitative risk analysis matrix (Furness and Muckett, 2007).

Semi-Quantitative analysis techniques for risk assessment are widespread and it is often referred to as a quantitative method, however, it is easily seen that although risk is expressed as a numerical value, the estimation of the magnitude of the risk is in fact subjective and therefore qualitative. Semi-Quantitative evaluation of risk allows numerical values to be assigned to both severity and likelihood in the absence of data (Furness and Muckett, 2007). At present there is no quantitative method of assessing the adequacy of any escape route provided in a building other than by empirical means. The current method of providing means of escape from buildings is by specification and rules, i.e. rules that have evolved through time and are deemed to provide a satisfactory escape route (Shields & Silcock, 1989).

Coelho, (2004), introduced a conceptual model for fire safety risk analysis in building proposed by The Laboratorio Nacional de Enginharia, Portugal, as in figure 2.17, which consist of 12 sub-models interlinked each other centred into data information management model for fire risk analysis.

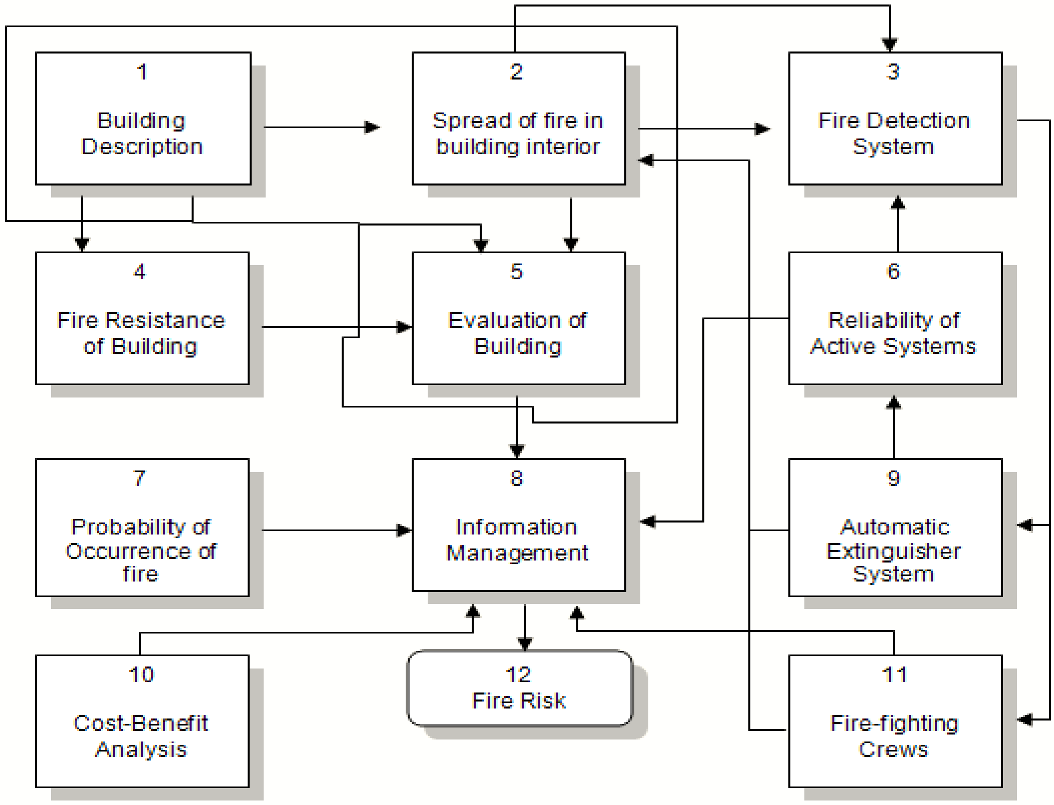


Figure 2.17: Conceptual model for fire safety risk analysis in building (Coelho, 2004)

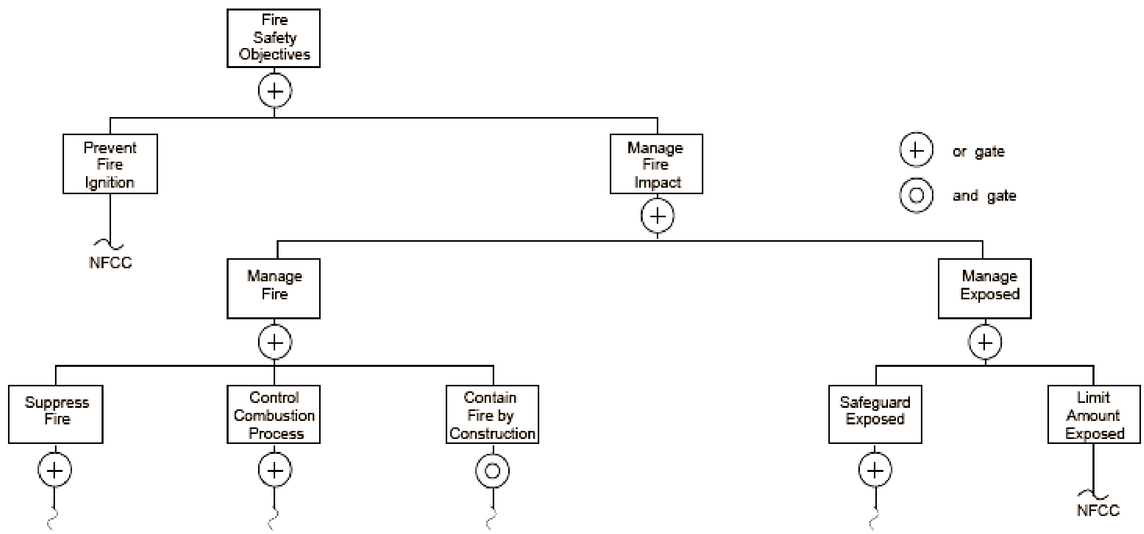


Figure 2.18: Fire Safety Concept Tree (NFPA, 2000)

The National Fire Protection Association (NFPA, 2000) has developed a basic approach to minimise fire risk called The Fire Safety Concepts Tree (FSCT) (see figure 2.18). FSCT was derived to achieve the fire safety objectives, first for life safety and second for structure protection. There are two fundamental principles of the FSCT, Prevention of

Fire Ignition, and Managing Fire Impact. Prevention of fire ignition can be done in the early stages of the building design process by eliminating fire sources but to completely eliminate fire sources is impossible. No matter how much effort we put in to prevent ignition, fires continue to start. Once a fire has started, we have to manage the fire to minimize the impact on the people and structures. FSCT emphasizes fire suppression, control of combustion and containment of fire by construction. To manage the impact, FSCT emphasizes safeguarding the exposure and limiting the amount exposed. Among measures that can be applied to achieve the fire objectives are prevention of fire ignition, providing the means of detection, equipping with fire extinguishing equipment, controlling fire from spreading to the other parts of building and allowing time for people to evacuate from the building.

2.8.3 Fire safety risk assessment in buildings

The purpose of risk assessment is to assist an employer and/or a 'responsible person' to identify the preventive and proactive measures required to comply with the law and in doing so, ensure, as far as reasonably practical, the safety of their workforce, premises and those around them who could be affected by their activities (Furness and Muckett, 2007).

Risk management explained in NFPA 1500 consists of four components i.e. (Angle, 2005):

i. Risk Identification;
ii. Risk Evaluation;
iii. Risk Control; and
iv. Risk Management Monitoring

According to Douglas (2002), besides the four components of risk management proposed by NFPA, there is one more component i.e. Audit, Review and Feedback.

Information from the fire risk solutions web site, (FRS, 3/2008), suggests general requirements of fire risk assessment are:

i. Fire fighting equipment measures,
ii. Signage,

iii. Adequate training of personnel,

iv. Escape routes and exits,

v. Maintenance, and

vi. Records

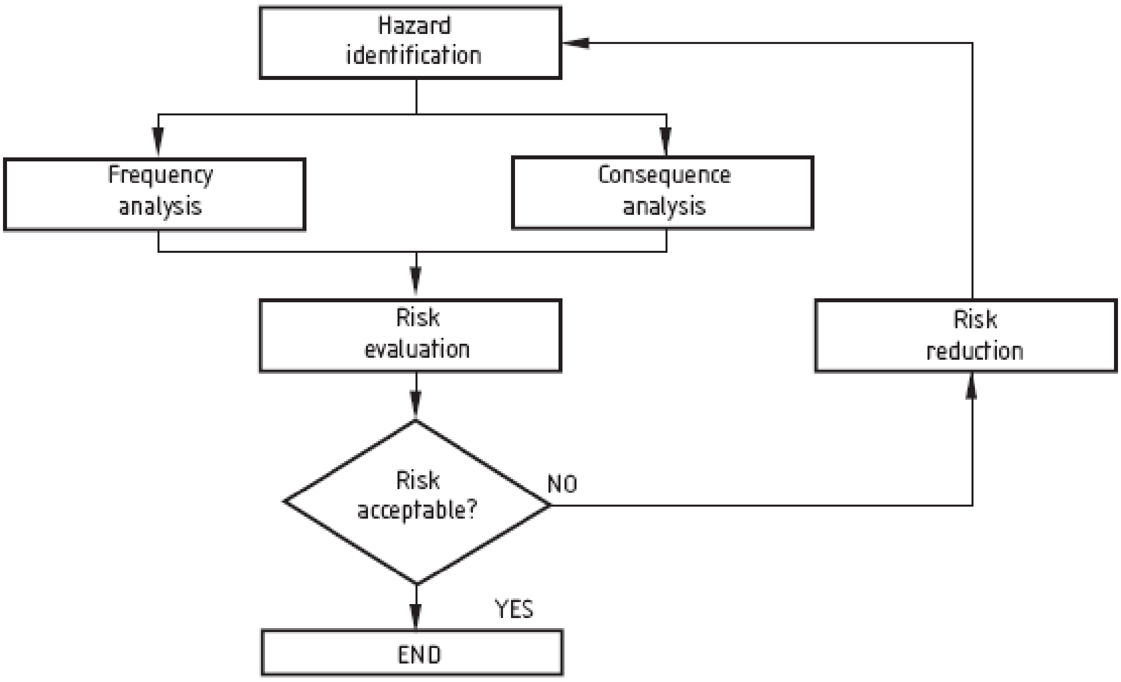


Figure 2.19:General approaches to probabilistic fire risk assessment (BSi, 2003)

According to FPA (3/2008), fire risk assessment involves identifying the potential sources of ignition in the workplace, the combustible materials that are present as part of the business operations, the furnishings and the structure in which the business is carried out. The people who use the premises must also be considered. These include staff, customers, visitors, or members of public. The means of escape, equipment for detection and giving warning in case of fire and fire-fighting apparatus are appropriate for the premises and numbers of people present also must be considered. Primary fire risk assessment is to ensure a satisfactory escape route, suitable arrangements are made to detect and give warning of a fire, and that appropriate fire-fighting equipment is strategically located around the workplace. FPA provides online self assessment by answering 51 questions to fulfil minimum requirements for fire risk assessment. Those 51 questions are as in appendix 2.1. Example of a fire risk assessment report is as in appendix 2.2.

British Standard Institution (BSi, 2003) in document PD-7974-7:2003: Application of fire safety engineering principles to the design of buildings, gives a general approach for probabilistic of fire risk assessment process as in figure 2.19. After hazards have been identified, frequency analysis or consequence analysis should be carried out before evaluation of risk can be done. There are two outcomes i.e. either risk is acceptable or unacceptable. If the risk is acceptable, it means that fire safety is adequately installed, the building is safe to be occupied. If the risk in unacceptable, it means fire safety is inadequately installed and the building is very risky to live in. Therefore the risks identified should be reduced. Appropriate measures should be taken to ensure all instruction, recommendations and suggestions from the fire safety personnel who carried out a fire risk assessment are seriously being considered to ensure all identified risks are eliminated or reduced at acceptable level.

According to the guideline produced by HMSO (HMG, 2006) on how to do a fire risk assessment, there are fire steps for fire risk assessment. Different premises have different guidelines but the steps in fire risk assessment are all the same. Those guidelines, unfortunately, all of them are intended to be used for non-domestic premises. There is no guideline for domestic houses or for high-rise residential buildings because there is no compulsion for domestic buildings to have a fire risk assessment. There is a web site, i.e. www.firesmart4home.co.uk, which offers a free online assessment for domestic fire risk assessment for those interested to do so. Meanwhile, FPA (3/2008) offers free online fire risk assessment for a workplace. Safeandhealthyworking.com gives an example of a fire risk assessment form as in appendix 2.3. So far the guidelines produced by HMSO which is close to the residential building occupancy is fire safety risk assessment for residential care premises as follows:

Step 1: Identify fire hazards

Step 2: Identify people at risk

Step 3: Evaluate, remove, reduce and protect from risk

Step 4: Record, plan, inform, instruct and train

Step 5: Review.

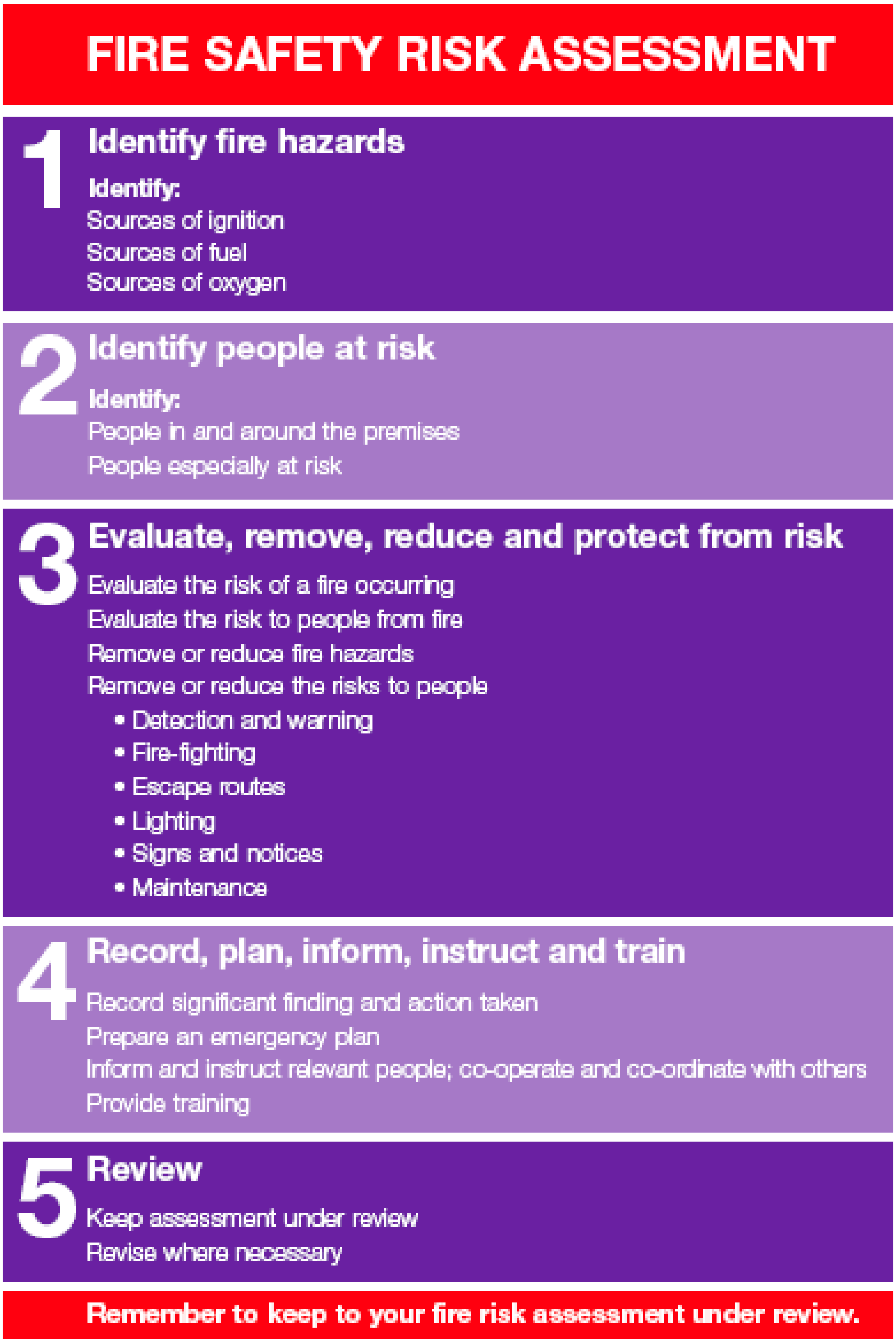


Figure 2.20: Five steps to carry out a fire safety risk assessment (HMG, 2006)

Figure 2.20 shows the five steps and components need to carry out when exercising a fire safety risk assessment in premises.

Step1: Identify fire hazard

Identify source of ignition, e.g. smoking material i.e. cigarettes, matches and lighters; naked flame i.e. candles or gas or liquid-fuelled open flame equipment; electrical, gas or oil-fired heaters; cooking equipment; faulty or misused electrical equipment; lighting equipment; hot surface; hot processes e.g. welding by contractors; arson, deliberate ignition, vandalism and so on.

Identify source of fuel i.e. anything that burns is fuel for a fire e.g. toiletries, aerosols, plastics and rubber, wood and wood based furniture, flammable products e.g. petrol, white spirit, methylated spirit , cooking oils and so on.

Identify source of oxygen i.e. the main source of oxygen for a fire is in the air around us. In an enclosed building this is provided by the ventilation system in use. Additional source of oxygen can sometime be found in materials used or stored at premises e.g. some chemicals i.e. oxidising materials which can provide a fire with additional oxygen and so help it burn; oxygen supplies from cylinder storage and so on.

Step2: Identify People at Risk

Identify people at risk means that all people who may present in the premises either on the permanent or occasional visitors i.e. the location they may present either regular or at specific times, person or persons who may need special assistance e.g. disable, elderly, children. Identify who they are, why they are at risk and where to find them in the event of fire

Step3: Evaluate, remove, reduce and protect from risk

Evaluate means examining critically the possibly of the risk of fire occurring and the risk to people, and try to identify the accidents waiting to happen and any acts or omissions which might allow a fire to start. Evaluate the actual risk to those people, listed out in step two, should a fire start and spread from various locations that have been identified earlier.

Evaluate the risk of fire occurring: In general, fires start in one of three ways i.e. accidentally e.g. smoking materials are not properly extinguished or when bedside lights are knocked over, by act of omission e.g. electrical equipment is not properly maintained or waste is allowed to accumulate near to a heat source or deliberately e.g. arson attack involving setting fire to external rubbish bins place too near to the building.

Evaluate the risk to people: Need to understand the way fire can spread. Since smoke is a major threat to the people, it is essential to evaluate the possibility of smoke spread within the building. It is essential that the means of escape and other fire precautions are adequate to ensure that everyone can make their escape to a place of totally safe before the fire and its effects can trap them in the building.

Remove or reduce the hazards that may cause a fire: Upon identifying the possible hazard that may cause fire, recommendations should be made to remove or reduce it instantly. There are various ways that it can be reduced, for example:

- Replace the possible high hazard by a safer alternative.
- Operate a safe smoking policy and ensuring sufficient ashtrays are provided and always keep it clean appropriately.
- Ensure all electrical, mechanical and gas equipment is installed, used, maintained and protected in accordance with the manufacturer's instructions.
- Ensure that all electrical fuses and circuit breakers are of the correct rating and suitable for the purpose and that electrical sockets are not overloaded.

Remove or reduce sources of fuel: All sources of fuel are needed to be reduced or stored in a very secure place. There are many ways its can be done, for example:

- Reduce the amount of combustible materials.
- Ensure all combustible materials especially highly combustible materials are separated from potential ignition sources.
- Do not keep flammable solids, liquids, and gasses together.
- Take appropriate action to ensure all premises particularly storage areas being vulnerable to arson or vandalism, and so on are secured.

Other aspects that need be closely looked are:

To remove or reduce the risk to people i.e. by providing a flexibility of fire protection measures, providing fire detection and warning systems, ensure escape routes are safe and ready to be used at all material times, all occupants are aware of the evacuation strategies, the number of escape routes and exits, management of escape routes, emergency evacuation of people with mobility impairment, emergency escape lighting, escape signs and notices, maintaining safety equipment, and so on.

Step 4: Record, plan, inform, instruct and train

Record the significant findings and action taken for further reference. Significant findings may include details of; fire hazards that have been identified, actions that have been taken or will be taken to remove or reduce the chance of fire occurring, persons who may at risk particularly for those who required a special needs, actions that have been taken, or will be, taken to reduce the risk to people from the spread of fire and smoke, and so on.

Plan: need to have an emergency plan and record all detail if necessary, ensure that the emergency plan takes into account other emergency plans which may applicable to the same building, the plan should be readily available to all occupants, and emergency plan available to the enforcing authority.

Inform: There should be clear information, instruction, and what to do in the event of fire or if somebody discovers a fire in the building. It should be available to all people in the building, occasional visitors or persons who are working in the building. The information and instruction that should be given is based on the emergency plan and must be include: the significant findings from a fire risk assessment, the measures that have been put in place to reduce the risk, who responsible for what if there is a fire, identification of people who will be responsible for the fire safety, the importance of closed doors, and any special arrangements for serious and imminent danger to persons from fire.

Training: The type of training should be based on the particular features of the premises or building and it should takes into account the emergency procedures, work activities take place during normal occupancy, and test by fire drill.

Step 5: Review

Fire risk assessment should constantly monitor and review. If there is any reason to suspect that there are significant changes in certain circumstances and the previous fire risk assessment is no longer valid, it should be reviewed or if necessary revised. Reasons for review could include: change in works activities, alteration to the building, substantial changes to furniture and fixings, increases in storage of hazardous substances, significant problem reported by residents or staff, significant increase in the number of people, and so on. Example of fire risk assessment checklist is as in appendix 2.4 which can be downloaded at www.communities.gov.uk/fire.

BRE, (3/2008), using the same format as in the guideline proposed by HMSO i.e. five steps fire risk assessment process. Fire Risk Assessment Online, (FRAO, 3/2008), state that a fire risk assessment should identify fuel sources, ignition sources, means of escape, fire fighting equipment, arson prevention, fire warning systems, emergency signage and lighting, and so on.

2.9 Human Behaviour study

Behavioural analysis – generally used in psychology study but lately its application has been extended including area of social concern, is a scientific approach to human psychology derived initially from the work of Skinner. There are four main parameters which mainly influence the behavioural analysis (Leslie, 2001):

i. Behaviour must be understood and analysed at the level of the individual person,
ii. Behaviour of the individual is situation-specific,
iii. Behaviour in a situation is a function of previous experience in that and similar situations,
iv. Situation and historical factors largely account for observed behaviour i.e. historical of interaction the individual has in relevant situations.

Leslie mentioned that how we behave in a particular situation is largely determined by what we have done on the previous occasions in that and similar situations. There are two types of experiences ‘hands-on experience’ and ‘knowledgeable experience’. Hands-on experience is an experience where persons have been involved personally in any occasions and knowledgeable experience is where persons get information and understood how it had happened mainly based on literature and discussion. The main focus of behavioural analysis is intervention in behavioural assessment by asking questions i.e. when and where did the behaviour occur? What action do the people concerned take? And why do they do it?

Functional analysis – generally is assessing the motivation of behaviour of people action in an emergency event. It has to be dealt with on an individual basis and practical for a small research sample. However, in a real situation when fire breaks out, human behaviour is unpredictable and can be very strange. Chandrakantan (2004) has cited that Sime (1990) has discussed the panic behaviour of some people in emergencies, and Wood (1990) has analyzed the way people react to fires. For example in findings reported by Wood, some people went only short distances through the smoke, but many of them advanced farther than they could see. Knowing the fact that people navigate through smoke, it is a responsibility to provide evacuation systems that are visible in smoke, wherever feasible. Exit signs are essential components of evacuation systems (Ouellette, 1993). Clintock *et al* (2001) studied a behavioural solution to the "learned irrelevance" of emergency exit signage and concluded that people recognise the current emergency exit signage and associate it with safety in an emergency. However, people for the main part do not notice emergency exit signage when they are involved in everyday activities, e.g. shopping. Part of the reason people have underused emergency exit signage is because they have acquired learned irrelevance to it. However there are a number of factors affecting the perception of risk and their impact on human behaviour in fire and it varies between individuals and groups for various psychological, social, and cultural reasons. For some individuals, fire may be dreaded, while for others, it is something that will never occur. There are many reasons for these, which is known as part of the psychometric paradigm of risk, among them are (Meacham, 2001):

i. Perceived voluntariness of the exposure,
ii. Perceived level of protection affordable,
iii. Familiarity of the risk,
iv. Catastrophic potential,
v. Immediacy of the effects,
vi. Distribution of risks,
vii. Judgements about who or what is perceived as causing the hazardous situation,
viii. Controllability,
ix. Degree of technical knowledge available, and
x. Exposure pattern.

Success in a building evacuation depends on many factors including (Livesey *et al*, 2001):

i. Floor plan of the building i.e. building-specific constraint which has multiple sub-attributes e.g. signage, corridor width, staircase width, floor finishing, and alarm system.
ii. Occupants profile i.e. people-specific constraint with multiple sub-attributes e.g. age, mobility impairment, panic behaviour and number of occupants or density.
iii. Potential visual and sensory capabilities i.e. wayfinding depends on lighting and architectural layout as more significant design criteria then travel distance in

modelling evacuation.

They suggested that more extensive study on the occupants profile, relationship between evacuation times and the structural measures of building complexity, depth and measure of integration are needed.

To enable people to evacuate a building quickly and safely in an emergency it is important that they can navigate around parts of a building that are new to them, no matter what the conditions are. One aspect that should be investigated is how effective various emergency lighting systems or low mounted wayguidance systems are when the air contains smoke (Wright *et al*, 2001).

Research in the field of fire engineering into human behaviour in fire is largely directed by the needs of the models of response that are currently accepted. Primary areas of research are those that provide data to first profile the occupants and then to predict; cue recognition by occupants or occupant groups, their subsequent actions, their times for starting to respond, their movement times and their sensitivity to fire product. The outcome of occupants experiencing a fire is the product of their responsiveness to fire cues and some behaviour is generally occupants *react to fire* rather than *interact with fire* (Brennan and Thomas, 2001).

2.10 Chapter conclusion

Fire safety in high-rise buildings is a very important issue but it has not been given proper intention by many parties, especially for residential buildings. Economy factor is claimed to be the main factor in providing fire safety measures in residential buildings. The building cost will increase if all aspects of fire safety measures are installed in residential buildings and it will significantly increase the total price of property and pose unnecessary burden to the purchaser. However, the importance of fire safety measures in high-rise residential buildings should not be viewed from the prospective of economics factor but equally important is to view them from the perspective of fire safety as well. The occupants of high-rise residential buildings as well deserve high safety measures equal to that of workplace buildings. Therefore, the provision of escape routes design and specification in high-rise residential buildings need to be given appropriate attention by the relevant authority.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

Generally research falls into two categories i.e. library research or experimental research (Thomson, 2003). Library research mainly involves searching activities on secondary data i.e. information limited to books and other published materials normally available in the library, whilst experimental research mainly involves experiment and/or observation, questionnaire study and validation of the questionnaire feedback by carefully selected sampling. Research can broadly be categorised into two groups, theoretical and empirical. Theoretical research is focused on the development and refinement of a body of abstract knowledge, whilst empirical research observes events in context and seeks to make sense of those observations (Owarish, 2000). Development of research needs a basic skill in research design and research knowledge. Richey and Klein (2007) defined design and development research as “the systematic study of design, development and evaluation processes with the aim of establishing an empirical basis for the creation of instruction and non-instruction products and tools and new or enhanced models that govern their development. Commonly used data collection tools such as work logs, surveys, questionnaires, interviews, observations and the use of technology i.e. testing, simulation, for data collection are among the key factors of design and development research.

3.2 Research methodology overviews

Davis (1992) stated that in most cases research can be conducted in a variety of ways and suggested a strategy to investigate a given area:

- Conduct a literature review to give a good understanding of the existing state of knowledge in the field.
- Conduct a case study in an organization or have a period of observation which will allow the researcher to observe the phenomenon under study in a real setting, and allow an appreciation of the validity of the research in terms of its relevance and potential contribution to knowledge and interest.
- Conduct a field survey or experiment to obtain confirmation and validation of the ideas explored in the case study.

Research methodology in fire safety and human behaviour began as early as 1900s. The earliest documented human behaviour study was in 1909 and involved studying the velocity of the pedestrians walking in New York by counting the number of people walking in that city. This was the first methodology used in human behaviour study and is known as "observation". The second methodology was "Interviews". This method was used to interview selected occupants of building fires and was used in 1956 following the fire incident at Arundel Park, in the United States. In the 1970s and early 1980s two critical studies were conducted at the University of Maryland. Both studies replicated the methodology of Peter Wood's study in Great Britain using a "Structured Questionnaire". Peter Wood assisted in the development of the questionnaire for the University of Maryland study to assure the compatibility of study data for comparative purposes (Bryan, 2002). The first study involving fire service personal interviewed 2,193 occupants from 952 fires using a structured questionnaire. The second study involved 584 participants in 335 fire incidents in Washington D.C., and Baltimore, Md. area. The outcome of the studies confirmed the *Reentry Behaviour* where members of the primary group were involved. Occupants as well have tendencies *to move through smoke and to fight the fire*.

Schneider (2001) used computer simulation ASERI to study the individual-based evacuation model in designing safety concept in his research. According to Schneider, to use a simulation tool in designing safety concepts, required detailed knowledge of its predictive power. Certain features of behavioural response are modelled in a probabilistic rather than a deterministic way. This probabilistic approach allows for more profound evaluation of the evacuation process by performing Monte-Carlo simulations.

Observation is among the methods used to collect research data. This technique can be in the form of critical observation or forensic-like analysis of any event either by real exercise or through recorded material. Galea and Gwynne (2001) used response-base analysis techniques to observe human behaviour exhibited during rail crash accidents. They also used full-scale tests to estimate the flow rate capacity of an overturned rail carriage end exit. Response-base technique normally includes interviewing the respondents or serving the respondents with structured question and answer questionnaires. Shields and Boyce, (2000) used video tape of unannounced evacuation processes of large retail stores to evaluate the total evacuation times and pre-movement times of evacuees in four Marks and Spencer retail stores. Forensic-like techniques in many cases are used in analyzing the building structures or process of any activities involved in any event or to trace the root of the problem. The data and findings using this technique can be either in qualitative or quantitative in form. In this research, this technique will be used to verify the compliance of escape route design in selected high-rise residential buildings and to identify the actual problems encountered regarding the provision of escape routes in high-rise residential buildings.

Questionnaires are one of the most popular research tools to collect data. They can be used to collect either qualitative or quantitative data. Sekizawa et.al. (2001) used a questionnaire survey to study the behaviour of people in selecting the type of escape route to evacuate from building fire. The outcome of his study was that 47% used elevators for their evacuation, while 42% used stairs and 7% used both elevator and stairs. Proulx (2001) used a questionnaire to study the occupant's behaviour during the Ambleside Fire in Ottawa on 31st January 1997. During the fire, although initially the majority of occupants decided to stay-in-place in accordance with the Fire Safety Plan for that building, many of them immediately complied with the evacuation order delivered through the voice communication system. Only 17% decided to stay in their apartments. The findings of the research using questionnaire methodology are normally demonstrated in percentage form. However sometimes it can be in qualitative form such as questioning individual responses.

One more method, but not a very common one is Heuristic Research. The root meaning of heuristic comes from the Greek word 'hueriskein', meaning to discover or to find. It refers to internal search through which one discovers the nature and meaning of experience and developed methods and procedures for future investigation and analysis (Moustakas, 1990).

Many research projects adopt more than one method. A combination of several methods of data collection and analysis techniques can make the research more interesting and significant. Starting from establishing the problems, develop a heuristic research framework for further study, build-up research data collection tools and gather data for analysis. The research findings will be more significant if several methods of testing and analysis are used. However those methods used should not to be limited to and must be well defined of its processes and procedures to work with. There are three forms of research methodologies i.e. quantitative, qualitative and mixed. Table 3.1 below gives the differences between qualitative and quantitative research.

Mixed methodology is defined by incorporating the collecting and analysing of both quantitative and qualitative data in a single study. Mixing as well might be within one study or among several studies in a programme of enquiry (Creswell, 2003) and is among the most popular methods of research adopted recently. This research will be in this category.

Difference with respect to:	Quantitative research	Qualitative research
Underpinning Philosophy	Rationalism: "That human beings achieve knowledge because of their capacity to reason".	Empiricism: "The only knowledge that human beings acquire is from sensory experience"
Approach to inquiry	Structured/rigid/predetermined methodology	Unstructured/flexible/open methodology
Main Purpose of Investigation	To quantify extent of variation in a phenomenon, situation, issue etc.	To describe variation in a phenomenon, situation, issue etc.
Measurement of variables	Emphasis on some form of either measurement or classification of variables	Emphasis on description of variables.
Sample size	Emphasis on greater sample size	Fewer cases
Focus of inquiry	Narrows focus in terms of extent of inquiry, but assembles required information from a greater number of respondents.	Covers multiple issues but assembles required information from fewer respondents.
Dominant research value	Reliability and objective (Value-free)	Authenticity but does not claim to be value-free
Dominant research topic	Explains prevalence, incidence, extent, nature of issues, opinions and attitude; discovers regularities and formulate theories	Explores experiences, meanings, perceptions and feelings
Analysis of data	Subjects variables to frequency distributions, cross-tabulation or other statistical procedures	Subjects responses, narratives or observation data to identification of themes and describes these
Communication of findings	Organisation more analytical in nature, drawing inferences and conclusions and testing magnitude and strength of a relationship	Organisation more descriptive and narrative in nature.

Table 3.1: Differences between qualitative and quantitative research methodologies (Ranjit Kumar, 2005)

3.3 Research Outline and Process

Figure 3.1 below shows the research outline and process to be carried out.

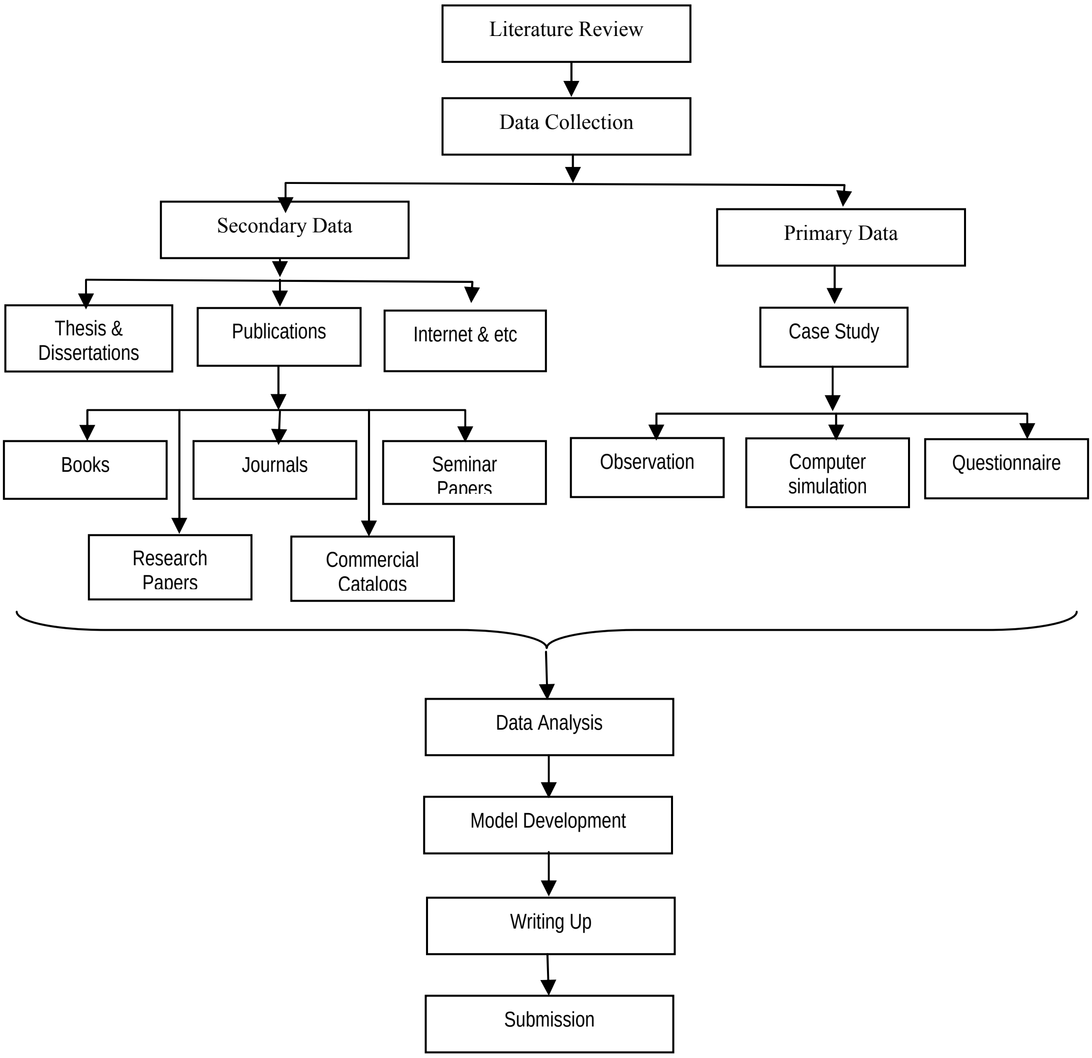


Figure 3.1: Research outline and process

3.4 Research steps

There are six steps to this research as follows:

i. Literature review
ii. Pilot study to develop and enhance the research tools
iii. Observation and analysis of problems encountered in high-rise residential buildings.
iv. Computer simulation and analysis of designed parameters
v. Questionnaire and analysis of variances
vi. Model development

3.4.1 Pilot study

Figure 3.2 shows the framework for the pilot study. The purpose of the pilot study is to establish data collection tools before the main data collection can be carried out.

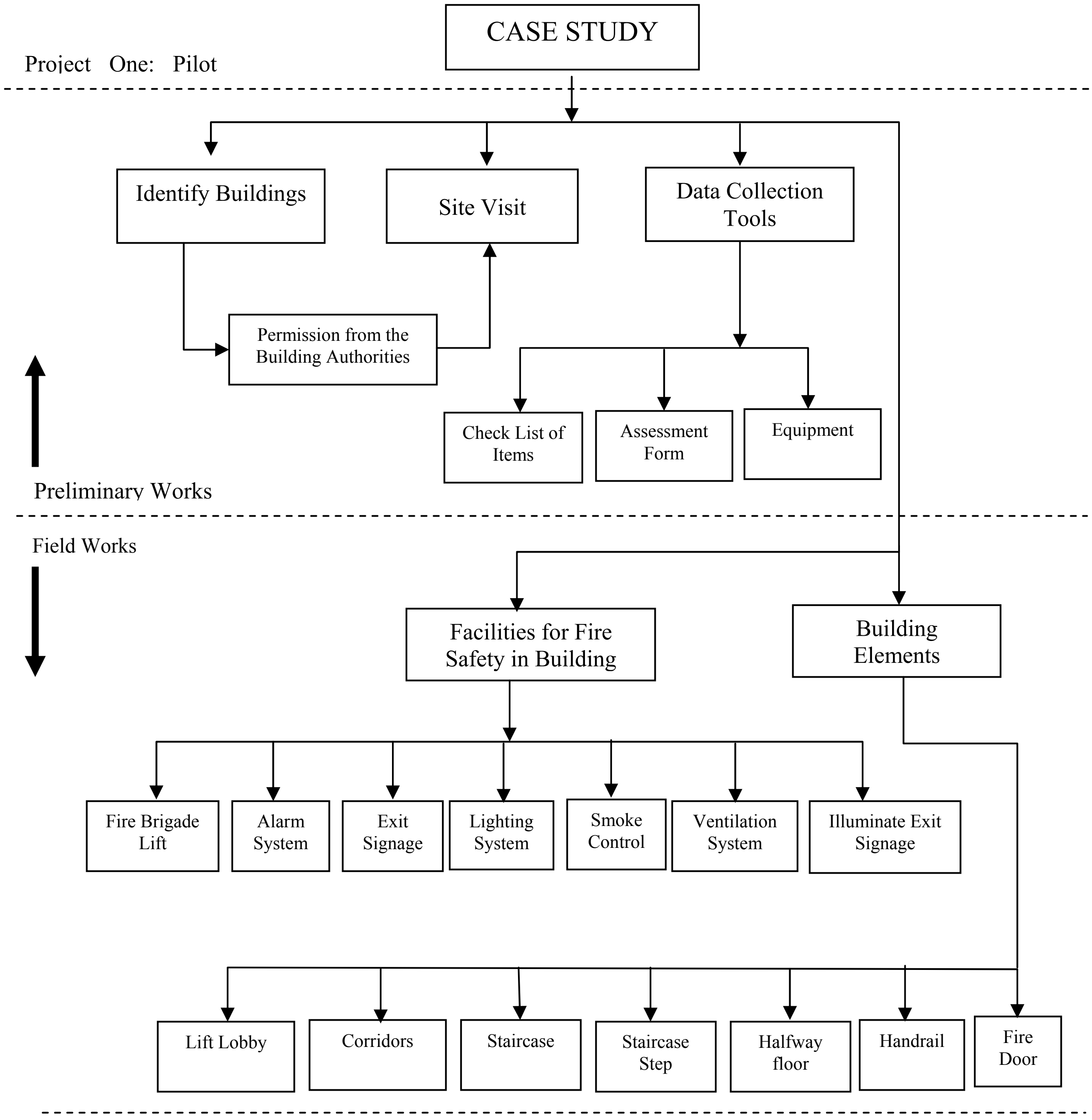


Figure 3.2: Pilot study and field works model

Data collection tools or instruments are the keys factors in research which, without it, there will be no research data. These tools have to be developed and tested before the main research data can be collected. Referring to figure 3.1, i.e. research outline and process, primary data for this research will be gathered by three methods i.e. observation, simulation and questionnaire. The case study focuses on the development of the data collection tools for observation, and data from this exercise will be used for the computer simulations. Computer simulation and questionnaire will be discussed later on in the relevant sections.

Basically there are three research tools used in the pilot study i.e. Checklist Form (Appendix 3.3), Assessment Form and Equipment. Two of them i.e. Checklist and Assessment forms are derived from Building Regulation: Approved Document Part B1 (fire safety) 2000 and Uniform Building By-Laws 1984 for the case study in the UK and Malaysia respectively. The purpose of the checklist is to observe the compliance of escape route in the existing building to the current building regulation and mainly regarding with the provision of facilities for fire safety and escape routes provided in the building as in figure 3.4.

The Assessment Form is purposely to examine the detailed specifications of escape route in terms of design, construction and dimensions of those elements constructed in the real world. It includes the dimension, size, number of stairs, types of lobby, fire doors, protected areas, corridors, handrails, platform etc. To do so, some basic equipment needed i.e. digital camera, measuring tape etc.

Pilot study process (Pilot study was conducted in the UK)

- Identify the building to study and obtain permission from the building authority before and to carry out assessment.
- The researcher entered the building and went to the top floor by lift. Upon reaching the top floor, the researcher then walked down using the escape stairs provided. In the case where two or more escape stairs were provided the researcher change the escape stair in every alternate floor. For example if there two escape stairs from the top floor, the researcher walked down through one escape stair and upon reaching the below floor, the researcher walked through the corridor to reach the other staircase. From there the researcher walked down to the next floor and so on.
- Whilst the researcher walked through the escape stair and corridor, those elements in figure 3.2 i.e. facilities for fire safety and building elements, were examined. Staircase width, riser height, tread dimension, fire door width and height, handrail height, corridor width and so on were measured. All evidence was then photographed for further analysis. All facilities for fire safety in the building were inspected regarding its physical appearance and working condition accept for the

fire alarm systems and fire fighting systems for which no testing was completed. It was assumed that all fire alarms and fire fighting equipments were in a good working condition if their physical appearance was good. This is because the researcher was not allowed to do the test without being accompanied by a professional fire engineer.

From this exercise, the researcher was able to enhance the checklist and assessment forms to be used for the main data collection in Malaysia. The following section discusses the process of building observation carried out in high-rise residential buildings in Malaysia.

3.4.2 Building observation and analysis of problem encountered

Twelve high-rise residential buildings have been observed, five in Kuala Lumpur, six in Penang and one in Edinburgh. The building in Edinburgh was used as a pilot study to assist in the formulation of the data collection tools and analysis method. There were four purposes of building observation:

i. To identify the problems encountered in escape routes;

ii. To examine the design and orientation of corridor, fire door, staircase layout and traffic flows to assist in developing of study models. 260 study models have been developed (see chapter 4) as a result of these exercises to be further analysed in computer simulation;

iii. To observe the detailed specifications of staircases, corridors and fire doors i.e. staircase width, intermediate floor width and depth, step numbers, riser and tread dimensions, handrail height, fire door width, corridor width, and

iv. To evaluate the condition of services equipment provided in escape routes i.e. lighting systems, emergency lighting systems, ventilation systems, lift, and so on.

Observation method: The observation processes as described in the pilot study i.e. pilot study process are applied here. Hundreds of photos were taken for qualitative analysis and all escape routes elements were measured for quantitative analysis.

Counting and measuring the escape stairs: The number of escape stairs is counted by the number of staircase shafts provided. For example if building A has two storey exits on each floor where each storey exit leads straight to the staircase shaft, (see figure 4.29), the number of escape stairs is two.

Counting and measuring of staircases: The staircase connecting the landing floor and intermediate floor is counted as one. It is very common that two staircases are designed for connecting the floor level. In figure 4.30 (a) between ground floor and 1st floor, there are two staircases with an intermediate floor between them. Figure 7.4 shows a common staircases schematic drawing for high-rise residential buildings. There are two staircases between floor levels. The number of staircases is calculated by counting each of the staircases from the top floor until the ground floor.

Counting and measuring tread and steps riser: There are four elements measured in staircase i.e. staircase width, tread depth, step riser and handrail height. Staircase width is measured by measuring the width of tread. Tread depth and step riser are measured by randomly selecting three or four staircase steps of every staircase inspected. The tread depth and riser height are then measured and some photos are taken for further analysis.

Measuring fire doors: Fire doors width is measured by measuring the exact width of the doors and clear width opening of the doors.

Measuring handrail height: Handrail height is measured by measuring from top level of the handrail to the tread level.

Measuring corridor width: Corridor width is measured by measuring the distance across the corridor.

3.4.3 Computer Simulation and analysis of design parameters

The purpose of the computer simulations is to analyse floor clearance time and total evacuation time on different floor layouts of some of the high-rise residential buildings observed, the optimum specifications of staircase, corridor and fire door and the effect of staircase designed with and without an intermediate floor by measuring the total evacuation time recorded by number of people placed in study models. For this purpose, computer simulation package i.e. Simulex was used.

3.4.3.1 Overview of SIMULEX applications

SIMULEX is an evacuation tool which specialises in modelling the physical aspects of evacuation movement, and is widely used as a consultancy and analysis tool around the world. Simulex enable the user to simulate occupant behaviour in the event of a building evacuation, identify potential problems and find solutions. It uses a series of 2D floor plans, with exits and staircases linked together. Each floor plan and staircase is displayed in its own simulation window so that every event in Simulex environment can be viewed simultaneously (Thompson, iesve, 02/2008).

After defining a 'distance map', the building population can be defined by age and gender, and take into consideration different walking speed, body shapes and time to respond to a fire alarm. Occupants can be placed in space inside the room, building or in walkways, corridors, or lobbies by placing individuals or groups of people (IES, 03/2008). Further application of the Simulex programme can be found in Thompson and Marchant (1995a, 1995b, 1996) and validation references can be referred to Olsson and Regan (1998) and Thompson and Marchant (1995c). Generally, Simulex features can be summarised as follows (IES, 03/2008):

Model building

- Simulex uses 2D DXF file drew in CAD system or from the 'Virtual Environment' i.e. simulex integrated programme to create and define floor plan.
- Allows users to create staircases to connect floor plans together for a multi-storey building analysis. Staircase width and length can be added or edited.
- Users define and position 'Final Exit', either outside or inside the building.
- 'Links' are used to connect each doorway from a floor plan into staircase.
- Users can place people on each floor or staircase individually, or as groups over defined areas.

Building analysis

- Define the building fabric with exactly the same accuracy as the DXF files.
- Automatically generates a 0.2m x 0.2m spatial mesh, overlaid onto the DXF plans.
- Can generate a 'distance map' which calculates the total distance-to-exit for every point on the spatial mesh.
- Distance maps can be displayed graphically as distance 'contours' – in similar way to height contours on a geographic map.

- Route analysis can be carried out by 'dropping' test people into the model and observing their escape route, based on the distance maps. The total distance travelled is displayed while movement occurs.

Populations (occupants)

- Different 'population groups' are defined. Each population group contains combinations of following features:
    - Body shape and size
    - Walking speed
    - Time to respond to alarm
- Any combination of individuals with specific characteristics can be combined in one model, in any part of the building.
- All aspects of the population demographic can be changed, allowing the user to customise body size, walking speed, stairs ascent and descent speeds. This enables any range of occupant disability to be tested.

Analysis of evacuation simulation

- The user initialises the evacuation when the model has been built and populated.
- Live on-screen display on the plan views of any part of the building, which can be zoomed in or out.
- Each person is shown, and movement animated every 0.1 seconds.
- Still shots of this movement can be captured at any time and pasted into a graphics or word processing package.
- All queuing, congestion, overtaking etc. is viewed by user as it happens.
- The user can change views of any of the building as the simulation progresses.
- The evacuation proceeds until all occupants have escaped from the building.

Simulation procedure on the study model can be found in section 7.4, chapter 7 – An evaluation of the provision of escape routes in high-rise residential buildings in Malaysia.

3.4.3.2 Example of applications of SIMULEX

In this research, applications of Simulex are used in three circumstances, to investigate the optimum escape route specifications, to investigate the correlation of escape routes and evacuation time, and to investigate the people movement patterns and behaviours in high-rise residential buildings with different internal layouts.

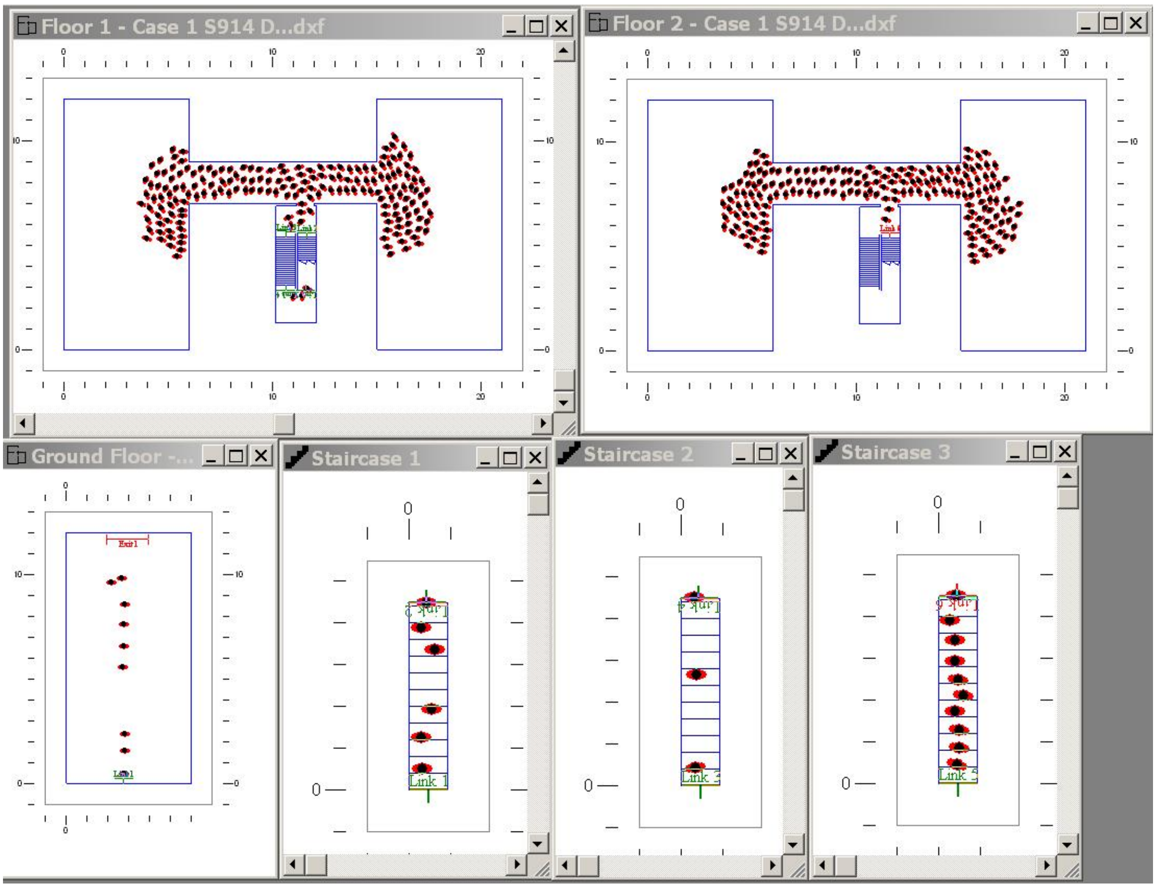


Figure 3.3: Example of investigation of the effects of staircase, corridor and fire door width simulation on occupants from a study model.

Figure 3.3 shows an example screen-image of Simulex modelling occupants' evacuating one of the study models. This simulation is to investigate the optimum width of staircase against the fire door width. Staircase, fire door and corridor widths as in table 4.9 are used in this investigation. For example, to test the effects of fire door width against the staircase width, study models are designed with the fire door width e.g. 762mm with the staircase width of 914mm i.e. the smallest until 1524mm i.e. the widest and so forth. The same design principles are applied to the other fire doors width and for corridor too.

Figure 3.4 shows the information window of a simulation which shows a number of people evacuating the building and simulation time. There are eight scenarios of models, as described in chapter 4, section 4.6.1, with 260 study models developed to be studied for the optimum specification of staircase width, fire door width and corridor width by comparing the evacuation time taken by 200 evacuees evacuating the building. All analysis graphs are plotted using Microsoft Excel worksheet.

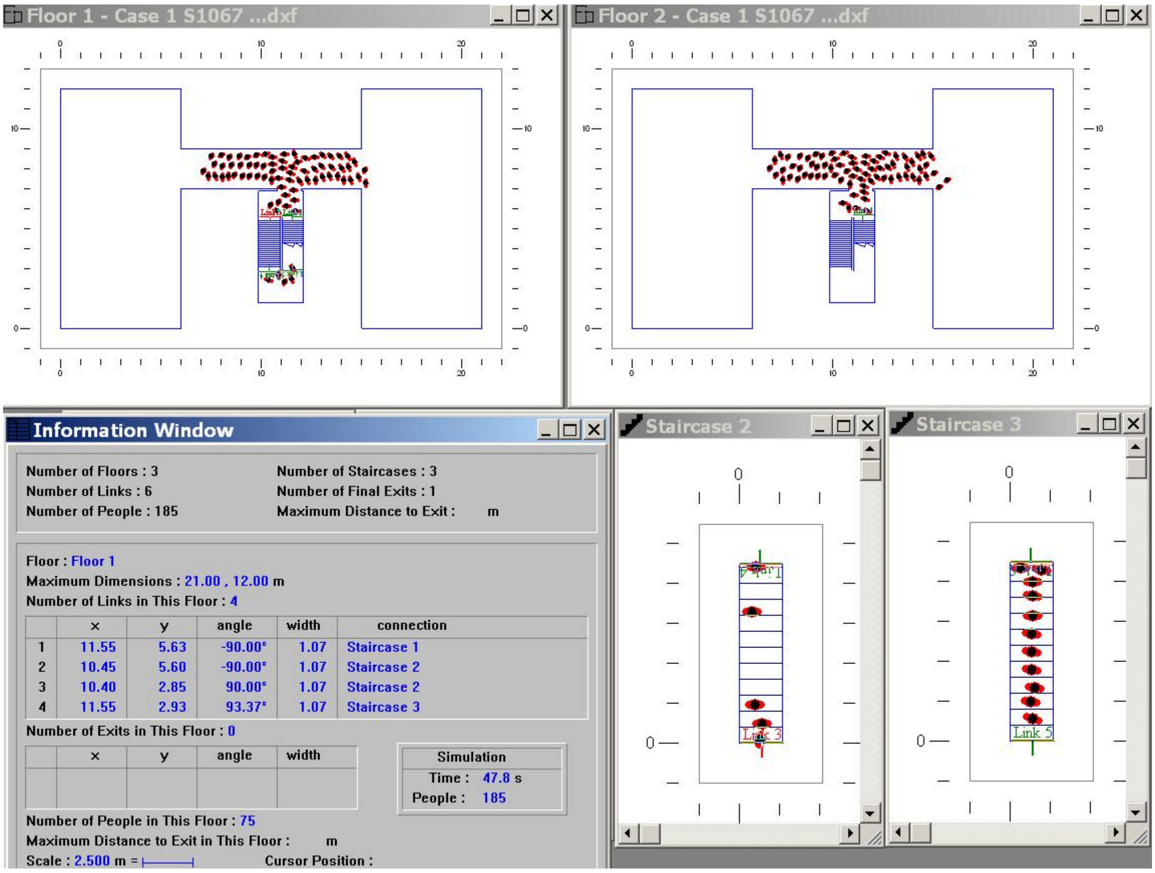


Figure 3.4: Information of the number of people evacuating the study model and simulation time.

Analysis of floor clearance time and total evacuation time in high-rise residential buildings in relation to the building characteristics (i.e. space orientation of the internal circulation, location of escape stairs, and location of final exit) were investigated based on four selected high-rise residential buildings mentioned in chapter 4 i.e. building A, C, D, and F. These buildings were chosen because of the internal layout differences. Examples of Simulex screen-image captures are as in figures 3.5, 3.6, 3.7 and 3.8 below.

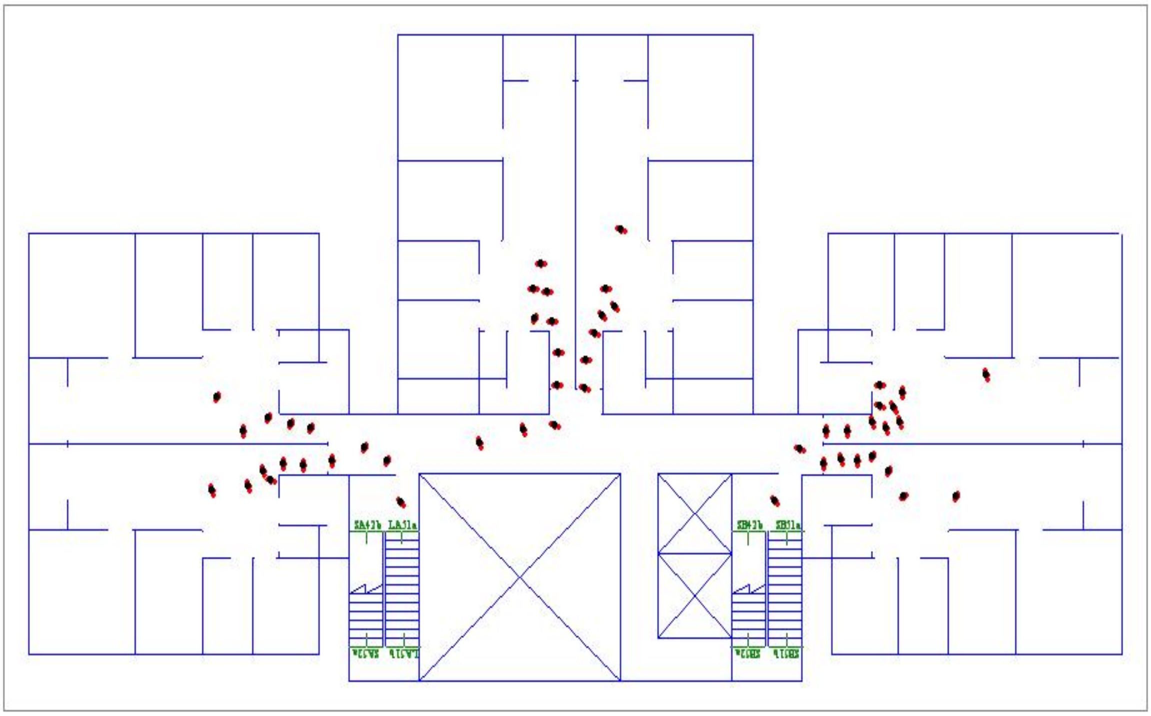


Figure 3.5: Occupants started to evacuate their flat after fire alarms go off

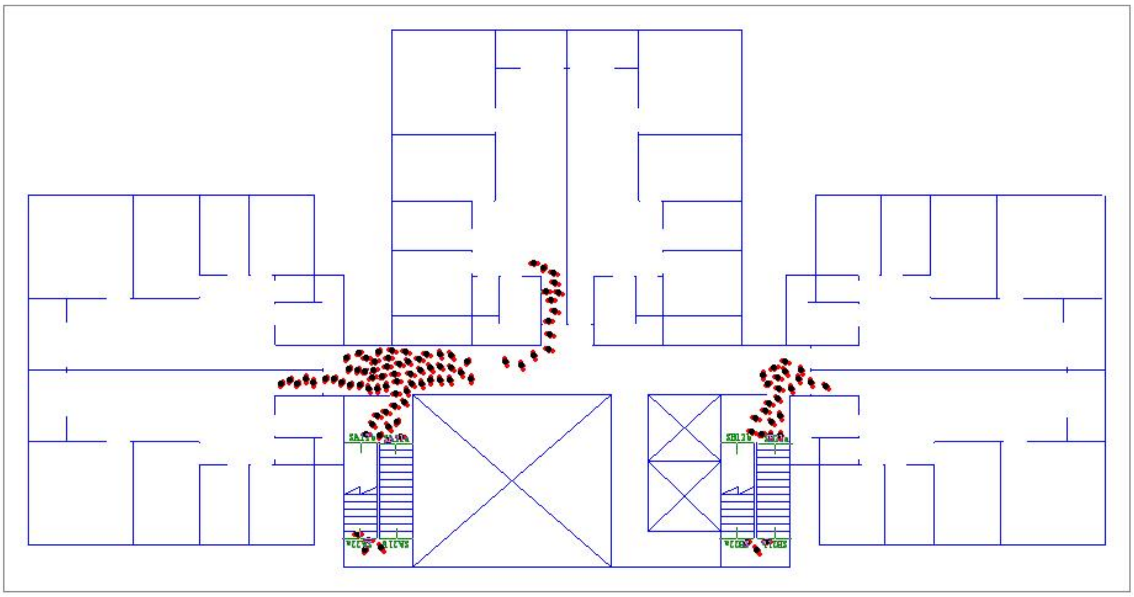
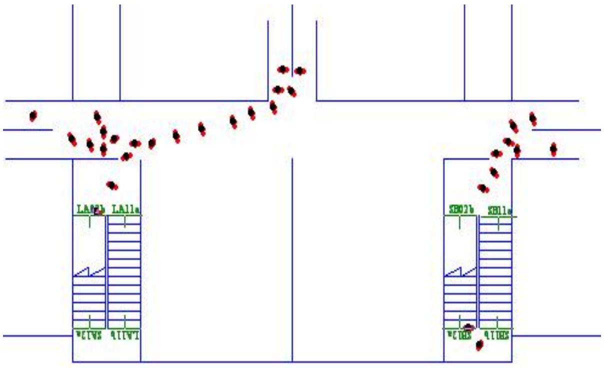
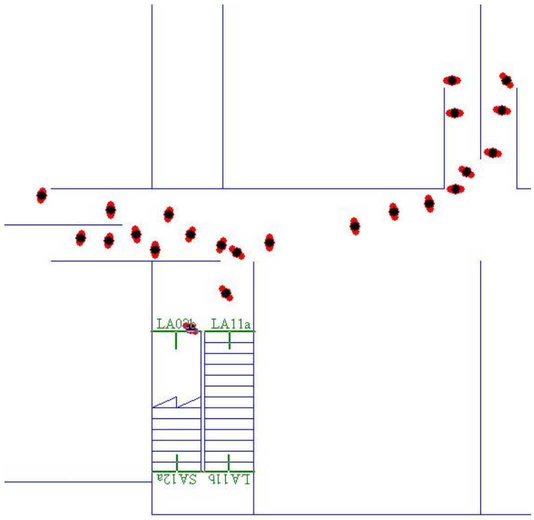


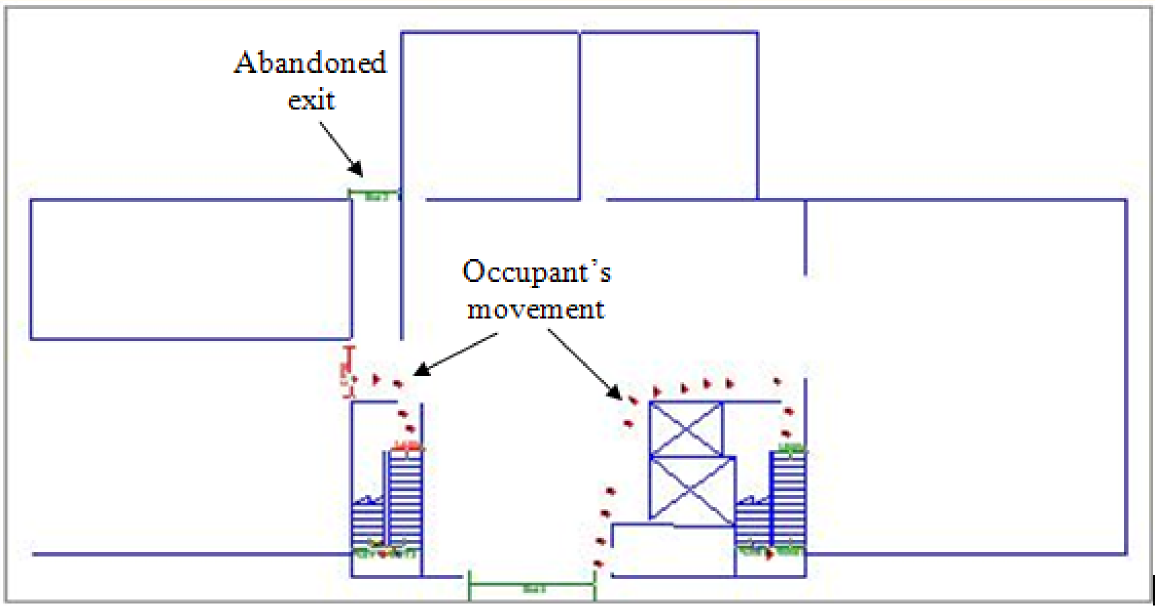
Figure 3.6: Occupants move forward to the nearest escape stairs and are scattered at the front of the storey exits.



(a)



(b)



(c)

Figure 3.7: (a) Occupants have chosen the staircase which is nearest to their flats,

(b) Occupants from the four flats have chosen one staircase and the other two have chosen another staircase,

(c) One exit was abandoned because occupants had exited by the nearest final exit to the staircase.

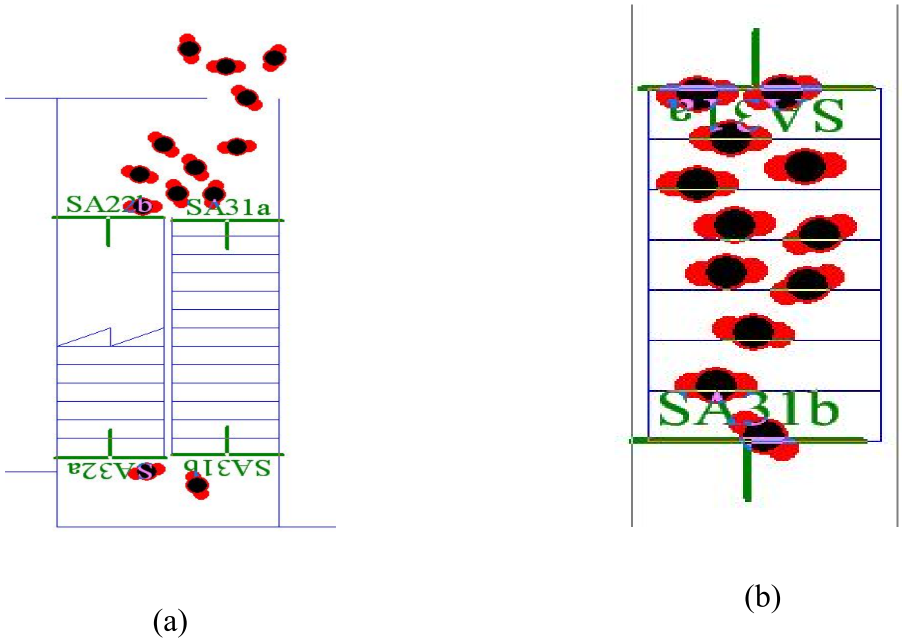


Figure 3.8: (a) Occupants approaching the staircase, (b) Occupants are on the staircase

3.4.4 Questionnaires and analysis of variances

Another methodology used in this research is questionnaire survey to the occupants of high-rise residential buildings and professional opinions on fire safety aspects in high-rise residential buildings. Two sets of questionnaires were sent out i.e. Human Behaviour Questionnaire (HBQ) (Appendix 3.1) and Building Audit Questionnaire (BAQ) (Appendix 3.2). HBQ was served to the occupants of five high-rise residential buildings in Kuala Lumpur. It consists of two parts e.g. Part one – Respondent’s General Information and part two – Respondent’s perception. In part 1, questions are asked about the respondents’ gender, education level, age, occupation, knowledge on fire safety and fire safety equipment, experience in any building fire or fire drill, and where they stay in residential flats. In part 2, questions are asked about their perceptions i.e. what they are going to do if they see or hear any fire cues, what is their perception if they hear the fire alarm, what are the factors that will motivate them to evacuate, what are the factors that describe their characteristics during evacuation processes, and what are the factors that highly influence their behaviour during evacuation process. There were 360 questionnaires sent out to the five selected high-rise residential buildings in Malaysia and 115 were returned with answer. All questionnaires were distributed through the post box and date and time were set to collect them back. 360 questionnaires sent out are based on the number of flats in those five buildings. The out come of this study is in chapter 6 i.e.

Human behaviour response issues in high-rise residential buildings in Malaysia. Figure 6.6 shows a human behaviour model of fire safety in building.

BAQ consisted of five parts i.e. Part 1 – General Information, Part 2 – Fire Safety Management, Part 3 – Risks of Fire In The Buildings, Part 4 – Risks of Casualty, Part 5 – Evacuation Risk Elements. This questionnaire was sent out to professionals e.g. Architects, engineers, fire brigade offices, etc. The responses from them was rather low, out of 100 questionnaires sent out, 25 were returned. Those professionals are chosen based on the average numbers of them dealing with the fire brigade department in submitting proposals for new building plans for checking and approval of the fire safety features. Their valuable comments and responses were used to develop a fire safety audit form for fire safety audit in high-rise residential buildings as in Appendix 8.1. SPSS was used to analyse all the questionnaires using "frequency analysis" of variables and "comparison of means" analysis.

3.4.5 Models Development

The model of the fire safety that will be developed is based primarily on the concept of a multiattribute evaluation model, point system, the Edinburgh model (Rasbash et. al, 2004) and fire safety concept tree (NFPA, 2000). This conceptual model designed to achieve fire safety standards in high-rise residential buildings (as in figure 8.4) resulted from the combination of mixed research methodologies and analysis as in figure 1.1. Details can be read in chapter eight.

3.5 Chapter conclusion

A mixed methodology is used throughout the research i.e. a combination of both quantitative and qualitative data collection and analysis. There are three mains components of research carried out i.e. observation, computer simulation and questionnaire survey.

CHAPTER 4

OBSERVATION OF ESCAPE ROUTES IN HIGH-RISE RESIDENTIAL BUILDINGS AND DEVELOPMENT OF THE STUDY MODELS

4.1 Introduction

Observation is one method that can be used to collect research data. This technique can be in the form of critical observation or analysis of any event, through recorded material or observation and photographic evidence for further analysis in the laboratory. Forensic analysis is a technique that analyses identified problems by putting all information or raw data together, step by step. This technique is widely used and known as ‘Techniques of Crime Scene Investigation’ i.e. gathering and analysis of evidence by visiting the place to identify what the problems are actually. In this work, this approach was adopted by visiting buildings and taking pictures of the building layout, staircase orientation, staircase step, corridor and fire door. By applying logical analysis, i.e. asking the question to the problem arising by using the notation ‘IF’ to the questions, we should be able to attract two possible answers, ‘YES’ or ‘NO’. E.g. of this skill is ‘If there is only one staircase provided in this building, would occupants be trapped when fire broke out?’ The answer could be YES or could be NO. Both answers need justification which will trigger other questions and this begins the forensic effect that analyses in detail all the data available. There are basic tools needed in observation techniques, e.g. abstract of building regulations, checklist form, digital camera, and measuring tape.

4.2 High-rise residential buildings in Kuala Lumpur

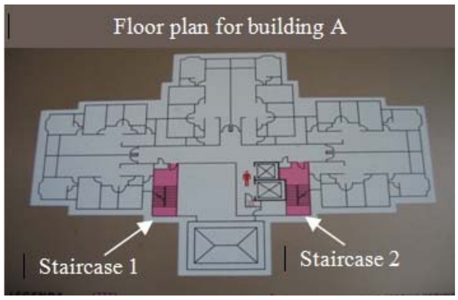
Five buildings were selected for observation as case studies in this research. The building selection was based on the criteria set in research scope (see chapter 1 - research scope). For the purpose of confidentiality, the buildings observed are referred to as Building A, B, C, D, and E.

4.2.1 Building A

The building observed is shown in the circle in Figure 4.1 (a. There are three blocks all together and only block 3 (Figure 4.1 (b)) was observed because it is the biggest and has the highest occupancy among them. It has 15 storeys, but only 14 storeys are occupied, and there are 6 residential units on each storey. Floor 15 is used as utility floors i.e. water tanks for domestic and for hose reels systems. It is provided with two lifts for use as main access by the occupants and two staircases to be used in case of emergency. Figure 4.1 (c) shows the floor plan and staircase location of building A. Figure 4.1 (a) shows the general location of building A, which is located in a densely populated urban area. The building is surrounded by other low rise residential buildings and is very near to the main road at the north and oxidation pond at the south. Access to the building is via the access road off the main road to the southeast. Because the building is in a dense urban area, limited land area did not allow for a proper safe assembly area to be designated to be used in the case of fire. The only possible areas that can be used by occupants are along the main road at the north of the building or at the access road off the main road.

(a)

(b)



(c)

Figure 4.1: (a) Location of Building A, (b) Site view, (c) Floor plan

4.2.2 Building B

There are two blocks of U-Shape design in this catchment area, Block 1 and 2. Block 1 has been chosen for the study case because both blocks have similar characteristics and design layout. Figure 4.4 (a) shows the blocks surrounded by other low-rise residential buildings. The building was chosen because of its shape and layout. This block comprises 21 storeys with 7 residential units on each floor. There are four staircases provided to be used in case of emergency and two lifts for occupants' daily use. The middle area in a 'U' block is used as common area for social and other events. Figure 4.4 (a) and (b) shows the location and façade of the block 1 respectively. Figure 4.5 shows the floor plan and the location of emergency escape stairs provided in this building. From the fire safety point of view, the middle area in a 'U' block is inappropriate to be used as a safe assembly area if fire breaks out at this building because it is too near to the building. Two staircases at the end of the building (Figure 4.5) are smaller than the other two. These are steel staircases which are purposely for use in emergency only, and occupants of the building seem never to use this staircase for daily use. The other two staircases made from RC (Reinforced Concrete) here become an alternative access way for occupants in case the lift is out of service. For occupants who live at the first or second floors, these staircases are common access ways to their flats.

(a) (b)

Figure 4.4: (a) Location of Building B, (b) Façade view of building B

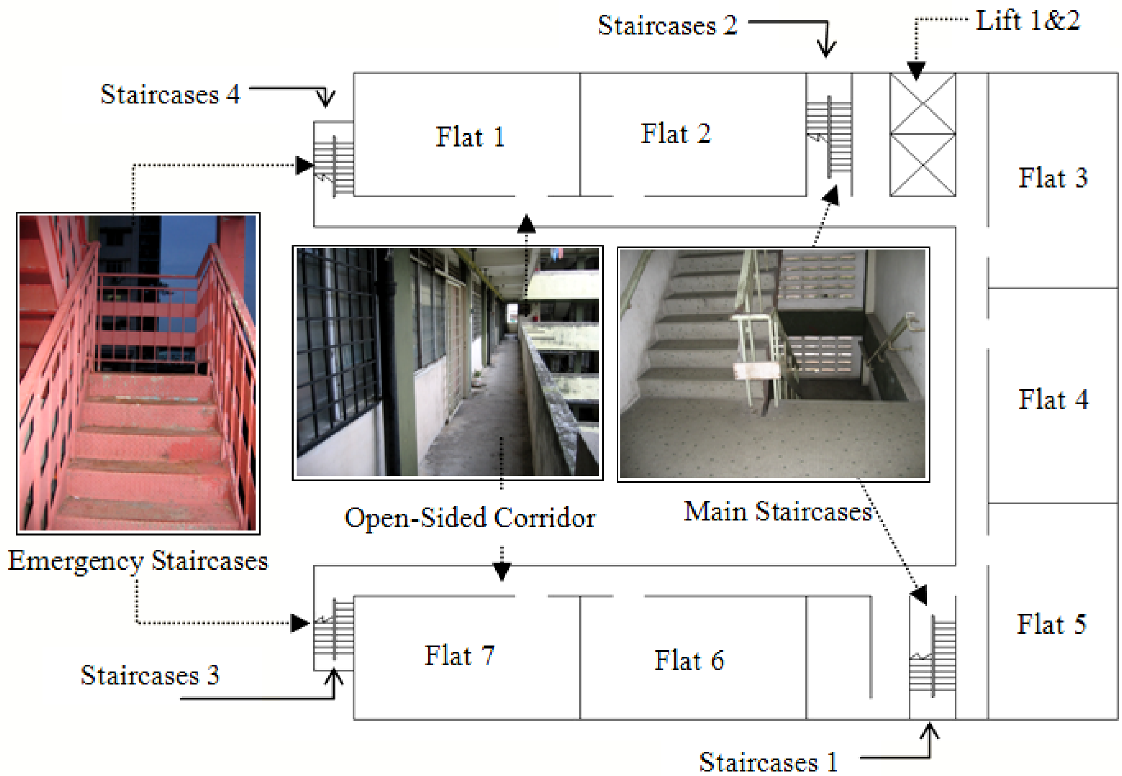


Figure 4.5: Floor Plan of Building B

The building was designed with open sided corridors therefore no fire doors are fitted at any staircases. Detailed analysis of occupants' behaviour in this regard will be discussed further in chapter six.

4.2.3 Building C

There are four blocks, block 1,2,3,4 clustered together with shared parking facilities and a common area. All buildings are provided with the same facilities and have the same building layout. Figure 4.6 shows a satellite picture of building C. Because the buildings are equal design and specification, Building 3 was chosen as a study case. However, for the purpose of evacuation analysis, the external layout of the buildings is taken into consideration too. There are two lifts located at the centre of the building and eight residential units at each floor.

The building is 15 storeys and can be accessed through an access road off the main road. Figure 4.7 is a floor plan showing the floor layout and location of emergency staircases and lifts. Other than the covered parking facility, a limited open space parking facility for the visitor's use is also provided and located at the west part of the catchment area of the building. The building has been chosen for study because of its design and floor orientation, i.e. central floor lobby surrounded by flats. There are two staircases provided for emergency use and located at opposite angles. Fire doors are fitted to each of the staircase and at every floor.

Figure 4.6: Satellite picture of building C

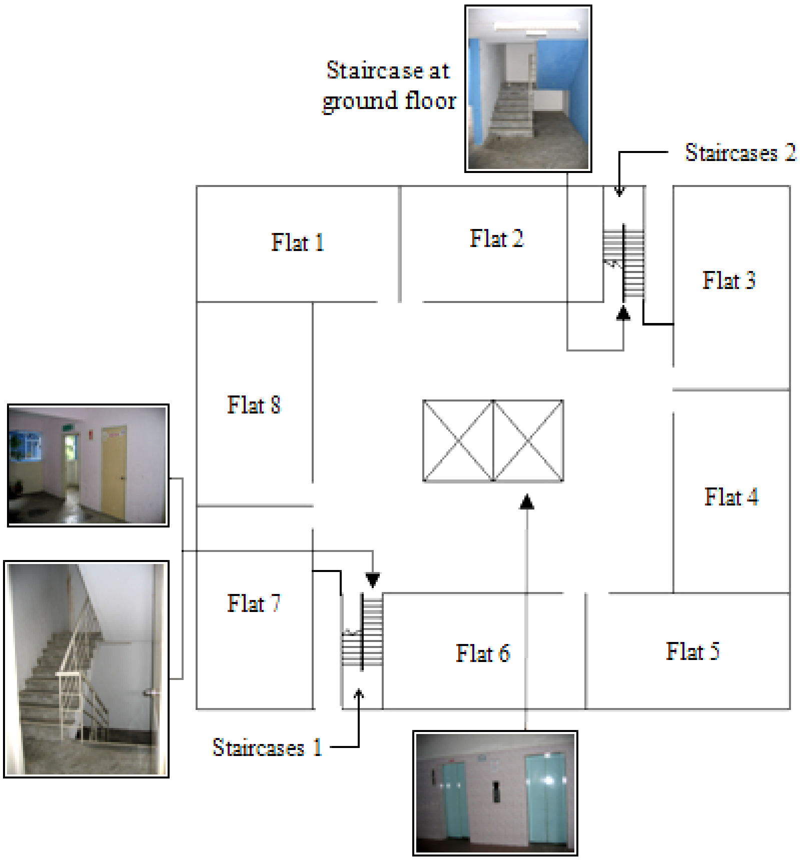
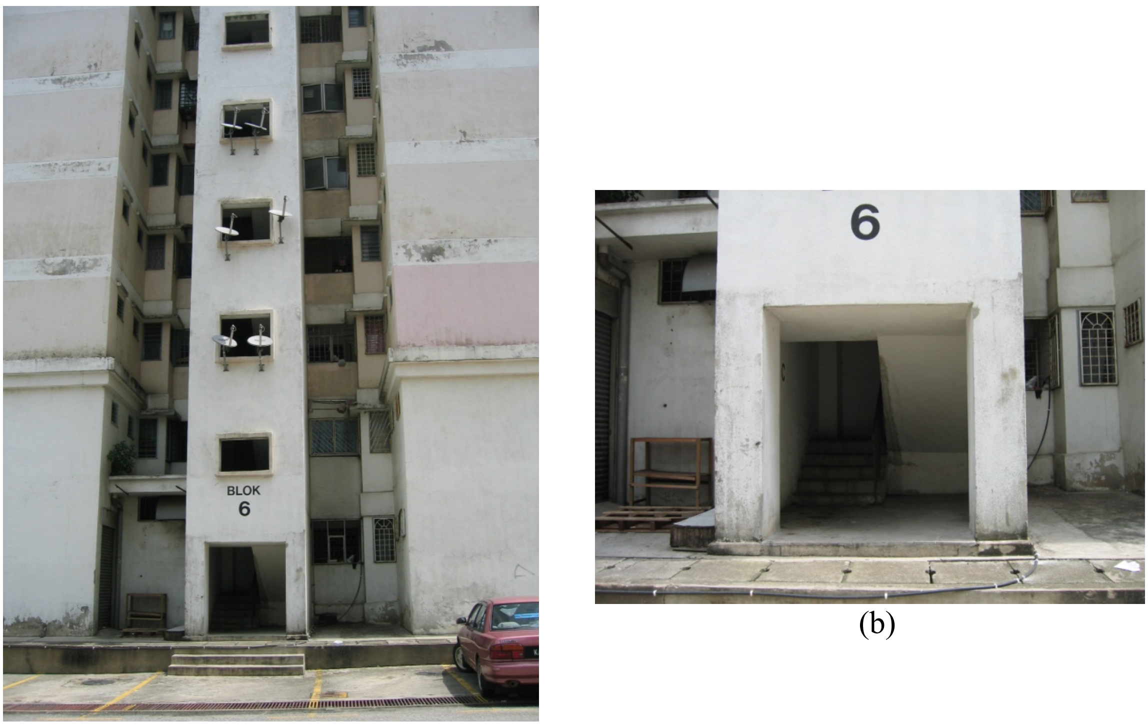


Figure 4.7: Floor plan for building C

4.2.5 Building D.



(a)

(b)

Figure 4.8: (a) Font view of building D, (b) Main entrance for building D

Building D is 15 storey building with eight residential units for each floor. The main entrance (Figure 4.8 (a)) is located at the middle of the building. To reach the lift lobby, occupants have to enter under the staircase which looks like a tunnel entrance (figure 4.8 (b)). In the author's experience no other building has a main entrance like this. Occupants have to climb up five steps of staircase before they can reach the lift lobby.

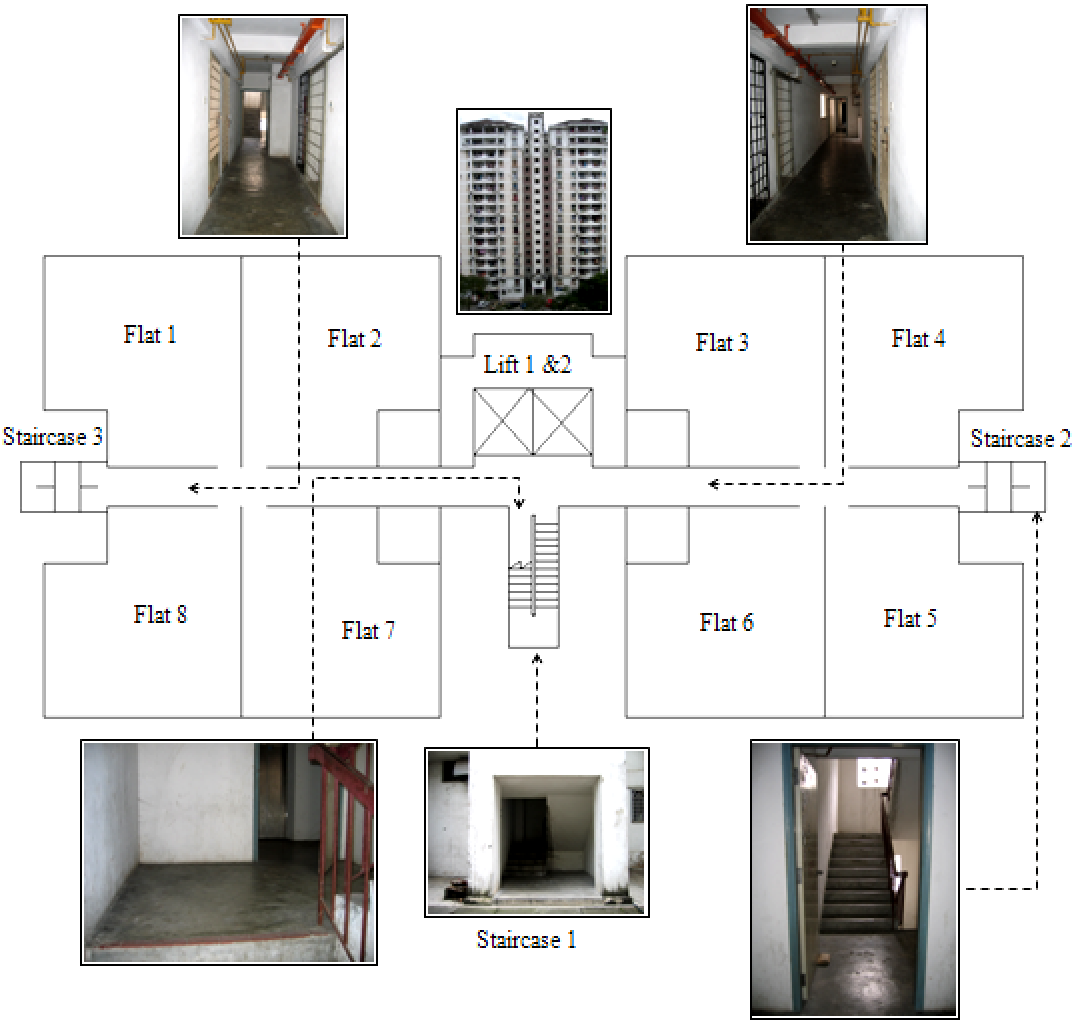


Figure 4.9: Floor plan of building D

However, it has an alternative entrance which is located at the both ends of the building. Occupants have to pass through on enclosed corridor to reach the lift lobby located at the centre of the building. There are two lifts provided and working in moderate condition. The escape route design in this building required occupants to move along the enclosed corridor to reach the escape stairs located at either end or at the middle of the building. Detailed analysis of the problems encountered in studying this building will be discussed further under the appropriate sub-topic in this chapter. Figure 4.9 shows the floor plan of building D. Escape stairs are separated from the lift lobby with a fire door which becomes a fire barrier to prevent smoke from entering the escape stair if fire breaks out in this building. There is no mechanical smoke control system installed in any escape stairs but there are natural smoke control systems by means of wide openings at every level of the staircases.

4.2.6 Building E.

Building E as in figure 4.10 is somewhat similar in terms of building layout to building C, but there is a difference in terms of the staircase provided for emergency evacuation. Fire doors fitted to the staircases create a “Staircase Cabinet”. Access to the staircase is at the side of the “Staircase Cabinet” while in building C access to the staircase is direct. This is why this building has been chosen, because of the difference in occupants’ directions approach to the staircase. The intention is to analyse the effect of the occupants’ moving direction on the evacuation time.

Figure 4.10: Satellite picture of building E

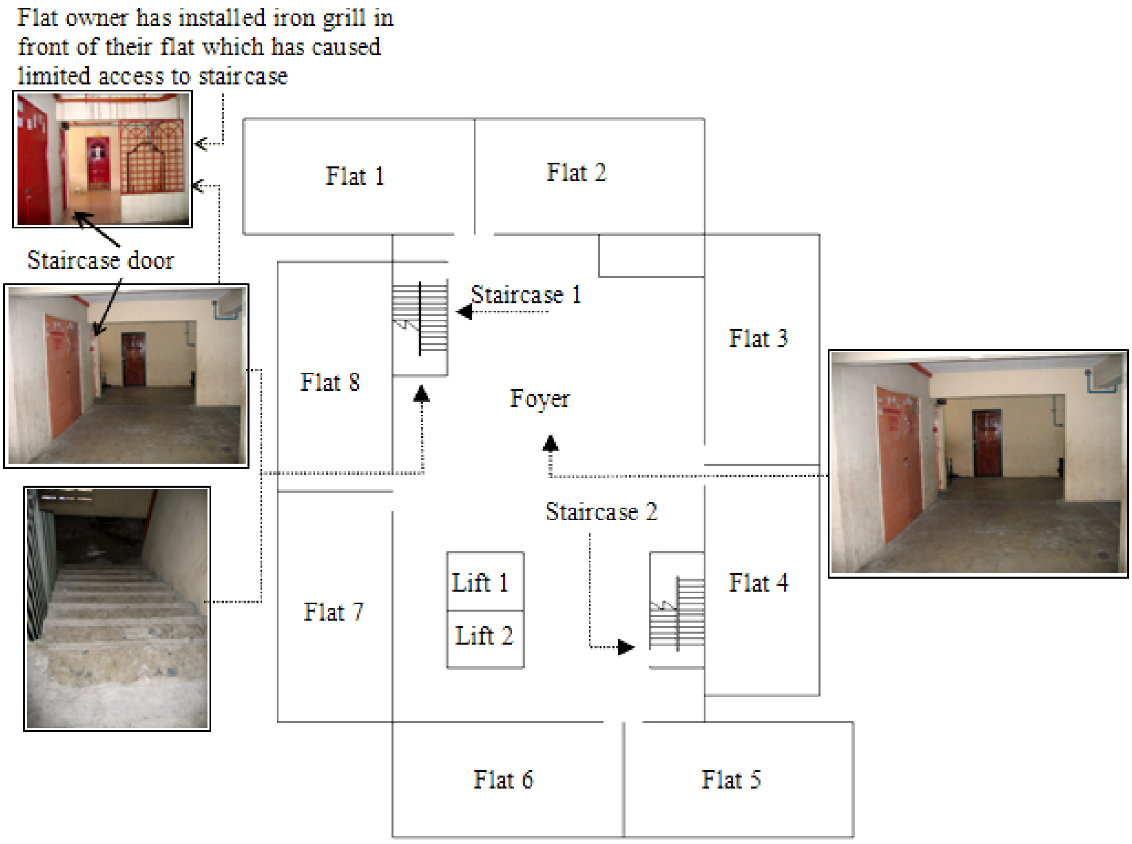


Figure 4.11: Floor plan for building E

There are four buildings clustered together but no inter-relation in terms of access into those buildings. Each of the buildings has its own entrance and lift service to go to the upper floors. There are two lifts, lift 1 and 2 as in figure 4.11 provided side-by-side, but not located at the centre of the building. The reason for this location is unknown. The buildings share a common place and parking facilities built at the middle of the buildings. Parking facilities are very limited and can not cater for the whole population. Therefore, most of the occupants park their vehicles along the roadside near to the building. Observation of the surroundings of the building shows that there does not seem to be any safe place for assembly in case of fire rather than along the road side located near to the building.

These five buildings were chosen to participate in a detailed human behaviour study. The occupants of buildings A, B, C, D, and E were served with a structured questionnaire to be answered. Details of the questionnaire study will be discussed in chapter 6.

Besides these five buildings observed, six more buildings located in Penang, Malaysia were observed.

4.3 Observation of High-Rise Residential Buildings in Penang

Penang is a tourist island located at the north of the Malaysian peninsular, where recently there has been much development in the construction of high-rise residential buildings to cater for the high demand from local and foreign purchasers. High land prices and property values in the centre of the island have caused the development to the nearby area to be extended as far as the Balik Pulau which is a Malay dominancy area. Many high-rise residential buildings have been built along the costal area facing the sea, which has become very popular among property investors. It can be expected that the value of properties in this area will be increased about 20 % – 30 % annually in the near future. Besides the newly constructed buildings, some of the existing high-rise residential buildings have undergone rapid renovation and upgrading of the internal and external appearance of the building. This process, when completed, will enhance the value and the prices of the respective properties slightly above the current market. The existing buildings which were built about 10 to 15 years ago are still in use and most of them are located in highly populated areas with mixed occupancies. Observation of these buildings has given useful information about the internal layout and escape route design for emergency evacuation. The following buildings marked as P1, P2, P3, and so on are used for confidentiality. Those buildings together with the buildings observed in Kuala

Lumpur have been used to develop the study models to be tested in computer simulation. The outcome of the test results can be found in chapter 8 of this thesis.

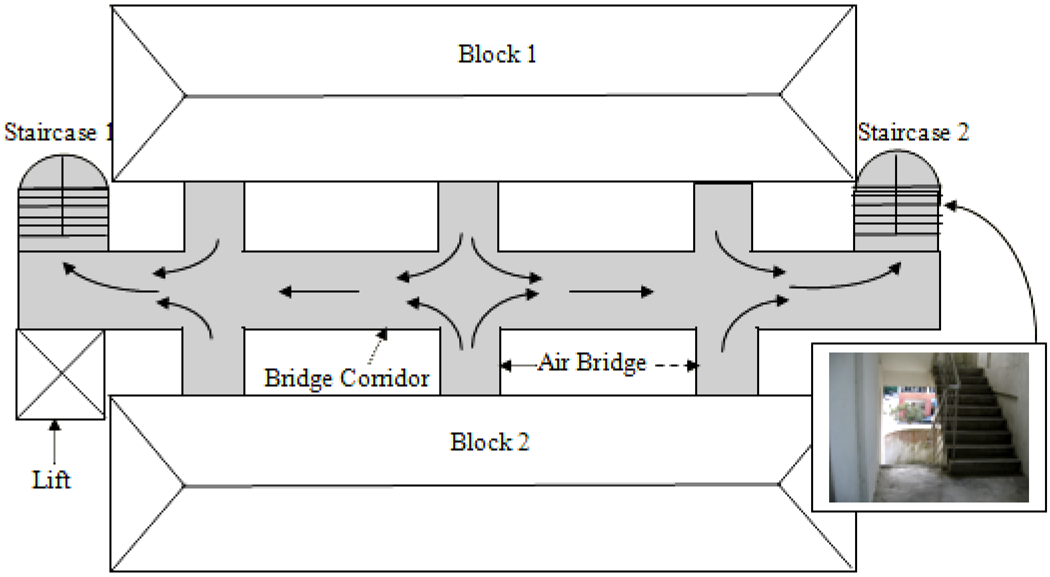


Figure 4.13: View of location of bridge corridor, air bridge, staircases and lift for building P1. There are two blocks connected with a Bridge Corridor and Air Bridge to access to occupants' flats.

Figure 4.13 shows building P1 with residential flats housed in two separate buildings connected to each other by a *Bridge Corridor* (see figure 4.14a). It is called a *Bridge Corridor* because it is used as a corridor but has been built in the form of a bridge parallel to the residential block and located between the two residential blocks. This bridge is attached to the residential block by connecting the bridge to the residential block using a component called an *Air Bridge* (see figure 4.14b). The building internal layout has been designed in such a way that there is only one bridge corridor built detached from the building. Occupants are only able to access their flats through the air bridge from the bridge corridor. Each air bridge serves two flats (figure 4.14c) and there are six flats on each side to total twelve flats all together on each floor i.e. six flats on each building. Escape stairs are located at both ends of the bridge corridor with only one lift provided opposite staircase 1 (see figure 4.13). This is a main access to all residents' flats above floor two. Staircase 1 and 2 will be only used by occupants in an emergency situation except those who are staying at floor 1 or 2 who sometimes use them as a main means of access to their flats.

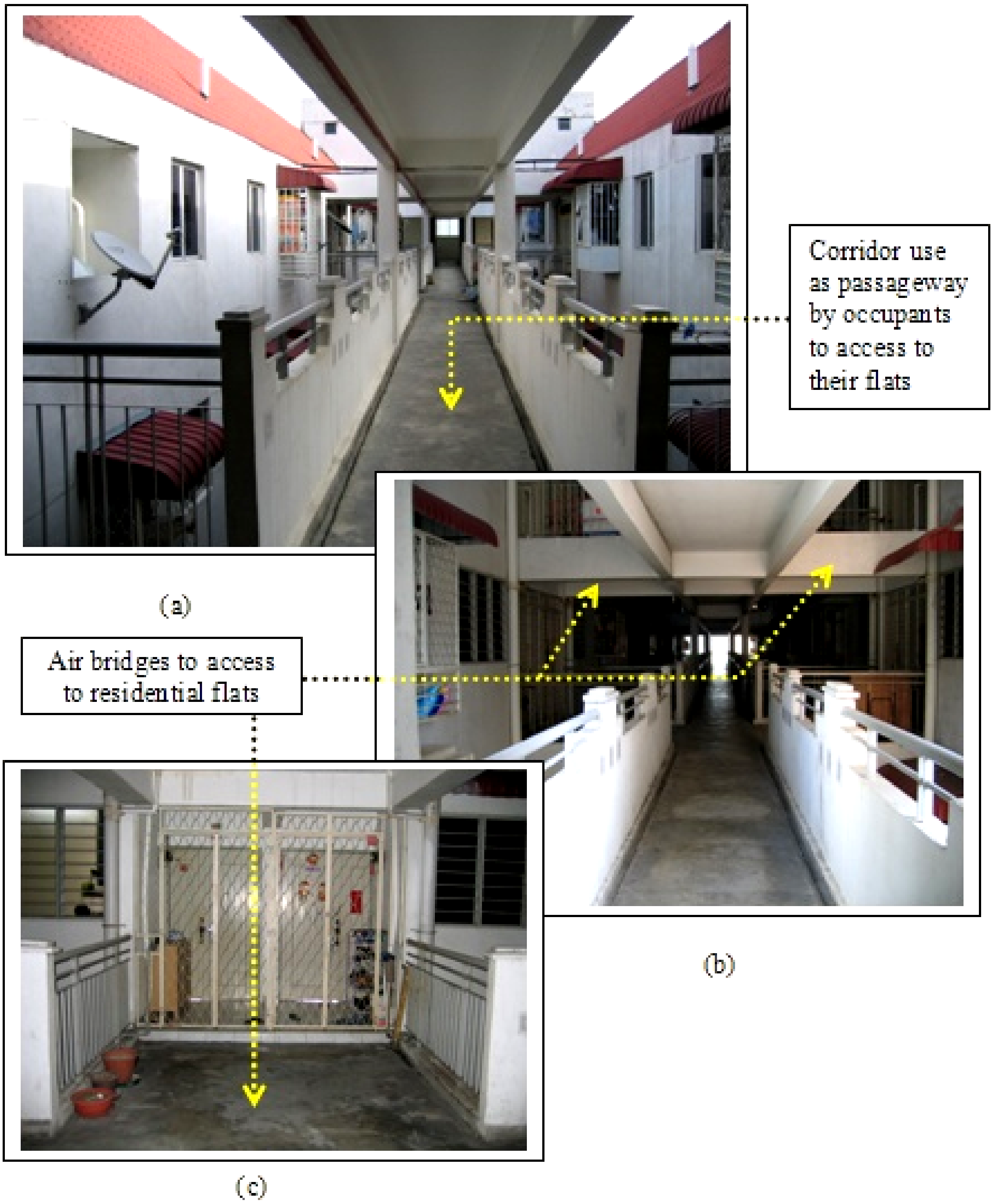


Figure 4.14: (a) Top floor of building P1 shows roof of two separate buildings with one corridor used as passageway to access to residential flats.
(b) Corridor at intermediate floor with air bridges for the above floor to residential flats.
(c) Air bridge to access the residential flats.

The escape route is designed in such a way that occupants have to travel somewhat further to arrive at the safe designated area. Furthermore, the only alternative that the occupants have is evacuating the building using the main door in emergency cases. They are not able to use the windows as an alternative means of escape because the corridor is designed like a bridge detached from the building, which restricts the use of windows for escape, except to those who stay at ground floor level.

The corridor width from c/c of balustrade of corridor is 60 inches (5 ft). The staircase width is 3 ft. 6 inches with 9 treads to each staircase. There are two staircases per flight connected to each floor having tread size of between 9 inches to 10 inches and rise between 7 to 8 inches without any fire door fitted to the staircase.

Figure 4.15: (a) View of building P2. Main entrance through passageway at ground floor besides the staircase shaft.

(b) Corridor designed with access to both staircases and lifts.

(c) Staircase designed parallel with corridor and having a wide opening for natural ventilation.

(d) Staircase designed with access from both corridors

(e) View the location of one of the lifts provided in this building. Another lift was located opposite the lift shown in this picture.

The intermediate floor for the staircases was semicircular which, allows the occupants to move smoothly downwards, but rescue personnel could be faced with difficulties in moving up using the same staircase whilst occupants are moving down the staircase. The half round platform on the intermediate floor is only able to allow occupants to move in the same direction, because on the 3 ft 6 inches radius of half round intermediate floor it is very difficult for two people to walk side-by-side.

Figure 4.15 shows the main entrance, internal layout, staircase and lift for building P2. A common problem encountered for the people trying to evacuate the building is obstructions in the middle of the escape route. Every flat in this building is fitted with an iron grill on the main door. Some occupants put their belongings e.g. flower pots and unwanted furniture, bicycles etc, in the corridor near to the escape stairs. This will impede the evacuation process and could slowdown the occupants.

This building has 4 storeys parking facilities shared with the building P3 which is built between them. There two corridors are attached to the residential blocks with a staircase and lift located between them (see figure 4.15d and e). There are two staircases and two lifts provided for the occupants for access to their flats. Internal circulation designed for this building as in figure 4.16. The staircase can be accessed from the both sides of corridors. It is a common design that the corridors are attached to the residential block. There are two blocks with four residential flats per floor of each block and in total there are eight residential flats for each floor of the building.

Figure 4.16: Parking facilities for building P2 and P3

The main access into the residential flats of this building is either via the access from the parking facilities or from the ground floor (see figure 4.16). Occupants who park their vehicle in the car park provided will normally use the access door at the level where they park their car to the lift lobby. From there they can use either the lift or staircase to go to their respective flat. Whether they use the lift or staircase depends on where their flat is located. If their flat is one level above or below the level where they parked the car, normally they will use the staircase, but if their flat is located more than two levels above or below the level where they parked the car, they normally will use lift.

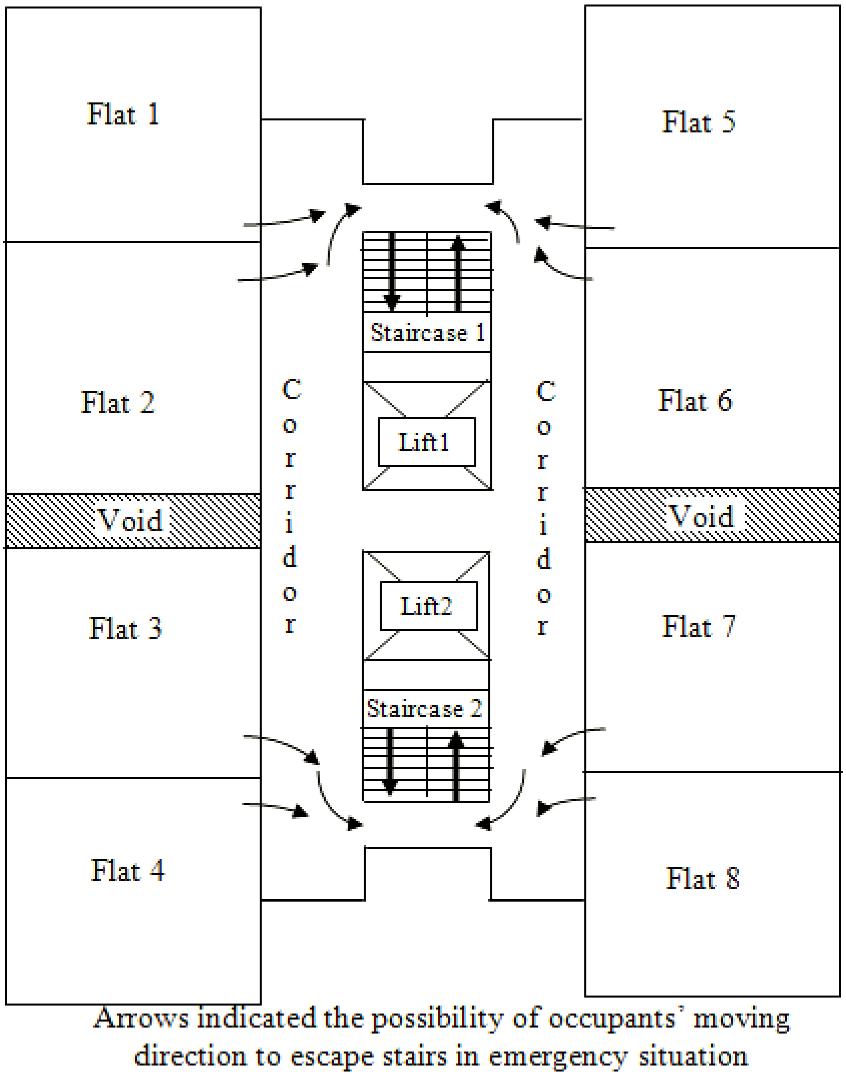


Figure 4.17: A floor plan of building P2 which have eight residential flats and occupants moving at opposite direction if they have to evacuate the building.

In emergency situations e.g. fire in the building, occupants can use the same route by which they entered the building. There is an alternative route to evacuate from this building. Referring to figure 4.17, if they want to use staircases, occupants will move to the staircase in the opposite direction. It means that occupants from both corridors will move toward each other to the staircase. If a number of occupants are moving at the same time it could cause traffic congestion. Detailed analysis of this possibility will be tested in computer simulation and the results are discussed in chapter 7.

Staircase specification and design for building P2 and P3 are similar with staircase width 3 ft 3 inches without fire door, with opening 2 ft 10 inches to access staircase. Staircase tread is between 10 to 11 inches and rise between 5 to 7 inches. There are two openings at left and right of the staircase in building P2, whilst in building P3, there is only one opening on the right of the staircase for the occupants to access the staircase (see figure 4.18).

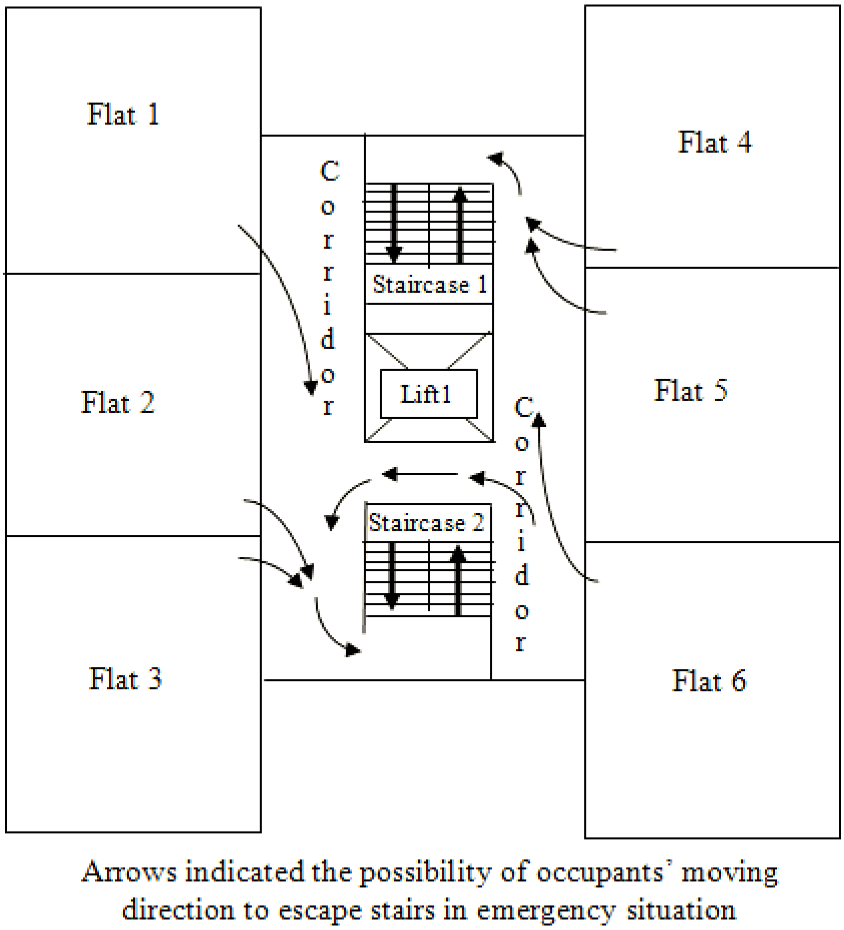


Figure 4.18: Floor plan for building P3 showing the direction of possibility of occupants moving direction in an emergency situation.

The reason the staircases in building P3 were designed in such a way is unknown, but it could be to limit the number of people using the staircase in an emergency situation, to reduce the possibility of congestion at the staircase. This scenario will be tested in simulation software to compare with the scenario in building P2. Test results will be discussed in the respective chapter. The advantage to those who stayed at flat 6 at every floor level is due to the ability of them to evacuate using both staircases provided because both staircases are located about the same distance from flat 6 (see figure 4.18).

The disadvantage is for those who at flat 1 at every floor because they are furthest distant from the nearest staircase compared with the other people in the same level. They have to walk longer to reach either staircase 1 or 2. The risk is slightly higher compared with other people if fire starts at flat 2 or in their own flat. For this category of design, it is consider as *dead end* design, where occupants staying in this flat have only one access to escape in emergency situation.

To compare with the building P2 which the building orientation and internal layout design is much better than building P3 because every flat at every floor level in building P2 is able to access to the both of the staircases provided. If fire starts at any of the flats in the same level, the occupants in the other flats have a better chance of evacuating the building safely because there is an alternative escape route provided and no *dead end* design at the floor level.

Figure 4.19d shows the connection of the air bridges and figure 4.20 and 4.22 shows the location of the air bridges in both buildings. Figure 4.19b shows the staircase where the intermediate floors are in half round form with the intention to smooth the flow of traffic going down the building. However it may create another difficulty that in case of emergency, rescuers would have a problem entering the building using the same staircases, particularly, if they brought together with them heavy and bulky rescue gear. It is very common that fire fighters are equipped with such gear e.g. oxygen cylinder, first aid, portable extinguisher, etc. The main access for both buildings is at both ends of the building where the staircases and lifts are located. Observing those buildings, it was found that the occupants commonly use the access near to the car park because it is nearest to the place where they parked their car. Parking facilities are located around the building with the majority of parking lots being near to staircase 2. Every flat was provided with one parking lot, and occupants have to pay extra on a monthly basis if they require more than one parking lot. Visitors parking facilities are very limited and located near to the rubbish collection centre. Those buildings are fenced with security guards on duty at the main gate. All visitors have to get an entrance pass before they can be permitted to enter any of the buildings in this compound.

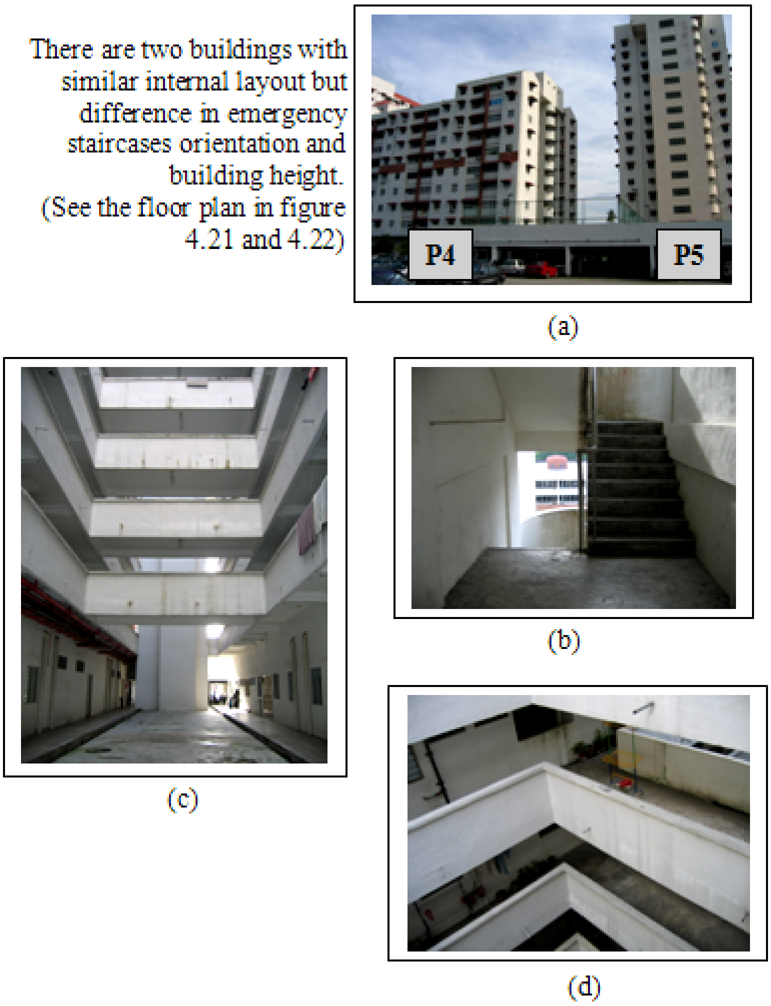


Figure 4.19: (a) View of building P4 and P5 with staircase orientation parallel with corridor (P4) and cross with corridor (P5).

(b) View of the staircase design for both buildings

(c) View of the air bridges connected both side of corridors

(d) View of the connection of air bridges to the corridor.

Building P4 and P5 are similar in terms of internal circulation design but different in the orientation of staircases and lift location. Figure 4.19a shows building P4 and P5, building P5 being taller than building P4. Staircase and lift orientation is twisted by 90^0. Staircase and lift in building P4 are parallel with the corridor, whilst in building P5, they are at right angles (see figure 4.20 and 4.22).

Internal layout: Floor plans for both building P4 and P5 are as in figure 4.20 and 4.22 respectively. Figure 4.19c shows the internal design of those buildings with air bridges designed to connect both corridors of two residential blocks in buildings P4 and P5. There are two air bridges designed which occupants in the other block of the building can use to access to the corridor opposite their block.

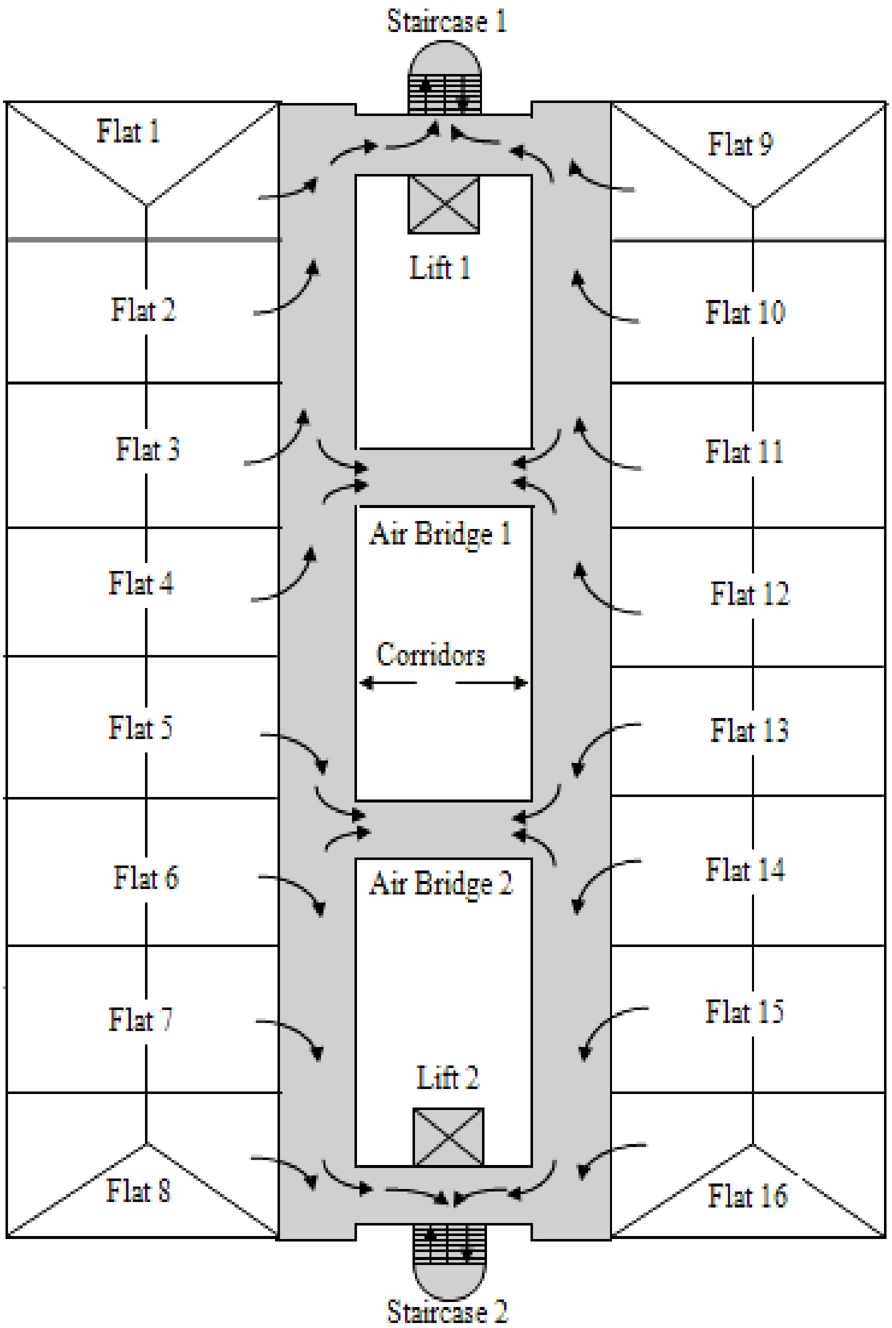


Figure 4.20: Floor plan for building P4 with staircases and lift located at both end of corridors and showing the possibility of occupants moving direction in an emergency situation. Occupants can use the Air Bridge to cross to the other side of corridor to evacuate the building.

(a) (b)

Figure 4.21: (a) Facade view of building P4 and (b) Façade view of building P5 shows the staircase design and orientation.

There are quite a number of public parking facilities at a nearby commercial centre under the management of the municipal council. The surrounding area is quite congested with shop units with housing above, low-rise houses i.e. double storey and single storey terrace houses, built scattered around these buildings. Those houses and commercial buildings are privately owned properties as well as high-rise residential buildings (see figure 4.21 (a), (b)).

Assembly Area: Parking spaces are assumed to be used as safe assembly area in an emergency case for the occupants to congregate. However, there is no signage to direct them to this place in emergency. Even though there is exit signage in the buildings to lead the occupants to the emergency staircases, once the occupants are out of the buildings, they may be scattered and separated everywhere because there is no sign to lead them to the place of assembly. Some of the occupants, when asked about where to congregate if they have to evacuate the building, state that they have no idea. It could be at the parking space or outside of the main gate. Some occupants assumed they had to assemble somewhere outside the building, without knowing of any particular location.

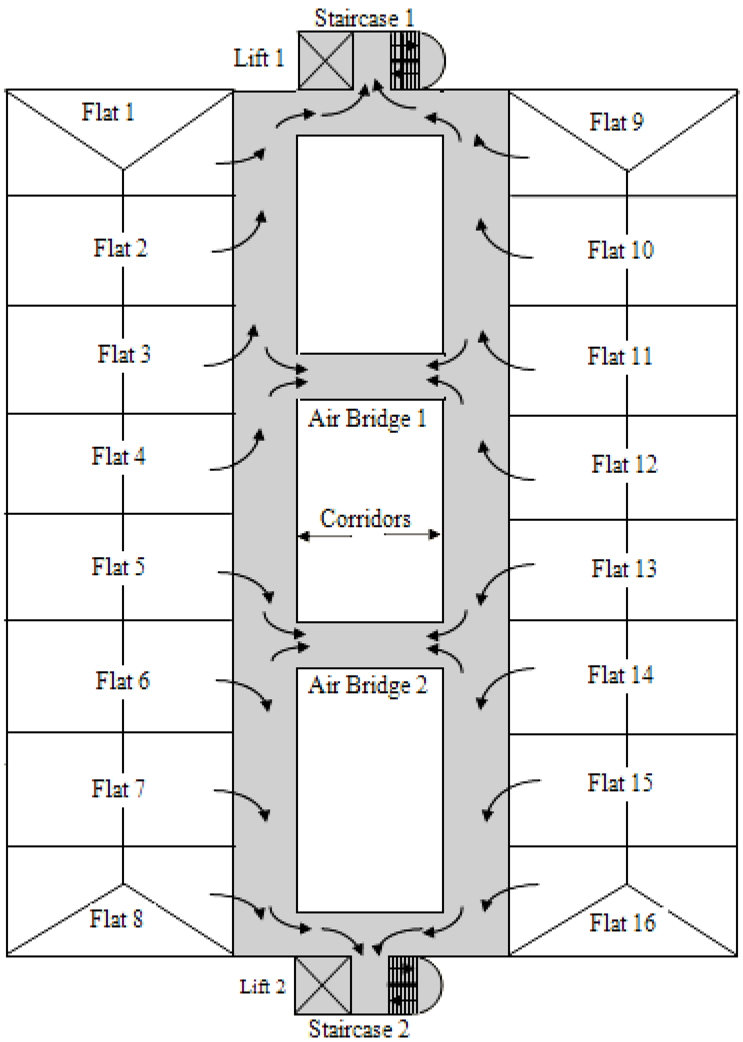


Figure 4.22: Floor plan for building P5 which the staircases and lifts are located at the both end of corridors

Staircase specification: Every staircase in both of the buildings is designed with nine steps and step rise range between 7 inches to 8 inches. Steps rise norm are at 7 inches, while steps tread designed in range between 9 inches to 10 inches with the tread norm is 9 ½ inches. Fair quality cement rendered staircases designed with one side handrail fitted to the left and solid wall to the right, the width of the staircase is between 3 ft 2 inches to 3 ft 4 inches and without fire door but it has an opening 2 ft 3 inches for the occupants to access to the staircase.

Meanwhile, 4 ft 6 ½ inches corridors measuring from c/c of corridor balustrades of this building are attached to each of the residential blocks respectively. These corridors link each other by two air bridges having the same width as the corridors and having a balustrade the same height as the corridors as well. The idea of linking both residential blocks with air bridges is a brilliant idea which is enables the occupants to cross to the other block either when they are in emergency situation or for social visits.

(a)

(b)

Only one corridor designed on each floor to cater the occupants on the both side i.e. both residential blocks built side-by-side. Both blocks are connected with a number of Air Bridges to enable the occupants to access to their flats. Floor plan is as in the figure 4.24.

(c)

Figure 4.23: Views of the corridor designed of building P6

Building P6 in figure 4.23 shows the pictures of corridor and staircase designed to be used in case of emergency. As with previous buildings, this building consists of two residential blocks to form a high-rise residential building. This 12 storey building has a unique corridor design in which only one corridor is provided at one block and the other block is linked by means of individual access bridges called air bridges (see figure 4.23 (a) and (b)). Each air bridge is designed to serve two flats connected to the shared space designed to look like a veranda in front of the flats' main door.

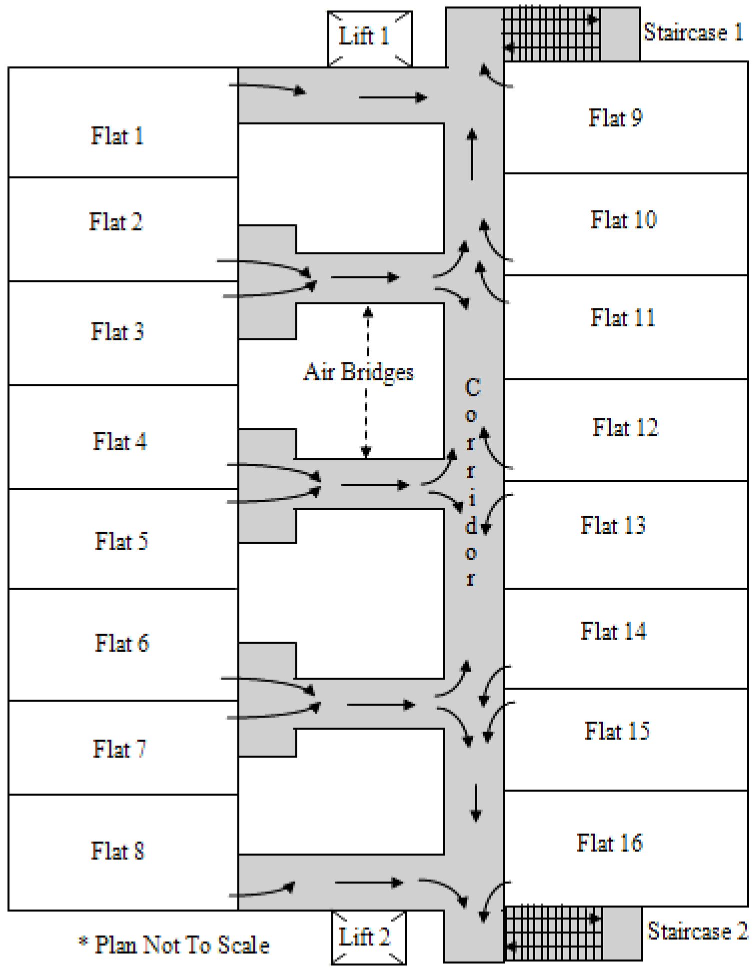


Figure 4.24: Floor plan for building P6 showing the location of staircases, corridor and air bridges. Arrows indicate the possibility of occupants to evacuate the building in emergency situation.

There are two lifts and two staircases provided for the occupants to use to get access to the flats. Both staircases are located at the each end of one block (see figure 4.24) as well as the lifts which are located at the each end of the building. Figure 4.24 shows the typical floor plan of this building having 16 flats on each floor with 8 flats on each side of the residential block. The occupants' expected moving direction as marked on the floor plan shows that there is an advantage to those who stay in the block with the corridor attached to their flats. This is because in an emergency situation i.e. if a fire starts in their own flat, they have an alternative means of escape i.e. they can use the window to get out from their flat. The disadvantage is for those who stay in the opposite block because there is no way that they can use the window to evacuate from their flat because there is no platform for them to step on. The only accessible way for them to evacuate is through the main door which is attached to the veranda and the air bridge connected to the opposite corridor. From a fire safety point of view, this design could create a higher risks of being trapped for those living in flats 1 to 8 in the same block as marked on figure 4.24.

Staircase 1 and 2 as in figure 4.23 (c) are designed with square intermediate floors and square openings for natural ventilation. There are 8 steps with cement rendered finishing with metal vertical straight square bars handrail fitted on the left side of the staircase and solid wall at the right. Staircase measured from the wall to the handrail was 3ft 3inches with step tread in between 8 inches and 10 inches and step rise between 5 ¾ inches and 7 ¾ inches. The outcome of these observations will be discussed in section 4.5 below and in chapter 5.

4.4 Analysis of the Escape Routes Design and Specification

The staircase analysis has the purpose of obtaining several parameters for the simulation processes. The parameters sought are the step tread and riser, which will be obtained by calculating the common staircase parameter length and height. Staircase parameter length and height in high-rise residential buildings varies and mostly depends on the staircase slope angle. The main reference for this is Uniform Building By-Laws 1984, (Malaysia), Building Regulation (Approved Document B), UK, and research data. Research data was gathered from observing a number of selected high-rise residential buildings in Kuala Lumpur and Penang. Observing and measuring escape routes in existing high-rise residential buildings have driven the development of a number of study models for further analysis. In this regards, photographic data has been analysed to look for the significant evidence and a statistical analysis technique has been adopted. The findings of this exercise can be found in tables 4.1, 4.2, 4.3 and 4.4.

4.5 Analysis of Staircases in Buildings Observed

Observation findings discussed here will be generalised, in that specific buildings are not referred to. From the research point of view, generalising research findings using this approach will not decrease the validity and credibility of the research finding because the data analysed was real data from the field work study. Detailed staircase analyses are made based on the six main buildings observed but an appropriate consideration was given to the other buildings when discussing the study models developed. From the twelve buildings observed, it can be concluded that there are at least eight scenarios of internal building circulation designs used as escape routes in high-rise residential buildings in Malaysia. Those scenarios will be discussed in section 4.7 of this chapter. In this section, analysis of staircases in detail will be discussed.

4.5.1 Staircase steps analysis

Table 4.1 shows staircase steps analysed in the observed buildings. Five buildings in Kuala Lumpur have been identified to participate in this study. The detailed design and construction of staircases will be prudently analysed to help in the development of the study models. The purpose of this study is (1) to calculate the *equivalence (equivalent?) length* of staircase to be used in the simulation process, (2) to compare the actual construction detail to the specification given in Uniform Building By-Laws.

Staircase Equivalence Length (SEL) is known as travel distance on escape stairs calculated from storey exit to final exit. Storey exit means a fire rated door to a protected staircase or a corridor protected with a fire resisting structure in accordance with the Ninth schedule of By-laws, and in the case of ground floor accommodation, storey exit means a door leading direct to a place of safety outside the building. Final exit means a point of discharge for the escape route from a building providing direct access to the street, passage-way or open steps sited to enable the evacuation of persons from the vicinity of a building so that they are safe from fire or smoke. Escape stairs means any staircase which persons in any storey of a building may use to evacuate the building to reach a place of safety. This forms part of the escape route which is also known as Exit Route. Exit route means a route by which persons in any storey of a building may reach a place of safety outside the building and may include a room, doorway corridor, stairway or other means of passage not being a revolving door, lift or escalator. Calculating SEL does not take into account the measurement of travel distance within the building. Travel Distance means the distance required to be traversed from any point in a storey of a building to either (1) the fire-resisting door in the staircase enclosure; or (2) if there is no such door, the first stair tread of the staircase. It means the distance from any point in the rooms or storey or flat to the exit door or exit discharge. Exit Door or Exit Discharge means a door from a storey, flat, or room which gives access from such storey, flat or room on to an exit route. By providing alternative escape stairs, we can avoid the building from having a design known as a dead-end design. Dead-End means an area from which escape is possible in one direction only and in an open plan includes any point from which the direct routes to alternative exits subtend an angle of less than 45º.

From all buildings studied, there were 81 floor levels, 13 escape stairs, 438 staircases, and 3,774 staircase steps. Overall, 38.84% i.e. 1,466 staircase steps have been prudently analysed by measuring step treads, risers, steps width, and taking photographs of those steps measured for further analysis. On average 3 or 4 staircase steps were analysed for each of the escape stairs in those buildings studied.

Building	A	B	C	D	E	Total
No. of Floor	15	21	15	15	15	81
No. of escape stair	2	4	2	2	3	13
No. of Staircase	60	168	60	60	90	438
No. of Steps	600	1,344	540	480	810	3,774
Steps Analysed	168	750	165	165	218	1,466
Percentage (%)	28.00	55.80	30.56	34.37	26.91	**38.84**

Table 4.1: Staircase steps analysis in observed building

When examining the number of staircase steps on escape stairs in buildings studied, a variation in the number of steps were found. They fall in the range of 5 steps to 12 steps and both numbers are included per escape stairs. However the vast majority of escape stairs were designed with 9 steps per staircase. When analysing the step average per staircase by dividing the number of overall steps with the number of staircases from those six buildings studied, i.e. 3,774/438 = 8.6, it can be concluded that the average steps per escape stair is 9. Therefore, 9 steps will be used to calculate the staircase equivalence length. Furthermore, it is still in a number permitted by the By-law which does not exceed 16 steps per flight of staircase.

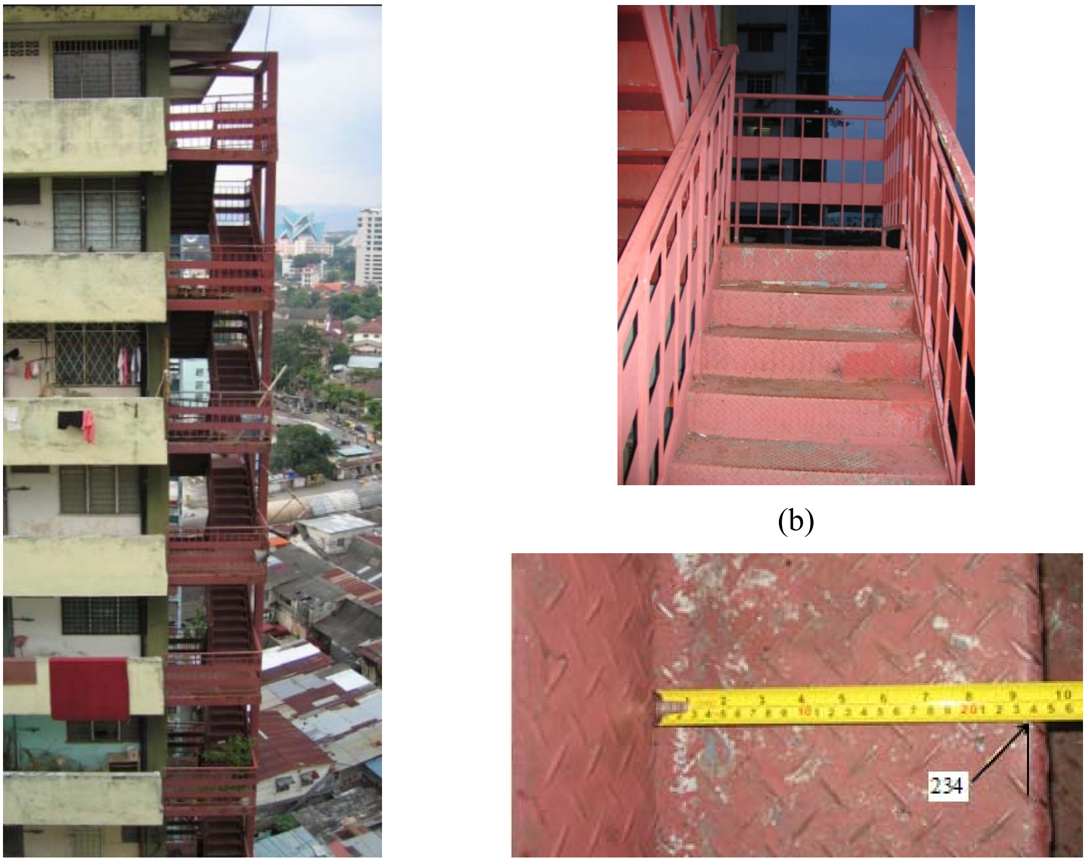
4.5.2 Staircase tread dimension analysis

Tread analysis is essential to determine the actual tread dimension compared with the specification given in UBBL. In UBBL all staircase treads shall be not less than 255 mm. From early observations, it was found that the staircase treads widths are variety in dimension and ranging from the minimum 228 mm (9 inches) to the maximum of 298 mm (11 ¾ inches). For analysis purposes, tread dimensions have been grouped as in table 4.2. Table 4.2 is the outcome of the staircase tread analysis for the five selected buildings mentioned earlier. Minimum group is set at 235 mm because from observation, the vast majority of staircase treads designed are above 255 mm. There were 375 cases (25.58%) where staircase treads fell below 234 and no such cases where any treads fell between 235 mm and 244 mm. The cases falling below 375 were in building B with two metal escape stairs designed for emergency purposes (see figure 4.27). Treads are then grouped in a range of 10 mm until the maximum 300 mm. There are no such cases where treads are designed over 300 mm. The biggest dimension of treads found in the five buildings studied is 298 mm.

Treads(mm)	< 235	235-244	245-254	255-264	265-274	275-284	285-294	295-300
Bldg: A	0	0	0	17	108	38	5	0
B	375	0	0	0	216	159	0	0
C	0	0	12	0	6	124	23	0
D	0	0	0	0	12	176	30	0
E	0	0	0	0	0	21	46	98
Total	375	0	12	17	342	518	104	98
Percentage	25.58%	0%	0.82%	1.16%	23.33%	35.33%	7.09%	6.68%

Table 4.2: No. of treads and percentage analysis

Overall, staircase treads designed in high-rise residential buildings are complied with the Uniform Building Regulation By-Laws 84 i.e. 73.6% staircase treads were designed wider than 255 mm as required by the By-law. Out of those that complied with the By-law, 1.16% complied at the minimum requirement of 255 mm. However, 26.4% do not comply with the By-law. Out of 26.4%, 25.58% fall below 235 mm as mentioned earlier. Analysis shows that the majority of cases i.e. 35.33% were in the range of 275 mm to 284 mm with the treads mode being 280 mm (11 inches). There is significant evidence to say that in term of staircase tread design, most of the high-rise residential buildings complied with the By-law and the most popular dimension was 280 mm or 11 inches. For that reason, dimension 280 mm will be used as design criteria to calculate the SEL.



(b)

(a) (c)

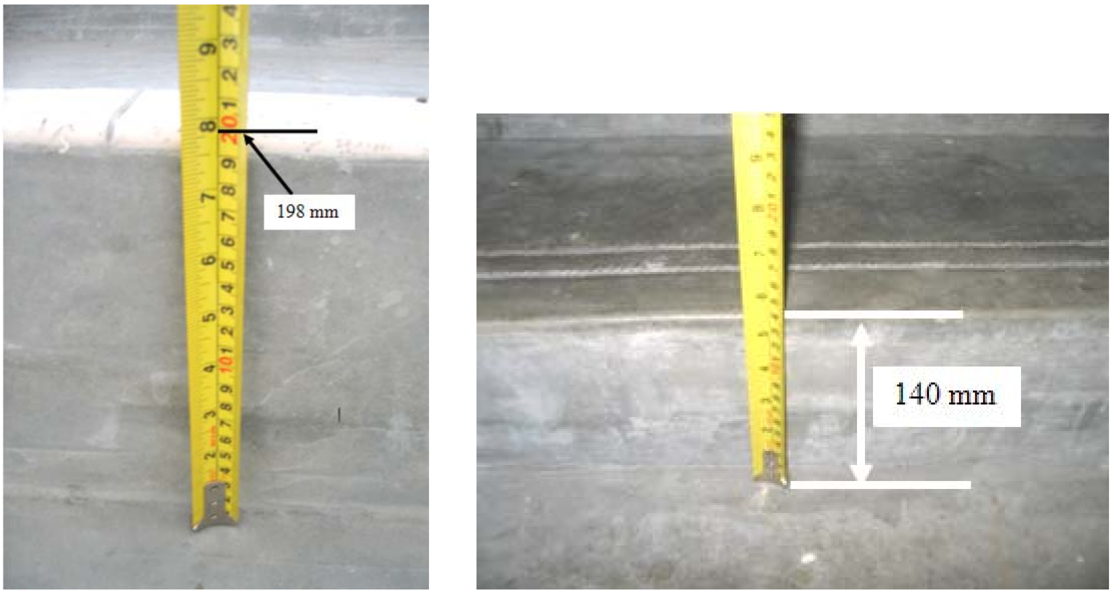
Figure 4.27: (a) Emergency metal staircase, (b) Close view of staircase, (c) Tread measurement 234 mm

4.5.3 Step risers Analysis

Another aspect that needs to be analysed is the step riser. The purpose of this analysis is to inspect whether the step riser in staircase design in high-rise residential buildings complies or not with the By-law. If they comply, at what dimension are the majority of them designed. The By-law requires all step risers to be not more than 180 mm. However, the By-law does not state a minimum size. From the examination of five high-rise residential buildings, there is significant evidence that step risers are being designed between 131 mm to 180 mm (5 1/8 inches to 7 1/8 inches). There were only two cases i.e. 0.001% step risers designed over 180 mm and 43 cases i.e. 2.93% step rises designed between 131 to 140 mm out of 1466 staircase steps analysed. Figure 4.28 shows examples of those step risers in both categories as mentioned. It can be said to be an isolated case because the number is small.

Riser (mm)	<130	131 - 140	141-150	151-160	161-170	171-180	181-190	>191
Bldg A	0	14	64	85	5	0	0	0
B	0	29	274	321	126	0	0	0
C	0	0	26	82	55	0	0	2
D	0	0	0	62	137	19	0	0
E	0	0	0	25	93	47	0	0
Total	0	43	364	575	416	66	0	2
%	0.00	2.93	24.83	39.22	28.38	4.5	0.00	0.001

Table 4.3: Step risers' analysis



(a) (b)

Figure 4.28: (a) Step riser designed at 198 mm, (b) Step riser design at 140 mm.

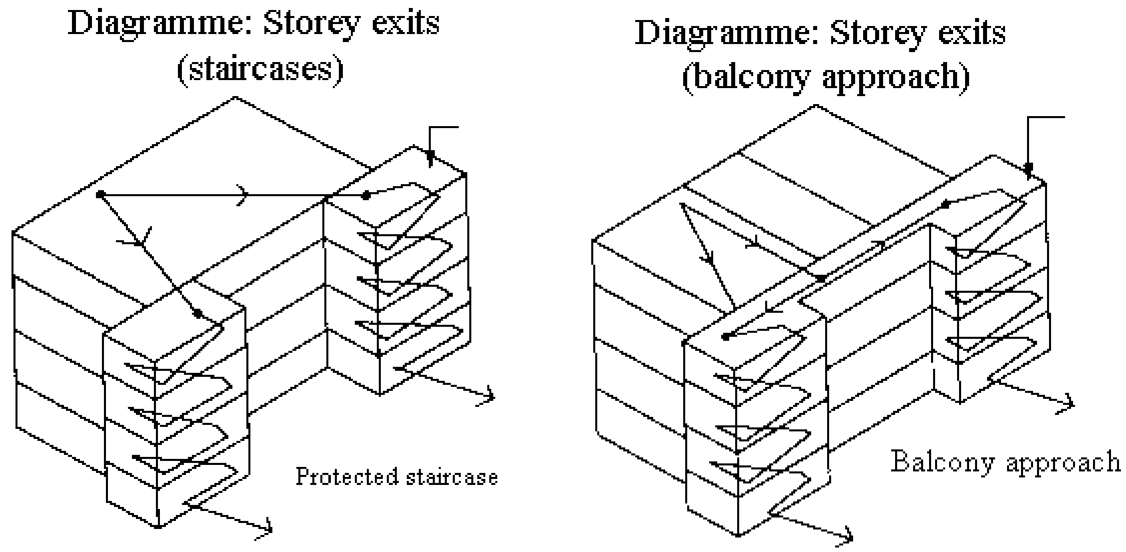
Table 4.3 shows the outcome of step riser analysis of the six buildings' studied. The vast majority of the step risers, i.e. 39.22%, designed were between 151 mm and 160 mm (6 inches to 6 5/16 inches). 28.38% were designed between 161 mm and 170 mm (6 3/8 inches to 6 11/16 inches).

From the study, there is strong evidence to say that all high-rise residential buildings, in term of step riser design, comply with the By-law. This is because 99.99% complied with the By-law. Among the most popular dimensions used in step risers design is between

151 mm to 160 mm with the riser mode being 153 mm (6 inches). For this reason, dimension 153mm is chosen to be used as design criteria to calculate SEL.

4.5.4 Travel distance on escape stairs

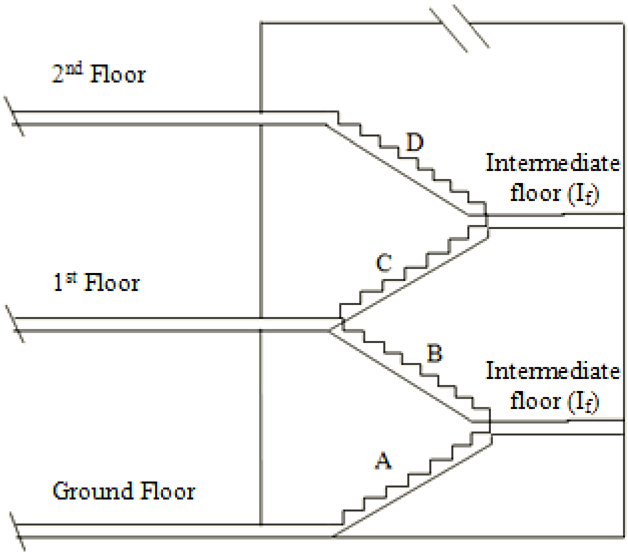
Travel distance on escape stairs is measured from the storey exit until the final exit. There are two possibilities of storey exit in high-rise buildings, the storey exit staircase approach or storey exit balcony approach.



(a) (b)

Figure 4.29: (a) Diagramme for storey exit (staircase) and (b) balcony approach

Figure 4.29 (a) shows the diagram of storey exit staircase approach, that is, escape stairs attached immediately to the resident's flat without any corridor. Occupants can access their flat immediately from the staircase landing floor. Figure 4.29 (b) shows the diagram of the storey exit balcony approach. It means that occupants have to go through the corridor before they can reach the escape stairs. Storey exits in this case are the fire door of the escape stairs, or if there is no fire door, the first tread of the staircase if the corridor is not an enclosed fire rating corridor. For both cases, travel distance on escape stairs is measured from storey exit to the final exit.



(a)

(b)

Figure 4.30: (a) Cross section view of the most common of staircase designed,

(b) Picture one of staircase in the building studied.

Figure 4.30 (a) shows a common cross section of escape stair in high-rise residential buildings and (b) shows a picture of a staircase with the occupants possible moving direction down the staircase. This is a part of the travel distance that occupants might have to travel in case of an emergency. There are two segments in staircase evacuation, (1) moving down on the staircases, (2) moving on landing floors or intermediate floors. Landing floors and intermediate floor dimensions are designed according to the dimension of the staircase. The depths of landings shall be not less than the width of the staircase. This specification is applied to the intermediate floors and landing floors between the staircases as well. Therefore, the width of landing floors and the width of intermediate floors will be the double of the width of the staircase.

Staircase Equivalence Length (SEL) or Staircase Total Length (*St*) can be calculated using the following formula: i.e.

$$St = \sum_{1-n}^{i} Si + \sum_{1-n}^{i} Pi \qquad (4.1)$$

Where,

$$Si = (Nsi.Lsi) \qquad (4.2)$$

$$Pi = (Npi.2Wsi) \qquad (4.3)$$

By put in equation (4.2) and (4.3) into equation (4.1), equation (4.1) becomes;

$$St = \sum_{1-n}^{i}(Nsi.Lsi) + \sum_{1-n}^{i}(Npi.2Wsi) \tag{4.4}$$

Where;

Ns is the number of staircases.

Ls is the length of one of the staircases.

Ws is the width of the staircase

Np is the number of platforms.

Referring to figure 4.30 (a), analysis of two storeys staircases can be done. Where A i.e. Staircase A (S_a), B i.e. Staircase B (S_b), C i.e. Staircase C (S_c), and D i.e. Staircase D (S_d) which have the same length, therefore (S_a) = (S_b), = (S_c), = (S_d) = (L_s). Staircase Equivalence Length can be calculated using equation (4.4).

$$St = \sum_{1-n}^{i}(Nsi.Lsi) + \sum_{1-n}^{i}(Npi.2Wsi)$$

$$= Ns.Ls + 2Ws.Np$$

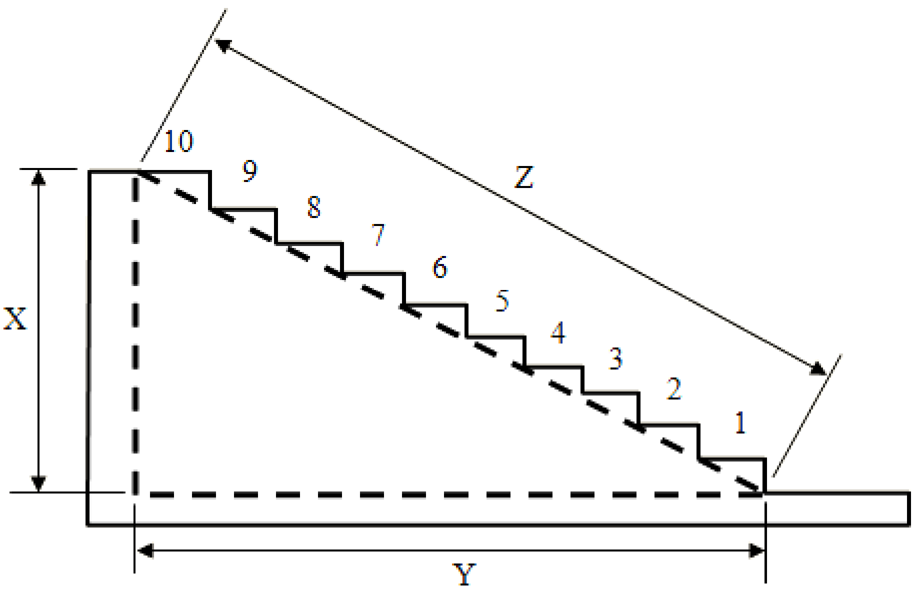


Figure 4.31: Staircase diagramme.

Based on the above analysis, SEL for staircase in figure 4.30 can be calculated. Design data are as follow; (1) Riser dimension is 153 mm, (2) Tread dimension is 280 mm, and

(3) Step number is 9 steps per staircase. The diagram below represents one staircase. Parameter Z is the travel distance on the escape stair with length of staircase (*Ls*).

Referring to figure 4.31, by using trigonometry formula, parameter Z i.e. *Ls* can be calculated if parameters X and Y are known.

X = No. of steps x Riser dimension

9 x Riser dimension

9 x 153

1377 mm

Y = No. of steps x Tread dimension.

9 x Tread dimension

9 x 280

2,520 mm

$$\text{Tan } \theta = \frac{X}{Y}$$

$$= \frac{1377}{2520}$$

Tan θ = 0.5464

$\theta = 28.65^0$

The parameter Z which is the staircase effective length can be calculated by using the sine formula i.e. $\text{Sin } \theta = \frac{X}{Z}$

$$Z = \frac{X}{\sin\theta}$$

$$= \frac{1377}{0.4795}$$

= 2,872 mm

Z = Ls = 2,872mm

Referring to figure 4.30 (a),

Ns = 4 and Np = 5

Therefore Total Staircase Length

(S_t) = Ns.Ls + Np 2Ws.

= 4(Ls) + Np 2Ws.

= 4(2,872) + 5($2W_s$)

=11,488 + $10W_s$

Staircase Width (Ws) mm	914	1067	1220	1372	1524
Staircase Length (St) mm	*20,628*	*22,158*	*23,688*	*25,208*	*26,728*

Table 4.4: Calculated equivalence length of the staircase to the staircase width.

If only one no. of staircase and one no. of intermediate floor, staircase length can be calculated as follows:

(S_t) = Ns.Ls + Np 2Ws.

= 1(Ls) + 1(2Ws)

= 2872 + $2W_s$

= 2872 + $2W_s$

Staircase Width (Ws) mm	914	1067	1220	1372	1524
Staircase Length (St) mm	*4,700*	*5,006*	*5,312*	*5,616*	*5,920*

Table 4.5: Equivalence length of the staircase to the staircase width

4.6 Models of Building Evacuation Scenario

Evacuation from building fire is essential and has to be done as soon as the fire alarm is sounded or fire cues have been detected, the sooner the better, because it could save lives.

The issue of how safe is safe enough in escape route design and construction is yet to be answered. This is because "to evacuate or not to evacuate" high-rise residential buildings has been hotly debated in all sectors of the fire protection industry (MacLennan, 2001). According to MacDonald, (1985) and Proulx (2001), non-evacuation or "stay-in-place" procedure is proposed as an appropriate behaviour during high-rise building fires for high-rise residential, hotel and dormitory buildings. According to Proulx, over the past decades, a number of people have died in the process of evacuation from high-rise buildings during fire and many of them have been found in corridors and stairwells which are often far away from the place of origin of fire.

After the September 11, 2001 tragedy, the idea of not evacuating from a high-rise building seems to be inappropriate any more. The theory of buildings being built with fire resistant materials sufficient to withstand fire, so that residents can stay in their own flats or flats of their neighbour until the fire is put out, seem now to be inappropriate. The risk that a high rise building could completely collapse if fire breaks out as at the World Trade Centre is still high, especially if it is a steel structure building. However it is not ruled out that a building design with sufficient fire resistance material in place will increase fire safety in buildings. The Canadian Wood Council (2000) note that fire safety in a building can be achieved through proven building design features intended to minimize the risk of harm to people from fire to the greatest extent possible. We also cannot rule out the fact that in the real world many combustible materials may be brought in to flats by residents after the building is completed. The intensity of fire, especially if highly flammable material stored in a flat catches fires, will cause devastation and could cause the building to collapse. The critical aspect is to ensure that all occupants are evacuated from the affected building before its collapse. The evacuation time is also influenced by the building design, specification, and the location and layout of escape routes provided in the building. Even though the occupants' behaviour plays a vital role, escape routes provided in the building will have a large influence on the people's behaviour. People have a tendency to become tense and will behave in an irrational way if they become stuck in traffic congestion during the evacuation process. There are cases where occupants have jumped through a window to their death during a fire in a high rise building. To study the effect of escape route design on evacuation processes, study models for the evacuation scenario have been developed as in figure 4.32 to figure 4.39. These models were developed after prudent appraisal of the observed data. To investigate the specification of escape stairs, corridors and fire doors, the numbers of study models were then expanded to 260 models as in table 4.6. To do so, computer simulation software called SIMULEX was used as a research tool to analyse the models. In this regard, the parameters considered in the investigations are as in table 4.7.

Study Models	Number of Staircases	Number of Fire doors	Number of Corridors	Number of cases investigated
Model 1	5	8	1 = 2 m	40
Model 2	5	-	5	25
Model 3	5	5*	5	25
Model 4	5	5*	5	25
Model 5	5	8	1 = 2 m	40
Model 6	5	-	5	25
Model 7	5	8	1 = 2 m	40
Model 8	5	8	-	40
			Total cases investigated	**260 Cases**

***Note*:** Fire door width is equal to corridor width. Therefore, only corridor width is considered in this study.

Table 4.6: Number of cases studied

4.6.1 Evacuation Models

There were 260 evacuation models investigated. Model scenarios were set according to the different cases of escape route design and construction, orientation of the escape stairs and the possible direction in which occupants can move to evacuate from high-rise residential buildings. There are eight scenarios altogether and the description of each of the scenarios is in table 4.8; details of the eight cases of staircase layout investigated are as shown in figure 4.32 to figure 4.39 below. Eight scenarios were selected because in the high-rise residential buildings observed, the escape stairs constructed were, parallel, vertical, straight, L-Shape, or staircase built to serve clustered flats, are with or without fire door.

Meanwhile, escape route design and construction in high-rise residential buildings either permitted the occupants to move in one direction or both directions. The direction in which occupants can move is mainly influenced by the type of corridor design in the internal layout of the building. Different types of internal layout can be found in section 4.3 and 4.4. The decision on the development of study models was based on the observations of the existing high-rise residential buildings in Kuala Lumpur and Penang as described in section 4.3 and 4.4 above. Table 4.7 shows the relationship between the buildings observed and type of model developed.

Building \ Model	1	2	3	4	5	6	7	8
A	✓	✓						
B	✓	✓	✓					
C								✓
D								✓
E	✓	✓		✓				
P1			✓					
P2					✓	✓		
P3							✓	
P4	✓	✓						
P5					✓	✓		
P6			✓					

Table 4.7: Relationship between buildings observed with the model scenarios.

Model	Description
1	Opposite directions with fire door.
2	Opposite directions without fire door.
3	L-Shape direction with fire door.
4	Straight direction with fire door.
5	Opposite direction horizontal staircase with fire door.
6	Opposite direction horizontal staircase without fire door.
7	One direction horizontal staircase with fire door.
8	Cluster types with one staircase.

Table 4.8: Model description

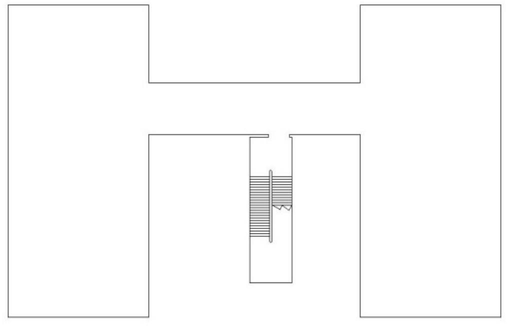


Figure 4.32: Study model scenario 1

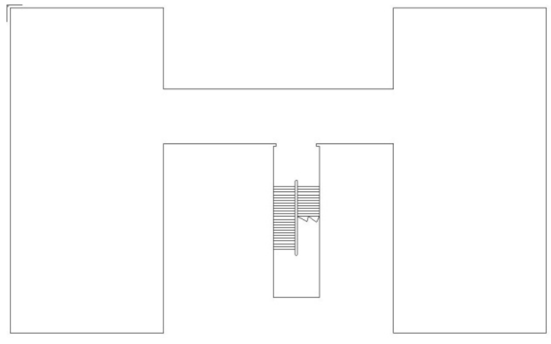


Figure 4.33: Study model scenario 2

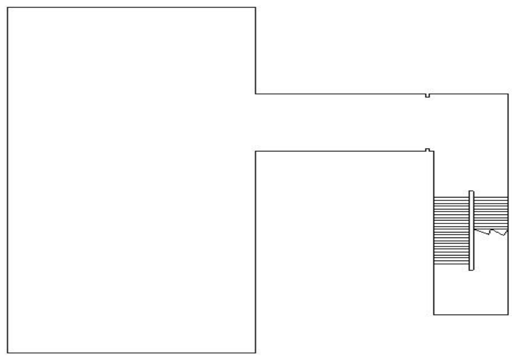


Figure 4.34: Study model scenario 3

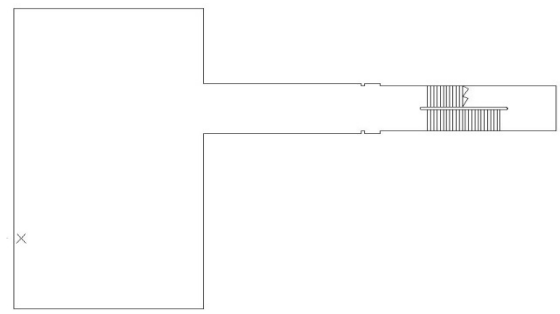


Figure 4.35: Study model scenario 4

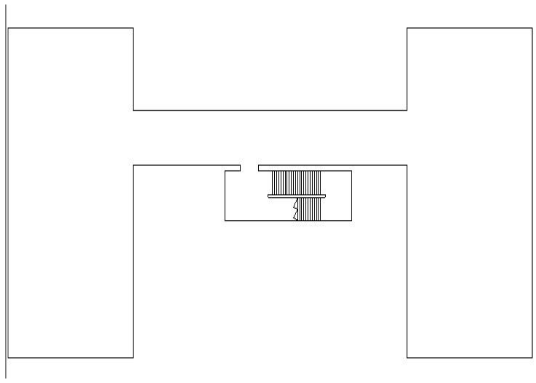


Figure 4.36: Study model scenario 5

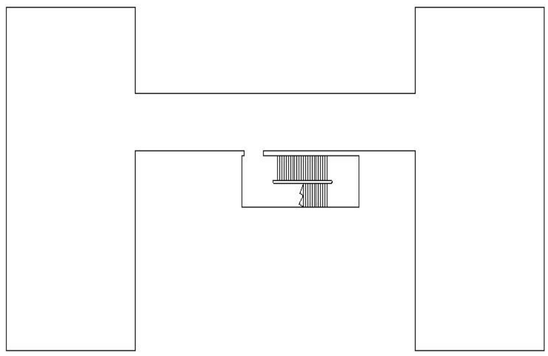


Figure 4.37: Study model scenario 6.

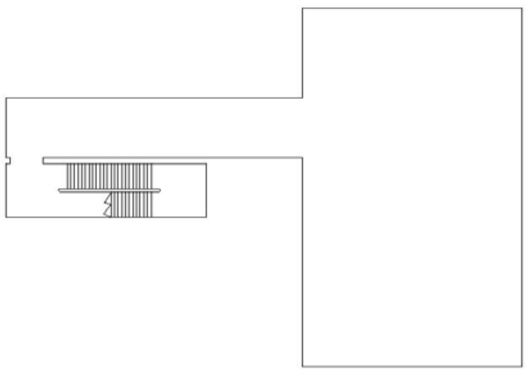


Figure 4.38: Study model scenario 7

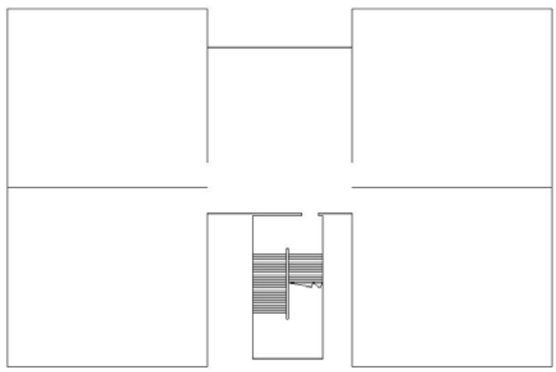


Figure 4.39: Study model scenario 8

4.6.2 Parameters considered in analysis

There are seven main parameters considered in this regard i.e. (i) Escape route specifications, (ii) Occupant characteristics, (iii) Number of occupants, (iv) Occupants velocity or walking speeds, (v) Distance of flats to the nearest escape stairs, and (vi) Evacuation patterns.

i. *Escape route specification*

The components in the escape route consist of corridors, escape stair, fire door, lobbies, and internal circulation. In this regard internal circulation and lobbies are assumed to be the corridor because the nature of the design is not much different, except the lobby is slightly larger than the corridor. It is common in designs for the corridor and lift lobby to be attached because escape stairs are normally located near to the lift. Therefore only corridors are considered in the analysis. There are two types of corridor, open sided and closed sided. In analysis of people's movement, those designs do not have any effect except when smoke starts to enter the corridor. In an open sided corridor, smoke is free to move upward and in close-sided smoke will fill up the corridor and could impede people's movement. For the purposes of analysis, the assumption has been made that people start evacuation immediately after the fire alarm goes off. At that time smoke is still contained in the place where the fire started. The specifications measured here are the width of staircases, fire doors, and corridors. Further detail of fire doors, staircases and corridors specification will be discussed under sub-topic model determination.

ii. *Occupants Characteristics*

Occupants' characteristics measured are the physical aspect and not the behaviour of the occupants. Occupants' behaviour will be measured using the questionnaire distributed to the high-rise building residents and will be discussed in the relevant analysis chapter. The physical aspects that have been measured are body types, i.e. elderly, male, female, or children. This is because body types influence the walking speed and the response time. The response time is the time taken by the occupants to react after the fire alarm goes off. This time varies depending on the occupants' physical characteristics and is a very significant contribution to the total evacuation time.

iii. *Numbers of occupants*

In theory, the number of occupants has a significant effect on the evacuation time. To increase the number of people will increase the time taken to evacuate from the building. Analysis of the number of people occupying the building will give us clues as to what is the optimum number of people that can safely occupy the high-rise building. This figure then can be used in deciding the maximum occupant density design factors for fire safety. Analysis of the number of occupants is based on the number of rooms available in the buildings studied. Minimum occupancies are calculated on the assumption that one room is occupied by one person. Maximum occupancies are calculated on the assumption that one room is occupied by four persons. This assumption was made by doubling the normal occupancy that two persons occupy one room. There will be three cases to analyse; low occupancy, 1 person per room; normal occupancy, 2 persons per room and high occupancy; 4 persons per room. (is there justification for these numbers based on the observations?

iv. *Occupants' velocity or walking speed*

In theory if occupants' velocity increases the time taken will be reduced. Analysis will look for the correlation between the evacuation time and the numbers of people occupying the building. There are five scenarios of walking speed chosen here, a random mixture of people with various walking speeds, walking speed set for all males, all female, all elderly, or all children. In theory, increasing the number of the building residents has a tendency to create congestion in the escape stair.

v. *Distance of flats to the nearest escape stairs*

The distance of flats or residents' units from the escape stair will be analysed to determine whether there is any significant evidence that the distance and location of the flats or residential units contributes to the congestion occurring in the escape stair. Is there any significant evidence of the residential flats layout design, i.e. scattered compare with the designed side-by-side, with the corridor joint to the escape stairs contribute to traffic congestion during evacuation process. If there is an alternative staircase provided, is there any significant evidence that occupants will choose the most visible staircase instead of the nearest staircase to them? Analysis of this part will be discussed when discussing the results of the questionnaire. At this point the analysis will only look at the significant evidence by using the evacuation time as a measurement gathered from the different building design and orientation.

vii. *Evacuation pattern*

The evacuation pattern in a building fire needs to be analysed to determine how people are going to react in the case of emergency. In this analysis, the occupants' evacuation pattern will be analysed when the fire alarm sounds to identify the safest design of escape route to be used. Analysis is done by adopting the philosophy that '*Any design which does not cause traffic congestion at any level, and allows people to be smoothly evacuated from the building with the minimum time taken, is the safest*'. (is this a quote? Is so ,ref needed)At the end of the analysis, suggestions should be able to be made regarding which design is the safest one to use in a high-rise residential building. In this regard for the simulation purposes, the number of occupants to test in evacuation model is 180, 360 and 720 for low, normal and high density respectively. The number of occupants is calculated using the following formula that $O_d = P_r \times R_f \times F_f \times N_f$

Where:

O_d = Occupants Density
P_r = Numbers of person / Room
R_f = Numbers of Room / Flat
F_f = Numbers of Flat / Floor
N_f = Numbers of Floor in the Building.

An example calculation of low occupants' density for ten storeys building with six, three bedrooms flats per floor as follow:

For low occupancy, that is one person occupant per room, the number occupancy is:

$O_d = P_r \times R_f \times F_f \times N_f$
$= 1 \times 3 \times 6 \times 10$
$= 180$ persons.

4.6.3 Model Determination

The study models used are based on the analysis of observation data of the existing high-rise residential buildings which was carried out earlier. There are five main components in the study models developed i.e. (i) Room / Chamber, (ii) Corridor, (iii) Staircase, (iv) Fire Door, and (v) People.

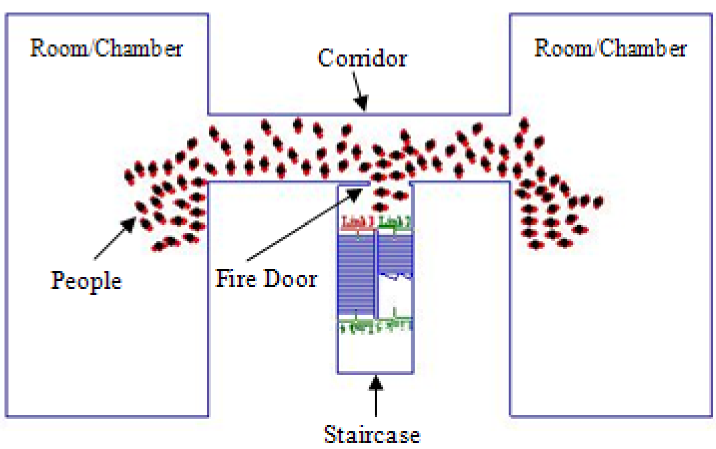


Figure 4.40: Detail of one of the study model

i. *Room/chamber*

There are three types of room, single room, double rooms and four rooms. A room is used to place people for simulation purposes. The number of people to be placed in the room / rooms is the numbers of Occupants Density calculated, i.e. 180, 360 and 720 for low, normal and high density respectively. If the models are double chambers, the number of people to be placed in each chamber will be divided equally. For example for 180 occupants, each chamber will have 90 people. The same principle applies to the four room type model. The number of rooms designed is based on the traffic flow analysis of high-rise residential buildings, single room when traffic flows are only one direction, double rooms when traffic flows are in two opposite directions and four rooms when traffic flows are from multiple directions. Figure 4.40 shows an example of a study model with double chambers. Other types of evacuation models for different staircase layout scenarios can be found in Figure 4.32, until 4.39.

ii. *Corridor*

The corridor is an important component in an escape route which people have to go through before they are able to reach the escape stair. There are two types of corridor, open sided corridor and close sided corridor (see figure 4.41).

In this regard both types of corridor are equally important and therefore in evacuation model corridor both corridor types are represented. For analysis purposes, the corridor width is selected to be in the range of 1220mm (4ft) to 2440mm (8ft) with 305mm (1f t) intervalsin each category. Therefore, design of corridor size will be 1220mm (4ft), 1524mm (5ft), 1828mm (6ft), 2134mm (7ft) and 2440mm (8ft). A corridor width less than 1220mm (4ft) has not been selected because it seems to be not a realistic design for two persons to walk in opposite directions. A widthof more than 2440mm (8ft) has not been chosen because in the buildings observed there was no such case of a corridor more than 2440mm (8ft). From observation the most common sizes of corridor for residential buildings are between 1828mm (6ft) and 2134mm (7ft). Table 4.9 shows the various sizes of corridors used in the evacuation model together with the staircases and fire door sizes.

(a)

(b)

(c)

(d)

(e)

Figure 4.41: (a), (c) and (e) Open sided corridors, (b) and (d) Closed-side corridors

iii. *Staircase*

The staircase is another important component in the escape route. It is widely known as escape stair which is purposely used not only during emergency situation but can be used as a means of access to resident's flats especially for those who are staying at level three and below of high-rise residential buildings. During an emergency evacuation such as a building fire, all occupants are advised to use the staircase to evacuate tall buildings in a fire emergency. Even though recent research shows that some people are keen to use elevators to get out quickly from tall buildings,(reference) a majority still choose to use the staircase for emergency evacuation. Portsmouth's Spinnaker Tower is 170m high (two and a half times the height of Nelson's Column in Trafalgar Square) and it is estimated that 60% of the occupants could be evacuated using the staircase and the remaining 40% would use the passenger lift for evacuation (Tarada, 2005). Furthermore, current regulations recognise that lifts may be used to evacuate disabled people who normally use wheel-chairs.

Figure 4.42: (a) Metal staircase, (b) Staircase with square opening, (c) Closed staircase, (d) Staircase with halve round floor, (e) staircase with windows

For analysis purposes, staircase widths of 914mm (3 ft), 1067mm (3.5 ft), 1220mm (4 ft), 1372mm (4.6 ft), and 1524mm (5 ft) were chosen for the evacuation model. Staircase widths of less than 914mm and greater than 1524mm have not been chosen because in the observations no building was found with that size of staircase. The most common staircase designed for emergency use is 1067mm (3.5 ft) for one person per flight. Staircase design for two persons per flight is 1372mm (4.5 ft). This size is to enable the occupants to walk comfortably side-by-side or to walk in different directions. Unlike commercial buildings where the staircase could be wider than 1372mm, in high-rise residential buildings no case of a staircase wider than 1372mm was observed. Therefore, for analysis purposes, staircases between 914mm and 1524mm inclusive ware chosen. In order to analyse the optimum size of staircase, 153mm (6 in) was added to the model design until it reached the maximum size of 1524mm. From the construction point of view, adding sizes smaller than 153mm is impractical. Figure 4.42 is an example of a staircase observed in a residential building.

iv. Fire door

The minimum width of the fire doors is 2 ft 6 inches (762 mm) and the maximum size of the door is 5 ft (1524 mm) with a difference of 3 inches (76 mm) assumed as the optimum size of door to analyse. In the vast majority of flats, fire door analysis showed that there were no such cases of fire doors smaller than 2ft or greater than 5ft. This is not taking into account fire doors fitted in corridors. Fire door fitted to corridors can be up to 8 feet. Therefore, for analysis purposes, door sizes as in table 4.9 are chosen.

Staircase Size (mm)	Fire Door Size (mm)	Corridor Size (mm)
914 (3')	762 (2' 6")	1220 (4`)
1067 (3' 6")	838 (2' 9")	1524 (5`)
1220 (4')	914 (3')	1828 (6`)
1372 (4' 6"	990 (3' 3")	2134 (7`)
1524 (5')	1067 (3' 6")	2440 (8`)
	1220 (4')	
	1372 (4' 6")	
	1524 (5')	

Table 4.9: Staircases, door & corridor sizes

Common Doors Sizes		
feet & inches	Metrics mm	Inches
1'	305	12
1' 3"	381	15
1' 6"	457	18
1' 9"	533	21
2'	610	24
2' 3"	686	27
2' 4"	711	28
2' 6"	762	30
2' 8"	813	32
2' 9"	838	33
2' 10"	863	34
3'	914	36
3' 6"	1067	42
4'	1220	48
4' 6"	1372	54
4' 9"	1448	57
5'	1524	60
6'	1828	72
7'	2134	84
8'	2440	96

Table 4.10: Conversion Table

Table 4.10 shows the conversion size of fire doors in imperial (inches) and metric (mm) which is commonly used in residential buildings. There are either one or two door leaves used as fire door and they vary and are not always symmetrical. In many cases a combination of two different sizes of door leafs are commonly used. However, if the size of the second door is smaller than 1ft 6 inches, only one door, the larger one is fitted with a door knob.

4.7 Model design environment

Models were designed using CAD software and saved as dxf files. If there was more than one floor to be analysed, dxf files have to be uploaded as many times as desired and the floor plan then named accordingly. All floors uploaded into the SIMULEX have to be connected to each other by a staircase which needs to be designed in the SIMULEX environment. Apparently, only one staircase is needed to every escape stairs and links to each floor at the storey exit at one side and to the staircase designed at the other side. Link sizes must be the same as the door width. After links have been made, the final exit has to be assigned to enable the assigned occupants in the designed chamber/room to leave the building. The exit assigned is an end destination for the occupants to evacuate from the building. It must be the final exit of the study model. However, the final exit still can be assigned anywhere in the SIMULEX environment. The purpose of the study will mainly determine where to put the final exit. People then have to be put in before we can start the simulation. People's characteristics should be determined and can be selected from the choices given in the SIMULEX environment. It, however, can be changed later on and can be done at any time if required.

4.8 Chapter conclusion

In the observation exercises, 462 staircases in six high-rise residential buildings were investigated. In addition, another six buildings were visited to study their internal layout and circulation patterns. From the investigation, 74.8% of steps tread in six high-rise residential buildings complied with the By-laws.

According to the By-laws the minimum depth dimension requirement for the step treads is 255 mm, and the vast majority of staircases are designed with 280 mm treads depth. Similarly, for the step risers, the maximum height set in By-laws is 180 mm, but the vast majority of the staircases are designed with step risers at 153 mm.

The number of steps per staircase was designed within the permitted number in By-laws which say that they shall not exceed 16 steps per flight, i.e. the average of being nine steps per flight.

Eight scenarios of study model have been developed as a result of the observation exercises on the buildings studied for further investigation in simulation software.

CHAPTER 5

AN EVALUATION OF THE CONDITION OF ESCAPE ROUTE IN HIGH-RISE RESIDENTIAL BUILDINGS

5.1 Introduction

As mentioned in Chapter 4, observations approach was adopted, to investigate the issues and problems encountered in high-rise residential buildings. A number of high-rise residential buildings located in Kuala Lumpur and Penang discussed in chapter 4 were observed. In this chapter, discussions focus on the evaluation of the condition of escape routes and internal circulation areas in the high-rise residential buildings.

In this chapter, discussions focus on the actual condition and problems encountered in escape routes in high-rise residential buildings in Malaysia. Some photos provide evidence to support the arguments of the research finding. However, discussion will be focused on the categorised issues which were highlighted during the research exploration, without mentioning a particular building where the problem was encountered. This is to avoid some degree of sensitivity in certain aspects especially when the rules and legislations are involved. Uniform Building By-Laws were used to consider the aspects of the requirements as they relate to escape route design and fire safety in buildings.

If we can understand the fire safety aspects, and we know what are the actual problems encountered in those buildings, appropriate measures can be taken to enhance fire safety standards.

5.2 Brief methodology used in research and analysis

The basic principles of the observation method are applied, where selected buildings are identified prior to observation being carried out as described in chapter 3.4. Chapter 4.2 and 4.3 are parts of the observation outcome on the same buildings. There are some basic research tools needed i.e. checklist form formulated earlier based on the Uniform Building By-Laws 1984 – Malaysia and The Building Regulation: Approved Document Part B – Fire Safety United Kingdom as a benchmark. Other tools are a digital camera, measuring tape and laptop computer used to take evidence such as photographs, measure the escape routes dimensions, and to store this data respectively. Observation took place by walking through all internal circulation areas at every floor beginning from the top floor to the ground floor. The researcher used the lift to reach the top floor and walked down through the corridors and escape stairs.

At present there is no quantitative method of assessing the adequacy of any escape route provided in buildings other than by empirical means. The current method of providing means of escape from buildings is by specification and rules, i.e. rules that have evolved through time and are deemed to provide a satisfactory escape route (Shields & Silcock, 1989). Therefore a qualitative method of assessing the adequacy of provision and condition of escape routes in high-rise residential buildings has been chosen. In this regard, a number of tasks are involved i.e. taking evidence such as photos, measuring structure dimensions, examining the condition of the building elements, checking the compliance against the specifications, etc. All data were then analysed, i.e. all photos, measured escape routes dimensions i.e. corridors, fire doors, staircases, and information from the checklist form. The outcome is then categorised based on the issues encountered. Categorization of the problems encountered is made based on the principle of similarity behaviour analysis i.e. the actual problems are grouped together if they are similar in its nature, e.g.:

(1) Problem occurs on escape routes structure, for instance, treads constructed shorter than the minimum specification, risers exceeded the maximum height permitted, corridor designed detached from the occupant flats and so forth. Because those problems are mainly related to the building elements, then they are categorised as problems regarding the Structural Design and Construction.

(2) Problem occurs related to the provision of services to the occupants e.g. no artificial lightings, no emergency lighting, ventilation insufficient and so forth. They then are categorised as a problem related to Facilities for Fire Safety in Buildings.

The same analysis techniques are applied to the rest of the problems by listing them out in a table and rearranged to form a problem encountered as in table 5.1 which can be found at the end of this chapter.

5.3 Categorisation of issues encountered

Fire safety issues in residential buildings have not been given appropriate attention even though statistics show a large number of fires occur in residential buildings compared to the other types of buildings (Bomba, 2001). From the observations, among the issues encountered is the trend in Malaysia of installing extra safety precautions in the form of an iron grill, which, besides providing security against intruders, created an additional obstacle for occupants in the event of fire. Escape stairs were blocked with unwanted material dumped by irresponsible tenants. Some staircases did not comply with the minimum requirement. Illumination systems and ventilation systems were insufficiently installed or maintained. Fire doors were insufficiently maintained. Fire doors were locked from the other side by irresponsible tenants. Fire suppression systems were insufficiently maintained, etc. Using similarity analysis behaviour, i.e. all the problems encountered are grouped together if they are similar in nature, those problem can be summarised into five categories as follows:

i. Structural designs and constructions

ii. Facilities for fire safety in buildings

iii. Maintenance

iv. Attitudes

v. Management

However, there are several others factors that are equally important which would be able to impede the evacuation process. Those factors not only potentially impede the evacuation processes, but could increase the risk of casualty or could severely jeopardise the occupants' life in building fires. Those factors are:

i. Lack of facilities for disabled people to evacuate from the building.

ii. No alternative escape route provided in the building.

iii. No fire-fighting lift provided.

iv. Difficulty to identify the location of egress due to unfamiliarity with the building environment, this factor is applicable to particularly new tenants.

v. The size and shape of escape route.

vi. The numbers of people occupying the building at one particular time exceeding the maximum number permitted.

vii. Difficulty in finding the exact location of escape stairs due to unclear or no exit signage.

It is very important to address that in order to achieve one of the fire safety objectives in building i.e. human protection or life safety in the event of fire, those encountered factors should be immediately rectified once discovered. An appropriate measure needs to be put in place, such as regular checking, enforcement by the relevant authority, proper maintenance, etc.

5.4 Some important issues in evacuation processes

The cause of fire cannot be completely eliminated (Mehaffey, 1987a). Even though the potential for being killed or injured in a building fire cannot be completely eliminated, if the design of the building from the early stage was seriously considered, the consequences of fire threat would be minimised by optimising the resources available. However, fire safety in a building can be achieved through proven building design features intended to minimize the risk of harm to people from fire to the greatest extent possible (CWC, 2000). If sufficient data is available and analysis has been made to identify the top most risks associated with people in residential buildings during evacuation processes, probably the casualties and death of people in building fire can be eliminated. So what we should stress here is the ability of people to evacuate from the building in a case of fire. Time is becoming the determining factor in life safety during building fires. The faster occupants are evacuated from the building the greater the chance of saving their lives.

The National Fire Protection Association (NFPA, 2000) has developed a basic approach to minimise fire risk called *Fire Safety Concepts Tree* (FSCT). FSCT was derived to achieve the fire safety objectives, first for life safety and second for structural protection. Among measures that can be applied to achieve the fire objectives are prevention of fire ignition, providing the means of detection, equipping with fire extinguishing equipment, preventing fire from spreading to the other parts of building and allowing time for people to evacuate from the building. Life safety is also influenced by the knowledge and experience that people have about the fire and fire spreading in buildings. With understanding of the fire behaviour and fire characteristics, casualties can probably be reduced if appropriate measures have been taken when evacuating from the building. In the real world do these measures i.e. managing the fire and managing the fire impact as suggested by FSCT implied in high-rise residential buildings exist? The following section will discuss the findings from the observations.

5.5 Problem encountered in high-rise residential buildings.

The research findings generalised here is not referring to a specific building but rather generalise to avoid a certain degree of sensitivity that could arise. From the twelve buildings observed, it can be concluded that there are eight scenarios of internal building circulation designs used as escape routes in high-rise residential buildings. Those scenarios have been discussed in chapter 4. From the research point of view, generalising research finding using this approach will not decrease the validity and credibility of the research because data analysed was the real data from the field work study. There are a number of evacuation issues in high-rise residential buildings pertaining to structural designs that could pose a danger to building occupants if fire breaks out. Issues in fire safety, particularly issues of fire safety in residential buildings, have not been addressed as it supposed which it would able to create a "chain reaction" of residents awareness. Unlike the issues of fire safety at the place of work, issues in residential building are only discussed if there is a fire tragedy that claimed lives. Many say that to control fire in buildings we should control it at the source of fire. Many believe the philosophy that *prevention is better than cure*. I do believe to the same philosophy too, but in fire safety, one should take both measures to prevent and cure.

Difficulties in escaping from building in a fire event are largely due to several factors as mentioned in section 5.3 above. Those factors have a potential to increase the risks of injury or kill if the problems encountered remain as they are without taking any appropriate measures to rectify those problems as soon as possible. The following section will discuss the problems encountered in high-rise residential buildings.

5.5.1 Structural design and construction.

Structural design and construction regarding the provision of egress route from the buildings is one of the key problems categorised. It includes the internal circulation for horizontal escape and staircases for vertical escape. There are four components identified i.e. (1) no alternative escape stairs provided, (2) staircases specifications do not comply with minimum requirement, (4) corridor designed and orientation, and (4) fire doors do not fitted at the storey exit.

i. No alternative escape stairs provided.

An alternative escape stair and/or alternative egress should be provided in high-rise residential buildings. According to the UBBL a single staircase may be permitted in any building, the top most floor of which does not exceed 12 meters in height (clause 194). In any other high-rise building means of egress must be via at least two separate staircases (clause 168). If windows are provided, the size of escape window situated in an external wall should be at least $0.33m^2$ and at least 450mm high and 450mm wide. The bottom of the openable area should be not more than 1100 mm above the floor (BR, UK). However in high-rise buildings i.e. building more that ten storeys to use windows as an alternative to escape from the building fire is impractical because there is no rescue ladder that can reach high enough to save the occupants. It may be practical for low rise buildings i.e. one or two storeys building. Therefore, it is important to have an alternative escape staircase in high-rise residential buildings. This is to ensure that occupants are provided with an alternative to escape if fire or smoke spread into the other staircase. Furthermore, we can not just rely on only one staircase to evacuate all occupants out from high occupation buildings. If a large number of occupants want to evacuate at the same time from a high-rise residential building, it can cause congestion and will increase tension among the people. Evacuation time will be longer than expected.

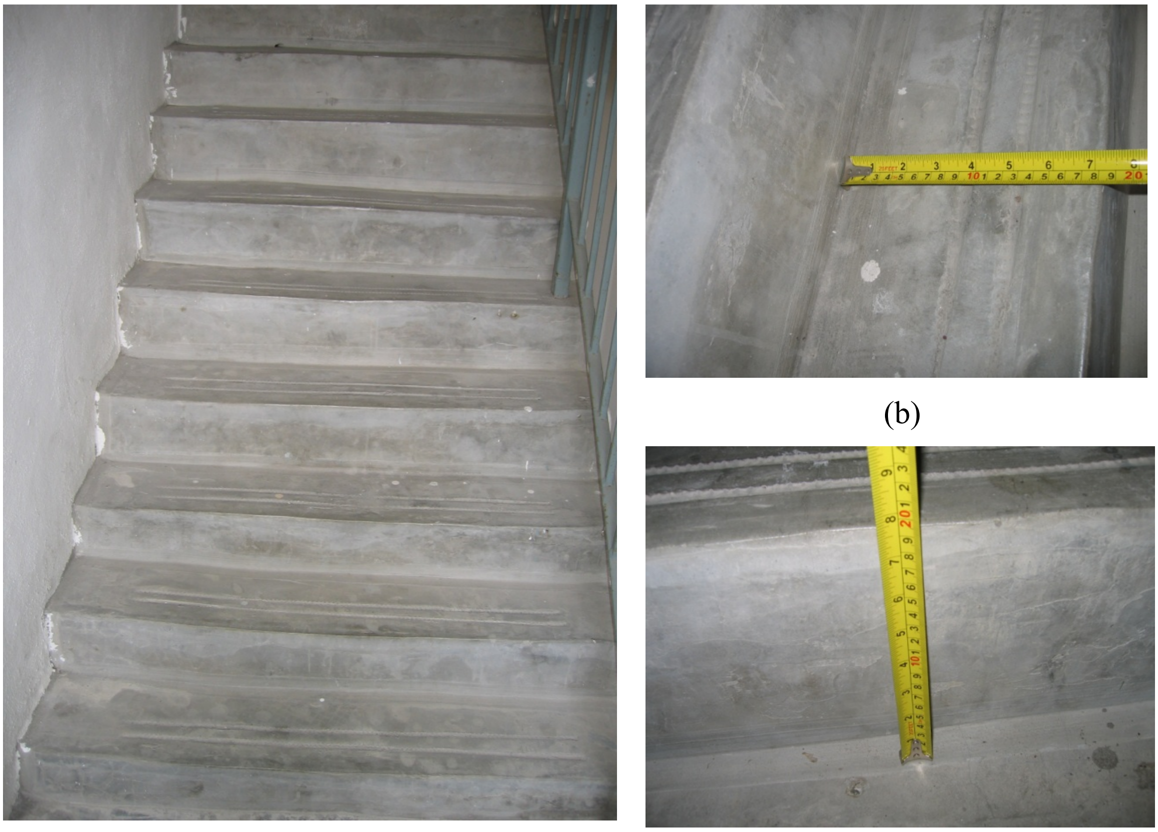
There are two locations at the staircase where congestion always occurs, (1) at the intermediate floor where occupants have to make a 'U' turn to enter the next staircase, and (2) at the entry point where occupants from the above floor meet with the occupants from the lower floor (Figure 5.1). This will slow down the movement of people and increase the evacuation time. If too many people want to evacuate at the same time, they would cause congestion at the staircase. The worst scenario is if panicking people start pushing others, which may result in some people falling down and impeding the evacuation process.

Other factors of equal importance are people characteristics such as age, body size, gender, and health condition. These factors apparently will slow down the occupants' walking speed especially if the number of people involved is large. Close relatives normally will try to carry down the mobility impeded person e.g. walking disability, old people, sick people etc. during emergency situation. These will definitely slowdown the occupants walking speed. Therefore either an alternative escape stair is essential for high-rise residential buildings or they are allowed to use a fire lift (if provided) to evacuate the building. This can reduce the risk of congestion at the escape stairs.

Figure 5.1: Location where congestion always occurred during evacuation

ii. Staircase specifications do not comply with the minimum requirement.

There are three problems encountered in staircase specifications i.e. tread, riser and intermediate floor dimension that did not comply with the requirement of the By-Laws. In some staircases observed, the tread dimension was shorter than the minimum requirement. Figure 5.2 (a) is an example of the staircase poorly designed and constructed whilst not only both tread and riser did not comply with the requirement, but every staircase steps itself is not equal, even in terms of tread and riser dimensions. Figure 5.2 (b) and (c) are examples of tread and riser dimensions that did not comply with the requirement.



(a) (b) (c)

Figure 5.2: (a) Staircase view; tread and riser dimension is about the same size. (b) Tread dimension is only about 7 feet (185mm), whilst minimum requirement is 225mm at least. (c) Riser dimension is about 200mm, whilst maximum dimension should not exceed 180mm.

Another aspect is staircase width and intermediate floor depth designed and constructed at different dimensions. They should be designed and constructed at the same dimension as requested by the By-Laws. Clause 168 (4) By-Laws said that the depth of landings shall be not less than the width of the staircase. This specification is applied to the intermediate floor or landing floor between the staircases as well. In clause 108 (1), for residential buildings, a landing of not less than 1800 mm in depth shall be provided in staircases at vertical intervals of not more than 4250 mm. In figure 5.3 (a) and (b), the staircase width and intermediate floor depth were not equal. Intermediate floor depth was designed and constructed at 840 mm whilst staircase width was designed and constructed at 990mm.

The risk for this design is that traffic flows could be interrupted when occupants want to change their direction to the next staircase. This 'bottle neck' designed should be avoided. It will be worse if a fireman has to access the building using the same staircase and at same time occupants are evacuating the building.

(a)

(b)

Figure 5.3: (a) Staircase width from wall to the handrail is about 3 ft 3 inch. (990). (b) Intermediate floor depth is about 2 ft 9 inches. Those dimension should be uniform i.e. staircase width and intermediate floor depth must be equalled.

iii. Corridor design and orientation.

Corridor design and orientation in a high-rise building is very important and should be done properly because wrong design could cause the occupants to be trapped in the event of fire. It is very common that corridors are designed according to the shape of the buildings and the orientation of the flats. Whatever design and orientation of internal circulation, it should not encourage the occupants to take unfair advantage of it. Figure 5.4 is an example of where the flat's owner misused the public area provided in one of the buildings observed. Public areas are illegally occupied by built-up wall and grilled beyond the premises boundary.

There are cases where some of the flat owners completely grilled the area for their private use. These scenarios happened because the corridor was designed as an open space (see figure 4.11). It has given the owners the chance to abuse the situation. Furthermore, lack of enforcement from the relevant authority has caused this misbehavior to remain as it is. The risk will be to those who live at the same level with the flats in figure 5.4 (c). They are denied access to the escape stair in the event of fire. Furthermore, rescuers will face difficulties to access this level due to these circumstances. The flat owners are allowed to put on grill at their main door for security purposes, but a built-up iron grill to form a private compartment in the public area is obviously trespassing on the public area.

(a)

(b)

Figure 5.4: (a) The original look of internal circulation where fire door unobstructed.

(b) The flat owner has put up wall, grilled and tiled the floor as a private space.

(c) The flat owner put on a grill extended beyond his premises. This public area is illegally occupied.

(c)

(a)

(b)

Figure 5.5: (a) Original appearance of corridor to access four flats from the lifts lobby.

(b) Shows two flats and another two flats opposite them.

Another example of the flat owner abusing the public area is shown in figures 5.6 and 5.7. The building in figure 5.5 is designed with eight flats, where four flats are located at each end of the corridor. The lift lobby is located at the middle of the corridor (see figure 5.5

(a)) and both ends of the corridor are designed with two flats located side-by-side and another two opposite them (see figure 5.5 (b)). There are three escape stairs provided, one at each end of the corridor and another one is beside the lift at the middle of the corridor.

(a) (b)

(c) (d)

Figure 5.6: (a) Shows the location of escape stair.
(b) Corridor views from the other end.
(c) Flat owner has put up grill in front of his premises on the public area.
(d) Stainless steel compartment grill in front of flat in the same building.

Figure 5.6 (d) shows the whole corridor view from the other end. This beautiful and finely finished building is spoiled by some flat owner who has built up a private compartment at the public areas (see figure 5.6 (c) and (d)) for their personal use. Very strong and expensive materials used for the grill (stainless steel) reflect a good economic status, but demonstrate the selfishness of those who practised this misbehaviour.

The same situation seems to have occurred in the building in figure 5.7 (a) and (b). The only difference is that they put up an iron grill instead of stainless steel. To put up a grill at one's own main door is allowed, but to put up a grill that can restrict access to a public area should be avoided. Furthermore it blocks the only available opening at this level. The risk is to those who are unable to use the escape stair due to certain circumstances, i.e. smoke and fire spread into the stairwell, escape using this opening, with the help of fire brigade ladder from the outside, would face with difficulty.

Figure 4.5 in chapter 4 page 91 is a good example of corridor design. Space orientation in this design is fully utilized by the public and it reduces the possibility of being abused. This open-sided corridor design with emergency staircases located at both ends and another two staircases located at the angle of the ‘U’ shape are fully utilized by the occupants as a main access to their flats. Therefore, there is no way it can be transformed to be a private space. On the other hand, with four alternative escape stairs provided, the occupants are given more opportunity to choose the way out at their own convenience and reduce the probability of being trapped in the event of fire.

(a) (b)

Figure 5.7: (a) and (b) Flat owners put grill in corridor

An enclosed corridor as in figure 4.11 is good for fire compartmentation, which besides effectively restricting the smoke and fire spreading, also limits the occupant’s ability to abuse the space provided. Fire compartmentation is good to limit fire and smoke from spreading into sensitive areas, but the risk will be for those who stay in the same compartment of fire origin i.e. four flats clustered at the left and the right wings of the lift facility. If a fire broke out in one of those flats, and if the main door was not designed according to the fire door specifications, smoke could fill up the entire compartment area and would pose a danger to other flat's occupants to rescue themselves.

Figure 4.7 and 4.9 show an enclosed foyer corridor type of internal circulation design. From a fire safety point of view, this type of design is not very good if ventilation systems are insufficiently installed. This is because the enclosed foyer could create a smoke trap in the event of fire. Smoke is a major cause of fatality in fire. This design may be good for a social event, but it might be abused by irresponsible people who might put up a grill to form a compartment in front of their main door for private use.

There are two types of corridor in the buildings observed which in the researcher's opinion are quite unique but risky. Figure 4.13 and 4.14 show the corridor designed as a bridge located between two apartment blocks with an air bridge connecting the corridor to the flat as a passageway. This design will not allow windows to be used to escape in emergency situation. The main door is the only way for the occupants to exit from their flats. Risk is high to those whose flat has caught fire and the flat which is sharing the same air bridge. Another design is as in figure 4.23 and 4.24 where the corridor is attached to one block and the other block is connected with air bridges to serve two flats each. High risk is to the flats connected with the air bridge where the only way for them to evacuate is using the main door. Windows can not be used as an alternative to evacuate because there is no place for them to step-on, unlike those who stay in the block of which where the corridor is attached.

An example of a good corridor and internal circulation area is in figure 4.17, 4.20 and 4.22. The building in figure 4.17 is designed with two lifts and two escape stairs located in the middle between the two residential blocks which has created a fire barrier if fire broke out. All occupants can easily access the escape stairs or lifts. The only problem is there is no fire door at the staircase shaft. In contrast the building in figure 4.18, has a corridor which is designed and constructed at a good location but the escape stairs are designed with only one accessible way, i.e. only one side opening without fire door. It could pose a difficulty to the occupants to evacuate the building in the event of fire. The buildings in figure 4.20 and 4.22 are built with two corridors attached to each of the residential block. This open-sided corridor has air bridges connected to those corridors. This interlink air bridge is good for the occupants to crossover to the other corridor if they have difficulty to reach the escape stairs from their side. Furthermore, there are two escape stairs and two passenger lifts provided at ends of the both corridors.

iv. No fire doors at the storey exit

Section VII, clause 162 part (1) By-Laws states that "fire doors of the appropriate Fire Resistance Period (FRP)[3] shall be provided" and part (2) stated that "openings in compartment walls and separating walls shall be protected by a fire door having a FRP in accordance with the requirements for that wall specified in the Ninth Schedule to these By-laws". Meanwhile part (3) stated that "Openings in protecting structures shall be protected by fire doors having FRP of not less than half the requirement for the surrounding wall specified in the Ninth Schedule to these By-laws but in no case less than half hour". It means that fire doors must be at least 30 minutes FRP in most of the cases for the buildings provide with an alternative escape stairs. If only a single staircase is provided, FRP must be at least one hour and the height of the building must be not more than 12 meters as stated in clause 194 in By-Laws.

Some of the buildings observed do not have any fire door at the storey exit as in figure 5.8 (a), (b), (c), (d), and (f). This would cause a problem in the event of fire where smoke can easily penetrate into the staircase and would impede the evacuation process. Therefore fire doors should be properly installed in all escape stairs as requested by the By-Laws. From the observations, the researcher found that those staircases that were not installed with fire doors are designed with large opening for ventilation and natural lighting purposes (see figure 5.8 (b), (c) and (f)). This is probably because of By-Laws 162 said "openings in compartment walls…", those staircases are designed with a wide opening for natural lighting purposes. However, figure 5.9 (a) and (b) shows the escape stairs designed without fire doors and both are located in an enclosed compartment with glass windows for daylight purposes. This design can create a problem where smoke can enter the stair shaft and jeopardise the occupants during evacuation processes in the event of fire. Both staircase shafts are provided with glass windows for natural lighting systems.

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[3] FRP means fire resistance period as specified in the Nine Schedule of UBBL 1984 that the minimum fire resistance for any structure elements which being a part of the ground floor and any storey above then if the floor area is not exceeded 3000 m^2, 60 minutes FRP is needed for all compartmentation floors and 30 minutes for non compartmentation floors.

(a)

(b)

Figure 5.8: (a), (b), are staircases without fire door.

(c)

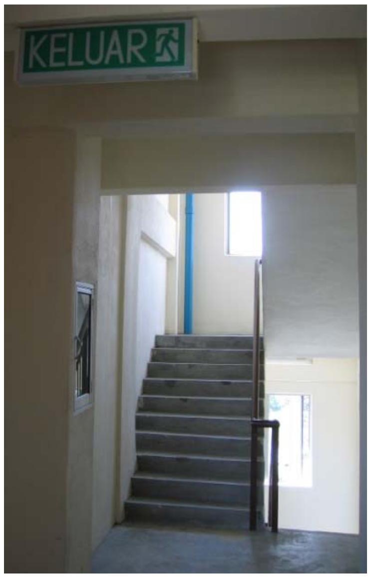
(d)

(e)

(f)

Figure 5.8: (c), (d), and (f) are staircases without fire door. (e) Type of fire door should be fitted to those staircases.

(a)



(b)

Figure 5.9: (a) Staircase in 'compartment wall' with narrow entrance designed and without fire door (b) Wide opening designed for 'compartment wall'

5.5.2 Facilities for fire safety in the building.

i. Insufficient Smoke Control System.

Every escape route and escape stair should be installed with a smoke control system to ensure the smoke is prevented from entering those places. Smoke control by means of a mechanical control system such as a pressurization system or smoke extraction system is compulsory by the regulation for the buildings or any compartment wall designed without a window. Most of the buildings observed are equipped with natural smoke ventilation system by means of permanent opening in stairwell for air circulation as in figure 5.10 (a), (b), (c) and (d). None of the buildings are equipped with mechanical smoke control system by any means.

Some of the buildings observed used the window as a smoke vent, as in Figure 5.11. However, some of them are insufficiently large (when fully open because some of them are tied up with a security plat limiting the opening for some reason) to allow smoke to pass through them because the size of opening was not as specified in the building regulation (see figure 5.11 (b), (c), and (d)). The minimum combined clear cross-sectional area of all smoke outlets should not be less than $1/40^{th}$ of the floor area of the storey they served as stated in the Building Regulation (BR (UK), 2000). In the By-Laws (Malaysia) clause 200 (a) stated that the opening of not less than 5% of the floor area of the enclosure should be provided or mechanical pressurisation system should be installed. In clause 202 state that '*all staircases serving buildings of more than 45.75 metres in height where* *there is no adequate ventilation as required shall be provided with a basic system of pressurization'*.

(a)

(b)

(c)

(d)

Figure 5.10: Opening for natural ventilation and day-light designed in staircase shafts.

Clause 198 stated that '*all staircases enclosures shall be ventilated at each floor or landing level by either permanent opening or openable windows to the open air having a free area of not less than 1 square meter per floor were not achieved'*.

Smoke produced by fires can kill in a minute especially if the materials burnt contain highly toxic substances. Smoke and toxic gases are involved in about 50% of all fire fatalities, and are the primary cause of death in over a third of fire cases (Jerome, 1994). Smoke consists of small particles of partly burnt carbonaceous materials, gases, water vapours, and hot fumes. About 70 – 75% of fire victims succumbed to smoke inhalation and this is the cause of the vast majority of fire deaths (Richard, *et. al*., 2001). The danger of smoke is toxic potency of the smoke which is mainly due to the toxic gases produced during the combustion process. If the smoke control systems are insufficiently installed, this will be the main lethal effect to the building occupants in building fires. Besides that there are sub-lethal effects that could be caused by smoke. The sub-lethal effects of smoke on people e.g. disruption in evacuation process, reduced egress speed due to, e.g. sensory irritation on eyes or lung, heat or radiation injury, and visual obscuration, tendency to choose a long egress path due to, e.g. decreased mental acuity, visual obstruction, etc.

(a) (b)

(c) (d)

Figure 5.11: Window type natural smoke vents

ii. Ventilation system insufficiently installed.

Most of the observed buildings were designed with natural ventilation systems by means of *permanent opening* and some are using either air brick ventilation systems fitted on the wall of escape stairs or just using a window for ventilation. Figure 5.10 and 5.11 shows permanent opening of air brick ventilation and window type ventilation systems respectively. Those stairwells constructed with permanent openings and air brick ventilation systems are fine, provided that there are fire doors fitted, because if there are no fire doors, it will pose a danger to the occupants because smoke could enter the escape stairs due to pressure created in the staircase shaft caused by the wind.

(a)

(b)

(c)

(d)

Figure 5.12: (a) Enclosed staircase shaft without opening and lighting system. (b) and (c) staircase shafts without opening for ventilation, (d) Example of staircase shaft with permanent opening at every intermediate floor.

For window type ventilation, there might be a problem because those windows have not installed with automatic window opening devices. In the event of fire, smoke entering the staircase shaft would be trapped inside and would pose a deadly risk to the evacuees.

Some of the windows are closed and locked from inside. They are probably intended for day-lighting and not for the ventilation. Someone has to open it manually for ventilation to occur. In the event of fire, everyone is expected to be very busy with the evacuation and to save some possessions instead of opening the locked windows for ventilation.

In all residential buildings observed, it was found that none of them were fitted with a mechanical ventilation system in any enclosed escape routes. According to the By-Laws, they should be provided with an automatic opening ventilator or ventilators operated by smoke control for an enclosed escape stair where the aggregate opening area is at least 1 m^2. Mechanical ventilation needs to be provided if there is no adequate natural ventilation in any high-rise building staircase shaft as stated in the By-Laws clause 202.

iii. Illumination systems are not properly installed

In some buildings observed the illumination systems showed a lack of maintenance. There are possibilities that vandalism was the cause for these lighting systems being broken. Figure 5.13 (a) shows a broken lighting system which needs to be changed for a new one. The lighting casing is about to fall down and there is no bulb in it. The reason why there is no bulb in it is not known. There are a few possibilities i.e. (1) The bulb has been taken away by an irresponsible tenant in the buildings, (2) The management does not have enough stock to put it back after the lamp has been removed. (3) There was no lamp fitted in the first place.

Close examination of the picture in figure 5.13 (a) shows a black spot on the ceiling, which shows that the lighting system has been used for quite some time. The black spot is caused by the heat produced from the ballast while the lamp is on. Therefore the possibility number (3) is invalid.

In another building observed it was found that one of the staircases was not fitted with a lighting system. It left the staircase in absolute darkness during the night time. The only source of light is a small air vent fitted on the right staircase shaft near to the ceiling. This mistake was probably due to the carelessness in lighting design by the electrical engineer or during construction by the contractor. The project manager has a responsibility to check and issues a variation order to rectify the problem during the construction period on behalf of the client. Figure 5.13 (c) shows that this staircase provided with both electric lighting and emergency lighting systems. However the bulb cover on the lighting casing is missing. Figure 5.13 (d) shows a complete lighting system with the emergency lighting provided in one of the staircases observed.

(a) (b) (c) (d)

Figure 5.13 : (a) Broken lamp in one of the staircase shaft. (b) There is no lighting system installed in this enclosed staircase. Staircase is completely dark during the night time. (c) Both artificial lighting and emergency lighting systems provided but lighting cover is missing. (d) Example of complete lighting systems which every staircase should have them.

iv. No Exit Signage.

In some of the high-rise residential buildings observed, there were no exit signs posted to show the way out or to lead the occupants to the escape stairs. In the By-Laws part VII clause 172, sub-clause (1) states that "*Storey exits and access to such exits shall be marked by readily visible signs and shall not be obscured by any decorations, furnishings or other equipment*" and sub-clause (2) stated that "*A sign reading "KELUAR" with an arrow indicating the direction shall be placed in every location where the direction of travel to reach the nearest exit is not immediately apparent*". There are some posted "KELUAR" signages at the storey exit (See figure 5.8 (a) and (b)) but there are still many buildings that did not have any signage to indicate the egress route. There will be problems for the person who is not really familiar with the building environment or to the first time visitors. In case of emergency, those people might not know the nearest escape stairs and this could pose a danger to them. Meanwhile sub-clause (3) states that "*Every exit sign shall have the word "KELUAR" in plainly legible letters not less than 150 millimetres high with the principal strokes of the letters not less than 18 millimetres wide. The lettering shall be in red against a black background*" and sub-clause (4) states "*All exit signs shall be illuminated continuously during periods of occupancy*."

(a)

(b)

(c)

(d)

Figure 5.14: (a) Exit signage about to fall down, (b) Corridor and staircase without any exit signage, (c) No exit signage at staircase, (d) Exit sign in white lettering with green background.

Even though there are exit signs posted at the storey exit, they are not specified as in sub-clause 3 i.e. the lettering shall be in red against a black background (see figure 5.9 (a) and (b), and figure 5.14 (a) and (d)). Those exit signs are white lettering with a green background and not illuminated at all times. Example of Illuminated exit signage is as in figure 5.15 (a). However there are buildings which posted exit signage exactly as specified in sub-clause (3) as in figure 5.15 (b). However the use of white lettering with the green background is stated in Malaysian Standard (MS982) i.e. the specifications for fire safety sign, notice and graphic symbols for fire exit or emergency exit must be written in white lettering against a green background and shall be illuminated throughout the usage of the buildings.

Figure 5.13 (a) shows KELUAR sign that it is about to fall down from the ceiling though lack of maintenance. If it fell down and at the same time as there are people walking underneath, it could result in casualty or death.

Regarding the sign lettering colour and background used is a secondary issue. As long as people understand the purpose of it existence, that is sufficient. Therefore the existing By-Laws should be emended to make it relevant with the current practice or Malaysian Standard which is more current than the By-Laws. If not, enforcements by the relevant authorities are needed to ensure all rules and regulations are followed. Figure 5.15 (a) and (b) comprise both scenarios i.e. KELUAR sign as discussed above. KELUAR sign in figure 5.15 (a) is more appropriate to be used because in the event of fire, smoke might enter the corridor. If a black background is used for the exit sign, there is not enough contrast. However the sign must have pictograms employing the running man, an open door, and directional arrows. These pictograms may be augmented by the text signs, but text only signs are no longer acceptable on their own.

(a)

(b)

Figure 5.15 (a) Illuminated KELUAR sign of white lettering with green background
(b) KELUAR sign of red lettering with black background

5.5.3 Maintenance

Regular maintenance is very important. Whatever maintenance systems they want to use are a secondary issue. The main issue is maintenance should be done to ensure that all building elements and services equipment are in place and ready to be used when needed.

i. Fire suppression systems insufficiently maintained.

Regular maintenance is essential to ensure all fire suppression systems are ready to use when needed. There are three types of fire suppression system commonly provided in the high-rise residential building i.e. portable fire extinguisher, dry riser or wet riser systems. From the observations, it is found that fire suppression systems like dry riser, have a problem at a component called inlet breaching, used to connect the system to the fire engine for water supply to the entire building. The inlet breaching is normally located at the ground floor either with two or four water intake valves. The usual problem was either this inlet breeching was broken or blocked with something due to vandalism.

(a) (b) (c)

Figure 5.16: (a) Fire suppression systems i.e. hose reel, hose cradle, portable fire extinguisher and wet riser with landing valve fitted on it.
(b) Only dry riser left without landing valve and canvas hose dumped.
(c) Compartment to put fire suppression systems has been turned in to a cleaner's cupboard.

ii. Lighting system insufficiently maintained.

The illumination system is a very important feature in escape route (corridors or similar) and escape stairs. The escape stair is a part of the escape route by definition, that it is part of a vertical evacuation process. Even though there is a lighting system installed in the escape route, the location was either on the wall near to the ceiling or on the ceiling. Some of the lighting systems are not sufficiently maintained as in figure 5.13 (a) and (b). In the building observed, most of the lighting in the corridor was installed on the ceiling. When fire breaks out, smoke will fill up the upper part of the corridor and gradually spread downwards until the entire area is filled up with smoke. This will restrict the light from reaching the floor and poses a difficulty to the evacuees to see during the evacuation especially at night. Visual incapability will definitely reduce the walking speed in the evacuation process. Therefore sufficient lighting system in the escape routes needs to be assured during periods of occupancy. Alternatively an illuminated strip applied on the floor along the evacuation path and/or on the wall near to the floor edge will be able to provide a sufficient guide to the escape stairs.

iii. Fire doors insufficiently maintained

(a)

(b)

Figure 5.17: (a) Broken fire door lied down on the floor.
(b) Missing fire door

There are a number of cases where fire doors in high-rise residential buildings observed were broken. Some of them were left on the floor and others left in the stairwell. Those broken doors if not replaced will pose a significantly high risk to the building's occupants in the event of fire. Smoke containing fatal substances which can kill if exposed over certain time periods (depending on the degree of toxicity) can penetrate into those escape stairs with broken fire doors. The reasons why those fire doors are broken are unknown. There are two possibilities that might have caused this to happen i.e. aging or vandalism.

Figure 5.17 (a) shows the broken fire door left on the floor. Figure 5.17 (b) shows broken fire door laid against the wall with the top cover of the door hanging down.

(a)

(b)

Figure 5.18: (a) and (b) Show fire doors with a broken automatic door closer device

(a)

(b)

Figure 5.19: (a) One of the door hinge screws loose, causing the door to stick on the floor.

(b) One of the door hinges went missing, causing the door to stick on the floor.

Figure 5.18 (a) and (b) show fire doors with broken automatic door closer devices. It has caused these doors to hardly open because the broken door closer devices prevent the door from being open. Friction between the door leaf and the broken automatic closer (see figure 5.18 (b)) has caused the defect on the door. A certain amount of force is needed to push the door open. It defeats the purpose of having an automatic door closer when the door is hard to open and when opened remains so.

(a)

(b)

(c)

Figure 5.20:

(a) Fire door with missing doorknob.

(b) Type of doorknob supposed to be on the door.

(c) Other door with missing doorknob.

(d) Door with missing doorknob too.

(d)

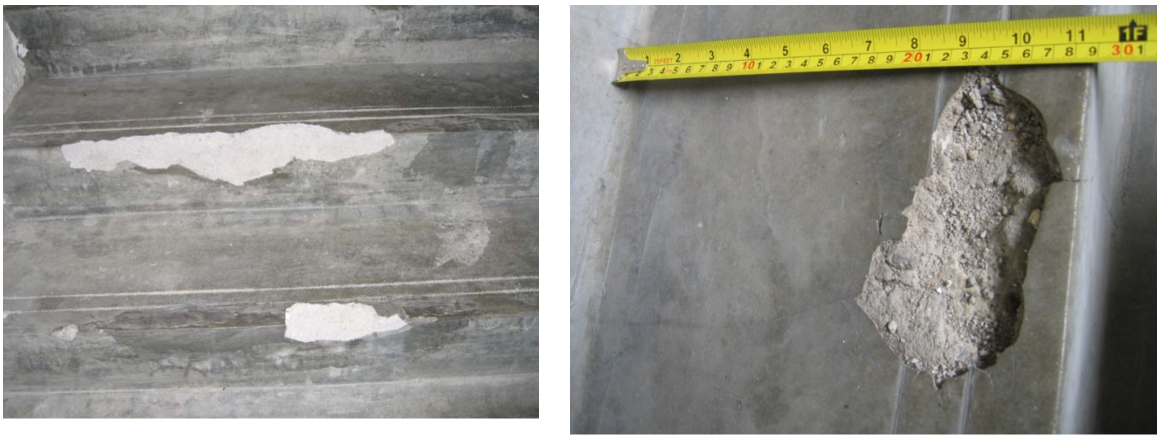
There were a few cases where door hinge screws were loosed and caused the door to stick on the floor. Another case is a door hinge missing and the door left hanging on two hinges instead of three. It has caused the door to be unbalanced and stick on the floor (see figure 5.19 (a) and (b)). We need to push the door to open or to close it. This may pose a significantly higher risk to the building’s occupants if fire breaks out. The consequences of the door being unable to close properly is that smoke can go in into the stairwell, and occupants may be trapped, traffic congestion, etc. A possible result of those consequences is fatality or injury to those living in these buildings.

Another problem related to lack of fire door maintenance is a missing doorknob. The reason why a number of fire doors were missing their doorknob is unclear. Observing the condition of the doorknob hole, it seems that it has been removed by someone knew how to do it because the hole is undamaged. It might have been removed on purpose. Figure 5.20 (a), (c), and (d) show examples of those fire door with the doorknob missing. Figure 5.20 (b) shows the type of doorknob supposed to be on it. This type of doorknob is similar to the one used in the residential flats in the same building.

There is significantly high risk associated with having a fire door in this condition where it defeats the purpose of the fire door. It is unable to serve as a smoke barrier as it is supposed to because smoke can penetrate through the open hole and the door itself can not be properly closed, hence, smoke and heat easily enter the escape stairs.

iv. Staircase insufficiently maintained

Good condition of escape stairs is very important in evacuation process. Therefore all escape stairs need to be maintained in a reasonably good condition and safe to be used at all times. There are five main components of staircase design i.e. tread, riser, intermediate floor, landing floor and handrail, and it is necessary to keep them in a reasonably good condition. If not, risk of casualty is high to those who use them, especially in emergency situations where everybody is in a hurry to evacuate the building. Among the casualties or fatal accidents that could happen are people falling down from the staircase.



(a) (b)

Figure 5.21: (a) Staircase with broken tread nose.

(b) Hole on staircase step.

(c)

(d)

Figure 5.21: (c) Staircase with broken handrail.
(d) Staircase with missing balustrade guards.

(a)

(b)

(c)

Figure 5.22: (a) Uneven staircase tread and rise

(b) Defect on the emergency metal staircase.

(c) Broken tread nose.

The most common problem is as in figure 5.21 i.e. tread nose broken, hole on tread, broken handrail, balustrade safety guards, etc. There are cases of poor staircase workmanship where the staircase is constructed unevenly as in figure 5.22 (a). Furthermore, if it was not built according to the specification ruled out in Building Regulation i.e. tread dimension less that 255mm and some steps rise more than 180mm. Lack of maintenance on the staircase could result in a significantly higher risk of people falling down during the evacuation process, especially when a large number of people are evacuating the building at the same time.

Some of the buildings are provided with metal emergency staircases. The main problem with a metal staircase is rust which has caused the staircase to be seriously corroded (see figure 5.22 (b)). In the tropical climate, with high moisture, metal is inevitably corroded if maintenance is not regularly completed.

5.5.4 Attitude of people.

There are two things associated with the people's attitude i.e. good or bad. Good attitudes will normally result in a good outcome. In contrast is a bad attitude. Bad attitudes of people, when living in high-rise residential buildings, can create problems and jeopardise the safety of others. Among the behaviour that can be considered as bad attitudes are selfishness, insensitivity to the environment, abuse, vandalism, etc. This misbehaviour can create obstructions in escape route of different sorts. Among the interruptions in the evacuation process that may be caused by attitudes of people are obstacles in escape route, dumping rubbish in escape stairs, purposely denying access to escape stairs and vandalism.

i. Obstacles in escape route.

All escape routes should be cleared from any form of obstacles or any obstructions that can delay the evacuation process. Escape routes in high-rise residential buildings consist of corridors, passageways, staircases, lobbies, internal circulation areas for the occupants to access their flats, etc. Those components must be clear from any form of obstruction such as iron grills, items stored in passageway or corridors, dumping rubbish, etc. If these things happen, it will significantly impede the evacuation process.

The outcome if evacuation process is interrupted is increased the risk of being trapped if fire breaks out. The result could be human casualty or fatal injury. This will be catastrophic to those involved in fire tragedy. Figure 5.23 shows one of the residential flats fitted with double locks (padlocks) an iron grill at the main door. A very common iron grill fitted at the main door of every residential flat is as in figure 5.23 (b). In addition to being an extra security measure, it creates an unnecessary obstacle and increase the risk of been trapped in the event of fire. There is a case where five members of a family perished in a fire because they were trapped inside their flat in a fire tragedy[4]. Neighbours of the affected family attempted to rescue them but were unable to break through because of a securely locked grill fitted at the main door. When the fire brigade arrived at the scene, it was too late (NST, 2001).

Figure 5.23: (a) Double lock iron grill, (b) Iron grill fitted at the main doors, (c) Items placed in corridor, (d) Iron grill built-up beyond the property limit.

Obstruction to the evacuation process can happen if occupants put some of their items in escape routes. Figure 5.23 (c) shows some occupant's belongings stored in a corridor outside his flat. Figure 5.24 (a) and (b) show a bicycle, a motorcycle and furniture placed in a stairwell and corridor respectively.

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[4] Reported in The News Straits Times 15th January 2001 i.e. five family members perished in a pre-dawn fire occurred on Sunday 14th January 2001 at City Hall's Sri Kelantan Flats in Sentul, Malaysia.

(a) (b)

Figure 5.24: (a) A bicycle placed in stairwell, (b) a motorcycle and furniture placed in corridor.

(a) (b)

(c) (d)

Figure 5.25: (a) Flower pots placed in corridor; (b) some flower pots placed in landing area of staircase; (c) Some flower pots placed on staircase; (d) Flower pots in landing area of staircase.

Figure 5.25 shows how some of the residents have placed their flower pots in the corridor, on the staircase and on a landing floor. To green the earth is good but doing it in the wrong place is bad behaviour and uncalled for. Figure 5.26 shows some items left in the stairwell and some stored in the stairwell. Even if this is a temporary measure (i.e. left and stored), we can not take for granted that others will never use the staircase because lifts have been provided. We do not know when a fire will happen. If it happens, there is a significantly high possibility that occupants could be congested in corridors or staircases like these. These examples described above can be described as selfish and insensitive to the environment.

(a)

(b)

(c)

(d)

Figure 5.26: (a) Some items left in stairwell; (b), (c) and (d) Occupant's stored some belongings in stairwell.

ii. Escape stairs become a rubbish dumping site.

(a) (b)

Figure 5.27: (a) Unwanted sofa was dumped in stairwell; (b) Old mattress was dumped in stairwell;

(c) (d)

Figure 5.27: (c) and (d) Rubbish left in stairwell.

However, there are still cases where unwanted items are dumped in stairwells. Figure 5.27 shows examples of a few cases which not only embarrassed the whole community of the respecting building, but posed a high risk to people of being trapped, injured or a fatality if fire breaks out.

The evacuation process from these buildings is expected to be unnecessarily longer than it should be due to the obstructions caused by those items dumped in the escape stairs.

iii. Access to escape route denied (door locked)

The worst scenario is when fire doors are locked shut i.e. by padlock, slide-lock or tied-up with wire. Figures 5.28 and 5.29 are examples of fire doors fastened with different kinds of locking devices from the simplest i.e. tied-up fire door with a wire to the door frame, to the strongest i.e. padlock. Some use a slide-lock which can be opened to enter the escape stairs. However, the door can not be opened from the inside of the stairwell. The occupants may be able to enter the escape stairs at any time (if it is not fastened with the padlock) but rescuers can not access the floor level from the out side unless they are using an elevator.

For the doors fastened with the padlock or permanently tied-up with a wire, access to the escape stairs is absolutely denied. There is a significantly high risk to those staying at the floor level where those fire doors are fastened with any kind of locking devices. They might be trapped in the event of fire because they are facing an unnecessary difficulty to evacuate the building because fire doors are locked shut by a selfish person. The clear reason why they are locking the fire door is very doubtful because if they want to limit accessibility to the floor where they live, people are still able to access by the elevator provided in those buildings.

(a)

(b)

(c)

(d)

Figure 5.28: (a) and (c) Fire doors fastened with an unauthorised slide-lock; (b) Fire door fastened with a device that can be used to put on a padlock. (d) Fire door is firmly tied-up with a wire to the door frame.

(a)

(b)

(c)

Figure 5.29: (a) Fire door fastened with a slide-lock; (b) Fire door locked with a padlock; (c) Fire door tied-up with a wire to the door frame.

iv. Vandalism

New buildings normally are in a very good condition at first, where almost every fire safety component and equipment provided is in good working order. Fire doors, active fire suppression systems i.e. dry riser or wet riser, portable fire extinguisher, alarm systems, etc. are in a very good condition. Over time, once the buildings are occupied and a lot of people have moved in, the problems start to arise. Vandalism seems to take place where some of the equipment goes missing. Some are deteriorating not because of aging but because of vandalism i.e. figure 5.30 where a security metal plate has been removed from the door to give way to the locking devices to be illegally installed on the door leaf. A door handle i.e. located on the other side of the door, to pull the door to open, has been removed too, leaving two empty holes for the screws of the handle. This act of vandalism has caused the door to be difficult to pull out from the inside of the stairwell. Furthermore if the door is locked from the outside, any rescue operation i.e. rescuer or fire fighters might not be able to access the floor where a fire started.

Figure 5.30: Metal security plate from to avoid any locking devices from been fitted on the fire door has been removed by irresponsible person. This vandalism action has jeopardised the safety of others.

Another problem encountered was portable fire extinguishers going missing. Therefore, immediate action to put out the fire was not possible. Every floor should have a portable fire extinguisher stored near to the storey exit. If there are two storey exits, two portable fire extinguishers should be provided.

Figure 5.31: Portable fire extinguisher hanging on the wall.

Normally it will be put together with the other fire suppression system in the same cupboard as in figure 5.16 (a). Some may just be hanging on the wall near to the storey exit or in the middle of the building (see figure 5.31). Unfortunately, in some of the buildings observed, no portable fire extinguisher was provided. According to the respective building management, replacements had been made but they went missing again, hence the management had decided to put some portable fire extinguishers in the guard room at the main gate.

Figure 5.32: Fire doors have been vandalised by sticking all sorts of advertisements on it. Irresponsible persons have turned the fire doors to be a free advertisement billboard.

Figure 5.32 shows advertisement stickers posted on the fire doors. These fire doors have been turned into a free billboard for everyone to post their business advertisement and turned the fire doors into an ugly surface. Some fire door doorknobs as well have gone missing. They probably have been taken out by someone to replace their own and it leaves the fire door ineffective to provide a smoke barrier in the event of fire.

Fire suppression systems as in figure 5.16 (b) and (c) seem to be vandalised and can not be used any more. The landing valve for a dry riser system was missing and the hose was crumpled on the floor. The building is a high risk if fire breaks out. Existing fire suppression systems are not reliable any more and fire fighters have to carry the hose connected to a hydrant or fire engine at the ground floor to the place where the fire started.

5.5.5 Management

Management issues in managing high-rise residential buildings mainly can be categorised into four:

- Duty and responsibility,
- Inspection and rectification,
- Control and enforcement, and
- Feedback and response.

Management has a duty and responsibility to ensure the buildings are sound and safe for occupant's at all material times. Therefore they should inspect and rectify all building defects, replace or repair every faulty fire safety system and carry out regular maintenance as necessary. Control and enforcement needs to be firmly done to ensure that no one tries to abuse the situation. However, the management must respond to the tenant's complaints and appropriate measures are been taken upon receiving any feedback from the tenants.

i. Duty and responsibility

Internal circulation, escape routes i.e. corridors, escape stairs, lifts, lighting, smoke control and ventilation systems in circulation area and stairwell and parking facilities, public area outside the building and safe assembly area are the responsibility of the management to ensure that those are safe to be used at all material times. It becomes a duty of the management to maintain those components in relatively good condition and satisfy the Director General of Fire Services or the relevant Fire Authority.

ii. Inspection and rectification

If inspections have been carried out, any problems which arise can be rectified as soon as it been identified. Problems discussed early on the above sub-section could be solved if inspection and rectification are carried out. Building defects i.e. holes on tread, tread nose broken, handrail and balustrade guard missing, fire door locked, etc. will not be any problem any more. An inspection officer needs to be assigned to carry out an inspection on all the buildings under the same management. Alternatively, management can appoint a building audit firm to carry out an audit and report every year. By doing a building audit, recent data about the building and its condition can be updated, scheduled maintenance can be planned, budget can be allocated, building standard quality can be achieved, safety of people can be assured, corporate image can be maintained, etc.

iii. Control and enforcement

Some of the problems are caused by the people. Appropriate control measures need to be firmly taken and put in place. Any unauthorised modification on any building element i.e. extended iron grill beyond premises, illegal locking devices on fire doors, using fire safety cupboard as a cleaner cupboard, etc. have to be stopped immediately for the safety of people. Enforcement and stern action, after reasonable times have been given to the respective tenants, need to be taken to ensure all corridors and escape stairs are cleared from any kind of obstruction. If the respective tenants ignore the notice given to them, all obstructing items should be removed and destroyed. Any cost involved as a result from that exercise should be claimed from the respective tenants. Therefore, it can be assured that the fire safety objectives can be achieved.

iv. Response on feedback.

Management must duly respond to any feedback from the tenants. Any complaints should be investigated and appropriate action should be taken to rectify it as soon as possible. Feedback from the tenants can save management time and money. Encouraging them to lodge any problems arising to the manager's office can prevent the problem becoming serious. An appropriate notice should be give to those involved to let them know when these problems reported will be solved.

5.6 Chapter conclusion

Fire safety in high-rise residential buildings should be seriously considered to ensure the optimum safety of people as the highest priority by various parties such as building residents, professionals in the construction industries and relevant government agencies. They should play a vital role to ensure all fire safety aspects are maintained at a relatively high standard or at least at an acceptable standard set by the relevant authority. This can be done by not allowing any risk elements to be placed in the buildings during the building's occupation even though the intention of doing that is as an *extra security precaution* such as double locked iron grill, iron grill fitted beyond the owner's property, some items placed in the escape routes, etc. All obstructions should be removed soon after they have been identified. Some sort of enforcement determination should be imposed such as a fine penalty to those committed, removing and destroying all items placed beyond their boundary and passing and any cost involved for doing so to the respective flat tenant. This sort of ‘Hostile Education’ is effective at educating people with a bad attitude to make them understand the risk posed to other members of the community.

By understanding the consequences that residents will have to take if they did something that could have caused catastrophe to them and/or to others would help them to be more responsible about the fire safety in their own building. Therefore education and lessons concerning the impacts of fire, safety measures, necessary action to be taken if fire breaks out and the risks that residents of the high-rise residential buildings would have to take should be always been done from time to time.

There are proper places to put out all the unwanted items provided by the local authority. Every high-rise residential building has a rubbish collection centre for large items. Chute disposal systems are normally provided for domestic waste and regular collection is normally scheduled twice a week.

Table 5.1 gives an outline of the problems and consequences encountered in high-rise residential buildings based on the observational outcomes from a number of high-rise buildings in Malaysia.

Problem Categories	Problem Encountered	Actual Problems	Consequences
(1) Structural Design and Construction	No alternative escape routes provided.	Only one staircase provided.	Occupants might become trapped.
		Unable to escape through window because corridor designed detached from the flats.	Unable to escape from flats if other routes to the main door caught fire.
	Staircase specifications did not comply with the requirement.	Tread shorter than the minimum specification.	• Risk of slipping during the evacuation process. • Slows down the evacuation process.
		Step rise dimension exceeded the maximum specification.	Slows down the occupant evacuation speeds.
		Intermediate floor depth narrower than staircase width.	• Slows down the evacuation process. • Traffic may be congested.
	Corridor designed and orientation.	Open space or foyer-types corridor. (Tendency for tenants to abuse the space)	• Reduce spaces available for public use. • No smoke barrier. • Risk of smoke to filling up the entire areas.
		Corridor detached from the flats.	No escape through windows.
	No fire doors at the storey exit.	No smoke barrier.	• Smoke will enter the stairwell. • Escape stairs unsafe for use.
(2) Facilities for Fire Safety in Building	Smoke control systems incorrectly installed.	Smoke vents opening not sufficiently large.	• Smoke will fill up the entire enclosed corridor. • Smoke will enter the stairwell or escape stairs if fire door is broken.
		No smoke vent in the enclosed corridor.	
	Ventilation systems incorrectly installed.	Insufficient opening for natural ventilations in stairwell.	Concentration of fume and smoke in the corridor and stairwell.
	Illumination systems are not properly installed.	No artificial lighting installed in stairwell.	• Limits range of vision. • Difficulty in walking. • Risk of slipping on staircase.
	No emergency lighting system.	No emergency lighting systems in stairwell and corridor.	• Limits range of vision. • Will slow down the evacuation process. • Risk of casualty.
	Exit signage was not properly designed and installed.	No exit signage in corridor or on the storey exit.	Occupants might not know where to go in the event of fire.
		No illumination of exit signage.	Occupant might not be able to see the exit signage in the case of fire.
		Uneven illumination of exit signage.	

Table 5.1: Problems and consequences encountered in high-rise residential buildings

(3) Maintenance	Fire suppression systems were insufficiently maintained	No landing valve at riser outlet.	System useless.
		Missing canvas or rubber hose.	
	Lighting systems were insufficiently maintained.	Non replacement of broken/blown bulbs.	Lighting system useless.
		Dirty Luminaire.	Reduce intensity of light.
	Fire doors were poorly maintained	Broken fire door, automatic closer devices, and missing door handle,	• Door can not be closed properly. • Smoke penetrates into stairwell.
		Broken door hinge, door stuck.	Door can not be closed properly
	Staircases were insufficiently maintained.	Hole on tread, broken step nose,	Risk of slipping or falling
		Broken handrails, uneven tread and rise.	Problems for disabled and elderly people using the staircase.
(4) People's attitude	Obstacles in escape route.	Iron grill fitted at the main entrance.	• Occupants might be trapped inside. • Traffic might be congested. • Will slow down the evacuation process. • Obstructions evacuation of occupants. • Reduced corridor and staircase width.
		Furniture, flower pots, etc. left in corridor and stairwell.	
	Escape route has become a rubbish dumping site	Unwanted items left in stairwell.	
		Furniture left in stairwell	
	Access to the escape route denied.	Fire door locked	• Occupants may be trapped inside. • Rescuers will have difficulty rescuing occupants.
		Fire door hooked at door frame	
	Vandalism	Broken fire suppression system.	System useless or fails to function.
		Broken Fire door.	Smoke will enter the stairwell.
(5) Management	Lack of supervision during the construction period	Artificial lightings are not properly installed.	• Staircase dim or dark. • Difficulty in walking. • Risk of occupants falling.
		No fire doors at the story exit.	Smoke might enter the stairwell,
		Poor workmanship; tread and rise uneven.	• Risk of occupants to slip or fall down. • Traffic might be congested.
		Intermediate floor depth not equal to staircase width.	
	No regular inspection of the building.	Tenants abused public area.	• Reduced the available spaces. • Risk of trapping others. • Reduces corridor and staircase width. • Traffic might be congested. • Occupants might be trapped.
		Tenants left personal items in corridor or stairwell	
	Lack of control and enforcement.	Tenant built up grill beyond their property limit.	
		Personal items left in corridors	
	Insufficiently response to tenants' complaints.	No response to tenants' complaints.	Problems remain unsolved.
		No maintenance on escape route.	Risks of casualty to occupants.

Table 5.1 (Continue)

CHAPTER 6

HUMAN BEHAVIOUR RESPONSE ISSUES IN HIGH-RISE RESIDENTIAL BUILDINGS IN MALAYSIA

6.1 Introduction

Integration of human behaviour and structural design in high-rise residential buildings has become an important topic for study, but even though there has been growing research on human behaviour and awareness of fire safety in public and commercial buildings using response-based techniques, few studies have been carried out on residential buildings. In residential buildings, tenants come from various backgrounds and education levels from the lowest to the highest. Some may have proper training or may have attended fire safety courses, and some may have none. If fire breaks out in their building, what would they do? Do they know where to go and which route they should take to evacuate the building?

Understanding human behaviour in the region where the building is going to be erected for the residential purposes is equally important, and it will help in smoothing and shaping the decision making process. The reasons decisions are difficult and detailed analysis is necessary before any the decisions can be reached are basically influenced by four problem characteristics i.e. (1) Its complexity, (2) Level of uncertainties involved, (3) Conflict of interest where trade-off is necessary , (4) Parties involved in decision making have different perspectives on the method of problem solving (Henrik, 2001). This is particularly so when the decision makers are the occupants of a building in a fire situation, because every person has their own opinion and perception on everything. This opinion and perception may differ from one to another. Therefore, human perception and the actions that they are going to take in an emergency situation, i.e. fire emergency and evacuation process, need to be studied to enable the design of internal building circulation and escape routes e.g. escape stairs, and to model fire safety evacuation. This evacuation model can be formed and added as a sub-model to the main model proposed.

According to Bryan (2002), the recognition of occupants’ behaviour often identified in engineering investigations of major fire incidents had long been documented, but little study and analysis had been conducted to identify and determine the causal and principal variables involved. The question is what the factors are that most motivate occupants to evacuate if fire breaks out in their residential buildings? What are the factors that most influence their behaviour in evacuation processes? What is their choice of exit if they want to evacuate from high-rise buildings and what are their perceptions if they have seen fire cues or heard a fire alarm sounding?

Fahy and Proulx (1996), have conducted studies of the occupants' actions in building fires. They then grouped people's behaviour into the broader categories; (1) *investigate,* (2) *seek information,* (3) *prepare to evacuate,* (4) *alert others or report incident,* (5) *assist others,* (6) *seek refuge, and* (7) *wait*. A study by Canter (1990) on the survivors of residential fires in the UK revealed similar patterns.

In this chapter discussions are centred on the perceptions and actions that occupants of high-rise residential buildings are likely to take when they see fire cues or hear the fire alarm go off; the motivating factors which trigger the evacuation process; the choice of exit and evacuation behaviour; and factors that most influence human behaviour during the evacuation process.

6.2 Brief of research methodology

In this research structured questionnaires are used to collect data. Among the important points to identify and analyse are; the action that the residents will take when they see the fire cue or cues, and when they hear a fire alarm sound. What are the factors that most motivate them to evacuate the building in a building fire, their choice of exit and evacuation behaviour and factors most influencing their behaviour during the evacuation process.

6.2.1 Data Analysis

SPSS is used to analyse all the questionnaires using "frequency analysis" of variables and "comparison of means" analysis. Frequency analysis is used on the first two questions when respondents were asked to rank 1 to 12 the variables that they are likely to do first according to priority, 1 being the most likely to do first and 12 the least likely to do. Comparison of means analysis is used on the other four questions when respondents are asked to use their best ability and knowledge to indicate by circling the appropriate grades 1 to 5 in Likert scale meaning as follows: 1 = Strongly Disagree, 2 = Disagree, 3 = Uncertain, 4 = Agree, and 5 = Strongly Agree.

Respondents are grouped into four groups i.e. respondents having higher education have at least diploma until Ph.D., having only a school certificate, having attended a fire safety course, and those who have never attended any fire safety course.

6.2.2 Frequency Analysis

For the first two questions, data was analysed using a matrix analysis technique. All variables are listed and percentage frequency score assigned on the ranking number 1 to 12. First priority is given to the highest score across the board on horizontal line then followed by vertical line. If the highest percentages fall on both line, i.e. horizontal and vertical, it will be the place that respondents want it to be. For example, in table 6.1, variable 1 i.e. immediately evacuate from the building, percentage among the ranking was the highest at ranking 1, i.e. 44.3% and among the variable as well it was the highest i.e. 44.3%, then, this variable will be place at ranking 1. For variable 2, i.e. Activate fire alarm e.g. break glass, on horizontal analysis, the highest score was at ranking 2 i.e. 24.3% but on vertical analysis at ranking 2, the high score was for variable 3, i.e. 30.4%. But when analysed horizontally on variable 3, it has the highest score at ranking 3, i.e. 34.8% and on vertical analysis at ranking 3 as well it has the highest i.e. 34.8%.

Rank	Variables	Variables Ranking (%)											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Immediately evacuate from the building.	44.3	27.0	3.5	7.0	6.1	6.1	6.1	0	0	0	0	0
2	Activate Fire Alarm e.g. Break Glass.	14.8	24.3	15.7	14.8	5.2	17.4	6.1	0.9	0.9	0	0	0
3	Call 999/Fire Brigade/Police.	15.7	30.4	34.8	3.5	13.0	0.9	0.9	0	0	0	0	0.9
4	I will try to put out the fire.	1.7	1.7	6.1	8.7	20.0	11.3	18.3	7.8	16.5	3.5	2.6	1.7
5	Helping others with evacuation.	0	1.7	23.5	16.5	14.8	21.7	8.7	3.5	3.5	5.2	0	0.9
6	Shout "FIRE" to alert the others about the fire.	7.0	9.6	10.4	17.4	13.0	9.6	13.9	15.7	2.6	0.9	0	0
7	Try to save as many as possible of my valuables.	2.6	1.7	1.7	15.7	11.3	23.5	20.09	6.1	12.2	4.3	0	0.9
8	Investigate what caused the fire alarm to go off.	4.3	0.9	3.4	10.4	11.3	4.3	14.8	22.6	11.3	8.7	4.3	3.5
9	Curious and asked neighbour about what had happened.	8.7	0.9	0	5.2	7.0	3.5	10.4	27.8	27.0	7.0	0.9	1.7
10	Stay in my own unit hoping that other peoples will put out fire.	0	0.9	0	0	0	0	0	1.7	7.0	23.5	51.3	15.7
11	Just Wait, if other people started to evacuate then I will evacuate.	0.9	0.9	1.7	1.7	0.9	0	0.9	13.0	13.9	42.6	22.6	0.9
12	Go and stay in my neighbour's unit.	0	0	0	0	0	0	0	0.9	5.2	4.3	16.5	73.0

Table 6.1: Overall response from respondents when they have seen fire cues.

It is evident that respondents wanted the variable 3 to be placed either at ranking 2 or 3, but strong evidence shows that respondents wanted it to be placed at ranking 3 instead of 2 and variable 2 place at ranking 2 then. For variable 5, horizontal analysis shows that the highest score was at ranking 3 i.e. 23.5%, but vertical analysis at ranking 3, it was the second highest where the highest score was for variable 3. Because priority has been set that horizontal analysis will be the first priority, then variable 5 as well place at ranking 3, so in this case there are evident that both variables, i.e. 3 and 5, respondents wanted its to be placed at the same ranking. The same method of analysis was also used for those four categories of respondents. Because there are scenarios where more than one variable occupied the same ranking and there are scenarios where the same variable can be placed at two different rankings, i.e. variable 3 and 9, and there are scenarios where ranking has not got any variable on it, i.e. ranking 7, normalisation of data on analysis results had to be completed.

6.2.3 Normalising data

Because the data analysed has some gaps, normalisation of data is essential in order to reduce them. Normalisation is achieved by listing again all ranking positions of the variables analysed from all respondents in one table and running frequency analysis again to finalise the most popular ranking position of all variables.

Rank	Variables	Respondents catagories (Ranking)								
		A	B	C	D	E	F	Weightage	Priority	Legend
1	Immediately evacuate from the building.	1	1	1	1	1	1	High (100,000)	High: Rank 1 – 4; Medium: 5 – 8; Low: 9 – 12	A = All respondents B = High Education C = Have Attended Fire Safety Course D = Lower Education E = Never Attended any Fire Safety Course. F = Conclusion of ranking analysis
2	Call 999/Fire Brigade/Police.	2	2	2	2	2	2			
3	Helping others with evacuation.	3	3	5	3	3	3			
4	Try to save as many as possible of my valuables.	4,7	7	7	4	4	4			
5	Activate Fire Alarm e.g. Break Glass.	6	4	4,6	6	6	6	Medium (1,000)		
6	I will try to put out fire.	7	7	7	7,8	7	7			
7	Shout "FIRE" to alert the others about the fire.	8	3,7	4	7	7	7			
8	Investigate what caused the fire alarm to go off.	8	8	8	1,8	8	8			
9	Curious and asked neighbour about what had happened.	8	9	9	8	8	8			
10	Just Wait, if other people started to evacuate then I will evacuate.	10	10	10	10	10	10	Low (10)		
11	Stay in my own unit hoping that other peoples will put out fire.	11	11	11	11	11	11			
12	Go and stay in my neighbour's unit.	12	12	12	12	12	12			

Table 6.2: Normalisation variables gap.

For example, in table 6.2, the variable 'Immediately evacuate from the building' is placed at ranking 1 because all respondents' categories placed it in ranking 1. Some variables e.g. 'I will try to put out fire', some respondents put it in ranking 4, 5, 7, and 8, but the majority of them i.e. 3/5 or 60 % have put it at ranking 4, then this variable will be placed at ranking 4. The same method of normalisation is applied to the rest of variables.

6.2.4 Variables Priority and Weightage

Not all fire safety variables are equally important, therefore, priority and weightages are needed to express the importance of each attribute compared with the others. It is a key component of fire safety and risk evaluation. In this regard, priorities are set at three levels i.e. High Priority are those variables ranked at 1 to 4, Medium Priority are those variables ranked at 5 to 8, and Low Priority are those variables ranked at 8 to 12. Weightings are assigned to variables to reflect the level of importance of each variable. It is done by measuring the risk involved or the catastrophic devastation to the people or building contents if fire breaks out. Using the indication that at the bottom line of 'Risk Zero', with the assumption that low priority having a potency of possibility of at least 10% safe if this variable followed because in the real world, there is no such things as 'Zero Risk'. Not clear Medium priority having a potency of 100 times more importance than low priority and high priority having a potency of 100 times more than the medium priority. Table 6.2 shows the weightings assigned to the variable ranking.

6.2.5 Analysis of means

Means analysis is done on the basis that the overall score point calculated and the average is taken to indicate the significance level of variables. Using a Likert scale 1 to 5, variables are then grouped together in three priority groups i.e. High, Medium and Low. High priority group if variables' means are having a value of 4.0 to 5.0, Medium priority, 3.0 to 3.99 and Low priority, 0.0 to 2.99. As mentioned above, in the Likert scale, 5 is "Strongly Agreed", 4 is "Agreed", 3 is "Uncertain", 2 is "Disagreed" and 1 is "Strongly Disagreed"

6.3 Buildings studied

Five high-rise residential buildings in Malaysia were selected to participate in this study. These buildings were selected based on the criteria set in the research scope. Among the criteria are; it must be at least five storeys or above, at least 80% of residential units are occupied, and located in urban or near to the urban area with mixed occupancy i.e. variety in educational background expected, and having differences in orientation layout. For reasons of confidentiality, the buildings observed are named as Building A, B, C, D, and E. Every residential unit in these buildings was served with a questionnaire through their post box with a date and time set to collect them back. Out of 360 questionnaires sent out to the five selected high-rise residential buildings in Malaysia, 115 were returned. 360 questionnaires were sent out based on the numbers of residential units in these five buildings. On average, about 31.9% of the residents in each building returned their questionnaires. This figure was achieved after some follow-up had been made and some of them answered the questionnaire in person.

6.4 Respondents' Background

The respondents' backgrounds were analysed based on four categories i.e. gender, age groups, knowledge and experience, and education background. The age groups are divided into four groups i.e. young people, aged between 15 and 30 years old, middle aged people between 31 and 40 years old, upper age people between 41and 50 years old, and old people aged above 50 years old. The knowledge and experience means knowledge of fire safety i.e. respondents who had attended a fire safety course of at least one day, experience refers to respondents who had experience of a fire drill and/or experience of being involved in a building fire.

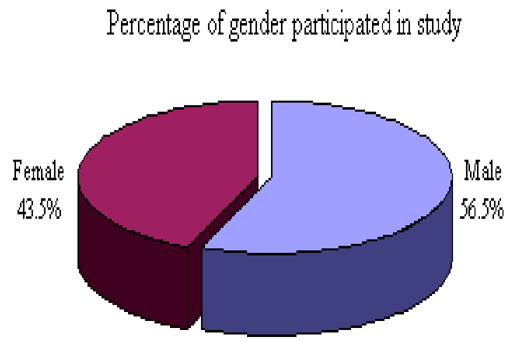
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	2	1.7	1.7	1.7
	3	9	7.8	7.8	9.6
	4	20	17.4	17.4	27.0
	5	15	13.0	13.0	40.0
	6	24	20.9	20.9	60.9
	7	4	3.5	3.5	64.3
	8	20	17.4	17.4	81.7
	9	1	.9	.9	82.6
	10	8	7.0	7.0	89.6
	12	11	9.6	9.6	99.1
	15	1	.9	.9	100.0
	Total	115	100.0	100.0	

Table 6.2.1: The number of people per flat in high-rise residential buildings in Malaysia

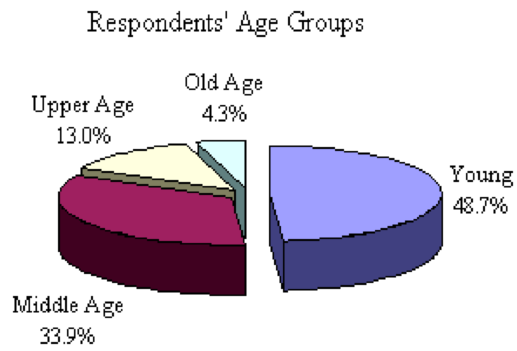
The number of people occupying the high-rise residential building in Malaysia ranges from 2 to 15 people per flat. Majority is 6 people per flat (20.9%), followed by 4 or 8 people per flat (17.4%), 5 people per flat (13%), 12 people per flat (9.6%), 3 people per flat (7.8%), 10 people per flat (7%), 7 people per flat (3.5%), 2 people per flat (1.7%) and 9 or 15 people per flat (0.9%). Table 6.2.1 shows the number of people per flat in high-rise residential buildings in Malaysia

6.4.1 Gender

From 115 respondents, the majority of respondents who answered the questionnaire are male (56.5%), with 34.5% female. Figure 6.0a shows the proportion of each gender who returned the questionnaire survey.



(a)



(b)

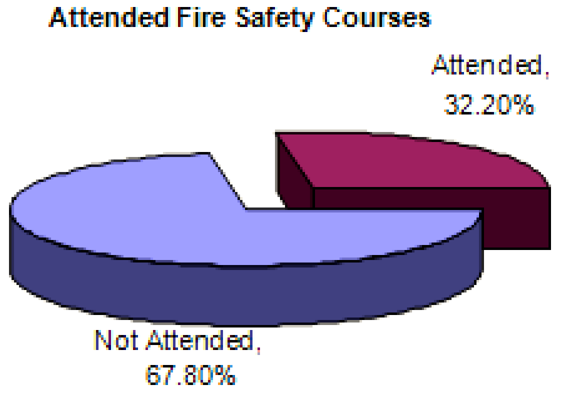
Figure 6.0: (a) Percentage of gender; (b) Respondents' age groups

6.4.2 Age groups

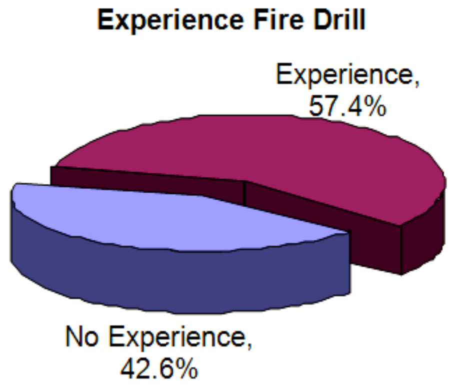
Among those respondents who answered the questionnaire, the majority of them (48.7%) are in the young group i.e. age between 15 to 30 years old followed by the middle age group (33.9%), upper age (13.0%) and old age (4.3%) as shown in Figure 6.0b. The research findings will be discussed further in section 6.5 and 6.6 below.

6.4.3 Knowledge and experiences

Respondents were analysed based on their knowledge of fire safety i.e. those who have or have not attended any fire safety course, and who have experience of a fire drill or a building fire. The minimum course is at least one day seminar conducted either during school or at work place. The majority of them had never attended any fire safety course i.e. 67.8%; only 32.2% of respondents had attended a fire safety course. Figure 6.1 (a) shows the percentage of respondents who have or have not attended any fire safety course. Further analysis of variables in the questionnaire will be based on these groups of respondents. Some of the respondents had experience of a fire drill and some never had any experience of a fire drill. Experience in fire drill may help them to react in an appropriate manner when in a fire emergency situation.



(a)



(b)

Figure 6.1: (a) Respondents who Have or Have Not attended fire safety course; (b) Respondents fire drill experience.

Figure 6.1 (b) shows that the majority of respondents i.e. 57.4% had experienced a fire drill and 42.6% had not. Out of the percentage that have an experience of a fire drill, 41.7% had the fire drill at their office, 10.4% during the school day or at college, 5.2% in a public building and none of them had an experience of a fire drill at their residential buildings (See figure 6.2).

Respondents were also asked about their experience of a building fire. The majority of the respondents (79.1%) had no experience of being involved in any building fires (see Figure 6.3).

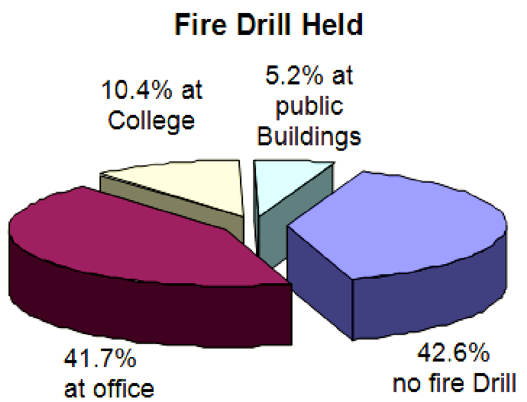


Figure 6.2: Where was fire drill held

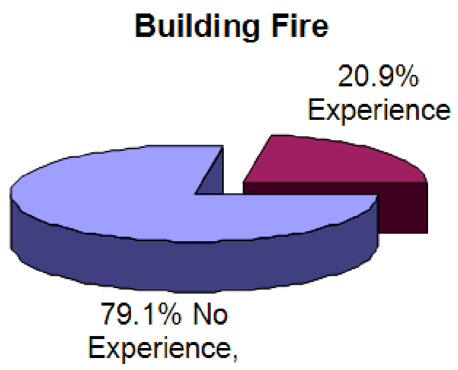


Figure 6.3: Respondents experience fire in building

6.4.4 Education background

There are six categories of respondents grouped according to their education level, from the lowest i.e. without any certificate until the highest i.e. doctorate. Figure 6.4(a) shows the proportion of respondents at each education level. However for analysis purposes, respondents were regrouped again into two groups. Group one is respondents with high education i.e. minimum education level is diploma until doctorate, and group two is respondents with lower education with maximum only school certificate.

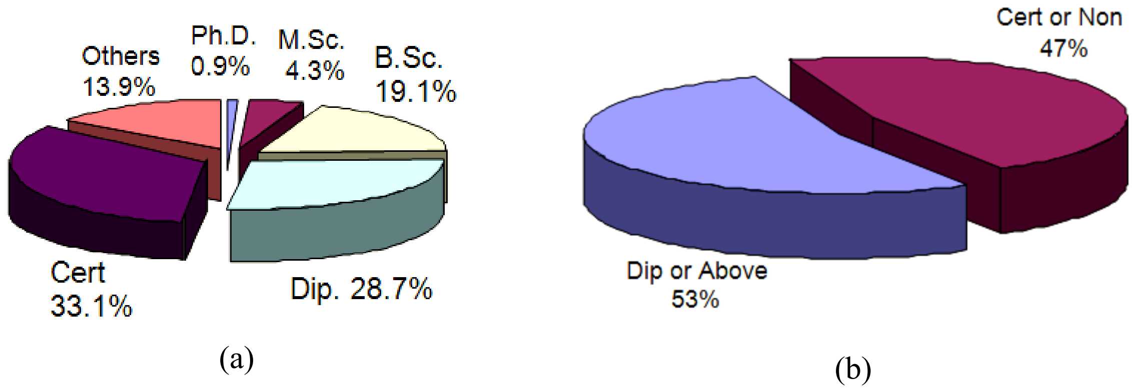


Figure 6.4: (a) Respondents' education Background, (b) Regrouped Respondents' education background

In total 115 respondents participated in this study and 53% of the respondents are in group one and 47% respondents are in group two. Figure 6.4(b) shows the percentage of respondents in the new group.

6.5 Questionnaire survey results

6.5.1 What would occupants of high-rise residential building normally do when they hear fire alarms or see fire cues?

Occupants in high-rise residential buildings normally attempt to evacuate the building in a building fire, but if the fire and smoke conditions are very bad and it is not possible to do so, then they may have no choice but to return to their respective apartments, or seek refuge in other apartments, and wait for the fire fighters to rescue them (Yung *et. al*., 2001). The main problem encountered in evacuation processes is when smoke enters into an escape route through a broken fire door and/or through the gaps between the door and floor or the door and door frame. Another problem is traffic congestion during evacuation processes (Yatim, 1999). Evacuation from a building fire could be fully successful if occupants have been given early warning about the fire before it becomes uncontrollable.

From this opinion survey 40.9% of the occupants of a high-rise residential building, when asked what they would do first if the fire alarm went off, said that they would immediately evacuate the building, 22.6% said that evacuation is the second thing they would do after they had done something else (e.g. call 999 or try to put out the fire before evacuation), 8.7 % said evacuation is the third thing they would do after they have done two other things, 10.4% ranked the evacuation in fourth place, 7.8% said evacuation would be a fifth place, 3.5% said it would be at the priority six and 6.10% ranked it at seventh. i.e. 59.1% of the occupants would do something else before evacuating the building.

When asked what they would do first if they saw fire cues i.e. smoke, flame, 55.7% said they would do something else before evacuating the building and 44.3% said that they would immediately evacuate the building (see table 6.3 and 6.4). Therefore, early fire warning is essential to help the occupants and to give them ample time to evacuate.

Rank	Variables	Variables Ranking (%)											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Immediately evacuate from the building.	40.9	22.6	8.7	10.4	7.8	3.5	6.10	0	0	0	0	0
2	Activate Fire Alarm e.g. Break Glass.	7.8	15.7	14.8	17.4	7.0	18.3	12.2	1.7	4.3	0	0	0.9
3	Call 999/Fire Brigade/Police.	19.1	37.4	19.1	6.1	12.2	3.5	0.9	1.7	0	0	0	0
4	I will try to put out the fire.	1.7	2.6	5.2	5.2	14.8	13.0	20.0	12.2	13.0	8.7	0	3.5
5	Helping others with evacuation.	0	1.7	27.8	13.0	16.5	22.6	7.0	2.6	2.6	6.1	0	0
6	Shout "FIRE" to alert the others about the fire.	7.0	7.8	9.6	13.9	10.4	8.7	17.4	15.7	7.0	2.6	0	0
7	Try to save as many as possible of my valuables.	3.5	2.6	4.3	19.1	13.9	16.5	19.1	7.0	9.6	2.6	0	1.7
8	Investigate what caused the fire alarm to go off.	9.6	1.7	7.0	8.7	11.3	4.3	10.4	20.9	11.3	9.6	3.5	1.7
9	Curious and asked neighbour about what had happened.	9.6	2.6	1.7	5.2	7.0	9.6	5.2	25.2	23.5	8.7	0.9	0.9
10	Stay in my own unit hoping that other peoples will put out fire.	0	0	0	0	0	0	0	0	7.8	22.6	53.9	15.7
11	Just Wait, if other people started to evacuate than I will evacuate.	0.9	5.2	1.7	1.7	0	0	1.7	12.2	19.1	32.2	22.6	2.6
12	Go and stay in my neighbour's unit.	0	0	0.9	1.7	0	0	0	0.9	1.7	4.3	16.5	73.9

Table 6.3: Percentage of variables ranking when alarm goes off

The level of fire safety that is provided to the occupants largely depends on how well the safety systems work. For instance if the fire alarm systems and fire suppression systems provided in the buildings were not checked or regularly tested for their efficiency and working condition, they might not work when needed. If they do not work properly or provide an inefficient service to the buildings' occupants, they might as well not be fitted.

Rank	Variables	Variables Ranking (%)											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Immediately evacuate from the building.	44.3	27.0	3.5	7.0	6.1	6.1	6.1	0	0	0	0	0
2	Activate Fire Alarm e.g. Break Glass.	14.8	24.3	15.7	14.8	5.2	17.4	6.1	0.9	0.9	0	0	0
3	Call 999/Fire Brigade/Police.	15.7	30.4	34.8	3.5	13.0	0.9	0.9	0	0	0	0	0.9
4	I will try to put out the fire.	1.7	1.7	6.1	8.7	20.0	11.3	18.3	7.8	16.5	3.5	2.6	1.7
5	Helping others with evacuation.	0	1.7	23.5	16.5	14.8	21.7	8.7	3.5	3.5	5.2	0	0.9
6	Shout "FIRE" to alert the others about the fire.	7.0	9.6	10.4	17.4	13.0	9.6	13.9	15.7	2.6	0.9	0	0
7	Try to save as many as possible of my valuables.	2.6	1.7	1.7	15.7	11.3	23.5	20.09	6.1	12.2	4.3	0	0.9
8	Investigate what caused the fire alarm to go off.	4.3	0.9	3.4	10.4	11.3	4.3	14.8	22.6	11.3	8.7	4.3	3.5
9	Curious and asked neighbour about what had happened.	8.7	0.9	0	5.2	7.0	3.5	10.4	27.8	27.0	7.0	0.9	1.7
10	Stay in my own unit hoping that other peoples will put out fire.	0	0.9	0	0	0	0	0	1.7	7.0	23.5	51.3	15.7
11	Just Wait, if other people started to evacuate than I will evacuate.	0.9	0.9	1.7	1.7	0.9	0	0.9	13.0	13.9	42.6	22.6	0.9
12	Go and stay in my neighbour's unit.	0	0	0	0	0	0	0	0.9	5.2	4.3	16.5	73.0

Table 6.4: Percentage of variables ranking upon seeing the fire cues.

PROFESSION: 1=Architec, 2=Engineer, 3=QS, 4=Contractor, 5=Fire Brigade Officer, 6=Developer.		RISK OF CASUALTY - LE - All fire suppression system checked and tested regularly	RISK OF CASUALTY - LE - Fire detection and alarm system checked and tested regularly
1	Mean	4.60	4.30
	Std. Deviation	.97	1.06
2	Mean	4.25	4.00
	Std. Deviation	.96	1.15
3	Mean	4.00	4.50
	Std. Deviation	.00	.71
4	Mean	4.00	3.75
	Std. Deviation	.82	.96
5	Mean	4.20	4.60
	Std. Deviation	.45	.55
6	Mean	3.00	2.00
	Std. Deviation		
Total	Mean	4.27	4.15
	Std. Deviation	.83	1.01

Table 6.5: Means analysis of Legislation and Enforcement of fire suppression and detection systems

Twenty six professionals involved in the construction industry e.g. ten Architects, four Engineers, two Quantity Surveyors, four Contractors, one Developers and five fire brigade officers, when asked about the importance of all fire suppression systems and fire detection systems installed in the high-rise buildings being checked and tested regularly, agreed or strongly agreed that legislation and enforcement are very important. The choice of professionals was based on those dealing with the fire brigade department in submitting a proposal for a new building plans for checking and approval of a fire safety features. Fire suppression systems and fire detection and alarm systems should be regularly checked and tested for working condition and ready to be used when needed. They were asked to give a score to every question i.e. 1 to 5, where 1 means strongly disagreed and 5 means strongly agreed. Analysis of means (Table 6.5) shows the question of fire suppression and fire alarm systems are 4.27 and 4.15 respectively.

Proulx, (1999), mentioned in her paper that occupants in public buildings are slow in deciding to evacuate and this contrary to what was mentioned by Sime, (1980), Keating, (1982), Donald and Canter, (1990) that occupants panic and rush to the nearest exit on hearing the fire alarm. Proulx said that in most cases the occupants continue with their activities in public buildings after the fire alarms go off. Among the factors that cause this lack of reaction is that there is no standard for the sound of fire alarm. The alarm sound would have been interpreted as pulsating, whoop, burglar alarm in shops, elevator fault alarms, security door alarms, etc.

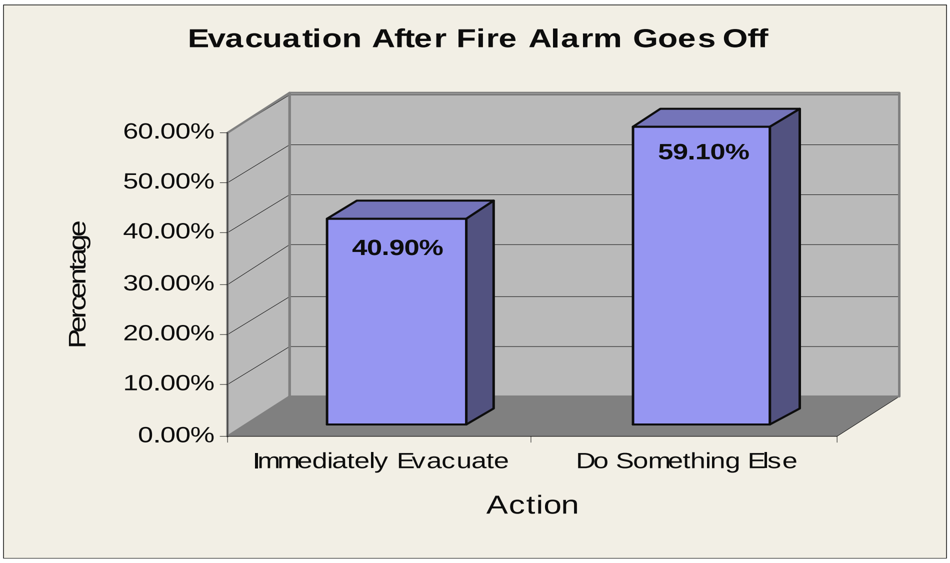


Figure. 6.5: Respondents' response when alarm goes off

This is in line with my survey to the residential building occupants that 59.1 % will do something else before evacuating the building and only 40.9% said they will immediately evacuate the building when a fire alarm goes off. This result came out after data been recoded i.e. 1 for the respondents who rated "immediately evacuate" as first choice and 2 for the respondents who rated "immediately evacuate" as second choice onwards (See figure 6.5). Out of 59.1%, 19.1% said they will call 999 first before evacuating the building. When asked about the factors that will most motivate them to evacuate, the fire alarm is in the third place in the list after announcement or command from the relevant authority and fire cues e.g. smoke, flame or heat (see table 1.5.4):

As Proulx (1999) said that "*They expect that someone will tell them what to do if something serious is really happening*".

In this respect fire safety awareness in high-rise residential buildings needs to be improved by means of educational approaches to emphasise the importance of immediately evacuating the building after the fire has been detected. Life is more important than saving possessions. A fire plan needs to be posted at a place where it is clearly visible and understood by all family members. Fire drills need to be carried out in high-rise residential buildings to familiarise the occupants with the evacuation process and procedure, to familiarise them with the escape route environment and the place to assemble after evacuating the building. Relevant legislation needs to be amended by inserting a clause that all high-rise residential buildings need to carry out at least one fire drill within three years.

6.5.2 Occupants' perception and behaviour during building fire.

One survivor of the Beverly Hills Supper Club's[5] fire in May 1977, Lise Bahannon, told NOVA[6] that at first she never realised that there was a fire because the alarm was not sounding. She just realised when she heard someone somewhat casually say "I don't know, somebody said it was a fire. I think we better get out of here". She thought it was worth trying and worth nothing to lose, and if nothing happened she would go back to continue her work. When she walked out through the door there were about 30 people already ahead of her going down to the door to the ground. At first she was calm but when smoke started to fill up and there has a huge burst of flame, people began to scramble to get out. There was a metal section in the middle of the doorway which one individual had his legs trapped around. It was very chaotic at the exit and a lot of people could not get out and were jammed in the exit door. She was very calm when she had exited the building, but once she began to think of her father, that's when panic developed and she had tried to go back into the building. Her father married and was in the building that day with his new bride and was sitting in her station. This fire tragedy has educated her not to ignore the fire alarm or tornado siren which she used to ignore by just saying "Ah, it will be over in a minute". She will reacts quickly whenever she hears any sort of alarm and instantly exits the building or whatever she has to do after this fire tragedy.

[5] Beverly Hills Super Club in Southgate Kentucky, fire broke out in evening 28th of May 1977 killing 164 people and many of whom are jammed in the exit doors as they tried to escape.

[6] See reference

People who stay in high-rise residential building are varied and there are differences in education level. If fire breaks out and they are able to react quickly and in a proper manner, they will have a better chance to save their lives. People's behaviour is unique and very often will be influenced by the surroundings where they live or an existing situation. In order to know and understand their behaviour, research was conducted by asking them to answer a few questions in a structured questionnaire. The following are the outcomes from the survey.

6.5.2.1 Upon seeing a fire cues

Item	Variables	Overall Ranking from Respondents	
		Ranking	Priority
1	Immediately evacuate from the building.	1	High
2	Call 999/Fire Brigade/Police.	2	
3	Helping others with evacuation.	3	
4	Activate Fire Alarm e.g. Break Glass.	3	
5	I will try to put out fire.	4	
6	Try to save as many as possible of my valuables.	5	Medium
7	Shout "FIRE" to alert the others about the fire.	6	
8	Investigate what caused the fire or fire alarm to go off.	8	
9	Curious and asked neighbour about what had happened.	9	Low
10	Stay in my own unit hoping that other peoples will put out fire.	10	
11	Just Wait, if other people started to evacuate than I will evacuate.	11	
12	Go and stay in my neighbour's unit.	12	

Table 6.6: Factors that occupants' going to do first if they have seen fire cues.

What are the occupants of high-rise residential buildings going to do first if they see fire cues in their building? Immediately evacuating the building became the first priority, followed by calling the fire brigade. However, calling 999 can be done concurrently especially nowadays when almost everyone has a mobile phone to hand. During evacuation they tend to help others with evacuation and activate the fire alarm, among the top priorities. Table 6.6 above listed out the factors that respondents would be likely to do according to priority.

6.5.2.2 When Fire Alarm Goes off

What are high-rise residential buildings' occupants going to do first if they hear the fire alarm activated? Table 6.7 below lists out what the occupants of high-rise residential buildings are going to do if they hear the fire alarm go off. Variables 1 to 4 are high priority, 5 to 9 are medium priority, and 10 to 12 are low priority. The top priority is to immediately evacuate from the building, followed by call 999, helping others with evacuation and trying to save as many as possible of their valuables.

Rank	Variables	Overall Ranking from Respondents	
		Ranking	Priority
1	Immediately evacuate from the building.	1	High
2	Call 999/Fire Brigade/Police.	2	
3	Helping others with evacuation.	3	
4	Try to save as many as possible of my valuables.	4	
5	Activate Fire Alarm e.g. Break Glass.	6	Medium
6	I will try to put out fire.	7	
7	Shout "FIRE" to alert the others about the fire.	7	
8	Investigate what caused the fire alarm to go off.	8	
9	Curious and asked neighbour about what had happened.	8	
10	Just Wait, if other people started to evacuate than I will evacuate.	10	Low
11	Stay in my own unit hoping that other peoples will put out fire.	11	
12	Go and stay in my neighbour's unit.	12	

Table 6.7: Factors that occupants' going to do first if they have heard fire alarm.

Meacham (1999) quoted Bryan as saying that the response to fire alarms and sounders tends to be less than optimum. Meacham concluded that the possibilities why people delay to response to fire alarm i.e. 30s to 24 minute (Proulx, 1994), because after occupants hear the alarm, six basic components i.e. recognition, validation, definition, evaluation, commitment, and reassessment take place in the decision process to decide what to do next. Some of the processes may occur concurrently and within a second. Some may take a few minutes to complete. However, the first thing first that they intend to do is immediately evacuating the building after the fire alarm goes off, but there is a delay time that called pre-movement time. A study by Proulx (1995), concluded that among the actions that had caused the occupants to delay to start their evacuation are; find pet, gather valuables, get dressed, find children, have a look at corridor and move to balcony (refer to table 7.1).

6.5.2.3 Perception when fire alarm goes off.

What are the occupants' perceptions when they hear a fire alarm go off or someone shout "FIRE" in their residential building? They will alert all members in their unit and other people in the building to immediately evacuate to the safe area. To them the alarm was genuine. The high priority for them is to evacuate the building because they think that the fire may spread into their own unit. Investigating what causes the fire is medium priority, and they believe that fire may spread into their own units. Table 6.8 shows the respondents' perception when they hear the fire alarm went off or someone shout fire. They do not think that the alarm is just a joke or it was a faulty alarm and strongly disagreed when asked about possibility that fire must not spread into their own units. Some said that they would like to wait a while if people started to evacuate, then they will follow them, but the vast majority of them strongly agreed that they will immediately evacuate from the building if fire alarm sounding.

Items	Perceptions	Analysis of Means	
		Overall	Priority
1	I will alert all people in my unit to immediately evacuate.	4.42	High
2	I will immediately evacuate to the safe designated area.	4.26	
3	That was a genuine fire alarm, I must evacuate immediately.	4.05	
4	The fire may spread into my own residential unit.	3.81	Medium
5	I will investigate before I evacuate from the building.	3.56	
6	The fire must spread into my own residential unit.	3.46	
7	Wait awhile if people start to evacuate, then, I will follow them.	2.71	Low
8	That was a faulty alarm or some one maybe plays a joke about fire	2.27	
9	The fire must not spread into my own residential unit.	1.84	
10	Fire did not pose any threat to my own unit	1.73	

Table 6.8: Occupants' perception when they have heard fire alarm or someone yelled "FIRE"

6.5.2.4 Factors most motivate occupants to evacuate the building in fire.

What are the factors that will most motivate the building occupants to evacuate if their residential buildings have caught fire? There are four factors that most motivate them i.e. Announcement from relevant authority such as fire brigade officer, police, building security, etc. second factor is fire cues i.e. smoke, flame or heat. The third factor is fire alarm or sounder and fourth factor is people moving out from the building. There are two factors which they are uncertain about, i.e. detected burning smell and insistence of people in their units. Table 6.9 shows the factors ranking based on the overall score of means from all the respondents who participated in this study.

Item	Factors Motivate Evacuation	Analysis of Means	
		Overall	Priority
1	Announcement or command from the relevant authority.	4.63	High
2	Fire cues e.g. Smoke, Flame, Heat.	4.55	
3	Fire Alarm/Sounder.	4.38	
4	People start moving out from the building.	4.09	
5	Detected burning smell	3.84	Medium
6	Insistence of the people in my own unit.	3.83	
7	None of the above.	0.66	Low

Table 6.9: Factors that will most motivate occupants' evacuation from building fire

6.5.2.5 Choice of exit and evacuation behaviour

What are the most popular exits chosen by occupants if they want to evacuate the building during fire emergency and what is their evacuation behaviour e.g. immediately evacuate, wait and see, attempted to put out fire, stay-in-place, etc. There are three choices that they are most likely to make during emergency situation i.e. they will use escape staircase instead of elevator, they will follow exactly the exit signage to the safe designated area, and they knew where the alternative escape stair was located. When asked about their familiarity of ways in and out of the building in evacuation, the vast majority of them were uncertain about that because in the high-rise residential building they normally use the lift to reach their residential unit. They would not use the lift even if they are familiar with it or because it is faster. They would not seek refuge or stay in place and remain in their unit and hope to be rescued. Table 6.10 shows the ranking factors in the evacuation process if the building has caught fire.

Rank	Factors choise of exit	Analysis of Means	
		Overall	Priority
1	I will use escape staircase to evacuate from the building.	4.59	High
2	I will follow exactly the exit signage to the safe designated area.	4.54	
3	I knew where the alternative escape stair is located, will use it.	4.36	
4	I knew exactly where the escape route was, will use it.	3.63	Medium
5	I will used my familiar way in out to evacuate from the building.	3.46	
6	I will choose staircase first, if it is crowded, then I will use elevator	2.95	Low
7	I will try to put out fire, if unsuccessful, then, I will immediately evacuate the building.	2.83	
8	I will choose elevator first, if it is out of service, I will use staircase.	1.90	
9	I will use elevator because I was familiar with it.	1.71	
10	I will use elevator because it is faster.	1.65	
11	I will refugee into my neighbourhood unit below the fire level.	1.53	
12	I will remain in my unit to be rescued by the fire man.	1.34	

Table 6.10: Ranking factors in evacuation process during building fire

They would not choose staircase then elevator or vice-versa, even though they are familiar with the elevator. The staircase becomes the first choice in all high-rise residential buildings in Malaysia. Therefore it is very important to ensure that all staircases in high-rise residential buildings are safe and sound to be used at any material time. Studies on staircase specification, design and layout are essential especially in the urban area where the density of high-rise buildings is overwhelming. Discussion on this aspect can be found in chapter 7.

6.5.2.6 Factors that highly influence the occupants' behaviour during evacuation from building fire

What are the factors that most influence the occupants' behaviour in escaping from building fire? Behaviour is defined as:

i. The state that occupants began to change their character from patient to impatient, calm to aggressive, etc.

ii. The state that people began to be irrational in any of their action like panic, wanted to return to their unit to rescue loved one, possessions, pets, etc.

iii. The state in which occupants start to become angry and so on.

From the survey it shows that the differences margin analysed of means are quite close. It can be said that there is no significant difference among the variables. However there are four factors that highly influence the occupants' behaviour i.e.:

i. Traffic congestion or escape stair crowded.

ii. Havoc cause by panicking occupants during evacuation process.

iii. Smell of burning materials, smoke or any fire cues.

iv. Number of people occupying the building.

Those factors score 4.0 and above and are classified as highly influencing people's behaviour. Table 6.11 shows those factors, as well as those close to the above four factors mentioned with average score 3.8 to 3.9 which are methods of fire door operating, size of escape stairs and corridors, smoke entering into escape route and people carrying too many and weighty possession during evacuation. From the opinion survey, a human behaviour model has been developed. Discussion on the human behaviour model's characteristics is included in the following section. Before further discussion about the human behaviour model can be done, a brief definition of human behaviour is essential.

Items	Factors in evacuation process during building fire	Analysis of Means	
		Overall	Priority
1	Traffic congestion or crowded at the escape stairs.	4.31	High
2	Havoc situation cause by the panicky evacuees.	4.26	
3	Smell burning materials, smoke or seeing smoke or flame.	4.01	
4	Numbers of people occupied the building	4.00	
5	Methods of fire doors operating e.g. door handle, direction of door swing, automatic door closer device, etc.	3.90	Medium
6	Size of escape stairs and corridors in the building	3.88	
7	Smoke entered into escape route	3.85	
8	People carrying too many and weighty possessions during evacuation	3.83	
9	Portable fire extinguisher does not work.	3.68	
10	Difficult to open the fire door or fire door stuck.	3.65	

Table: 6.11: Factors influence the occupants' behaviour during evacuation.

6.6 Human behaviour models

Human behaviour is defined as the collection of activities performed by human beings and influenced by culture, attitudes, emotions, values, ethics, authority, rapport, hypnosis, persuasion, coercion and/or genetics. Karl, (1947), mentions that human behaviour is inherited from generation to generation and mainly depend on the types of chromosome in their sexuality development.

Gender differences can cause the behaviour of sociological difference in daily life. This can form a physiological distinction and mental differences. Behaviour inherited from father and mother depends on the type of chromosome, i.e. X and Y, which besides develop the sex of the child, will generate the behavioural factors inside of the child.

Social class or social status - where the children grow up largely will be able to shape the people's behaviour. In many cases an adopted children behave differently from their biological parents. Adoptive parents also appeared to possess some sort of behavioural influence on the development of the child under their custody. The degree of influence from the adoptive parent and behaviour heritage from the biological parent is not yet known, but there are some links between those behavioural factors. However it is strongly believed that the community social behaviour where the children grow up has a significant influence on their behaviour.

Age differences; Maturity level increases as age increases, i.e. increases of age of people through interval time will be able to shape the human behaviour apart from those people categorised as 'never ever mature' even though they have grown up. Normally, the maturity level will increase as age increases. Increasing maturity level will change's people behaviour, unless one has been categorised as 'never grown up'

The education level; The quantity and quality of level of knowledge acquired are different at the different levels of education. The knowledge boundary is normally expanded once the level of education increases. Generally, people's behaviour reflects their level of education. The way of people thinking and analysis, and decision made during a fire emergency, largely depends on the knowledge and experience they have. However, in certain aspects like evacuation process and procedure, people need to have experience of fire drill before they can react efficiently.

The rules and regulations have a significant influence on the behaviour of people. In everyday life, there are rules and regulations to follow. To be effective, all rules and regulations are subject to review to ensure effectiveness and suitability for use at any material time.

Threat or danger situation can somehow or other shape human behaviour in building fires. However, sometimes, it is misleading to the perception of many people which resulted in assumption of the behavioural aspects in a difference sorts. A popular assumption that people are irrational or panic seems to be not true. When people are confronted with a serious building fire, they behave in a constructive, rational or even altruistic manner. The myth of people acting in a selfish, capricious, oppressive or other hostile manner is quite irrelevant because people seem to help each other in emergency cases such as in a fire situation. However, there are probably a few cases i.e. one or two of them could have reacted oppositely for a reason. In general, human beings are very cooperative and concerned in case of emergency. They tend to help other people with evacuation and even try to fight the fire as best they can. From the survey, it was found that among the highly important factors that building occupants are going to do first are immediately evacuate the building, call 999, help others with evacuation, attempted to put out fire, and save some possessions.

Figure 6.6 shows the model of human behaviour derived from the outcome of the questionnaires study done on a number of Malaysian occupying the high-rise residential buildings in Kuala Lumpur. Responses from professionals involved in the construction industry and from fire brigade officers are taken into consideration in developing of this model. There are thirteen models integrated to form this human behaviour model. Models 1 to 8 are derived from the questionnaire survey on the building's occupants and models 9 to 12 are derived from the expert judgement. Model thirteen i.e. Model A1: Action to be taken is the conclusion of the factors that occupants of high-rise residential buildings in Malaysia will take if they have seen any fire cue or they have heard a fire alarm. Those models are divided into five levels of intensity influencing components.

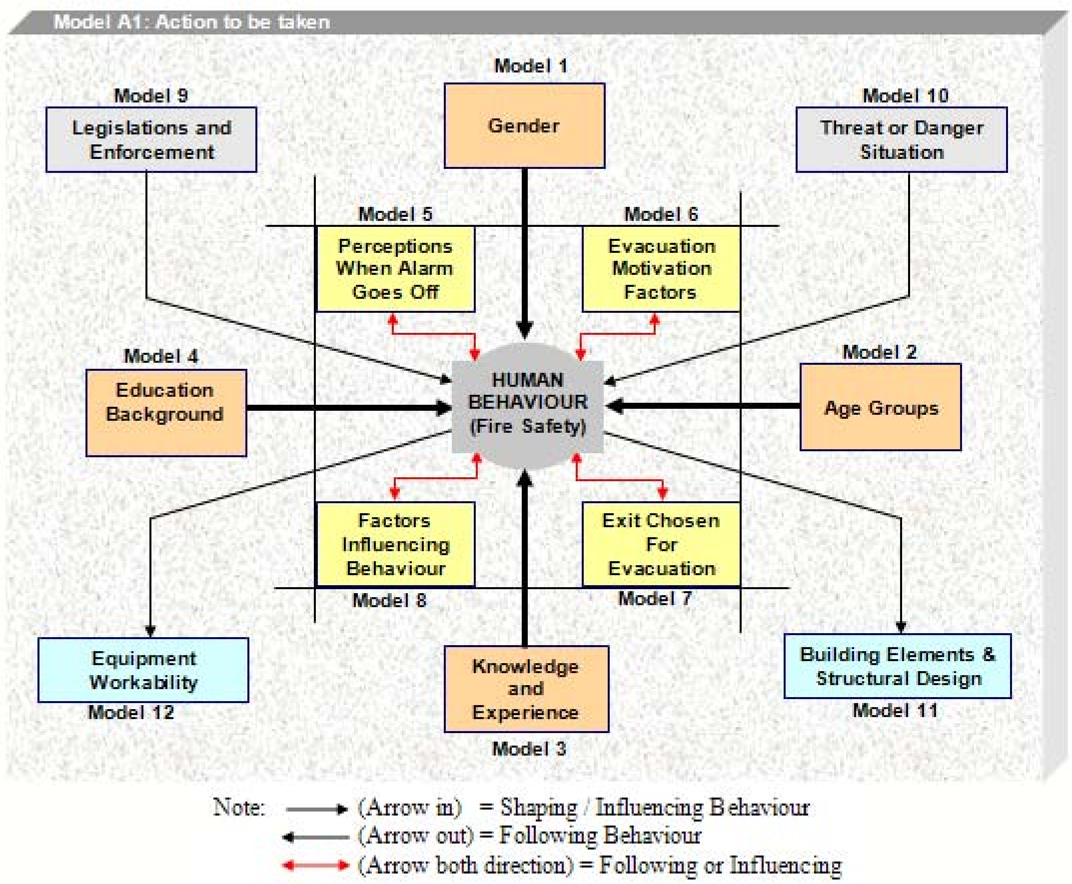


Figure 6.6: Human behaviour model of fire safety in building

However, human beings are naturally unique, which sometimes makes it difficult to predict to a high degree of precision their behaviour. Many have a tendency to say that people are unreliable, unlike a machine or robot which very reliable and never complains about anything. Human beings actually possess unique decision-making capabilities, and when equipped with adequate information, knowledge and experience, they can overcome the disadvantages of changing conditions, incomplete or inaccurate information and time pressure to make the decisions that computers and other technological systems remain incapable of. However, the fact is that, human behaviour can influence and be influenced. The intensity of influence and be influenced are mainly determined by the magnitude of those factors affecting them directly or indirectly in terms of the principle of belief, centre of feeling, amount of information and knowledge they have, enforcement of rules in a living system, situation where they live in e.g. threat or reward, and etc.

There are five levels of degree of components what influence human behaviour as described earlier that:

i. Factors that strongly influenced the people's behaviour.

ii. Factors that equally influence and influenced the people behaviour and those factor itself.

iii. Factors that will be able to control the people behaviour.

iv. Factors that should be followed the people behaviour.

v. Action to be taken by people during emergency situation

Detailed descriptions of these components and factors involved can be found in sections 6.6.3 to 6.6.7 below. Components that strongly influence the people's behaviour are indicated with the bold arrows toward the human behaviour and those factors are as in models 1, 2, 3 and 4. Red arrows with both directions are indicated as equally influent on the human behaviour and the models i.e. models 5, 6, 7, and 8. It means human behaviour is influenced and vice-versa. Arrows in indicate that these components (marks as model 9 and 10) are influenced and able to control the people's behaviour. Arrows out indicate that these components (marked as model 11 and 12) should follow the people's behaviour.

6.6.1 Human behaviour defined from the fire safety point of view

Human behaviour within the conceptual framework of evacuation and fire threat in buildings would be able to change the attitude and the action taken by the respective persons involved. The state-of-the-art of human behaviour is not only concerned with what people should do i.e. prescribing the actions they should take in emergency situation, but what they are most likely to do i.e. addressing the probable actions they would take in emergency situation.

In the evacuation process i.e. during a fire emergency, human behaviour is defined as a state where people start to evacuate when they have been notified about the existence of fire either by mechanical means or by people. The state where people start to change their behaviour from normal to abnormal and the state where people start to react e.g. actions taken to save their life from any threat of fire. Generally there are two states where people start to change their behaviour i.e.;

i. A state in which people begin to change their character e.g. from patient to impatient, calm to aggressive, etc and vice-versa.

ii. A state in which people begin to be irrational in any of their actions e.g. panic, start to take any action that could put themselves in a risky situation which could threaten their life or that of another person, and vice-versa.

However, the state when humans would possibly change their behaviour can be very complex to describe, and at this moment there is no any precise tool that can be used to calibrate human behaviour, except by means of opinion survey or questionnaire test form. These are the most popular methods used at this time. In general there are a few other factors that would affecting the human behaviour as described in the following section.

6.6.2 Factors that equally important in affecting of human behaviour:

There are four other equally important factors that could affect human behaviour in making any decision in any emergency situation, i.e. attitude, social norm, religious/belief/faith and perceived behavioural control (Nisbett and Valins (1972), Skinner (1953), Bem (1966, 1972)).

i. *Attitude*: – The degree to which the person has a favourable or unfavourable evaluation of the behaviour in question.

ii. *Social Norm*: - The influence of social pressure that is perceived by the individual (normative beliefs) to perform or not to perform a certain behaviour.

iii. *Religious/Belief/Faith*: - The individual belief concerning the daily practice and performing activities according to the divine rule in the daily live. Worship of God, to seek for the though guidance, human to human relationship etc.

iv. *Perceived Behavioural Control*: - This construct is defined as the individual thinking concerning how easy or difficult it is to perform any task. This behaviour will be able to control the outcome of any action to be performed. The perception in the mind will result in success or failure of action taken. Positive perception, e.g. high confidence, is likely to result in a greater chances of success but negative perception, e.g. doubtful, will result in a slim chance of success.

As mentioned earlier, human behaviour can be influenced and have an influence. The intensity of be influenced and influences are mainly determine by how much the magnitude of those factors are affecting them directly or indirectly. Nevertheless, to obtain data on human cognitive performance is extremely difficult pertaining of the nature of these activities. Many approaches have been done by many other researchers including protocol analysis (Park, *et. at*, 2003) field experiments (Woods, 1993), expert judgment (Roelen *et. al*, 2002), etc. Some of them (Nisbett and Valins (1972), Skinner (1953), Bem (1966, 1972)) have concluded the finding that mainly related to the above attributes mentioned

6.6.3 Factors that strongly influence and can shape the human behaviour:

There are four factors that strongly influence and are able to shape the character of human being; gender, age groups, knowledge and experience, and education background,. Figure 6.7 shows models of strong behavioural factors and possible action to be taken during a fire emergency. Human behaviour sub-model A that strongly influenced the people's behaviour will result in Model A1 (Action) to be taken. Those factors are:

i. *Gender:* - A degree of emotional and rational is belief to be different in differences of gender status because based on the questionnaire survey, the percentage of male and female, when tested on the variable 'immediately evacuate and do something else' shows a significant differences of the percentage margin. Therefore gender status could influence the action to be taken in certain situations. However it does not solely influence the behaviour of people by gender but the interrelationship between the other factors instead. Table 6.12 shows the respondents' proportion of gender tested on variable 'immediately evacuate and do something else'.

Analyses were based on the questionnaire survey and the survey results show that 59.1% (68 people) of respondents will do something else before evacuating the building and 40.9% (47 people) will immediately evacuate the building once a fire alarm goes off. The analysis of proportion of gender in evacuation behaviour between male and female, when tested on the variables of "immediately evacuate" or "do something else" once a fire alarm goes off, 64.6% of male would do something else and only 35.4% would immediately evacuate. Meanwhile 52.0% of female would do something else and 48.0% would immediately evacuate the building if fire alarm goes off. There is significant evidence that gender has an influence on the action to be taken in fire emergency. The majority of males have a tendency to do something else, while females show no significant differences between 'immediately evacuate' and 'do something else' because there is only 4% difference between the two variables.

			1 = Immediately Evacuate; 2 = Do something else		
			1	2	Total
Gender: 1 = Male; 2 = Female	1	Count	23	42	65
		% within Gender: 1 = Male; 2 = Female	35.4%	64.6%	100.0%
	2	Count	24	26	50
		% within Gender: 1 = Male; 2 = Female	48.0%	52.0%	100.0%
Total		Count	47	68	115
		% within Gender: 1 = Male; 2 = Female	40.9%	59.1%	100.0%

Table 6.12: Respondents' gender proportion.

			1 = Immediately Evacuate; 2 = Do something else		Total
			1	2	
Age group: Young: 1 = 15 - 30; Midle Ages: 2 = 31 - 40; Uper Age: 3 = 41- 50; Old People: 4 = Above 50	1	Count	24	32	56
		% within Age group: Young: 1 = 15 - 30; Midle Ages: 2 = 31 - 40; Uper Age: 3 = 41- 50; Old People: 4 = Above 50	42.9%	57.1%	100.0%
	2	Count	20	19	39
		% within Age group: Young: 1 = 15 - 30; Midle Ages: 2 = 31 - 40; Uper Age: 3 = 41- 50; Old People: 4 = Above 50	51.3%	48.7%	100.0%
	3	Count	2	13	15
		% within Age group: Young: 1 = 15 - 30; Midle Ages: 2 = 31 - 40; Uper Age: 3 = 41- 50; Old People: 4 = Above 50	13.3%	86.7%	100.0%
	4	Count	1	4	5
		% within Age group: Young: 1 = 15 - 30; Midle Ages: 2 = 31 - 40; Uper Age: 3 = 41- 50; Old People: 4 = Above 50	20.0%	80.0%	100.0%
Total		Count	47	68	115
		% within Age group: Young: 1 = 15 - 30; Midle Ages: 2 = 31 - 40; Uper Age: 3 = 41- 50; Old People: 4 = Above 50	40.9%	59.1%	100.0%

Table 6.13: Respondents' difference age groups proportion

ii. *Age Groups*: - The degree of thought, action, reaction and risk taken upon issues or situation arise will be different in different age groups. There are four age groups i.e.: group 1, young15 – 30 years old; group 2, middle age, 30 – 40 years old; group 3, upper age, 41 – 50 years old, and group 4, old people, above 50 years old. Table 6.13 shows the proportion of respondents according to the age groups when tested with the variables 'immediately evacuate' and 'do something else'; young people are inclined to do something else (57.1%); people at middle age are inclined to immediately evacuate (51.3%); but people above 40 years old are very keen to do something else if a fire alarm goes off.

iii. *Knowledge and Experiences*: - The action will be based on the knowledge and experience acquired by any individual when they are faced with any emergency situation. Knowledge refers to the specific fire safety courses that one has attended, technique and information about the fire suppression systems, the location of escape route and orientation of building environment where they live on, etc. Experience refers to the fire drill that one may have taken part in, or having been involved in building fires before. Table 6.14 shows the proportion of respondents who had attended or not attended any fire safety courses. Among those not attending any fire safety courses 56.4% would do something else and 43.6% would immediately evacuate the building. For those who had attended a fire safety course 64.9% would do something else and only 35.1% would immediately evacuate after a fire alarm goes off. It seems that the percentage of those doing something else has increased after attending fire safety course.

			1 = Immediately Evacuate; 2 = Do something else		
			1	2	Total
Attended fire safety courses: 1=Yes, 0=No	0	Count	34	44	78
		% within Attended fire safety courses: 1=Yes, 0=No	43.6%	56.4%	100.0%
	1	Count	13	24	37
		% within Attended fire safety courses: 1=Yes, 0=No	35.1%	64.9%	100.0%
Total		Count	47	68	115
		% within Attended fire safety courses: 1=Yes, 0=No	40.9%	59.1%	100.0%

Table 6.14: The proportion of respondents who have attended fire safety courses.

Table 6.15 shows the proportion of respondents with an experience of fire drill. The majority of those without an experience of fire drill i.e. 61.2% would do something else and the percentage had decreased for those who had an experience of fire drill. On the-other-hand, the percentage of those immediately evacuating had increased from 38.8% to 42.4%.

			1 = Immediately Evacuate; 2 = Do something else		
			1	2	Total
Experience fire drill: 1=Yes, 0=No.	0	Count	19	30	49
		% within Experience fire drill: 1=Yes, 0=No.	38.8%	61.2%	100.0%
	1	Count	28	38	66
		% within Experience fire drill: 1=Yes, 0=No.	42.4%	57.6%	100.0%
Total		Count	47	68	115
		% within Experience fire drill: 1=Yes, 0=No.	40.9%	59.1%	100.0%

Table 6.15: The proportion of respondents with a fire drill experience

The analysis of those who had an experience with a building fire (see table 6.16) shows that the percentage of those immediately evacuating the building once a fire alarm goes off had increased by only 1%, so there is no significant difference between those with and without an experience of being involved in a building fire.

			1 = Immediately Evacuate; 2 = Do something else		Total
			1	2	
Experience fire: 1=Yes, 0=No.	0	Count	37	54	91
		% within Experience fire: 1=Yes, 0=No.	40.7%	59.3%	100.0%
	1	Count	10	14	24
		% within Experience fire: 1=Yes, 0=No.	41.7%	58.3%	100.0%
Total		Count	47	68	115
		% within Experience fire: 1=Yes, 0=No.	40.9%	59.1%	100.0%

Table 6.16: Proportion of respondents with an experience being involved in building fire.

Further analysis on the male and female with and without an experience of a fire drill shows that the percentage of males immediately evacuating the building had slightly increased from 32.3% to 38.2%%. Meanwhile the percentage of females had slightly decreased from 50.0% to 46.9% (see table 6.17). Roughly the same pattern is followed by males who had an experience of being involved in a building fire, i.e. the percentage had increased from 33.3% to 42.9% and the percentage of the females again decreased from 50.0% to 40.0% (see table 6.18)

Gender: 1 = Male; 2 = Female				1 = Immediately Evacuate; 2 = Do something else		Total
				1	2	
1	Experience fire drill: 1=Yes, 0=No.	0	Count	10	21	31
			% within Experience fire drill: 1=Yes, 0=No.	32.3%	67.7%	100.0%
		1	Count	13	21	34
			% within Experience fire drill: 1=Yes, 0=No.	38.2%	61.8%	100.0%
	Total		Count	23	42	65
			% within Experience fire drill: 1=Yes, 0=No.	35.4%	64.6%	100.0%
2	Experience fire drill: 1=Yes, 0=No.	0	Count	9	9	18
			% within Experience fire drill: 1=Yes, 0=No.	50.0%	50.0%	100.0%
		1	Count	15	17	32
			% within Experience fire drill: 1=Yes, 0=No.	46.9%	53.1%	100.0%
	Total		Count	24	26	50
			% within Experience fire drill: 1=Yes, 0=No.	48.0%	52.0%	100.0%

Table 6.17: The proportion of male and female had an experience of fire drill

Gender: 1 = Male; 2 = Female				1 = Immediately Evacuate; 2 = Do something else 1	2	Total
1	Experience fire: 1=Yes, 0=No.	0	Count	17	34	51
			% within Experience fire: 1=Yes, 0=No.	33.3%	66.7%	100.0%
		1	Count	6	8	14
			% within Experience fire: 1=Yes, 0=No.	42.9%	57.1%	100.0%
	Total		Count	23	42	65
			% within Experience fire: 1=Yes, 0=No.	35.4%	64.6%	100.0%
2	Experience fire: 1=Yes, 0=No.	0	Count	20	20	40
			% within Experience fire: 1=Yes, 0=No.	50.0%	50.0%	100.0%
		1	Count	4	6	10
			% within Experience fire: 1=Yes, 0=No.	40.0%	60.0%	100.0%
	Total		Count	24	26	50
			% within Experience fire: 1=Yes, 0=No.	48.0%	52.0%	100.0%

Table 6.18: The proportion of male and female had an experience of building fire.

In contrast, the majority of them opting to ‘do something else’ if they had an experience of a fire drill decreased from 67.7% to 61.8% and the percentage for the female had slightly increased from 61.8% to 64.6%. The same pattern is observed when they had an experience of being involved in the building fire that the percentage of males ‘doing something else’ had decreased from 66.7% to 57.1% and the percentage of females ‘doing something else’ had increased from 50.0% to 60.0%.

iv. *Education background:* - The level of thinking and the ability to make a constructive decision are supposedly influenced by the level of education that one has completed. Higher education level theoretically should allow better risk calculation, and as a result should be biases towards more rational action to be taken in an emergency situation. Table 6.19 shows the proportion of respondents with education background shows that percentage of respondents opting to immediately evacuate’ had slightly decreased from 42.2% to 38.9% and for them to ‘do something else’ had slightly increased from 57.4% to 61.1%. It can be seen that the majority still opt to ‘do something else’ after a fire alarm goes off.

			1 = Immediately Evacuate; 2 = Do something else		Total
			1	2	
Education Level: 1 = Dip or above, 2 = Cert or Non	1	Count	26	35	61
		% within Education Level: 1 = Dip or above, 2 = Cert or Non	42.6%	57.4%	100.0%
	2	Count	21	33	54
		% within Education Level: 1 = Dip or above, 2 = Cert or Non	38.9%	61.1%	100.0%
Total		Count	47	68	115
		% within Education Level: 1 = Dip or above, 2 = Cert or Non	40.9%	59.1%	100.0%

Table 6.19: Proportion of respondents with difference level of education background.

6.6.4 Factors which equally influence and follow the human behaviour:

There are four equally important factors that either will influence or will be influenced by human behaviour. Figure 6.8 shows factors for model 5, 6, and 7. Figure 6.9 shows factor for model 8. Model 5 is people's perceptions when a fire alarm goes off. Model 6 is evacuation motivation factors. Model 7 is exit chosen for evacuation and model 8 is evacuation behaviour factors. Human behaviour could be determined by those factors and will be inter-related either between perception and action taken, human and elements, and knowledge and exit choice. Based on the results of the questionnaire study, the factors are grouped into three priority groups i.e. high priority, medium priority and low priority.

i. Perception when alarm goes off: - Perception means a level of thought or faculty of perceiving the effect or product of observing something in the individual mind. It then stimulates the action to be taken by sending a signal to the other organs of the body. In this respect it is what people thought when a fire alarm goes off and what action that they might take. The alarm is among the elements that would be able to jerk or wake up people from the state of illusion. Interpretation of the meaning of the sounder would be different to different people. Some might think that it was a false alarm and some might think that it was a service man testing the system or just someone played around with the alarm, some ones might have seriously interpreted that it is a genuine alarm and evacuation is needed to be carried out immediately, etc. It will influence the action to be taken by people in high-rise buildings. Action to be taken is mainly determined by the interpretation of the alarm they have heard or any fire cue that they have seen. If it has been interpreted as a serious warning of the existence of the danger, the action taken will be different.

In terms of perception once fire alarms go off, the respondents would tend to believe that it was a genuine fire and must evacuate the building immediately. They would not think it was only a joke or a faulty alarm. In terms of action to be taken, they will alert other people to evacuate and then immediately evacuate the building as a high priority. To wait awhile and if people started to evacuate then to follow them is a low priority.

ii. *Evacuation motivation factors*: - Motivation is an internal energy stimulating people to react accordingly. Some may have defined motivation as a non-specific energizing of all behaviour and some said it is a recruiting and directing behaviour, selecting any possible action that person might perform such as evacuating the building when the alarm goes off. Motivation can come from two different sources, from human or from elements or equipment. Motivation from inside the human is called internal motivation and if it comes from elements or from other people, it is called external motivation. In this regard external motivation is taken into consideration in the evacuation motivation factors studied.

From the study it was found that there are two high priority motivations from the human factors i.e. Command from authority and people evacuating the building. Insist from the other people in their unit is medium priority to them. In terms of motivation from element factors, there are also two factors i.e. fire cues and fire alarm are high priority that will motivate them to evacuate the building. Detecting a burning smell is medium priority. It can be concluded that motivation for humans, regarding the evacuation processes in any of the fire emergency can be divided into three categories i.e. 'Command', 'Encourage', or 'Insist' (CEI). The intensity of motivation effects on person involved are different and largely determined by how serious is the effects would be on the affected person if they did not follow the CEI. Meanwhile, motivation from elements can be divided into two categories i.e. Active Equipment (AE) e.g. fire alarm, bell ringing, siren, etc. and Passive Element (PE) e.g. fire cues, burning smell, etc.

iii. *Exit chosen for evacuation*: - Everybody has a choice of his own. An opportunity to choose any egress in an emergency situation should be given by the building's owner by providing an alternative escape route in their buildings. People can behave differently with the changing of the building environment, the opportunity or choices available and the knowledge or know-how about the egress provided in their building. On the other hand, the building elements or building environment should be designed to suit human behaviour.. Human behaviour influences the design of escape routes in any building and the circulation environment inside the building. This is to ensure that those elements can provide the best possible way to ensure all occupants can evacuate the building safely when needed.

iv. *Evaluation behaviour factors*: - Humans are sometimes being influenced by the situation happening around them. The degree of influence may be different among a group of people and it is mainly due to the level of passion and patience they have. Many would say that people panic if they are faced with a chaotic situation, difficulty in moving in congested traffic, etc. This is based on a popular assumption without any concrete evidence to support it. As mentioned earlier, people are very constructive and cooperate when they are faced with an emergency situation.

Even though one's mood can change, there is no certainty what causes one to change their behaviour. Are there people or structured element factors that have more influence to cause one to change their character? From the survey, it was found that people and structural elements play an equally important role in causing one to change their behaviour. Therefore, structural design, i.e. escape routes should be designed with the optimum specification to ensure the safety of people is at the maximum level. Meanwhile, among the human factors that could cause one to change one's behaviour are traffic congestion, havoc situation, and crowds in the evacuation process. Therefore, it can be concluded that people's moods change not solely because of the human factors but the building element also plays an important role.

6.6.5 Factors to control the human behaviour.

There are two main factors that would be able to control the behavioural aspect in human life i.e. (1) enforcement of legislation, (2) threat or danger situation. These factors are believed to be among the effective measures to ensure every individual will follow the framework as desired by the authority.

i. *Enforcement in legislation* is very important to ensure the effectiveness of any rules and regulations at the optimum level. Enforcement means ensuring that all legislation regarding safety measures in buildings are followed by all respective parties. . The effectiveness of any laws and legislations in use are solely dependent on the capability of enforcement.

ii. *Threat or danger situation* refer to the state that if any action are taken it could have serious consequences not only for the person but to the close family or the community. This factor would be able to trigger people to swing their mood and behaviour. This is to enable them to react accordingly to ensure they and the people around them are safe and sound.

6.6.6 Factors that should be followed the human behaviour

Active Equipment and Passive Elements are the factors that should follow the human behaviour for the safety of the people. The equipment should be capable of being used by the people without difficulty. If they are designed and installed beyond the ability of humans to use them it is similar to it being non-existent.

i. *Active Equipment* refers to all fire suppression, detection and alarm systems e.g. portable fire extinguisher, hose reel, sprinkler system etc. Current regulations require all high-rise residential buildings to be installed with the minimum of dry riser or wet riser together with a fire extinguisher system. For reasons of economy in a competitive property market, developers did not install automatic water sprinkler systems in any of the high-rise residential buildings observed. All active equipment needs humans to activate it except for the automatic fire detection system. Therefore, the equipment workability must be suited to the ability of human to activate it. Level of workability can be divided into three categories i.e. skill, semi-skill or non-skill.

ii. *Building Element and Structural Design* refer to the internal circulation of the building and egress route from the building. Building circulation includes corridors and staircases. One such building element is a fire door. This should be designed and installed to provide the best service to the building occupants to help them in evacuation if an emergency arises.

6.6.7 Action to be taken by people during emergency situation

Human behaviour in building fires is quite complex and involves many stages of interpretation of sequences of activities before any action can be taken. The most common activities involved are (1) Information gathering, (2) Information interpretation, (3) Risk calculation before action is taken, (4) Action taken based on the perceptions, (5) Environment and/or technological influences, (6) Intellectual capabilities, and (7) Person ability i.e. gender and age groups. Figure 6.6 explains the integration of human behaviour model with the action to be taken during an emergency i.e. when people have seen fire cues or heard fire alarm.

In the case of a fire breaking out, once occupants have been notified about the fire or if they have seen the fire cues, the actions to be taken by those respondents who were surveyed (see analysis survey results as in table 6.8, and model in figure 6.8) are; immediately evacuate the building after they alert other people to evacuate; seek help e.g. call 999; activate the fire alarm; and help others with evacuation, are other actions to be taken after information is gathered and analysed. Risk analysis is then taking place.

Risk calculation in an emergency situation is often driven by the knowledge and information available such as what would they do to evacuate. The vast majority of respondents said that they would use the staircase and follow the exit signage available to the safe designation area.

The specifications of the built environment i.e. internal circulation for egress, staircase design and specification, the orientation of corridors and fire doors are very important. Besides human motivation that would be able to trigger the evacuation to start, the equipment available in the building i.e. fire alarm system is among the important factors to motivate people to start.

Intellectual capabilities will determine how fast and accurate any information can be analysed. In the case of fire, a person with high intellectual capabilities, basically knows how to deal with the situation at minimum destruction and at what level is risk can be taken. Unlike machine intellect, human intellect can process data to give a possible result of irregular answer. Machine intellect will only process data 1 + 1 = 2, but human intellect may process data 1 + 1 = 2 or 3 or 4, etc., depending on the definition of what is 1, 2, 3, or 4, because the human cognitive system is able to convert numerical and non-numerical data automatically into meaningful information. This variability can be obtained due to the experience that is held in our cognitive system. Therefore knowledge and experience in fire safety is crucially important to everyone. As intellectual capability is reflected by the educational background, knowledge and experience can be gained through formal or informal learning processes. This can be accomplished by attending colleges or attending proper fire safety courses. Experience evolving from taking part in a fire drill or engaged in an actual fire tragedy is extremely useful.

A person's ability will determine how fast and smooth any evacuation process can take place. It is defined as the ability of one to move out from the high-rise building to the safe designated area. However, elderly people and people with a disability will not impede the evacuation process because most of them will wait in their flat to be rescued (Proulx, 1995). Nevertheless, a person's health condition, body size and ages apparently will influence the smooth of evacuation process. However, if elderly people or people with a mobility impairment are rescued using the same staircase used by other occupants, it will slow down the traffic flow.

6.7 Conclusion

Human behaviour is e complex;. today's decision by one person could be different on the following day, or even within an hour. Integration between human behaviour and escape routes in high-rise residential buildings needs further analysis. This can be carried out after we have understood how occupants of high-rise residential buildings are going to react if their building catches fire.

Among the important points to highlight are that the occupants want to evacuate the building using the staircase instead of the elevator. They will evacuate the building immediately after the fire alarm goes off or after any fire cues are detected. However, they have a tendency to help other occupants after calling 999 for help. The majority of them will not to try to put out the fire as a first priority even if they have attended fire safety courses. There is a tendency for some occupants to carry along with them some possessions during evacuation. This is a common phenomenon in which every human being has a desire to save some valuables, even to the extent that it could put themselves in danger.

Occupants' behaviour is highly influenced by crowds and traffic congestion in the escape stair. They are likely to react irrationally if a havoc situation occurs and furthermore, if they know that someone they love is still in the building. The smell of burning material can also highly influence the people's behaviour.

Factors that most motivate occupants to evacuate the buildings are a directive from a person with authority e.g. fire brigade officer, police or building security. Fire cues and fire alarm are also among the main factors that will motivate them to evacuate the building.

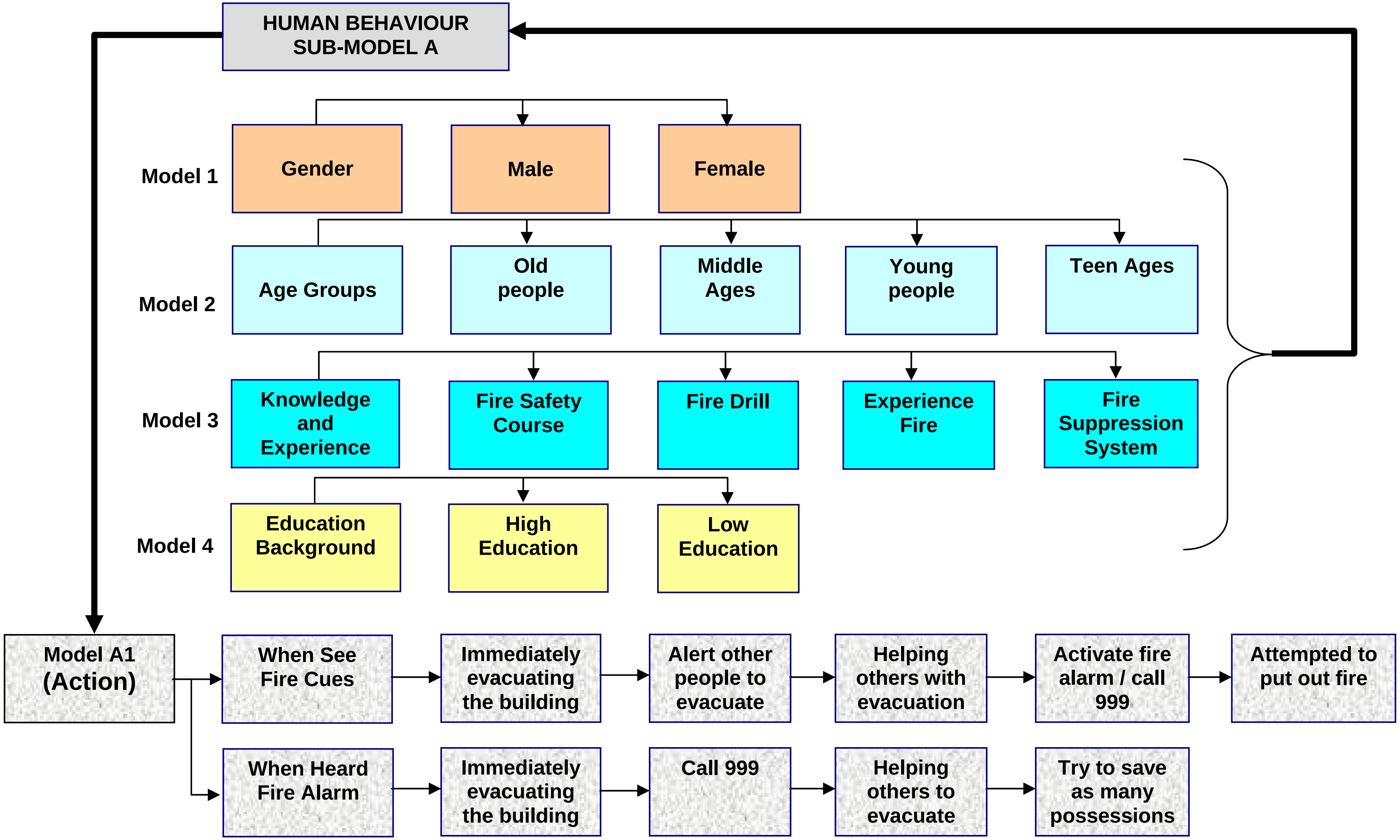


Figure 6.7: Model that will influence the character of human behaviour and the action that they would be taken

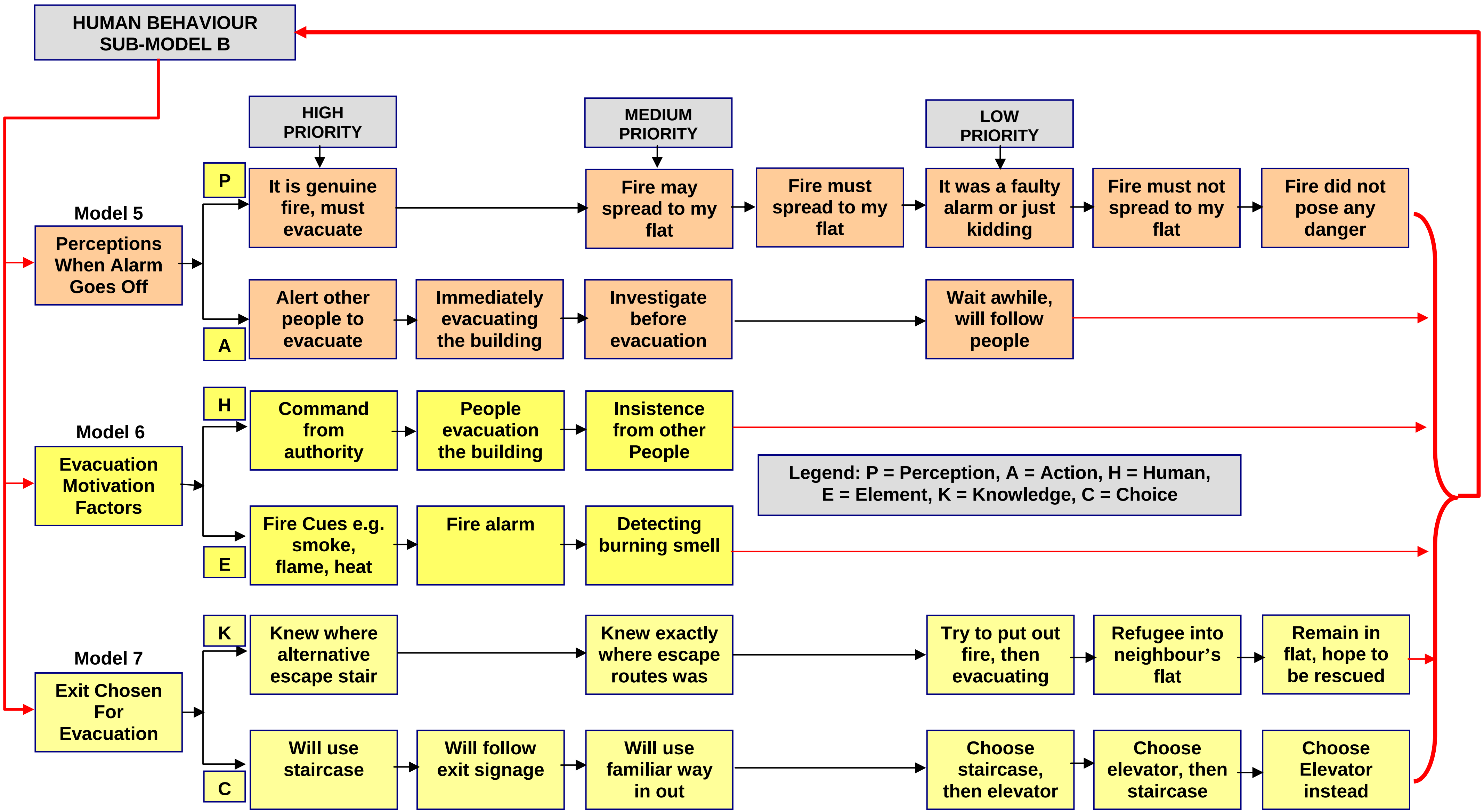


Figure 6.8: Factors influencing and following behaviour

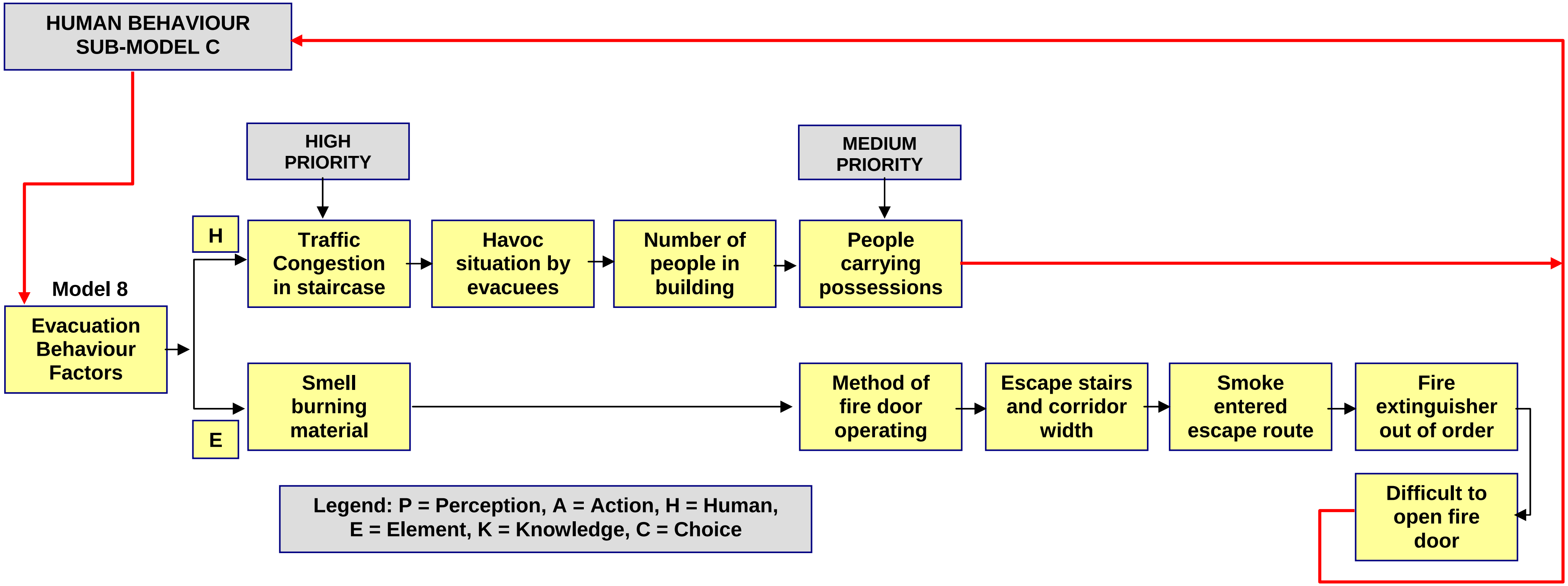


Figure 6.9: Factors influencing and following behaviour

CHAPTER 7

AN EVALUATION OF THE PROVISION OF ESCAPE ROUTES IN HIGH-RISE RESIDENTIAL BUILDINGS IN MALAYSIA

7.1 Introduction

High-rise residential buildings have become a common structure in urban areas in Malaysia especially in the capital, Kuala Lumpur. Rapid development of Kuala Lumpur during the last few decades has attracted a large number of people from rural areas, rapidly increasing the population. People migrated to Kuala Lumpur for various purposes e.g. working, business, seeking a new life, etc, and this has created a high demand for new homes. This trend seems to have drastically increased in the past decade. With the limited land available in the town area, construction of high-rise residential buildings by various developers e.g. private or Government Link Companies to cater for the demand of new homes, near to the urban area, seems to be an alternative solution for the immediate needs.

However, even though there is a high demand for new buildings fire safety should not be compromised. Residential buildings are exposed to high casualty risk, because if fire breaks out it would cause a high rate of casualties to the occupants, therefore careful design is needed, especially emergency fire escape routes. In order to maintain high-rise residential buildings at an acceptable fire safety level, means of escape should be designed according to the specification given in acts and regulations while taking into consideration the number of occupants and people's behaviour.

Purser, (2004), explains that the prescriptive approach concentrates on the structural aspects of means of escape and acknowledges only in a general sense the point that fire hazard and safe escape are basically time dependent. It does not consider occupant behaviour in emergencies and the time required for occupant responses. Best practice for structural design in relation to fire safety therefore takes into account the needs of building occupants for structural performance. This can be achieved by means of a performance-based Fire Safety Engineering approach. However Rasbash *et al* (2004) mentions that the consequences of inadequate means of escape have been highlighted in a number of incidents in which the absence of properly designed escape routes, inadequate protection, failure of alarm or warning systems, or some other shortcoming, has resulted in serious loss of lives.

This chapter will identify some important points in escape route design and specification if satisfactory escape is to be assured. Some basic principles of means of escape relevant to high-rise residential buildings will also be discussed. Although means of escape can be tested to a degree during fire drills, the ultimate test of whether or not occupants are able to escape safely in an emergency comes when there is a fire. When it happens, it is too late to rectify any problems. The best possible way is by using the existing advanced technology to identify or predict plausible solutions to future problems that might arise. Based on past experience, human behaviour and structural design can be integrated to find plausible answers to give the best possible way for the occupants to evacuate their flats. In terms of evacuation planning, the provision of escape routes is normally alongside the needs for normal access and circulation routes within the building.

In this chapter analysis of the specification of staircase, fire door and corridor will be carried out by simulating a number of people evacuating buildings of different layouts identified in the observation study. The first simulation will be carried out using the specification in UBBL to study the floor clearance times of different layouts. Further simulations will study the effects of intermediate floor, and staircase, fire door and corridor widths, to determine which one contributes more in reducing the total evacuation time and is there any significant difference in terms of total evacuation time recorded. Analysis will be carried out on the proposed specification to determine whether there is any significant difference in terms of floor clearance time and total evacuation time between it and the UBBL specification.

7.2 Evacuation Time

Evacuation from building fire is essential and has to be initiated as soon as the fire alarm is sounded or fire cues have been detected. When evacuation is in progress, two important elements have a strong influence on the evacuation time i.e. Occupants' characteristics and building characteristics. Purser (2004) mentioned that the behaviour of occupants escaping from fire depends on a range of factors including building characteristics i.e. occupancy types, method for detection and the provision of warnings, fire safety management systems and building layout. Other equally important building characteristics are spatial complexity of the buildings, travel distances, and escape route and final exit. However, occupant characteristics themselves also have a large influence on the evacuation time i.e. occupant numbers, state of alertness, whether they are awake or asleep, familiarity with the building environment, experience of fire drill, and physical abilities.

According to Rasbash *et al*. (2004), means of escape facilities such as maximum travel distance, number and widths of staircases should be designed according to the total evacuation time (ΔT_{evac}) based on the following equation:

$$\Delta T_{evac} = (D + B + E). \quad (7.1)$$

ΔT_{evac} = Total time from when the fire started to ignite until all occupants have completely evacuated the building. However, only sub-time E is generally considered explicitly in fire regulations, codes, and standards.

D = the period since the start of the fire until occupants are notified about the existence of fire.

B = refers to the recognition time and response time, i.e. the time between the occupants being notified about the fire and beginning to evacuate. This is known as pre-movement time.

E = an escape time that refers to an emergency or non-fire situation. It means that E is the total time for an evacuee's actual movement between beginning to evacuate and reaching a place of safety; i.e. entrance to a protected staircase, or outside the building.

Purser (2004) stated that for each occupied enclosure in a building, total escape time (ΔT_{esc}) depends upon a series of basically additive, sequential processes summarized in the following equation:

$$\Delta T_{esc} = \Delta T_{det} + \Delta T_{a} + \Delta T_{pre} + \Delta T_{trav} \quad (7.2)$$

where:

ΔT_{det} = time from ignition to detection.

ΔT_{a} = time from detection to the provision of a general evacuation warning to occupants. Alarm time varies and largely depends on the types of alarm system installed in the buildings. It can range from 0 for the A1[7] alarm system, 2 to 5 minutes for A2[8] alarm system and possibly longer and more unpredictable for A3[9] alarm system.

[7] A1 alarm system: Automatic fire detection system which generally immediately activates after fire starts.

ΔT_{pre} = pre-movement time is the time from when occupants become aware of the emergency to when they begin to move towards the exits. This may include the time required to recognise the emergency and then carry out a range of activities before traveling to exits.

ΔT_{trav} = travel time. (The time required for occupants to travel to a place of safety. Initially this might be by a protected escape route such as a corridor or stairway; ultimately it will be a place of safety outside the building)

In general, Total Evacuation Time is a sum of pre-movement time and travel time. Therefore;

$$\Delta T_{evac} = \Delta T_{pre} + \Delta T_{trav} \qquad (7.3)$$

Where pre-movement time consists of detection time and alarm time ($\Delta T_{det} + \Delta T_{a}$).

To summarise, Purser used terms Evacuation Time (ΔT_{evac}) in equation (7.3) to differentiate the terms used in equation (7.2) i.e. Total Escape Time (ΔT_{esc}) that consists of the last two terms in the escape equation:

Meanwhile, Marchant (1976), mentions that there are three main components which contribute to the cumulative total escape time (ΔT_{esc}) in an emergency situation i.e. perception time (T_p), action time (T_a), and travel time (T_{trav}). The relationship between them is written in mathematical form as follows:

$$\Delta T_{esc} = T_p + T_a + T_{trav} \qquad (7.4)$$

Where:

ΔT_{esc} = a total escape time

T_p = perception time, i.e. that time from ignition to where people start to realise there is a fire or perception of fire,

T_a = a time from perception to the start of escape action, and

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[8] A2 alarm system: Automatic fire detection system with pre-alarm to management or security with pre set a fixed time-out delay usually 2 or 5 minutes. If a fire is genuine, alarm throughout the building will be activated manually. If there is no fire, the alarm can be cancelled manually. If neither of the both actions taken, alarm will sound automatically according to the time-out delay set.

[9] A3 alarm system: Manual alarm system that relies on the personal detection and activation of the alarm system.

T_{trav} = a travel time, i.e. time taken to move to a safe area.

From the above description, the terms total evacuation time and total escape time have the same meaning. In the opinion of the author the term Total Evacuation Time is more appropriate to be used because it refers to prior, pre and post time action of occupants in the evacuation process. However the terms used by Purser, Rusbash and Marchant are not contradictory but can be understood as the same things. One thing that they are agreed on is that Total Evacuation Time consists of Pre-movement time and Travel Time.

Travel time has two components mainly known as horizontal travel time (T_h) and vertical travel time (T_v). Horizontal travel time refers to the time taken to evacuate the building by moving horizontally where occupants are walking from any room or along a corridor to the storey exit or protected staircase shaft or to the safe area or assembly area if the storey exit is also a final exit. Meanwhile vertical travel time refers to the time taken to walk down through the escape stair. If we incorporate this time into equation 7.4, it becomes:

$$\Delta T_{esc} = T_p + T_a + T_h + T_v \qquad (7.5)$$

To conclude, these three periods of time basically refer to (1) Time from when fire started until occupants are notified, (2) time when occupants started to evacuate after been notified about the fire (this is called delay time or response time), and (3) time taken for evacuees to completely evacuate the building. This is called travel time. However periods one and two can be incorporated into one term i.e. Pre-Movement Time. Therefore equation (7.3) i.e. $\Delta T_{evac} = \Delta T_{pre} + \Delta T_{trav}$ is more appropriate.

Where;

$$\Delta T_{pre} = T_p + T_a \qquad 7.6$$

$$\Delta T_{trav} = T_h + T_v \qquad 7.7$$

7.2.1 Pre-movement time

The response time is a time which indicates the occupants' delay to respond when the first fire alarm sounds. As mention in HMSO, (1993) "No matter how good the means of escape is, and no matter how well the facilities are maintained, people might still end up being seriously threatened as a result of their own actions. This can arise from people delaying the start of their escape, often because of a lack of appreciation of the speed at which fires can grow in buildings, or the fire is not seen as an immediate threat, indeed it may be seen as an interesting event to watch".

According to Proulx (1994), this delay time after which each of the occupants starts evacuation varies from between 30 seconds to over 24 minutes. Most of the occupants who have heard the fire alarm start their evacuation approximately 2½ minutes after the alarm has been activated. This was a result from the announced fire drills of occupants in four mid-rise apartment buildings. The occupants received a memo that a fire drill would take place during the upcoming week. The evacuation drills were recorded on video-cameras located throughout the buildings. As mentioned earlier, the result would be different if a real fire occurred and occupants have to evacuate from their flats under the threat of fire. This is due to the perception that this is only a drill and nothing to be worried about. Table 7.1 shows the action that occupants in high-rise residential buildings have taken before evacuating the building.

Pre-evacuation Action

Building	%	*Action*
1	19	'find pet'
	17	'gather valuables'
	15	'get dressed'
2	34	'have a look in corridor'
	21	'move to balcony'
3	23	'gather valuables'
	20	'have a look in corridor'
4	30	'get dressed'
	13	'find children'

Table 7.1: Pre-evacuation action (Proulx, 1995)

Among the actions that cause the occupants to delay the start of their evacuation are; find pet, gather valuables, get dressed, find children, have a look at corridor, and move to balcony. This increases the pre-movement time or time to start as mentioned by Proulx (1995), i.e. Time to start represents the elapsed time between the fire alarm sounding and the moment the person leaves his/her apartment. Table 7.2 shows the frequency of pre-movement time for the first 5 minutes taken by high-rise residential buildings studied by Proulx. Most of the occupants who heard the fire alarm started their evacuation approximately 2½ minutes after the alarm was activated.

Time to Start for the First 5 Min

Time intervals	Building 1		Building 2		Building 3		Building 4	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
0:00–1:00	11	26	5	9	8	10	17	21
1:01–2:00	14	33	10	18	12	16	13	16
2:01–3:00	7	17	8	15	6	8	26	33
3:01–4:00	4	10	3	5	5	6	9	11
4:01–5:00	3	7	3	5	3	4	4	5
Total		93%		53%		44%		86%

Table 7.2: Pre-Movement time for apartment buildings for the first 5 minute (Proulx, 1995)

Average Time to Start

Building	Time to start (min:s)
1	2:30
2	8:22
3	9:42
4	3:08

Table 7.3: Average Pre-Movement time in residential buildings (Proulx, 1995)

Table 7.3 shows the average pre-movement times in four high-rise residential buildings studied by Proulx; the minimum average is 2 ½ minutes and maximum average is 9 min 42 sec. If we average the pre-movement times for the four buildings the overall average pre-movement time is 5 minutes 55.5 seconds. It can be said that approximately 6 minutes are needed for the occupants to start evacuation after they have heard the fire alarm. Because they relate to different circumstances or building types, none of the pre-movement times recorded by other researchers is directly applicable here, but since the only comparison being made is between the buildings studied here, then the precise value assumed is unimportant so long as all the simulations have the same pre-movement time. In this case 30 seconds was used.

7.2.2. Travel time

Travel time was studied by Proulx (1995) as shown in table 7.4, and an average travel time of approximately 1 minute 2 second (62 seconds) to 1 minute 17 seconds (77 seconds) was determined for occupants moving out from the 6 – 7 storeys of four high-rise residential buildings in Canada. There are two types of time indicated in table 7.2, time to evacuate and time to move. Time to evacuate is the time occupants spend between the sounding of the fire alarm and the time at which they reach an area of safety i.e. Pre-movement time plus Travel time. Time to move is the time taken by a person to reach at outside or at final exit from the moment that person left the apartment, regardless of the distance traveled. This time is known as Travel Time.

Average Time to Evacuate

Building	*Time to evacuate* (min:s)	*(Time to move)* (min:s)
1	3:05	1:05
2	9:36	1:17
3	10:57	1:15
4	4:38	1:07

Table 7.4: Average time to evacuate (Proulx, 1995)

7.2.3 Occupant speed

Occupant speed is the velocity of the people moving out from the building. It can be divided into two main categories i.e. speed when people are walking on a horizontal plane, and speed when they are walking down the staircase. The speed when people are walking on a horizontal plane can easily be determined by measurement. Measuring the speed of people walking down the staircase is more difficult, since walking speed down the staircase usually is not steady.

The walking speed of the occupants is also influenced by the body type, age and physical ability. Because high residential buildings are normally occupied by various types of people, it is suggested that walking speed in simulation is set based on multiple occupancy and set at a typical distribution of types of people i.e. male, female, elderly and children. In the Simulex programme, different types of people have different walking speeds. Table 7.4.1 shows the range of occupants speed in Simulex. These walking speeds are obtained by checking each of the individual assigned in the models tested.

People	Male	Female	Elderly	Children
Walking speed (m/s)	1.15 – 1.53	0.97 – 1.34	0.52 – 1.23	0.62 – 1.19

Table 7.4.1: Range of occupants speed in Simulex

7.3 Simulation procedure on study models

Models were designed using CAD software and saved in a dxf file. If more than one floor needs to be analysed, dxf files have to be uploaded as many times as desired and the floor then named accordingly. All floors have to be connected to each other by using staircases designed in the SIMULEX environment.

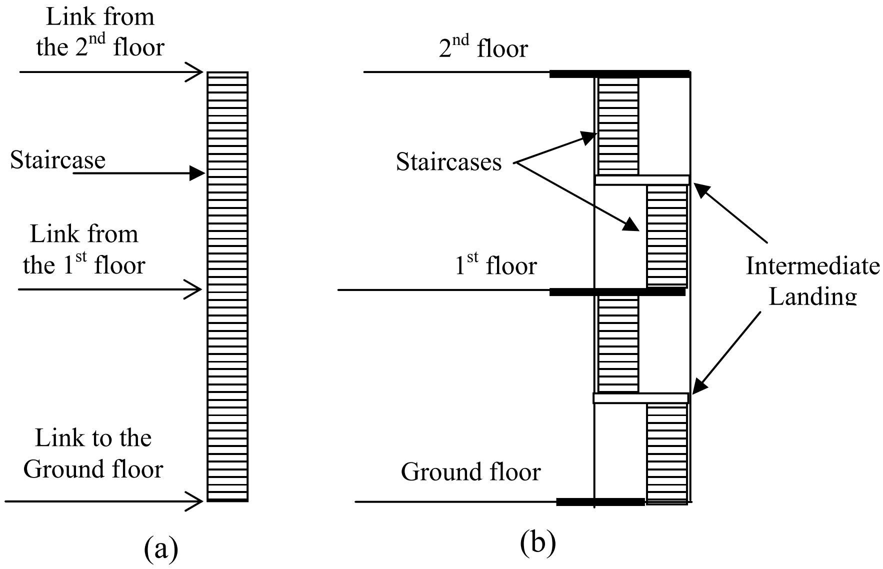


Figure 7.0: (a) Staircase without landing floor link to every floor, (b) Staircases with intermediate landing floors connecting the floors.

To determine the number of staircases needed, analysis of the effect of the intermediate landing i.e. landing connecting between two staircases (see diagram in figure 7.0b) on the evacuation time, needs to be carried out. If there is no significant time difference between the two cases, only one staircase will be designed in Simulex linking to each of the floors served by the staircase as in figure 7.0a. Analysis of this requirement will be discussed in paragraph 7.4.1. The staircase needs to be linked to the appropriate floor. The link must be the same as the door width. After links have being made, an exit or exits need to be assigned to enable the occupants to get out of the building. The exit assigned is an end destination for occupants to get out of the building. People then have to be put in before we can start the simulation. People's characteristics should be determined and selected from the choice given in the SIMULEX environment. These pre-installed people characteristics are easy to use and changes can be made at any time if wanted.

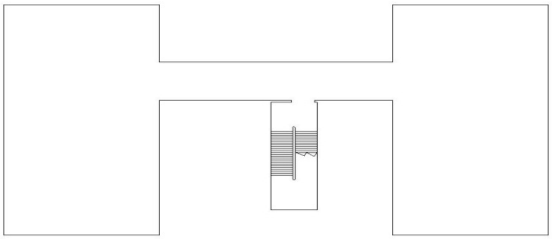


Figure 7.1: Example of the 1st and 2nd floor model

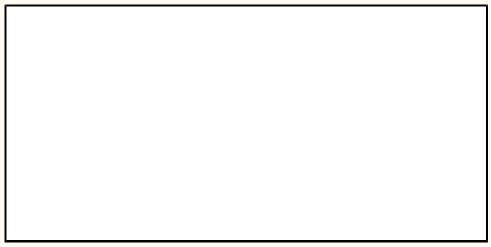


Figure 7.2: Example of the ground floor model

As described in chapter 4, there are 260 study models to test in the simulation software. Every model had to be designed in the CAD environment and uploaded into Simulex i.e. three building floor models for this purpose, floor one and two, and ground floor as shown in figure 7.1 and 7.2. Floor 1 and floor 2 models have been described in chapter 4 and the ground floor model designed as a rectangle to indicate the building line to enable people to move toward the final exit.

Both models were then uploaded into Simulex and named accordingly to indicate the appropriate floor level they represent. Staircases are then designed according to the width and length as shown in table 4.9. In general, the simulation procedures were as follows;

(i) Add floor; by clicking 'Building' button, floor plan can be added. Dxf file saved in appropriate folder can be imported and named accordingly i.e. ground floor.

(ii) Procedure (i) can be repeated to add other floor plans i.e. Floor 1, 2, 3 etc. The number of floor plans to be added depends on the number of floors we wanted to investigate.

(iii) Add staircases i.e. staircase 1, 2, 3, 4, etc by putting in the staircase specification e.g. staircase width as in table 4.9 and name them accordingly.

(iv) Add links to every staircase designed to the floor level i.e. link 1 is to link staircase 1 to the ground floor plan, link 2 is to link staircase 1 to the 1st floor, link 3 is to link staircase 2 to the 1st floor, link 4 to link staircase 2 to the landing floor, link 5 to link staircase 3 to the landing floor, link 6 to link staircase 3 to the 2nd floor and so on. All links widths have to be the same width as the staircase designed.

(v) Add 2 metres exit to indicate the normal main entrance width at the ground floor which is normally uses by the occupants to enter and leave the building. It is placed opposite to the link 1 made in procedure (iv).

(vi) Add people into all models by dividing equally into every chamber available in the study models. People characteristics are then set; in the analysis of the models the same typical distribution of people is used in each model tested to reflect the normal occupancy type of people in residential buildings, i.e. male, female, children and elderly.

(vii) Calculate the distance maps by clicking 'DistMap' button and then click 'Calculate All'.

(viii) Run the simulation by click 'Simulation' and then click 'Begin'. The simulation can be recorded and saved in an appropriate folder under an appropriate name.

(ix) After the simulation has been completed a popup window will show the simulation time. Click 'Yes' and another popup window will tell the time taken by all people who have reached the exit.

(x) Note down the evacuation time in table as in appendix 7.1 for further analysis.

Figure 7.3 shows one of the models that have been simulated in Simulex.

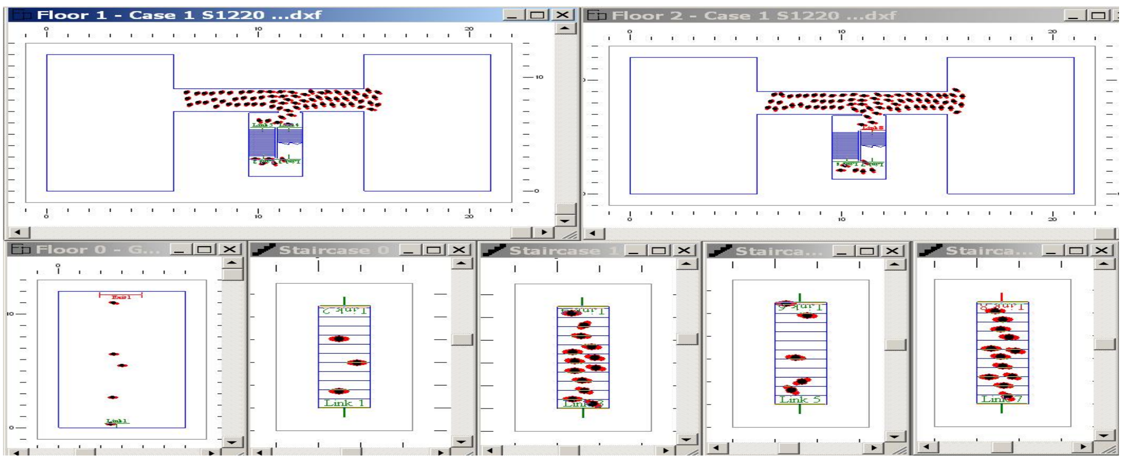


Figure 7.3: Example of simulation process

Figure 7.4 shows an example of a two storey schematic drawing of a common staircase in a high-rise residential building. There are four staircases with five landing floors for floor 2, 1, and ground floor. For the high-rise building, the same form of staircase is repeated to the number of the storeys required.

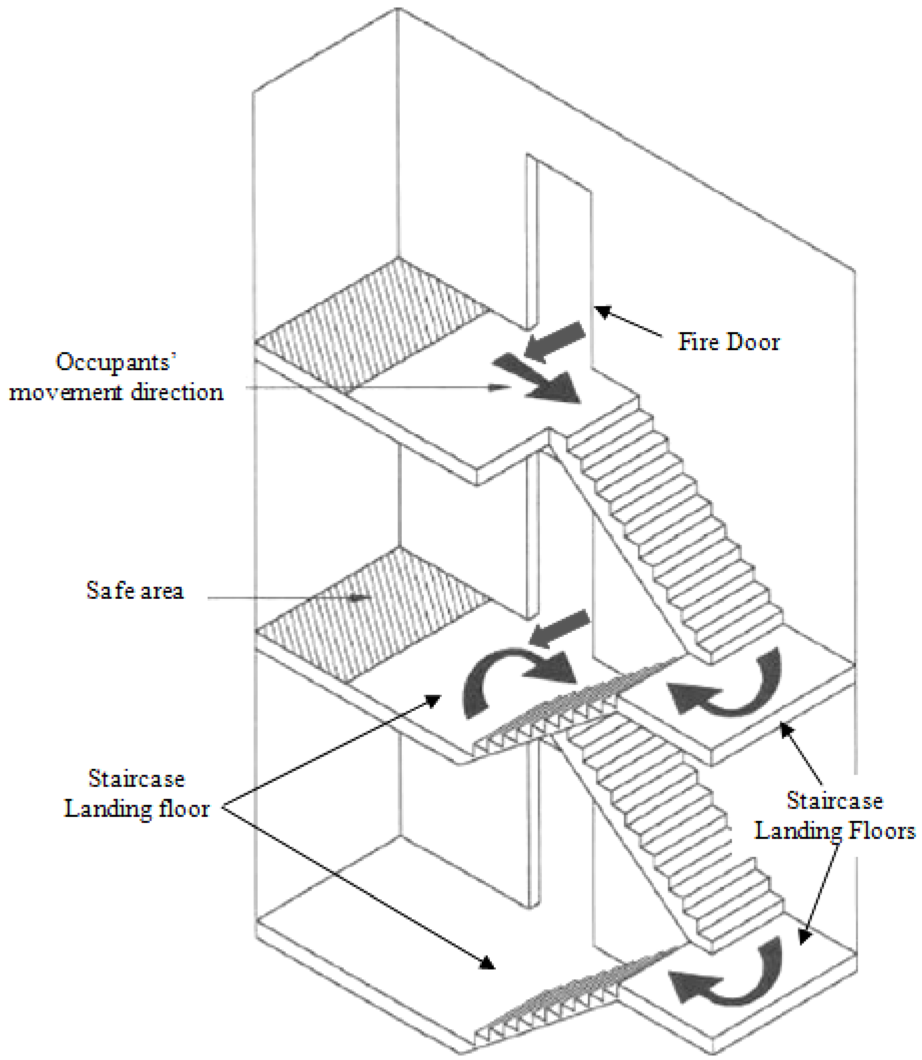


Figure 7.4: Schematic drawing of common staircase in high-rise residential buildings.

7.4 Analysis of escape route specification

The purpose of this simulation is to analyse the staircase, corridor, and fire door specifications. A further objective is to identify some important points concerning the internal layout of the building relating to the location of fire escapes. Analysis of various building floor layouts identified in the observation study will be carried out to investigate whether the design specification as stated in UBBL is satisfactory.

Before further investigation on escape stair specification can be done, analysis of staircases with and without landing floors will be carried out to investigate the effect of the staircase landing floor on the evacuation time. If there is no significant difference between them, further analysis on staircase, corridor and fire door width will be carried out by designing only one staircase and link it to the respective floors. If there are significant differences between them, then, analysis of staircase, corridor and fire door will be carried out by taking into consideration the existence of the landing floor on the evacuation process.

7.4.1 Analysis of staircases with or without intermediate landing floor

To analyse the effect of the staircase, comparison of two staircases is carried out, i.e. staircase width 914 mm with and without an intermediate landing. Tests have been carried out using Simulex software. The test results are shown in table 7.5. The test is carried out by adding the number of people in the model beginning from one person up to the maximum of 180 persons.

The purpose of the test is to understand the effect of the intermediate landing on people's movement. Comparison is made of two different staircases i.e. staircase with and without intermediate landing. In the first test the number of people is gradually increased from one to ten to investigate the effect of the number of people evacuating using both types of staircase.

No. of People	1	2	3	4	5	6	7	8	9	10	**36**	**72**	**180**
914w	33.0	33.0	33.1	35.5	42.3	43.0	45.4	43.1	48.6	48.1	87.0	163.4	391.7
914wo	28.2	28.3	29.8	31.1	32.1	32.5	33.4	35.5	36.8	38.0	54.3	93.6	196.9

Table 7.5: Evacuation Time for staircase 914 mm with and without intermediate landing

In the second test the number of people is based on different numbers of people occupying each flat. There are three occupation types i.e. Normal occupancy, 2 persons per room; high occupancy, 4 persons per room; and very crowded occupancy, 10 persons per room. The total number of occupants simulated is based on the number of flats per floor i.e. six flats with three bedrooms, normal density is 2 x 3 x 6 = 36 persons, high density is 4 x 3 x 6 = 72 persons, and over crowded is 10 x 3 x 6 = 180 persons. The total number of people is equal distributed on each floor. For example, for the over crowded occupancy, 180 people are divided by 2 i.e. 90 people to be placed on the 1st floor and another 90 people will be placed on the 2nd floor. The evacuation time recorded here is a total evacuation time when all people have evacuated the model.

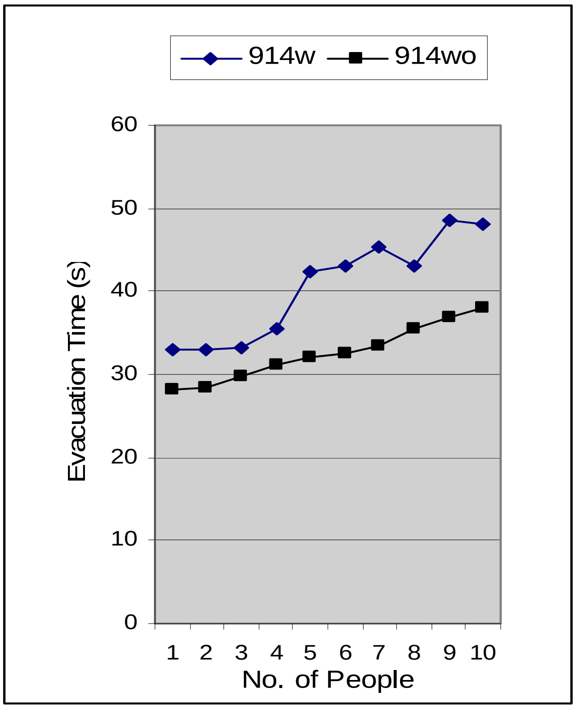


Figure 7.5: Evacuation time Vs No. of People of low occupancy for staircase 914 mm with and without intermediate landing floor.

For the staircase without intermediate landing, Staircase Equivalence Length is used, which takes into consideration the distance that occupants have to walk on the staircase and through the intermediate landing. There will be only one staircase design in Simulex environment that links from floor level to the ground floor. For the staircase with intermediate landing, the actual staircase length is designed and links from floor level to the intermediate landing then to the ground floor. There will be four staircases, 1st staircase from the 2nd floor level to the intermediate landing located between 2nd and 1st floor, 2nd staircase from the intermediate landing to the 1st floor, 3rd staircase from the 1st floor level to the intermediate landing located between 1st floor and ground floor and 4th staircase from the intermediate landing to the ground floor. Occupants have to change the staircase at every landing floor on their way out. Those test results are as in figure 7.5, evacuation time versus no. of people of low occupancy and high occupancy respectively.

The simulation shows that in increasing the number of people up to ten people, there is no congestion at any point on the staircase. People are smoothly moving down the staircase. In the case of the staircase with the intermediate landing, people have to change staircases at the intermediate landing, and this causes the walking speed to slow down. It causes a significant delay in the travel time. This demonstrates that the intermediate landing does have an effect on the travel time.

Figure 7.5 shows the analysis of travel time on the same width of staircase, i.e. 914 mm with and without intermediate landing. It shows that evacuation from the staircase with an intermediate landing takes longer than without. The difference is from 11.07% to 35.93%, with an average difference of 23.89%. A similar result occurred when a staircase 1524 mm wide with and without an intermediate landing was analysed. The results show that evacuation from the staircase with the intermediate landing took longer. The difference was from 8.87% to 29.74% maximum with an average difference of 14.63%. This is further evidence that the intermediate landing has an effect on the travel time, taking about 15% to 24% longer that the staircase without the intermediate landing.

There are significant differences between staircase with and without an intermediate landing. Therefore further analysis of staircases, corridors and fire doors in the study models takes into consideration the existence of the intermediate landing.

7.4.2 Analysis of floor clearance time and total evacuation time for different building layouts

Data used for the simulations shown in tables 7.6, 7.7 and 7.8:

No. of floors (Nf):	=	10 floors
No. of staircases (Ns):	=	20 staircase i.e. two staircases between the floors.
No. of platforms (Np):	=	21 platforms i.e. 10 intermediate floors + 11 landing floors
No. of steps per staircase:	=	9 steps per staircase: based on the observation that the great majority of staircases were designed with 9 steps.
Tread dimension:	=	255mm i.e. minimum requirement by UBBL
Riser dimension:	=	180mm i.e. maximum requirement by UBBL.
Staircase width (Ws):	=	1100 mm i.e. minimum requirement by UBBL
Door width (Wd):	=	914 mm (3 ft): based on the observation that the majority of fire doors fitted to the staircase shafts were 914 mm. The Building Regulations do not mention specifically the width of fire door that should be used. Normal practice is for the fire department to accept any standard size of fire door, i.e. standard size produced by manufacturer, as long as it has been approved by SIRIM i.e. Malaysian Standard.
Exit width:	=	Final exit door width or actual opening width.

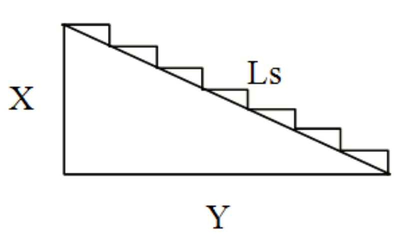
Link width: = Storey exit door width.

Staircase length (St): = 102.4 m: calculated using equation 4.4 for a staircase of 1100mm.

Response time: = 30 seconds +/- 0.5 seconds.

Example calculation of staircase length:

$$St = \sum_{1-n}^{i} (Nsi.Lsi) + \sum_{1-n}^{i} (Npi.2Wsi)$$



$Ls = \sqrt{X^2 + Y^2}$

Where;

X = No of staircase steps multiplied by riser dimension.

Y = No of staircase steps multiplied by tread dimension.

From the above design data,

X = 9 x 180 mm

= 1,620 mm

Y = 9 x 255 mm

= 2,295 mm

Ls = $\sqrt{(1620)^2 + (2295)^2}$

= 2,809 mm

Therefore,

St = (20 x 2809) + (21 x 2 x 1100)

= 102,380 mm

= 102.4 m

Simulation results for various building layouts can be found in tables 7.6, 7.7, 7.8 i.e. for low, normal and high occupancy respectively. The simulations were carried out by assuming that people begin to evacuate the building approximately 30 seconds after the fire alarm goes off. The simulation results for the low occupancy suggest that no significant problems will arise, as the floor clearance times recorded were 50 to 75 seconds. A floor clearance time below 150 seconds (2.5 minutes) is accepted in the UK as reasonably safe. This an average clearance time was proposed after the evacuation experience during a fire in the Empire Palace Theatre in Edinburgh in 1911 (Kendit, 1986). If we consider the response times studied by Proulx (1995), i.e. that most of the occupants in residential buildings will only start their evacuation approximately 2½ minutes after the alarm has been activated, most of the people in the high-rise residential buildings simulated are at high risk because the floor clearance time will be more than 2½ minutes even for low occupancy. Therefore the conclusion is that there is no clear guidance at present on what is considered as a safe floor clearance or total evacuation time for a high-rise residential building.

Building	A			B			C			D		
Floors per building	10			10			10			10		
Flats per floor	6			7			8			8		
Rooms per flat	3			3			3			3		
Occupants per room	1	2	4	1	2	4	1	2	4	1	2	4
Total people	180	360	720	210	420	840	240	480	960	240	480	960

Table 7.5.1: Number of people simulated in the buildings studied.

Table 7.5.1 shows the number of people simulated in the buildings studied for low, medium and high occupancy. Building C and D have the same number of people per floor level therefore any difference in evacuation time between the two is a result of the different layouts (see floor plans in Chapter 4).

Buildings A and B are included for comparison as they are typical of high-rise flats in Malaysia. The minimum number of staircases and appropriate staircase width is related to the number of occupants expected and is described in Chapter 2, along with an example of the calculation used.

Floor clearance time (s)	Low occupancy i.e. 1 person per room										
	Building A		Building B				Building C		Building D		
	S1	S2	S1	S2	S3	S4	S1	S2	S1	S2	S3
Floor 1	65	50	60	55	50	50	60	60	-	60	60
Floor 2	55	50	60	70	50	60	65	60	-	55	50
Floor 3	60	55	60	55	55	50	55	65	-	55	55
Floor 4	60	50	55	50	55	50	60	60	-	55	55
Floor 5	60	50	55	55	50	50	60	60	-	60	55
Floor 6	60	50	60	65	50	60	60	60	-	55	60
Floor 7	65	45	70	40	50	50	60	75	-	55	55
Floor 8	65	50	60	45	55	50	65	65	-	55	55
Floor 9	55	50	55	45	60	60	65	55	-	60	55
Floor 10	65	55	60	40	60	50	60	60	-	50	50
Total Evacuation Time(m:s)	5:21.3		5:08.9				5:24.1		5:31.0		
Note: S1 = Staircase No. 1, S2 = Staircase No. 2, S3 = Staircase No. 3, S4 = Staircase No. 4											

Table 7.6: Floor clearance time and total evacuation time for low occupancy

The simulations recorded (see table 7.6) that no occupants evacuated building D by staircase No.1 because it is the furthest from each flat, therefore the occupants have chosen either staircase 2 or 3 to evacuate the building. The total evacuation time from the building was 5 to 5 ½ minutes. Although building B has more occupants than building A the evacuation time is shorter. However, building B has four staircases compared with two in building A, because the layout of building B is such that the maximum travel distance required by the bye-laws would otherwise be exceeded.

Floor clearance time (s)	Normal occupancy i.e. 2 persons per room										
	Building A		Building B				Building C		Building D		
	S1	S2	S1	S2	S3	S4	S1	S2	S1	S2	S3
Floor 1	90	55	70	65	55	55	85	90	-	75	70
Floor 2	75	55	80	70	55	65	80	80	-	75	75
Floor 3	100	55	75	65	55	50	85	120	-	75	75
Floor 4	80	55	70	60	60	55	85	85	-	80	75
Floor 5	90	55	70	55	65	50	95	85	-	85	75
Floor 6	85	55	75	65	50	60	80	90	-	85	75
Floor 7	85	55	80	50	60	55	85	95	-	70	80
Floor 8	100	60	80	50	70	65	100	155	-	80	80
Floor 9	80	55	75	60	60	60	85	80	-	75	75
Floor 10	65	60	65	45	65	50	65	65	-	70	65
Total Evacuation Time (m:s)	6: 35.7		5:57.3				6:51.8		6:09.8		
Note: S1 = Staircase No. 1, S2 = Staircase No. 2, S3 = Staircase No. 3, S4 = Staircase No. 4											

Table 7.7: Floor clearance time and total evacuation time for normal occupancy

For normal occupancy (see table 7.7), i.e. two people per room, the simulation results show that the floor clearance times were mostly below 150 seconds, except for the building C i.e. at staircase no. 2 on the eighth floor where the floor clearance time was 155 seconds. Building C has a foyer type internal layout, and the simulation shows that some of the people on the eighth floor who have chosen to evacuate building C by staircase no. 2 may be at risk because the floor clearance time was more than 150 seconds. Increasing the number of occupants in the buildings tested, i.e. doubling the number from 1 person per room to 2 persons per room, increases the floor clearance time by between 5 seconds and 1 ½ minutes. The total evacuation time increases by between 30 seconds to 1 ½ minutes.

Floor clearance time (s)	High occupancy i.e. 4 persons per room										
	Building A		Building B				Building C		Building D		
	S1	S2	S1	S2	S3	S4	S1	S2	S1	S2	S3
Floor 1	150	80	125	70	75	60	155	150	-	125	110
Floor 2	150	75	135	75	75	60	160	160	-	120	165
Floor 3	180	85	160	60	80	60	205	190	-	165	180
Floor 4	180	80	150	80	75	65	260	215	-	195	170
Floor 5	275	80	150	100	75	60	280	285	-	225	230
Floor 6	305	75	150	75	75	70	320	200	-	250	245
Floor 7	340	95	245	70	105	75	345	235	-	295	300
Floor 8	380	85	270	70	85	70	315	415	-	240	270
Floor 9	415	80	120	70	85	75	305	285	-	175	305
Floor 10	90	70	105	60	70	60	95	90	-	80	85
Total Evacuation Time (m:s)	11:53.8		9:35.8				12:10.7		10:44.1		
Note: S1 = Staircase No. 1, S2 = Staircase No. 2, S3 = Staircase No. 3, S4 = Staircase No. 4											

Table 7.8: Floor clearance time and total evacuation time for high occupancy

Table 7.8 shows the simulation results for high occupancy, i.e. 4 people per room. These simulation results show that at certain floor levels the floor clearance time recorded was higher than 150 seconds. Simulation on building A shows that staircase No. 1 recorded a higher floor clearance time than staircase No. 2. From 720 people placed in this building, 480 people (66.67%) exited the building by staircase No. 1 and 240 people (33.33%) exited by staircase No. 2.

The staircase used by each occupant is determined by the distance of their flat exit from the staircase – Simulex assumes that people will select the nearest staircase. Where there is more than one staircase the overall floor clearance time at each floor is the maximum of those recorded through the different staircases.

The results for Building B, with four staircases, show that staircase No. 1 recorded higher floor clearance times than the other staircases. Out of 840 people (i.e. 4 people/room x 3 room/flat x 7 flat/floor x 10 floors = 840), 360 people (42.86%) exited the building by staircase No. 1, 174 people (20.71%) exited by staircase No. 2, 186 people (22.14%) exited by staircase No. 3, and 120 people (14.29%) exited by staircase No.4. The number of people occupied high-rise residential building is ranged from 2 to 15 people per flat (see table 6.2.1 in chapter 6) There are 9.6% i.e. eleven flats occupied by 12 people per flat. Therefore 12 people per flat have been chosen (i.e. 4 people/room x 3 room/flat).

Buildings C and D, with the same number of residential flats per floor, i.e. eight flats, recorded floor clearance times higher than 150 seconds except for the tenth floor. According to the simulation results, increasing the number of people i.e. double normal occupancy, will pose a high risk to the occupants. Building D has a more linear layout and in fact one of the staircases is not used in the evacuation simulation due to its greater distance from the flats (Tables 7.6, 7.7, 7.8). The contribution of the different floor layout to floor clearance time appears to be related directly to the distance of the staircase from the flats. Under low and normal occupancy the floor clearance and overall evacuation times do not appear to pose a major problem, but under conditions of overcrowding, which are common in some buildings in Malaysia, excessive floor clearance times can occur. Also, the simulations show that some staircases are not used or under-used, suggesting that their location is inconvenient for exit from some of the flats. Thus there is a possibility that the number of people using one of the staircases is greater than it was designed for, and the staircase width may therefore not be sufficient for the number of people using it.

7.4.3 Analysis of study models

Further analysis on the study models is important because technical solutions need to be determined, hopefully to reduce the risks to the building occupants by helping them in the evacuation process. It is difficult to change human behaviour but the building specifications can be changed more easily. From the opinion survey (see chapter 6) 72.6% of the occupants had no formal training or courses in fire safety and 77.4% had no experience of involvement in building fires. Even though 57.4% of them had experienced a fire drill, none of them had experienced a fire drill in their own residential building. In this regard, the building element best known as escape route, that is escape stairs, corridors and fire doors, should be designed and constructed to serve the occupants the best they can by not allowing any further delay in the evacuation process. The design and construction of escape routes needs to consider not only the evacuation time but also the construction time, economics, construction method and space utilization factors. The objective of this section is to analyse the optimum staircase width, corridor width, and fire door width. Table 4.9 show the staircase, fire door and corridor sizes that have been selected to be used for further analysis in SIMULEX software.

There are eight scenarios (refer to chapter 4.7.1) all together that were developed based on the observation of the high-rise residential buildings in Malaysia. The vast majority of high-rise residential buildings observed had emergency staircases, parallel, vertical, or straight with the corridor, or staircase without corridor that served the cluster flats. Those scenarios come with or without a fire door. The philosophy adopted here is *the faster is the safer*[10]. The purpose of this study is;

(1) To know at what point the design of staircase, fire door and corridor in the high-rise building provides an optimum safe route to be used by occupants.

(2) To test the popular assumption that wider staircase and corridor are better for evacuation process and the bigger space provided, the better people are evacuated.

Time is the determining factor for analysing the staircase specification. In this sub-chapter, discussion will be centred on the travel time taken by 200 occupants evacuating the pre-designed model through the specific staircase dimension, fire door and corridor width. From 200 people, 100 people will be placed at the 1st floor and another 100 at the 2nd floor. The number of people on each floor will be divided equally i.e. if the study model has two chambers, 50 people will be placed in each of the chambers. 260 models have been tested and the test results can be found in figure 7.8 to figure 7.15 below. 200 occupants were chosen based on the assumption of high occupancy i.e. 4 persons per room for a three bedroom flat. From the observation of high-rise residential buildings in Kuala Lumpur and Penang, the number of flats per floor level ranges from 6 to 16 flats with the majority having 8 flats per floor. Therefore; 4 persons/room x 3 bedrooms/flat x 8 flats/floor = 96 people. The nearest round figure to 96 is 100, therefore 100 people per floor level had been chosen for the simulation because in the seventh schedule of the UBBL says that the capacity in a number of persons of a unit of exit width (i.e. staircase width) varies from 30 persons per unit of exit width to 100 persons per unit of exit width for travel in horizontal direction. (Refer to Table 2.0 in Chapter 2 for example showing the maximum number of people per given staircase width). In engineering terms designing any building elements, for the safety of people, the extreme condition has to be considered. We do not have to worry about

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[10] The faster means that in all models simulated, evacuation time will be compared and the shorten time taken by occupants to evacuate the studies models is consider the safest one.

the lower cases if we have considered the extreme condition. For example when designing a building column, the maximum load that could be carried by the column has to be considered. On top of that it is commonly practice that 5% – 10% of the safety factors are added to accommodate the unforeseen circumstances of possibly the building is overloaded in the future especially when dealing with the live load i.e. people and movable equipment. The optimum dimensions derived below are for overcrowded conditions and for lower populations the optimum dimensions may be different.

(i) *Model one*

Figure 7.8 shows the graph of evacuation time versus fire door width for model one. This scenario has a staircase with a fire door and not parallel with the corridor. This model is named "Opposite Direction with Fire Door". There are five sizes of staircase from the minimum width 914 mm to the maximum width 1524 mm. Every staircase is designed with one fire door in the range 762 mm (2 ft 6 inch) to 1524 mm (5 ft), taking the evacuation times of 200 occupants.

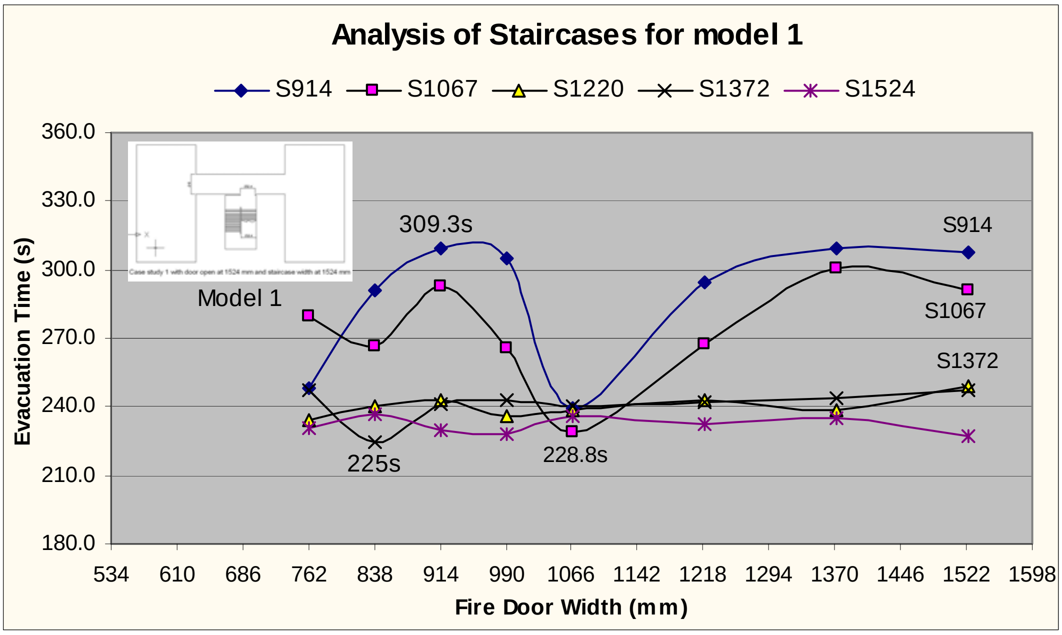

Figure 7.8: Evacuation Time Vs Fire Door; Model 1 i.e. Opposite directions with fire door.

Overall analysis of the test result of 200 occupants evacuating the study model showed a difference of 84 sec between the shortest and longest of the staircase design tested. The shortest time taken was 225.0 sec for the 1372mm staircase with 838 mm fire door width. The longest time taken was 309.3 sec for the 914mm staircase with 914 mm fire door width.

The staircases of width 914 mm and 1067 mm show the same pattern of evacuation time i.e. time increased when the fire door width increased. Fire door size 914mm (3 ft) has the longest time taken for all occupants to evacuate the model. The total evacuation time is slightly improved when the fire door width is increased to 990 mm (3ft 6inches). The shortest time taken recorded was when the fire door width was 1067mm (3.5 ft). The time is then increased again when the fire door width is increased to 1220mm (4ft) and 1370 mm (4.5ft) and remains about the same when the fire door width is further increased to 1524mm (5ft). Test results for staircases 1220 mm, 1372 mm and 1254 mm wide show that this has no significant effect on evacuation time even after the fire door sizes changed. This suggests that there is no significant correlation between the evacuation time and the fire door width if the staircase width is wider than 1220 mm for the number of people tested. There is significant evidence that traffic is not congested either if the staircase designed is wider than 1220 mm. For the same staircase orientation, a test is needed to determine the effect of corridor width on the evacuation time. In this regard, model two has been developed and tested.

(ii) Model two

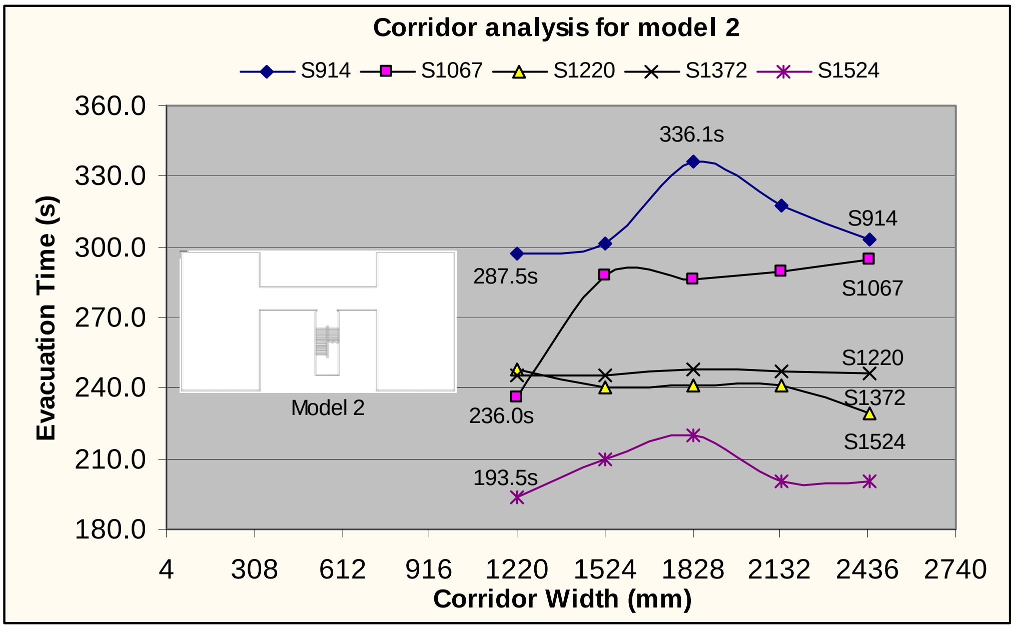

Figure 7.9: Graph Evacuation time Vs Corridor width, Model 2 i.e. opposite direction without fire door

The second test has been carried out on model two, which has been slightly modified from model one i.e. without fire door increased corridor width. Corridor widths ranged from 1220 mm (4 ft) to 2440 mm (8 ft). This model is named as “Opposite Directions without Fire Door”. The result of the test is in figure 7.9 i.e. evacuation time versus corridor width. The purpose of this analysis is to examine the corridor specification against the staircase width.

The test results show that the time taken for the staircase 914mm wide is slightly higher than model one. The shortest time taken is 287.5 sec at corridor width 1220 mm and the highest time taken is 336.1 sec at corridor width 1828 mm. The time taken seems to improve when the staircase width increases. However, there is no significant difference between staircases 1220 and 1372 wide, as for both models the time taken is around 4 minutes even though the corridor width has been increased. There is a significant time reduction in staircase 1524 that is around 30 sec faster than the time taken in model one. However, the time is seen to steadily increase when the corridor width increases from 1220 to 1524 and 1828mm. The evacuation time then decreases when the corridor width is further increased to 2134 and remains about the same after it is further increased to 2440mm.

The phenomenon in staircase 1067 is similar in that the evacuation time increases when the corridor width increases. Staircase 1067mm has the best evacuation time when the corridor width is 1220 mm (4ft) i.e. 236.0 sec. The evacuation time increases when the corridor width increases to 1524 mm (5 ft) and remains about the same even after the corridor width is further increased to 1828 mm. The evacuation time then increases again approaching the 300 sec when the corridor width is increased to 2440 mm (8 ft).

However, this phenomenon does not happen to staircases 1220mm (4 ft) and 1372mm (4 ft 6 inch) where the evacuation time is recorded steady throughout the test and shows no significant changes even after the corridor width has been changed. This suggests that the wider corridor does not contribute to improving the evacuation process in high-rise residential buildings if the staircase width does not increase.

The results suggest that in staircases 914mm and 1067mm wide congestion is likely to happen because the evacuation time for both staircases, if corridor width is increased, was nearly 300 sec (5 minutes). For the staircase 914mm wide it is worst, when all cases were above 300 sec except for the corridor width 1220mm i.e. 287.5 sec. An anomalous result appeared for staircase 914mm when the corridor width was 1828 mm (6 ft) i.e. the evacuation time increased very significantly to 336.1 seconds. At the beginning, it seems that congestion at the staircase might have caused this phenomenon but the evacuation time reduced when the corridor width was increased to 2134mm.

It can be concluded that:

(1) The fire door can contribute to minimise traffic congestion in staircases if staircases are designed as in model one.

(2) A wider staircase can improve the evacuation time provided that wider openings are designed to replace the fire door.

(3) A staircase width between 1220mm to 1372mm inclusive is the best dimension where it can be substituted at any fire door or corridor width.

(4) There is no significant evidence that increases in the corridor width will improve the travel time.

Further analysis will be carried out on other types of model to test the effect of corridor, fire door and staircase width on the different orientation and staircase layouts. Tests on model three have been carried out and the test result is as in figure 7.10 i.e. evacuation time Vs Fire doors, Model 3 i.e. One direction 'L' shape with fire door.

(iii) Model three

Model three is designed with 'L' shaped corridor and fire door attached t. The fire door has the same width as the corridor. Therefore in figure 7.10, only the corridor width is shown in the graph of evacuation time verses corridor width. The overall result shows that increasing the staircase width will improve the travel time. However, there is insufficient evidence to prove that increasing the corridor width will contribute to the decrease in travel time. The difference in travel time between the widest staircase i.e. 1524mm and the narrowest staircase i.e. 914mm is about 1½ to 2 minutes. Meanwhile, travel time differences among the staircases e.g. staircase 914 to 1067, staircase 1067 to 1220 and so on are within 20 to 30 sec. Analysis on every staircase shows that increasing the corridor width does not improve the travel time. The travel time remains about the same even though the corridor width is increased up to 2440mm.

It can be concluded that:

(1) Wider is not necessarily better for the corridor design.

(2) The wider the staircase the shorter the evacuation time recorded.

(3) The main attribute that can cause the increase of evacuation time is the number of people occupying the building. The evacuation time can increase by about 160% to

200% if the number of people occupying the building is multiplied i.e. doubling the occupant numbers.

(4) In terms of staircase orientation and layout as in model three, there is no correlation between evacuation time and width of corridor. Therefore a corridor width between 1220mm to 1524mm is sufficient for high-rise residential buildings.

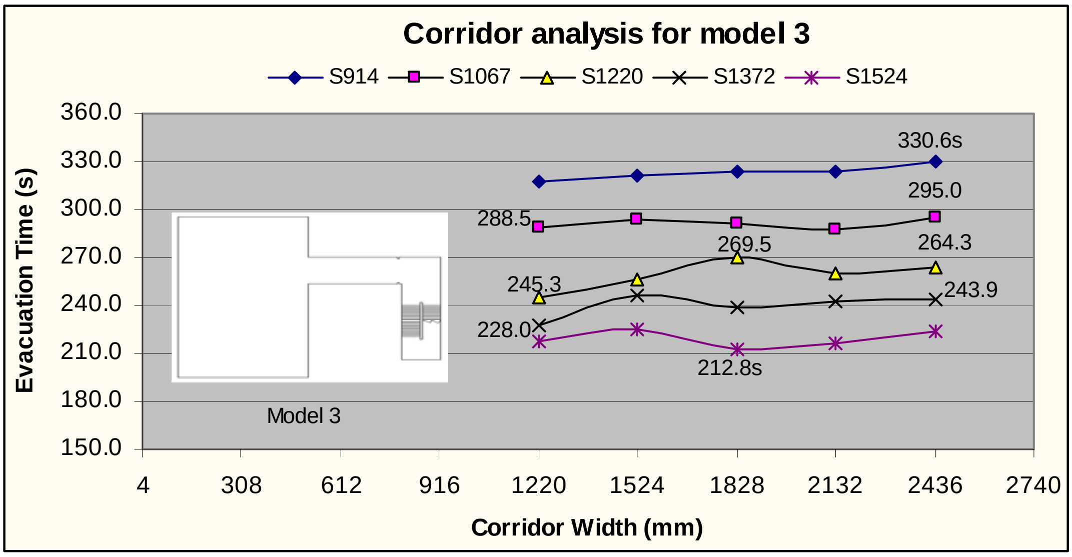

Figure 7.10: Graph evacuation time Vs corridor or fire doors width for Model 3

However, further tests on the corridor orientation with staircase designed straight with fire door needed to be done to test this correlation. Tests on the model have been carried out and the test results are as in figure 7.11. This model is known as model 4 i.e. straight direction with fire door. The fire door and corridor are the same width.

(iv) Model four

Model four is designed with the staircase attached at the end of the corridor. The corridor is fitted with fire doors having the same width as the corridor. The test results in figure 7.11 show that there is not a significant difference in terms of marginal differences of evacuation time recorded on the same staircase when the corridor width increases compared to the test results on model three. The tests on model four show about the same pattern as in model three. The difference in evacuation time between the widest and the narrowest staircase is nearly double i.e. 2 ½ to 3 minutes. However, the evacuation time for staircases 1607, 1220 and 1372mmwide are within 30 sec to 60 sec. The evacuation time for the staircase 1067 and 1372 mm wide is slightly increased when the corridor width is increased. The difference between model three and model four in terms of the total evacuation time recorded i.e. model four recorded higher total evacuation time for the same width of staircase e.g. staircase 914 mm gives 320 – 330 seconds but model four gives over 510 seconds because the corridor length in model four is nearly 2/3 longer than the corridor length in model three. The emphasis of the analysis is on the increase or decrease margin of evacuation time when the corridor width increases.

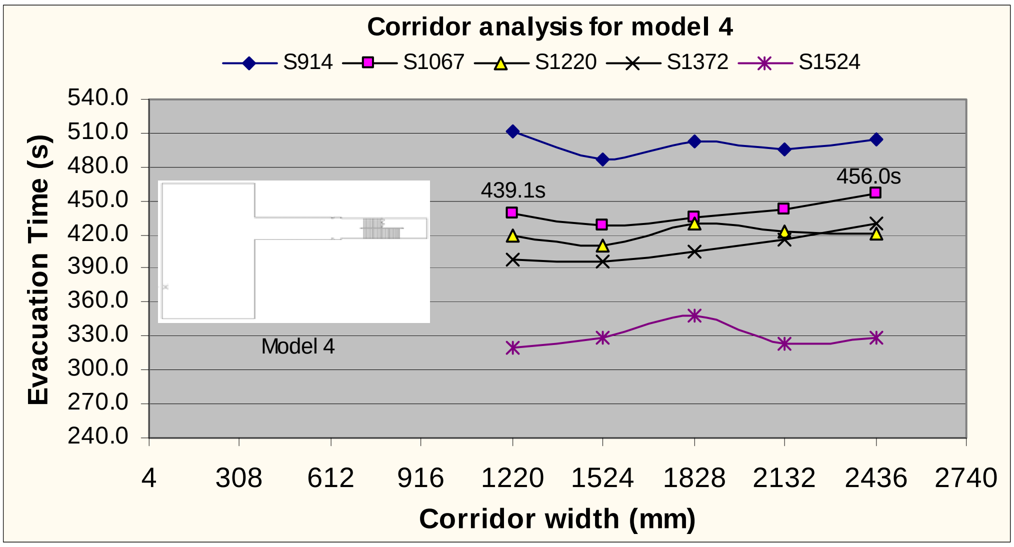

Figure 7.11: Evacuation time Vs corridor width for model 4 i.e. Straight direction with fire door. Fire door width is the same as the corridor

It can be concluded that:

(1) There is significant evidence that corridor width does not have much influence on the evacuation time but staircase width does.

(2) However staircases of width 1067mm and 1372mm show a slightly different pattern compared with the rest of the staircases. These staircases show that travel time is slightly increased when corridor width increases from1524 mm up to 2440mm. The increase of travel time occurs gradually and up to about 30 sec differences (depending on the number of occupants).

(3) A positive correlation of the staircases widths 1067mm, 1220mm, and 1372mm show that by increasing the corridor width, the evacuation time is slightly increased. It seems that the wider corridor does not necessarily give the better evacuation time.

(4) The others staircase test results show that there is no correlation between the corridor width and evacuation time. It is about the same pattern as the model three test results.

However, further tests are needed to understand the effect of the different design of the staircase layout. Tests on model five i.e. horizontal opposite direction with fire door have been carried out and the results are as in figure 12.

(v) *Model five*

Model five is designed with the fire door orientation parallel with the corridor. The occupants have to go through the fire door located at the side of the staircase shaft. Figure 7.12 shows the test results and small plan of model five. The test results from five different staircase widths i.e. 914mm to 1524mm show that staircase 914mm takes the longest time to evacuate. It shows that evacuation time increases when the fire door width increases.

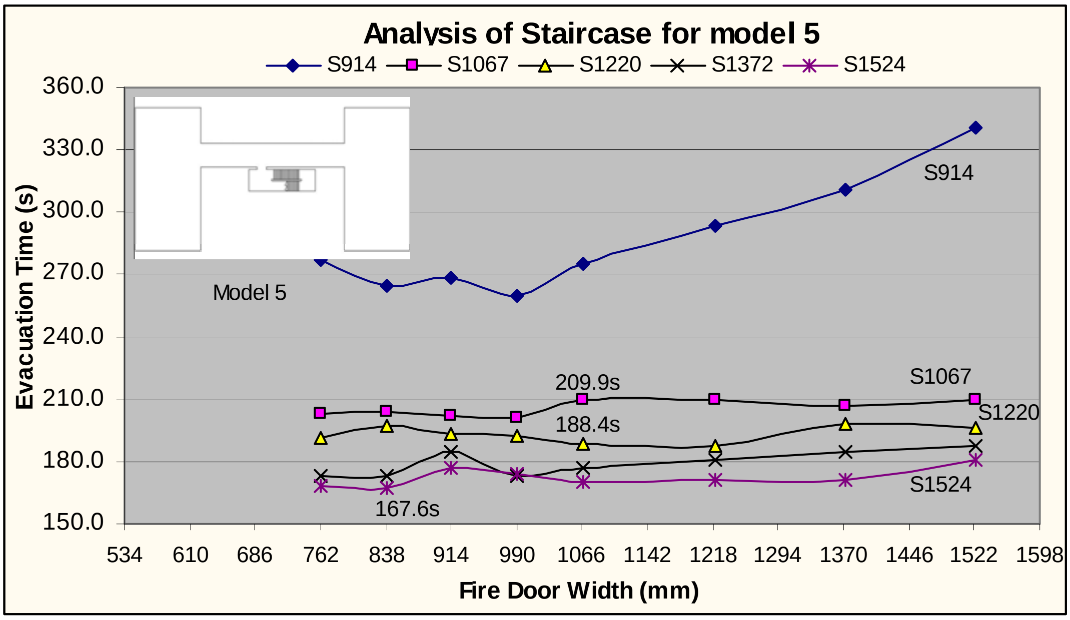

Figure 7.12: Evacuation time VS fire doors; Model 5 i.e. Opposite directions horizontal with fire door

Test results on the other model shows that staircase of width 914mm takes the longest time to evacuate. Therefore, there is significant evidence to say that staircase 914mm is not viable to be used in high-rise building because;

(1) It would not permit the occupants to exit from the building fast enough. However it depends on the number of occupants i.e. high occupancy. It would be no problem for the low occupancy.

(2) Traffic congestion is likely to happen in a staircase 914mm wide even though the fire door and corridor width increase, because the evacuation time increases when fire door widths increase.

(3) It only permits traffic to move in one direction, while in the real world rescuers may need to use the same staircase to enter the building while the occupants are moving out from the affected building.

The other staircases are seen to have quite steady recorded evacuation time. The test shows that the fire door widths do not make any significant difference even if they are wider. The evacuation time seems to fluctuate within 20sec for staircase width 1067mm to 1524mm. However, evacuation from the staircase 1220mm wide takes slightly above 3 minutes and staircase 1372mm about 3 minutes. This is significant evidence that staircase widths 1220mm and 1372mm are viable for high-rise buildings. However further tests need to be carried out to confirm this finding. Tests on model six, that is modified from model five by removing the fire door are carried out and the results are as in figure 7.13.

(vi) Model six

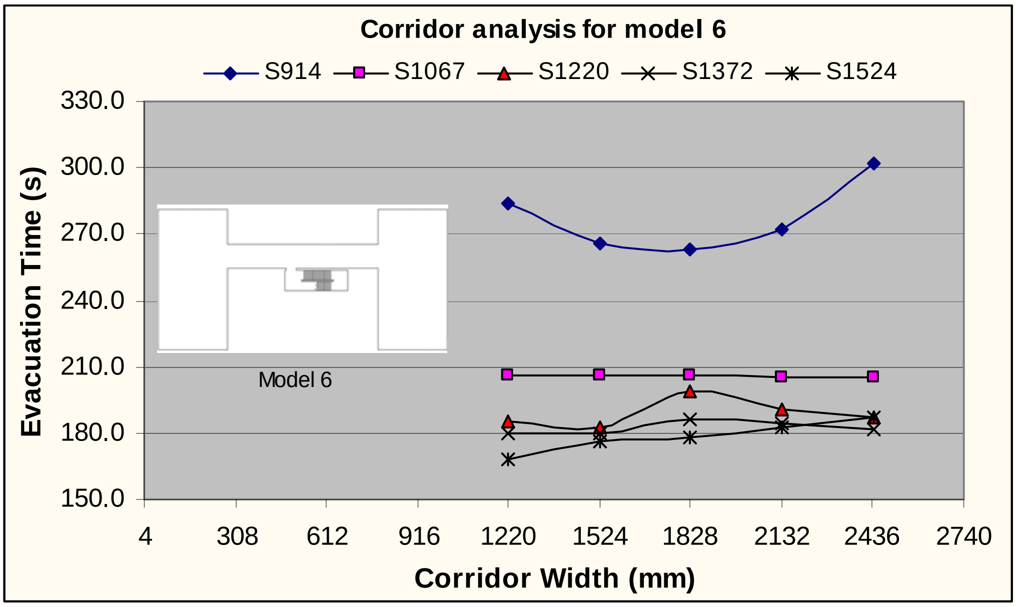

Figure 7.13: Graph evacuation time Vs corridor width for model 6 i.e. Opposite directions horizontal without fire door

The outcome of the test results on model six are not significantly different from model five in that the 914mm staircase takes the longest time to evacuate (see figure 7.13). The rest of the staircases show a roughly steady evacuation time except for staircase 1524mm which shows the evacuation time is slightly increased when the corridor width is increased. Staircase 1220mm and

1372mm indicated that they can let people out of the building within 3 minutes. This result was in line with the test result in model five.

The test results from the other models show that staircase 1220mm and 1372mm have no significance difference in evacuation time taken in the various fire door widths tested. It is significant evidence that these staircases are viable. It is evident that these staircases can be used as a benchmark to further analyse the fire door and corridor specification.

However, tests on model seven and eight are necessary to confirm this finding. Models seven and eight have a different staircase orientation and layout compared to the rest of the models described.

(vii) Model seven

Model seven is designed to enable the occupants to move in one direction to the staircase. Staircase orientation is horizontal with a fire door. The occupants have to make a 'U'-turn at the landing floor before they can reach the escape stair. The test results on model seven are in figure 7.14. Staircase 1220mm, 1372mm and 1524mm wide show about the same pattern in evacuation time taken i.e. evacuation time decreases when the fire door width increases from 762mm to 990mm and remains about the same when the fire door widths are further increased. Whereas, staircase 914mm and 1967mm show a unique evacuation time taken where evacuation time decreased, increased, then decreased again to form a 'S' curve graph when fire door width increased.

The evacuation time for staircase 914mm decreased from 354.6 sec to 271.3 sec when the fire door width increased from 762mm to 914mm respectively. The time is then gradually increased until it reaches the maximum of 388.6 sec when the fire door width is further increased up to 1372mm. It then sharply decreases when the fire door width further increases to 1524mm.

Staircase 1067mm follows approximately the same pattern but the evacuation time is further decreased when the fire door width increases to 990mm and 1067mm at 214.7 sec and 212.7 sec respectively and increases again to 285.8. It then gradually decreases to 206.9 sec when the fire door width further increases.

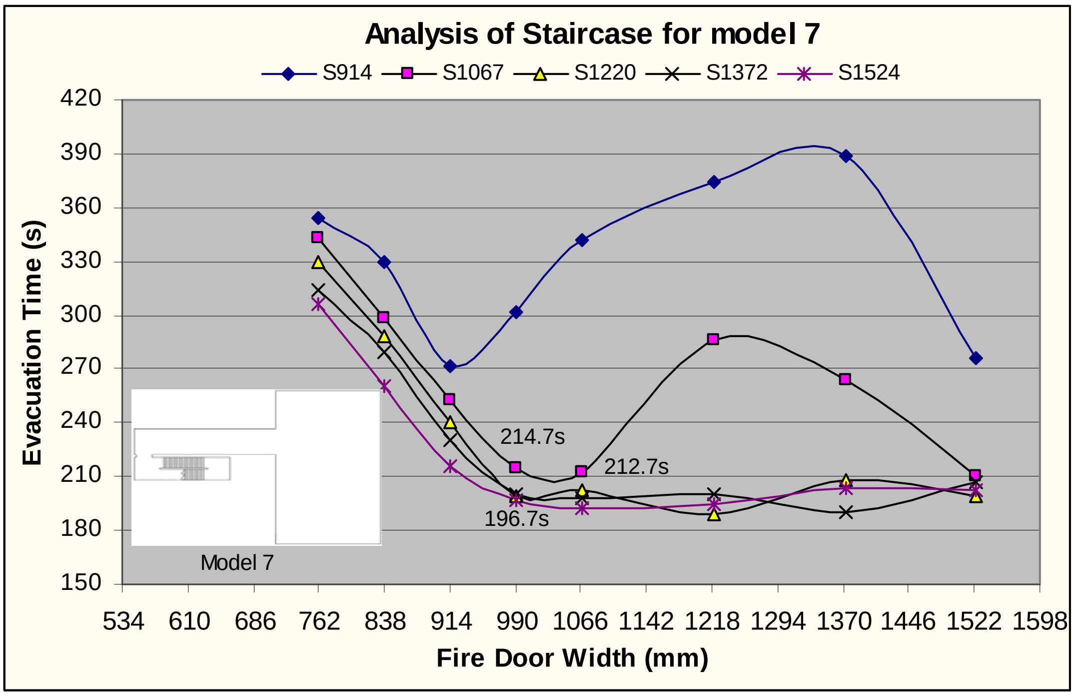

Figure 7.14: Evacuation time Vs corridor width for model 7 i.e. One direction horizontal with fire door

The graph in figure 7.14 shows that the best evacuation time recorded was when the fire door width was 990mm i.e. 196.7 sec. That was for staircases 1220, 1372 and 1524mm wide. The evacuation time remained about the same after the fire door width was further increased and recorded no significant changes throughout the test. Therefore, there is sound evidence to suggest that a fire door designed in high-rise building should be between 990mm and l067mm inclusive. There is no point in designing fire door wider than 1067mm because it will not improve the evacuation time, instead it will increase if the staircase is smaller than 1067mm.

As discussed in the previous test models, there is sound evidence that staircase widths 1220mm and 1372mm are the best staircase widths for high rise buildings. However, this finding needs to be tested on model eight which has a slight difference in terms of building internal circulation. Model eight is designed such that all residential flats are scattered and located near to the escape stair.

(viii) Model eight

In model eight, the best travel time recorded was when the staircase width is 1524mm and fire door width 1372mm (see figure 7.15). The worst travel time recorded was for staircase width 914mm when fire door width is 1524mm. The evacuation time recorded for staircase 914 mm was approximately the same pattern as in model 5. The evacuation time decreased at the beginning when the fire door width increased from 762mm to 914mm, then it gradually increased when the fire door width further increased.

Traffic congestion at the staircase could have caused this pattern when the fire door width increased. Staircase 1067mm shows that the evacuation time fluctuated i.e. increased slightly before decreasing, and increased again when the fire door width further increased. Staircase 1220mm has about the same pattern as the staircase 914mm, in that the evacuation time decreased when the fire door width increased from 762mm to 914mm, and then gently increased when the fire door width further increased.

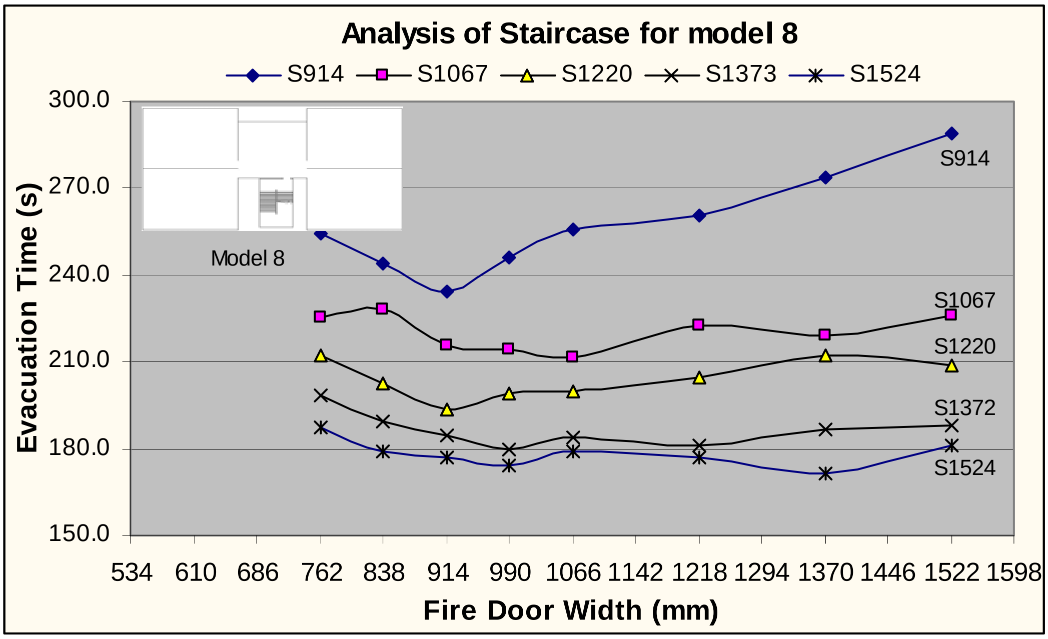

Figure 7.15: Evacuation time Vs corridor width for model 8 i.e. Cluster types with one staircase

Staircases 1372mm and 1524mm wide follow about the same pattern as the 1220mm staircase. The evacuation time started to increase when the fire door width increased from 990mm to 1067mm. The evacuation time then remains about the same without any significant changes even after the fire door width has been increased. It can be concluded, from the overall observations of the evacuation time versus fire door width, there is a small correlation between them. To some extent, it has a negative correlation i.e. when fire door increased from 762mm to 990mm. It has a positive correlation when fire door is further increased i.e. from 1067mm to 1524mm.

7.5 Analysis of staircase, fire door and corridor drawn from the study models

Table 7.10 summarise the staircase, fire door and corridor widths from the models studied. The analysis was made based on the assumption that if the evacuation time recorded fell within 30 seconds, it was considered as being of no significance. Therefore the staircase, fire door and corridor are assumed to offer the same efficiency i.e. able to allow people to evacuate the building safely. The assumption made is based on 30 seconds response time allowance for the occupants to start their evacuation once a fire alarm goes off.

For the optimum width, more staircases recorded within 30 seconds differences of evacuation time on any fire door or corridor width in any models are assumed as an optimum width. Optimum means that consideration is not only given to the minimum evacuation time recorded but at what fire door or corridor width is the most staircases recorded the evacuation time close together within 30 seconds differences. For example if there are three staircases recorded evacuation time within 30 seconds differences at fire door width 1067mm but evacuation time recorded says 180 seconds, even though the minimum evacuation time recorded was 160 second but only confers to one staircase at fire door width says 914mm, therefore fire door width 1067mm considered as the optimum one.

Model	Staircase Width (mm)	Fire Door Width (mm)	Corridor Width (mm)
1	**1220, 1372**, and 1524	914, **990, 1067, 1220**	-
2	**1220, 1372**, and 1524	-	**1220, 1524**, 1828
3	**1220, 1372**, and 1524	-	**1220, 1524**
4	1067, **1220**, and **1372**	-	**1220, 1524**, 1828
5	1067,**1220, 1372**, and 1524	914, **990, 1067, 1220**, 1372, 1524	-
6	**1220, 1372**, and 1524	-	**1220, 1524**, 1828, 1232 2436
7	**1220 , 1372**, and 1524	**990. 1067, 1220**, 1524	-
8	**1220, 1372**, and 1524	914**, 990, 1067, 1220**	-

Table 7.10: Optimum specifications suggested resulting from the models studied based on the evacuation time recorded.

The second analysis is what staircase, fire door and corridor width conform to the majority of the models tested. For example, staircase 1220mm and 1372mm conform to all models, therefore staircase widths 1220mm and 1372mm are considered as an optimum dimension for the staircase. Meanwhile, the optimum fire door width is 990mm, 1067mm and 1220mm, and optimum corridor width is 1220mm and 1524mm. These optimum specifications relate to the specific number of people simulated, i.e. overcrowded situation. For different occupancy levels the optimum specification may be different.

7.5.1 Escape route specification model

The escape route specification model can be summarised;

Staircase

Staircase width: 1220mm or 1372mm

Overall evaluation of the evacuation time taken by the occupant show that increasing the staircase width will increase the evacuation time within 10 to 15 sec. Staircase 1220mm and 1372mm remain within the best evacuation time recorded i.e. less than 3½ minutes. Therefore, it is reasonable to say that in terms of the staircase width, wider is not necessarily better.

Fire door

Fire door width: 990mm, 1067mm or 1220mm

It can be concluded that the best fire door dimension to be installed at any sort of staircase either in staircase compartment or protected staircase as a storey exit is between 990mm and 1220mm inclusive.

Corridor

Corridor width: 1220mm or 1524mm

Evacuation time does not show significant changes when corridor width increases. It seems that the corridor width does not have any effect on the evacuation process. Therefore, it is suggested that corridor widths between 1220mm to 1524mm inclusive are suitable fort a high-rise residential building.

Model

Analysis of the models with fire door found that models 5 and 8 are the best models in terms of evacuation time recorded for 200 people evacuating the model. However, it depends on the staircase width used. The time taken for the 1067mm staircase was around 3½ minutes, the1220mm staircase was around 3 to 3½ minutes, the 1372mm staircase was around 3 minutes and the 1524mm staircase was around 2½ to 3 minutes.

Analysis of the models without fire door and varying the corridor width showed that model 6 was the best among them. The time taken for 200 people evacuating the models was around 3 to 3 ½ minutes, depending on the staircase width used. The time recorded for the 1067mm staircase was around 3 ½ minutes and the 1220mm, 1372mm and 1524mm staircases was around 3 minutes.

7.6 Analysis of the effect of fire door and staircase width tested on building A.

Table 7.11 shows the simulation results of high occupancy people in building A using the same specification as in section 7.4.1 but varies in fire door and staircase widths i.e. 914mm and 1067mm for the fire door, and 1100mm and 1220mm for the staircase. The total evacuation time recorded that when fire door width increased from 914mm to 1067mm without increasing the staircase width, total evacuation time had increased from 11 minutes 53.8 seconds to 12 minutes 1.8 seconds.

Floor clearance time (s)	High occupancy i.e. 4 persons per room: Building A							
	D914, S1100		D1067, S1100		D914, S1220		D1067, S1220	
	S1	S2	S1	S2	S1	S2	S1	S2
Floor 1	150	80	145	80	150	80	145	75
Floor 2	150	75	155	80	160	80	155	75
Floor 3	180	85	235	95	175	85	185	80
Floor 4	180	80	225	75	140	75	165	80
Floor 5	275	80	175	75	130	75	185	75
Floor 6	305	75	320	80	240	80	250	75
Floor 7	340	95	240	100	245	100	275	80
Floor 8	380	85	400	75	140	75	210	85
Floor 9	415	80	415	80	130	80	145	75
Floor 10	90	70	90	70	90	70	85	70
Total Evacuation Time (m:s)	11:53.8		12:01.8		10.27.9		10.12.4	
Note: S1 = Staircase No. 1, S2 = Staircase No. 2, S3 = Staircase No. 3, S4 = Staircase No. 4								

Table 7.11: floor clearance time and total evacuation time of the building A on various fire door and staircase widths.

However when the staircase width increased from 1100mm to 1220mm without increasing the fire door width i.e. fire door width 914mm, total evacuation time had decreased from 11 minutes 53.8 seconds to 10 minutes 27.9 seconds. The total evacuation times were further decreased when both fire door and staircase width increased to 1067mm and 1220mm respectively that total evacuation time had decreased from 11 minutes 53.8 seconds to 10 minutes 12.4 seconds i.e.1 minute 41.4 seconds decreases or 14.2% decreases if fire door and staircase designed as specified in the UBBL.

7.6.1 Proposed specification tested on different building layouts

Simulation data:

No. of floors (Nf):	=	10 floors
No. of staircases (Ns):	=	20 staircases i.e. two staircases between the floors.
No. of platforms (Np):	=	21 platforms i.e. 10 intermediate floors + 11 landing floors
No. of steps per staircase:	=	9 steps per staircase: based on the observation that the great majority of staircases were designed with 9 steps.
Tread dimension:	=	280mm i.e. from analysis of treads in chapter 4 that majority of staircases were designed in the range of 275mm to 284mm and the most popular dimension was 280mm or 11 inches.
Riser dimension:	=	153mm i.e. from analysis of risers in chapter 4 that majority of risers designed between 151mm to 160mm and the most popular dimension was 153mm or 6 inches.
Staircase width (Ws):	=	1220 mm i.e. from the analysis of staircase width as proposed in study model analysis.
Door width (Wd):	=	1067 mm i.e. from the analysis of fire door width as proposed in study model analysis.
Exit width:	=	Final exit door width or actual opening width.
Link width:	=	Storey exit door width.
Staircase length (St):	=	108.68 m: calculated using equation 4.4 for a staircase of 1220mm.
Respond time:	=	30 seconds +/- 0.5 seconds.

Example calculation of staircase length:

X = No. of steps x Riser dimension

9 x Riser dimension

9 x 153

1377 mm

Y = No. of steps x Tread dimension.

9 x Tread dimension

9 x 280

2520 mm

Ls = 2,872 mm

St = (20 x 2872) + (21 x 2 x 1220)

= 108,680 mm

= 108.68 m

Floor clearance time (s)	High occupancy i.e. 4 persons per room, proposed design										
	Building A		Building B				Building C		Building D		
	S1	S2	S1	S2	S3	S4	S1	S2	S1	S2	S3
Floor 1	155	75	90	105	60	65	145	180	-	115	115
Floor 2	130	75	85	100	60	80	165	155	-	125	145
Floor 3	165	85	100	90	60	65	165	165	-	145	155
Floor 4	185	80	80	95	65	85	170	230	-	175	125
Floor 5	220	80	85	80	60	85	185	205	-	150	190
Floor 6	250	75	85	75	70	75	155	190	-	205	135
Floor 7	270	95	85	95	65	85	135	220	-	150	250
Floor 8	135	75	105	95	70	75	150	215	-	120	195
Floor 9	135	75	95	95	65	75	180	195	-	155	180
Floor 10	85	70	70	65	65	70	75	90	-	80	80
Total Evacuation time (m:s)	10:33.7		6:33.1				10:32.4		9:15.0		
Note: S1 = Staircase No. 1, S2 = Staircase No. 2, S3 = Staircase No. 3, S4 = Staircase No. 4											

Table 7.12: Floor clearance time and total evacuation time for the proposed design

Table 7.12 shows the simulation results for high occupancy i.e. 4 persons per room, applying the proposed staircase and fire door width to the building layouts used in the previous simulations. The staircase tread and riser dimensions are different from those used in table 7.11, therefore the overall staircase length is increased. Low and normal occupancy have not been simulated; in these cases there appears to be no significant problem, since the floor clearance times recorded were below 150 seconds (2 ½ minutes), which is accepted as reasonably safe.

The simulation results suggest that with the proposed specification the floor clearance time could be reduced by about 20% to 50% for some floor levels e.g. for building C, floors 3 to 9, in comparison with the figures for the same occupancy level but the original specification, as shown in table 7.8. According to the simulation results, floor 10 appears to be the safest as the floor clearance time was below 150 seconds even with high occupancy. A possible explanation for this is that the stair between floors 9 and 10 is used only by the occupants of floor 10 therefore has low occupancy and people can enter the stairs easily, whilst the lower staircases are used not only by the occupants of the adjacent floor, but also by those from the floors above, therefore there are large number of people trying to get into these stairs, leading to a certain amount of congestion and increased floor clearance time.

It is not certain how Simulex deals with the mingling of the streams of people already on the stairs and those leaving to join the stairs from an adjacent floor, but clearly a number of models are possible; those already on the stairs exit first, those coming from the corridor to the stairs exit first, or they mingle on a one-to-one basis like two lanes of traffic merging into one. Alternatively, a more random mingling seems likely to take place, depending on the individuals concerned and their state of mind.

7.7 Chapter conclusion

Appropriate escape routes specification i.e. corridors, fire doors and staircases, can help to smooth the evacuation process in high-rise residential building. The simulation results suggest that increasing the widths of the fire door and staircase together will improve the floor clearance time and the total evacuation time by about 14%. Based upon the simulation test results, it can be concluded that increasing the number of people i.e. high occupancy will increase the evacuation time to an unsafe level. These high occupancy levels are quite common in this region. Where there is overcrowding throughout the building, then the simulations show that the optimum width of staircase is 1220mm.

The simulation results suggest that with the proposed specification the floor clearance time could be reduced by about 20% to 50% for some floor levels.

In addition, the simulation results show that for some building layouts certain staircases may not be chosen as exits because of the distance from the flats, and they are therefore ineffective for evacuation. Also, some staircases are more likely to be chosen by the evacuating occupants and therefore become congested, causing floor clearance times to increase.

CHAPTER 8

FIRE SAFETY MODEL FOR HIGH-RISE RESIDENTIAL BUILDING

8.1 Introduction

Malaysia as a developing country in South East Asia is making good progress towards achieving the vision 2020 proposed by the then Prime Minister of Malaysia to achieve a fully developed country by the year 2020 (www.wawasan2020.com/vision/). The development of infrastructures i.e. road, highway, commercial and high-rise residential buildings are seen to be very progressive ways to meet the immediate needs for high living standards in the metropolis.

The development of housing schemes, including high-rise buildings for accommodation, has been rapid, and although some have achieved a very good standard in terms of building quality and space utilization, there is still have room for improvement in the fire safety aspect of these buildings. The specifications for the design and construction of escape routes in high-rise residential buildings currently is based on the building regulations i.e. Uniform Building By-Laws 1984 in Malaysia. It is now about 25 years since UBBL first come into force, therefore it is timely to review the Uniform Building By-Laws. A new chapter purposely for residential buildings should be introduced, similar to building regulation 2006, UK, because if we compare between residential and non-residential buildings, the number of fire cases and the deaths toll involving residential buildings is much higher. According to Wolski *et al* (2000) approximately 60% of civilian fire deaths occur in homes and garages and he questions why there so much more safety in high-rise office buildings when there is so much more risk in single family homes. However, further research is needed to look in more detail at what aspects of UBBL should be revised. At this moment, the researcher is only looking on the possibility of how a good fire safety standard in high-rise residential building can be achieved.

The researcher has investigated the problems encountered in high-rise residential buildings and found a lot of issues that could affect fire safety. These were discussed in chapter 5. The researcher also has carried out an opinion survey in five high-rise residential buildings in Malaysia, the findings of which were discussed in chapter 6. Because of the complexity of the topic, further investigations on the building designs and specifications are needed. Investigating of the escape route layouts and specifications has been completed, as discussed in chapter 7.

In this chapter the outcomes of those investigations are put together to propose a fire safety model for achieving acceptable fire safety standards in high-rise residential buildings. Before the researcher discusses further about the model developed, let we look what is actually the meaning of models.

8.2 What is model?

Tate and Jones (1975) defined a model as a representation of reality made sufficiently explicit for one to be able to examine the assumptions embodied within it to manipulate it and experiment with it, and, most important of all, to draw inferences from it which can be applied to reality. According to Babrauskas (1996), a model of anything is, simply, a systematic representation of that thing and proposed there are three examples of models that are normally used by scientists i.e.

i. Thought Models or Conceptual Models,

ii. Scale Models, and

iii. Mathematical Models.

Churchman *et al* (1957), explained that there are three types of models, known as *Iconic, Analogue*, and *Symbolic*. Iconic models are similar to the Scale Model proposed by Babrauskas that normally refers to architectural models or structural engineering models which represent a scaled down version of the building. Analogue models are models that represent the data found in research activities and represented in graph form, curved lines, contour lines, etc. Symbolic models are similar to Mathematical Models proposed by Babrauskas that represent a mathematical equation to be solved either by simple calculation or by computer program. Mathematical models in general are a series of mathematic equations which describe a certain process. Tate and Jones (1975) proposed that there is one more model called a Conceptual Model. This model is similar to the model proposed by Babrauskas as a Thought Model. The Conceptual Model represents our concept of which variables are relevant and how they are related. It normally takes the form of flow charts, diagrams, tables, or such like. However, because of the advances of computer technology available nowadays, another form of model is available, known as Computer Model or Simulation Model. These Simulation Models some time call Computational Fluid Dynamics (CFD) models simulation or Fire Dynamics Simulator (FDS) model simulation. There is another model known as building evacuation simulation model which developed to study the evacuation of people from the building in fire safety study. From the above overviews, to be concluded that there are basically five types of model, i.e.

i. Scale Models,

ii. Mathematical Models,
iii. Analogue Models,
iv. Conceptual Models, and
v. Computer Simulation Models

8.3 Literature review of models in fire safety related field

According to Bartlett (1990), "*Fire safety evaluation system or grading systems are used throughout the world as a means of determining levels of fire protection in buildings. Insurance interests have used such methods for decades dealing mostly with items related to risks and building protection*". From the literature review by Bartlett in 1990, he found that there were four credible Fire Safety Evaluation Systems (FSEF) which could be used for hospitals i.e. U.S. – Fire Safety Evaluation System; U.K. – Fire code: Assessing Fire Risk in Existing Hospital Wards; Australia – Dr. Vaughn Beck has developed a probabilistic method of evaluating the risk associated with office occupancies under the jurisdiction of the Australian building codes against the risk deemed to be acceptable under a given code; and France – A method of evaluation of health care facilities.

Meanwhile, Rasbash *et. at*., (2004), pointed out that there are four categories of point system, e.g. Gretener System, Dow Fire and Explosion Index, Fire Safety Evaluation System (FSES), and Multiattribute Evaluation Models.

The Gretener method measures the ratio of negative features that increase risk to the positive features that decrease risk. These relationships are best explained by the following equation;

$$R = \frac{(p \times A)}{(N \times S \times F)} \qquad (8.1)$$

Where;

R = Risk,

P = Potential Hazard,

A = Activation or Ignition Hazard,

N = Normal Protection Measures,

S = Special Protection Measures, and

F = Fire Resistance of the Structure.

Each of these five factors comprising fire risk is the product of several components, e.g. *P*, i.e. Potential Hazard, has nine components, e.g. P_1, P_2, ….. P_9. The values of these components are multiplied together to acquire the value for P. The same principle applies to the other factors. The process is normalized so that a standard building has a computed fire risk value of 1.00 and an acceptable risk if the risk value is equal to or less than 1.30.

The Dow Fire and Explosion Index developed by Dow in 1964 for the Dow Chemical Company was a modified version of the Chemical Occupancy Classification rating system developed by Factory Mutual prior to 1957. It is mainly used to quantify the expected damage from potential fire, explosion, and reactivity of an incident and to identify equipment that could contribute to the creation or escalation of an incident. This system can be used to evaluate the risk associated with the flammable, combustible, or reactive material stored, handled, or processed in a chemical plant with the intention of suggesting approaches to fire protection and loss prevention design.

The Fire Safety Evaluation System was developed in the late 1970s at the Centre for Fire Research, National Bureau of Standard which is currently known as The Building and Fire Research Laboratory, National Institute of Science and Technology. It was developed with the intention of providing a uniform method of evaluating fire safety for certain occupancies and what measures provide a level of safety equivalent to the Life Safety Code i.e. NFPA 101, published by the National Fire Protection Association (NFPA 101, 2000). The new edition of NFPA 101 Life Safety Code 2006 edition includes the maximized fire safety through new sprinkler mandates for all new 1 and 2 family dwellings, all nursing homes, and existing nightclub assembly occupancies.

It is understood that different occupancies will have different risk parameters. Risk parameters determined for certain occupancies will be valued by expert judgement of a group of fire safety professionals. For example, FSES for health care occupancies has fire risk parameters e.g. patient mobility, patient density, fire zone location, ratio of patient to attendants, and average patient age. FSES uses 13 fire safety parameters and up to seven levels of safety for each parameter. According to Rasbash *et al* (2004), the important concept of the FSES is redundancy through simultaneous use of alternative safety strategies, i.e. containment, extinguishment, and people movement. This serves to ensure that failure of a single protection device or system will not result in a major life loss.

This approach used the contribution values assigned as a points scheme based on the checklist provided as an evaluation tool. Using a point scheme is basically to form the basis for further judgement on the adequacy of fire safety components or the level of safety against the level of risk or hazard of fire that is available within the system in a particular area. The areas then can be summarised in terms of their acceptable or not acceptable level of fire safety based on the number of points scored compared to the stated benchmark.

Multiattribute Evaluation Models: By nature of the circumstances, fire safety decisions often have to be made under conditions in which the data are sparse and uncertain. It is complex and involves a network of interacting components, factors, elements, attributes, parameters, variables and so forth. Interactions are normally nonlinear and multidimensional. Sparseness and complexity of data, however, does not make it impossible to happen. A complex circumstance needs a complex system to solve it. Therefore one applicable approach to fire safety evaluation is Multiattribute Evaluation.

Rasbash *et at*, (2004) described that if the attributes for the decision problem are x1, x2, x3,....., xn, then the evaluation function E(x1, x2, x3, ….. xn) needs to be determined over these measures in order to conduct a performance assessment. According to Keeny and Raiffa (1976), quoted by Rasbash *et al*, if trade-offs among the attributes do not depend on the levels of the remaining attributes, then a single measure of the overall outcome of a system is given by;

$$E(x_1, \ldots\ldots x_i \ldots\ldots x_n) = \sum_{i-1}^{n} w_i R_i(x_i) \qquad (8.2)$$

Where w_i are weighting constants greater than zero, and the $R_i(x_i)$ are normalizing functions of attributes.

In the real world where resources are scarce, and efficiency is highly appreciated, maximizing the utility of point system approach to fire safety evaluation is clearly desirable for the many situations in which the evaluation of fire safety is fundamental.

There are five basic characteristics of multiattribute evaluation as mentioned by Rasbash *et al* (2004):

1. *Multi Attributes*: The nature of the decision is one of screening, prioritisation assessment, or selection of an object from among alternative objects based on values of a set of attributes for each object or alternative. Thus, each problem has multiple decision criteria of performance

attributes. These attributes must be generated for the specific problem setting. The number of attributes depends on the nature of the problem.

2. *Trade-offs among attributes*: In the typical compensatory evaluation, good performance of one attribute can be least partially compensated for low performance of another attributes. This is also call trade-off or equivalency. Since most attributes have difference measurement scales, accommodating trade-offs among them generally means that the method incorporates procedures for normalising data that are not commensurate.

3. *Units that are not commensurate*: The attributes of the problem are generally not all measurable in units that are directly proportional. In fact, some attributes may be impractical, impossible, or too costly to measure at all. This typically requires methods of subjective estimation.

4. *Attribute weights*: The formal methods of analysis generally require information regarding the related importance of each attribute, which is usually supplied by cardinal scale. Weights can be directly supplied or developed by specific methods. In some simple cases the weights default to equality.

5. *Evaluation vector*: The problem can be concisely expressed as a vector whose values correspond to the performance rating of each attribute for the specific object. If the attributes for a decision problem are $x_1, x_2, x_3, \ldots x_n$, then an evaluation function $E(x_1, x_2, x_3, \ldots x_n)$ needs to be determined over these measures to conduct a performance assessment.

Multiattribute Evaluation Process

1. Generation of Attributes: Also called parameters, elements, factors, variables, and so forth. Those identify the ingredients of fire safety. Attributes can be measurable or non measurable attributes.

Pardee (1969) quoted by Rasbash *et al* (2004) suggests that the attributes list should be complete and exhaustive, mutually exclusive and restricted to the highest degree of importance. As suggested by Keeny and Raiffa (1976), attributes can be identified by literature survey or opinion by a panel of experts of the particular problem.

2. Attribute Weighting: Not all fire safety attributes are equally important. The role of weight is to express the importance of each attribute compared with the others. It is a key component of multiattribute evaluation.

Rasbash *et al* (2004) suggested that the attribute weights are generally normalized to sum up to one, that if y_i is the raw weight of attribute I, then

$$w_i = \frac{y_i}{\sum_{i=1}^{n} y_i} \tag{8.3}$$

And

$$\sum_{i=1}^{n} w_i = 1 \tag{8.4}$$

This produces a vector of *n* weight is given by; W = (w_l, ….., w_j., …., w_n). Where w_i is the resultant weight assigned to the *i*th attribute.

Points system

Fire safety evaluation points systems have been referred to by various names such as risk ranking, index system, and numerical grading. They originated as insurance rating schedules in the nineteenth century, but in the last few decades the basic concepts have appeared in a wide variety of formats (Rasbash *et al*, 2004).

Point system assigns values based on the professional judgment and experience. The selected variables represent both negative and positive fire safety features and the assigned values are then operated on by some combination of arithmetic functions to arrive at single value or index. The variables are referred to as attributes. According to Rasbash *et al*, (2004) the purpose of a points system is to provide a useful aid to decision making. Usefulness requires the methodology to be simple yet credible. Applying it must be not only easy but also sophisticated enough to provide a minimum technical validity. The method includes identification of attributes and a method of weighting them. Point systems can be simple but powerful ways to use our increasing body of knowledge in the evaluation and communication of fire safety. If properly constructed, point systems offer a defensible combination of relevant attributes of fire safety. However, because they are heuristic models they are difficult to verify. What is a heuristic model? Point systems are heuristic models of fire safety. There are processes of modelling and scoring fire hazard and exposure factors to produce a rapid and simple estimate of comparative evaluation. The process heuristically relates known fire safety attributes that have varying degrees of accuracy in their measurement. The most valid point systems are those that follow the well-founded principles of multiattribute evaluation.

Defensibility, both internally and externally, is one of the strongest assets of a scientifically constructed point system. Internal defensibility provides management with justification of fire safety policies and expenditures. It facilitates the allocation of limited resources among fire and other risks. External justification of priority setting is important in litigation and in dealing with regulatory agencies (Rasbash *et. at.*, 2004).

Edinburgh Model

The Edinburgh model was developed in 1982 at Edinburgh University with the intention of improving the evaluation of fire in United Kingdom hospitals through a systematic method of appraisal. In the Edinburgh model, a hierarchical point system was used i.e. hierarchy of fire safety decision-making levels. It consists of five factors with hierarchy levels as follow:

1. Policy,
2. Objectives,
3. Strategies,
4. Attributes and
5. Survey items

These factors were used to identify the importance of each fire safety attribute (Rasbash *et al*, 2004). This hierarchy suggests that a series of matrices is appropriate to model the relationship among the various fire safety factors. According to Rasbash *et al* defining fire safety is difficult and often results in a listing of factors that together comprise the intent. These factors tend to be of different sorts. They agreed with the Edinburgh Model concept that it is a meaningful exercise of constructing a matrix of fire safety goals versus more fire safety features and it will help to identify the roles of two concepts, i.e. goals and aims, in both theory and practice.

8.4 The outline of a fire safety model developed

Based on this concept and multiattribute evaluation models, the researcher developed a study background by adopting a basic approach developed by NFPA (2000) called Fire Safety Concept Tree (FSCT). Attributes are weighted according to the priority level as in figure 8.1 that high priority will have high weighting.

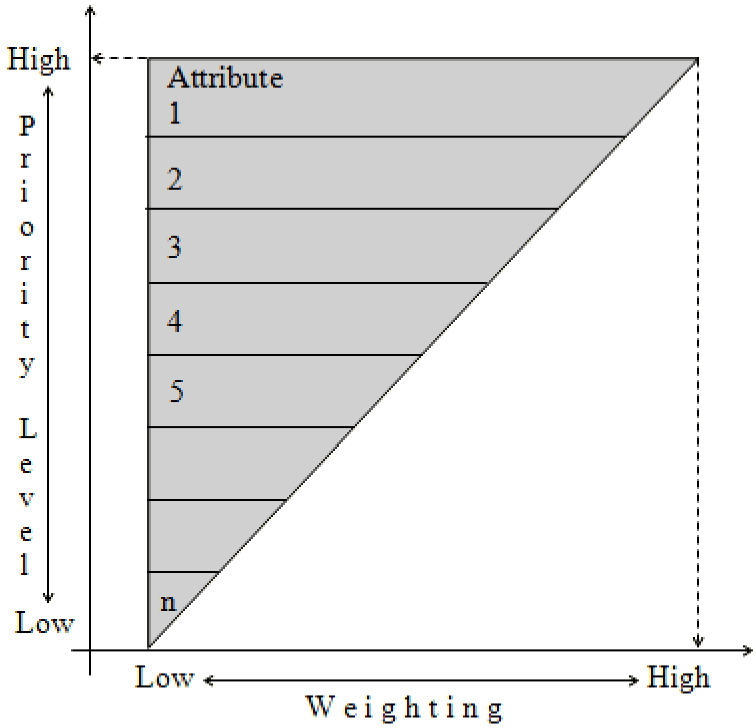

Figure 8.1: Equivalency of attribute weighting and priority level.

There are two fundamental principles of fire safety objectives in managing the fire impact i.e. minimising the impact to the people and structure. Among the factors considered in managing fire impact are containing fire by construction and allowing time for people to evacuate from the building. Therefore it is necessary to investigate the integration between human behaviour and structural design known as Variable A and Variable B respectively, and integrating them into a conceptual study outline model.

Figure 8.2 shows a conceptual study outline model and table 8.1 is the hierarchy of fire safety decision making levels which the researcher used to develop research methodologies to evaluate the evacuation process and escape route specifications in high-rise residential buildings in Malaysia.

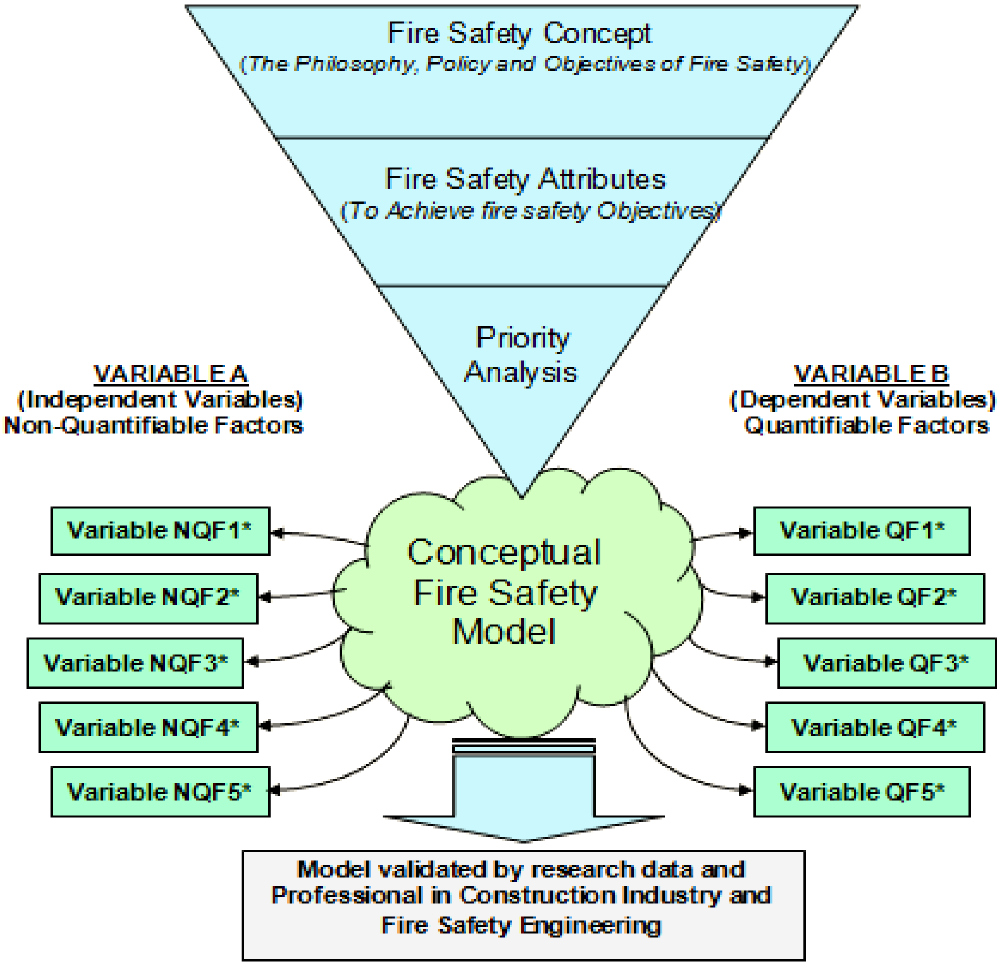

Figure 8.2: Conceptual study model

Level	Name	Description
1	Philosophy	General description of a whole fire safety concept and process adopted by organization based on the FSCT developed by NFPA
2	Policy	Course or general plan of action adopted by organization to achieve security against fire and its effects.
3	Objective	Specific fire safety goals to be achieved.
4	Strategies	Independent fire safety alternatives, each of which contributes wholly or partly to the fulfilment of fire safety objectives.
5	Attributes	Components of fire risk that determinable by direct or indirect measure or estimate.
6	Survey items	Measurable features that serve as constituent parts of fire safety parameter.

Table 8.1: Hierarchy of fire safety decision making levels (*After* Rasbash *et al*, (2004)

The fire safety conceptual model for high-rise residential buildings begins with the definition of fire safety philosophy, policy and objective to be achieved. These philosophy, policy and objective are defined based on the priority hierarchy of decision making level proposed in the Edinburgh Model as mentioned by Rasbash *et al* (2004). Descriptions of these factors are as in table 8.1 above. The researcher proposes the definition of philosophy, policy and objective is grouped under one attribute called Fire Safety Concept because these factors normally remain unchanged in many circumstances. However, when to carry out a fire safety audits to suit the specific organisation, it needs to be precisely defined.

An example definition of a fire safety concept i.e. the philosophy, policy and objectives of fire safety for the high-rise residential buildings, is given in table 8.2. It gives a general description of the fire safety concept regarding the construction of high-rise residential buildings. In this research, the emphasis is not on the strategies, fire safety performance and fire safety level because of the time constraint and the limited resources available to carry out the research on those aspects.

The philosophy of fire safety *(regarding the construction of high-rise residential building)* "All buildings designed and built should meet the following criteria i.e. Fire Safety Objective, Fire Safety Performance, and Fire Safety Level".	
Policy:	Implementing all fire safety measures to ensure fire safety standards in high-rise residential building can be achieved.
Fire Safety Objectives:	The purpose of fire safety objective is to ensure that: (1) The people in the buildings are safe if fire breaks out. (2) Structural protection i.e. building and its contents, so that the building itself is protected from serious damage if fire breaks out.

Table 8.2: The philosophy, policy and objective of the fire safety concept

Therefore, the emphasis will only be on the fire safety attributes to achieve the first fire safety objective i.e. to ensure that the people in the building are safe if fire breaks out. In order to achieve that, three methodologies are adopted i.e. observation, questionnaire survey and computer simulation. Figure 8.3 shows those methodologies used and summaries of the attributes analysed. Those attributes are generated from the literature review and the observation studies that have been carried out on a number of high-rise residential buildings in Malaysia.

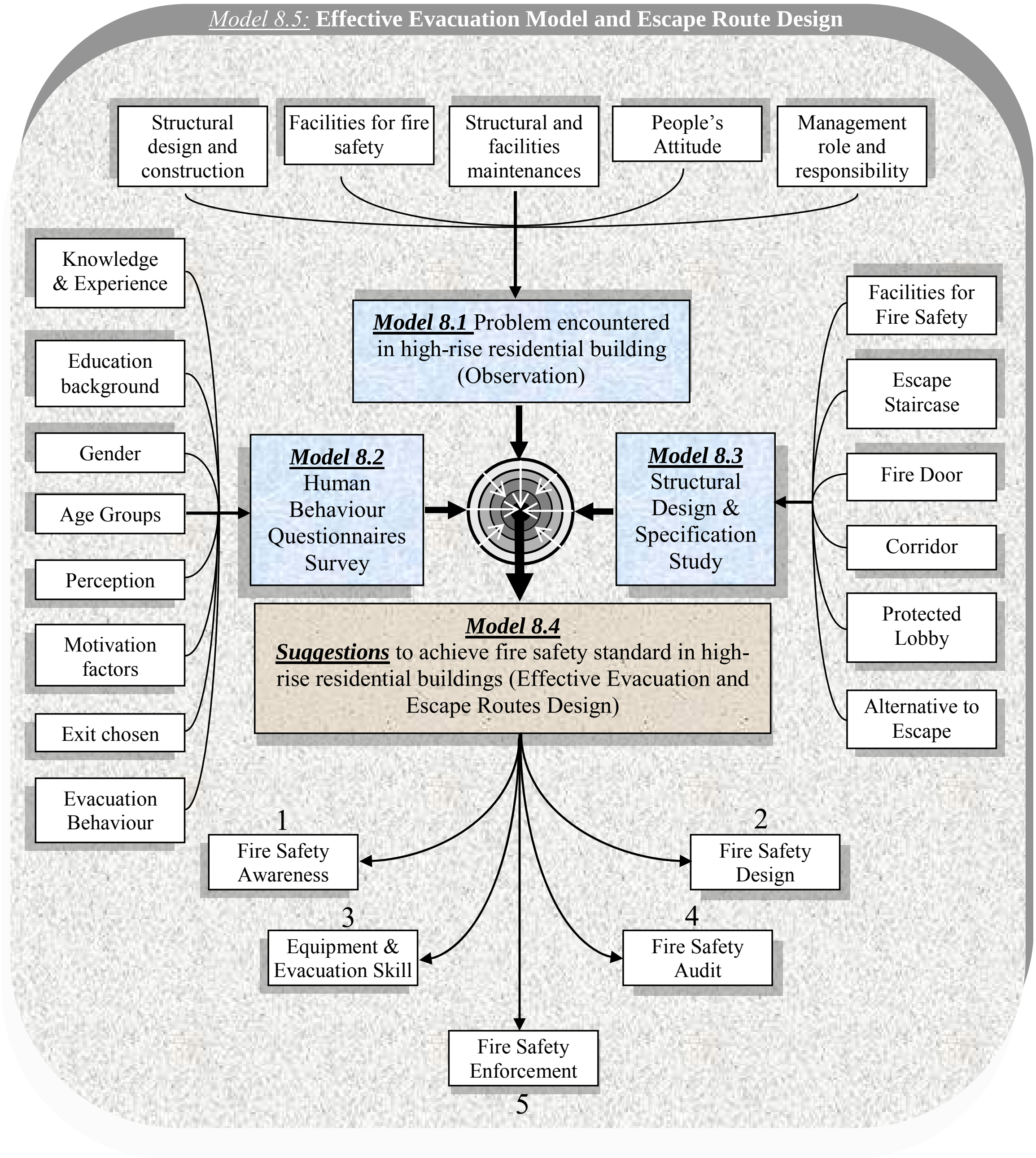

Figure 8.3: The conceptual model of development process of fire safety model for high-rise residential buildings.

Those identified attributes analysed using priority analysis method. There are three priority levels set i.e. high, medium and low priority based on the point score on the variables analysed as described in chapter six. Those attributes are then divided into two groups i.e. known as variable A, attributes related to human behaviour, and variable B, attributes related to structural design and incorporated into five fire safety components suggested as in figure 8.3 i.e. model 8.4. This model has been validated by professionals in the construction industry and by fire brigade officers in Malaysia as reported in section 8.6.

8.5 The development of the fire safety conceptual model for high-rise buildings

Figure 8.3 shows the development processes of how the conceptual fire safety model was developed. There are five integrated models with parameters linking to each other. Those five models are:

Model 8.1 – Problems encountered in high-rise residential building model,

Model 8.2 – Human behaviour model,

Model 8.3 – Structural design and specification model,

Model 8.4 – Fire safety components model, and

Model 8.5 – Effective evacuation and escape routes design model.

Model 8.1 was formulated based on the analysis in chapter 5 (refer to table 5.1), there are five parameters analysed, based on the observation of the condition of escape routes in a number of high-rise residential buildings in Malaysia. Categorization of the problems encountered is made based on the principle of similarity behaviour analysis i.e. the actual problems are grouped together if they are similar, e.g.:

Problems occurring on escape routes structure, for instance, treads shorter than the minimum specification, risers exceeded the maximum height permitted, corridor designed detached from the occupants' flats and so forth. Because these problems are mainly related to the building elements, they are categorised as problems of Structural Design and Construction.

The same analysis techniques are applied to the rest of the problems by listing them out in a table and rearranged to form model 8.1 i.e. the problem encountered model. Variables in this model are as in table 5.1.

Model 8.2 is a human behaviour model that derived from the questionnaire study and detailed descriptions can be found in chapter 6. Figure 6.6 shows a human behaviour model with the factors involved either influencing or being influenced by the human behaviour. From the questionnaire study, it is suggested that those factors have significance impacts on the evacuation process.

Model 8.3 is a structural design and specification study and detailed analysis and descriptions on this matter can be found in chapter 7. Table 8.3 shows the specifications model for structural design. The smooth operation of building evacuation partly depends on the structural elements designed, orientations and specifications, facilities provided in the buildings and availability of alternatives to escape.

Based on the best knowledge and ability the researcher has at this moment, with the research data analysed, using a professional judgement and experience, and after prudently analysing all data and information available, the researcher suggests fire safety components **model 8.4** to be adopted to achieve a fire safety standard in high-rise residential buildings. This model will be incorporated with **model 8.5** i.e. effective evacuation and escape route design model as in figure 8.4. There are five fire safety components in hierarchy order i.e.

i. Fire Safety Awareness,

ii. Fire Safety Design,

iii. Fire Safety Equipment and Evacuation Skill,

iv. Fire Safety Audit, and

v. Fire Safety Enforcement.

8.6 Suggestion to achieve fire safety standard in high-rise residential buildings

Figure 8.4 is a conceptual fire safety model i.e. how to achieve fire safety standard in high-rise residential buildings. There are two models incorporated i.e. Model 8.4 and model 8.5. Model 8.4 is a fire safety component model and model 8.5 is suggestions how to achieve fire safety standard and what factors need to be increased, enhanced, enforced, audited and/or designed in order to achieve the fire safety standard in high-rise residential buildings.

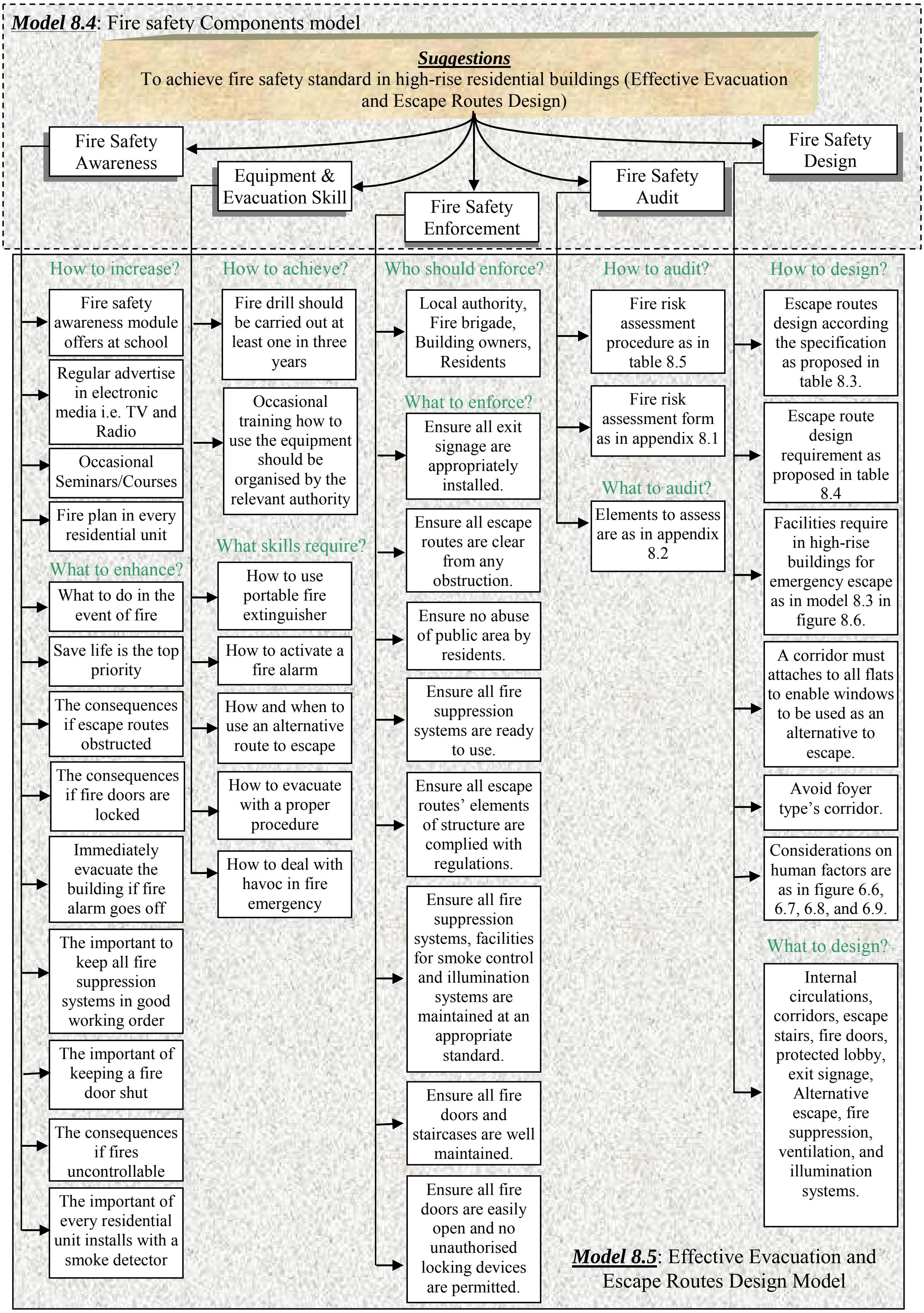

Figure 8.4: Fire safety conceptual model i.e. to achieve fire safety standard in high-rise residential buildings.

8.6.1 Fire safety awareness

From the questionnaire survey and observation study, it is found that fire safety awareness in high-rise residential buildings in Malaysia needs for improvement. Therefore fire safety awareness programmes should be enhanced in order to increase fire safety awareness on the high-rise residential buildings in Malaysia. The researcher suggests, not in hierarchy order, the following programmes i.e. how fire safety awareness can be increased. Some of the programmes suggested may be run concurrently. However at this moment there is no time limit suggests for the programme. The effectiveness of any programme can only be assessed after the programme has started. This suggestion is based on the finding of questionnaire survey and observation studies done as reported in chapter 6 and chapter 5 respectively.

Figure 6.1 (a) shows that 67.8% respondents never attended any fire safety courses. Meanwhile, appendix 8.0a shows the survey results analysed based on the age groups i.e. 78.6% (44 people) among the age group 1 (15 to 30 years old), 53.8% (21 people) among the age group 2 (31 to 40 years old) etc never attended any fire safety courses.

When analyse on the evacuation behaviour, table 6.12 shows that 59.1% would do something else instead of immediately evacuate the building if fire alarm goes off. From the fire safety point of view, occupants should immediately evacuate the buildings once fire was discovered in the building. Therefore it is suggested that fire safety awareness programmes should be introduced as follows:

i. Fire safety awareness modules should be offered at school and advance fire safety courses should be offered at college and university.

ii. Regularly advertise on TV and radio about the appropriate steps to follow if fire started in flats.

iii. Occasional seminars, colloquiums, short courses, etc. should be conducted at community centre and national level.

iv. Every residential flat should be provided with an easily understood fire plan i.e. what to do if fire breaks out and where to assemble after evacuating the building.

Two aspects should be emphasized in the fire safety awareness programme i.e. the appropriate action to be taken, and the importance of keeping the escape routes safe at all material times. This is because among the problems encountered in the observation studies were problems related to the attitude of people as discussed in section 5.5.4. Therefore, the following elements of fire safety awareness should be improved:

i. What to do in the event of fire.

ii. Life safety should be the top priority, therefore immediately evacuating the building is essential and it should be done immediately after the fire alarm goes off.

iii. The consequences if escape routes obstructed by any obstruction.

iv. The consequences if fire doors are illegally locked by any means.

v. The importance of keeping all fire suppression systems in a good working order.

vi. The importance of keeping all fire doors shut at all times.

vii. The importance of every residential unit having smoke detectors installed at a strategic location.

viii. The consequences if fire becomes uncontrollable.

8.6.2 Fire safety design

From the studies on escape route design and specification, there are a number of significant suggestions can be drawn on how escape routes should be designed and what elements should be included when designing it. These suggestions are based on the findings from the observations, questionnaire surveys, and simulation of the different layouts of high-rise residential buildings and further simulation analysis on the 260 study models developed. Detailed experiment and discussion can be found in chapter 5, 6 and chapter 7.

How to design?

i. Escape routes should be designed according to the specifications as proposed in table 8.3, figures 8.8 until 8.11 in appendixes 8.3 until 8.6 respectively.

ii. Escape routes also should be designed according to the requirements as proposed in table 8.4.

iii. Corridors should be designed attached to all flats to enable windows to be used as an alternative to escape.

iv. Corridor design should avoid a foyer type to limit the possibility of it being abused by the tenants.

v. When designing escape routes in high-rise buildings, consideration of human factors as in figures 6.6, 6.7, 6.8, 6.9 in chapter 6 should be given appropriate attention.

What to design?

Escape route elements and building services equipment that to be designed as follows:

i. Internal circulation in the buildings i.e. corridors, compartment floors, protected lobby, escape stairs, and fire doors.

ii. Communication systems in building: i.e. signage, exit signs, fire alarm and inter-communication.

iii. Building facilities systems: i.e. lighting, emergency lighting, ventilation and smoke control systems.

iv. Fire protection systems: i.e. fire detection system, fire suppression system, fire compartmentation.

8.6.3 Fire safety equipment and evacuation skills

From the questionnaire survey (see figure 6.2) the majority of the respondents had experience of fire drill, at their office building (41.7%), at college (10.4%) or at a public building (5.2%). None of them had any experience of a fire drill at their residential building. In terms of equipment skills, 59.1% of the respondents' surveyed do not know how to use any fire fighting equipment, 27.0% know how to use a portable fire extinguisher, and 13.9% know how to use a hose reel system (see appendix 8.0d).

Among those who had never attended a fire safety course, 84.6% of them said that they did not know how to use any fire fighting equipment. Only 14.1% knew how to use a portable fire extinguisher and 1.3% knew how to use a hose reel system (see appendix 8.0e). For those who had attended a fire safety course, 54.1% said they could use a portable fire extinguisher, 40.5% said they could use a hose reel system. It seems that knowledge and experience have significant influences in increasing the ability of respondents to use the fire fighting equipment.

In terms of the ability to activate a fire alarm system, 56.5% know how to use the Break Glass alarm, 21.7% will only shout if fire breaks out, 18.3% will call the fire brigade, etc (see appendix 8.0b). In terms of the ability to activate fire alarm system after attending fire safety course, 75.7%

said they knew how to activate a break glass alarm system and percentage of only know how to shout has reduced to 8.1% (see appendix 8.0c). As discussed in section 6.5.2.6 (factors highly influencing the occupants' behaviour during evacuation from the building fire), among the top factors which will influence the occupants are traffic congestion, havoc situation etc. Therefore it is proposed that the skills detailed below should be given to all residents in high-rise residential buildings.

How to acquire?

i. Fire drill should be carried out at least once every three years.
ii. Training on how to use the fire safety equipment should be organised by the relevant authority at regular intervals.

What skills required?

i. How to evacuate the building in a proper manner
ii. How to deal with the havoc situation in a case of fire emergency
iii. How to use a portable fire extinguisher
iv. How to activate a fire alarm in an emergency situation

8.6.4 Fire safety audit

From the observations on a number of high-rise residential buildings in Malaysia, (details can be found in chapter 4 and 5), a number of the problems encountered (see table 5.1) could be solved if a fire safety audit was carried out. Therefore, it is proposed that a fire safety audit should be carried out to ensure that all escape routes in high-rise buildings are safe to be used at all material times.

How to audit?

i. Audit procedures are as in table 8.5, which it should be carried out by a fire safety consultant, either in-house or privately appointed.
ii. A fire risk assessment form as in appendix 8.1 is proposed for use in the auditing process. This form has been constructed based on the research done here and benchmarked on the requirements in the UBBL.

What to audit?

i. Elements to assess are as in appendix 8.2

8.6.5 Fire safety enforcement

As discussed in chapter 5, there are a number of problem encountered in high-rise residential buildings in Malaysia. To ensure all escape routes are in a good condition and safe to be used in an emergency situation, regular inspection by relevant authority should be carried out.

Who should carry out the inspection?

i. Building Management (i.e. Management Corporation or Joint Management Corporation)
ii. Fire Brigade officers
iii. Local authority
iv. Building owners
v. Residents or tenants

What to enforce

i. Ensure all exit signs are appropriately installed.
ii. Ensure all escape routes are cleared from any obstruction.
iii. Ensure there is no abuse of public area by residents.
iv. Ensure all fire suppression systems are always ready to use.
v. Ensure all escape routes elements of structures comply with regulations.
vi. Ensure all fire doors and staircases are well maintained.
vii. Ensure all fire doors are easily to open and no unauthorised locking devices fastened at any fire doors.
viii. Ensure all fire suppression systems, facilities for smoke control and illumination systems are maintained at an appropriate standard.

8.7 Model validation

Model validation has been carried out by sending the proposed model to the professionals who have participated in the questionnaire survey earlier. A validation questionnaire (See appendix 8.8) was used to collect the validation data. Table 8.6 shows the comparison of percentage of respondents who has answered the validation questionnaire survey. Figure 8.8 shows a pie chart of those respondents who has participated in the opinion survey earlier and figure 8.9 shows a pie chart of those who has participated in validation survey.

Table 8.7 shows the results of the validation survey. It can be concluded that those professionals who participated in the validation survey i.e. 7 Architects, 5 Fire Brigade Officers, 3 Contractors, 2 Engineers and 2 Quantity Surveyors, agreed that models and tables show to them were original, workable, reliable, had integrity and were easy to understand. The model frame-work on how to achieve fire safety standards in high-rise residential buildings can be implemented provided that those parties involve are willing to work together. There are suggestions from some of them to carry out a pilot project on a selected high-rise residential building in Malaysia.

8.8 Chapter Conclusions

Construction of high-rise residential buildings to provide a proper shelter for the people and to meet a high demand for housing should not compromise the fire safety aspects. Construction of high-rise residential buildings should not only be viewed from the perspective of economics, construction and space utilization, but it is equally important to view them from the perspective of fire safety. Fire safety models for high-rise residential building proposed are:

(1) Escape route designs and specifications, table 8.3.

(2) Human behaviour model, figure 6.6.

(3) Fire safety model to achieve fire safety standard in high-rise residential buildings, figure 8.4.

It is proposed that to achieve the fire safety standard in high-rise residential buildings, there are five fire safety components suggested i.e. Fire Safety Awareness, Fire Safety Design, Fire Safety Equipment and Evacuation Skill, Fire Safety Audit, and Fire Safety Enforcement. It is proposed that a fire safety audit form as in appendix 8.1 to be used to audit the fire safety aspects in high-rise residential buildings.

A fire safety audit should be carried out once every three years and a fire safety certificate issued by the fire brigade should be introduced to all high-rise residential buildings if fire safety is to be assured. From the observation study, it can be concluded that the conditions of escape routes need significant improvement if the safety of people is to be assured.

Component / Element	Staircase	Corridor	Intermediate Floor	Fire Door
Optimum Width	1220 – 1372	1220 – 1524	1220 – 1372	990 – 1220
Effective Width	1220	1220	1220	1067
Optimum Length	7 – 10 steps	< 45* m	2 x SOW	-
Effective Length	8 – 9 Steps	< 30* m	2 x SEW	-
Treads	275 – 284	-	-	-
Risers	151 – 160	-	-	-
Handrail height	900	-	900	-
FRP (minute)	30 – 90	30 – 90	30 – 90	30 – 90
Lighting	A & E	A & E	A & E	-
ventilation	N or M	N or M	N or M	-
Signage	✓	✓	x	✓
Uniformity	✓	✓	✓	✓
Self-Closing	X	x	x	✓
Smoke-Seals	✓	✓	✓	✓
Protected Lobbies	Protected lobbies shall be provided to serve staircases if the staircase enclosures are not ventilated through external walls. It has to be inline with By-Laws 197			
Compartment floor	Compartment floor shall be provided if the building exceeded 30 m in height which every alternate floor shall be constructed with materials enabling to withstand fire of not less than 30 minutes. It has to be inline with By-Laws 136 and 137.			

All dimensions are in mm unless mentioned.
FRP = Fire Resistant Period; SEW = Staircase Effective Width; SOW = Staircase Optimum Width; A = Artificial, E = Emergency, N = Natural, M = Mechanical
* 30 meters for unsprinklered, 45 meters for sprinklered.

Table 8.3: Associated with model 8.3, Fire Safety specification for escape route components

Fire Safety Attributes: Escape Route Design Requirements

(*To Achieve fire safety Objectives*) – Part 1

Escape Route

i. Providing a safe egress and protected zone i.e. protected lobby at every alternate floor for refuges.

ii. The number, distribution and dimensions of escape routes and exits should be adequately designed to accommodate the maximum number of people occupying the building.

iii. Escape routes and exits should lead as directly as possible to the place of safety.

iv. Limit "Dead End" designs in residential units.

v. No obstructions of any kind or obstacles of any form in escape routes can be permitted.

vi. A place of safety or assembly area is designated and able to cater for the maximum occupancies.

Fire Door

vii. All emergency doors should open in the direction of escape.

viii. Escape and exit doors should be easily and immediately opened by any person requiring to do so and should not be locked.

ix. Fire doors must be kept shut. If it needs to be kept open, it shall be fastened with an automatic release device operated by an automatic fire detector.

x. All fire doors and fire barriers constructed shall be able to withstand fire for a reasonable period.

Escape Staircase

xi. Escape stair location within a maximum travel distance permitted.

xii. Escape stairs designed with a minimum bend and 'U' turn.

xiii. Staircase width shall be maintained throughout the flight.

xiv. The depths of landings shall not less than the depth of staircase.

xv. All staircases shall have a fire-resistance rating of not less than 30 minutes.

xvi. Tread and riser dimensions must be consistent throughout the staircase.

Table 8.4: Escape route design criteria for high-rise residential buildings

Fire Safety Attributes: Escape Routes Design Requirements

(*To Achieve fire safety Objectives*) – Part 2

Signage

xvii. Escape routes and exits shall be indicated by appropriate signs.

xviii. All exit signage shall be constantly illuminated at all material times during the time of occupancy.

xix. All exit signage shall be in a white lettering against a green background with directional arrows and graphic symbols of running man toward the open door.

xx. All exit signage shall be posted at a clear visible area and shall not be obstructed by any obstructions.

Alternative Escape

xxi. Evacuation lift and fire-fighting lift should have features and safeguards which may allow them to be used in the event of fire. Override by the fire and rescue services to enable the lift to be used for emergency purposes.

xxii. Alternative escape routes and exits shall be provided. Corridors designed should be allowed windows to be used as an alternative to escape.

Fire Suppression

xxiii. Portable fire extinguishers and other types of fire suppression systems shall be provided and well maintained.

xxiv. Smoke control systems in an enclosed escape route where necessary are sufficiently designed and installed to ensure the egress route is free from smoke.

Ventilation System

xxv. Ventilation systems shall be provided in enclosed escape routes either by mechanical ventilation i.e. pressurisation system or natural ventilation i.e. permanent opening or an automatic opening ventilator operates by automatic smoke detector system.

Illumination System

xxvi. Escape routes and exits should be adequately illuminated at all material times.

xxvii. Adequate provision of emergency illumination systems should be made to substitute the failure of normal lighting.

Table 8.4: Escape route design criteria for high-rise residential buildings (Cont.)

Fire Risk Analysis Procedure	**Define Hazard and Risk**	**Step 1**	**Step 2**	**Step 3**	**Step 4**	**Step 5**
Analysis Elements	Hazard* Risk**	Identify Potential fire hazard	Identify who might be in danger	Evaluate the risk components	Record finding and suggestion for remedial action	Review and revise finding
Assessment tasks to carry out		Source of ignition; fuel; heat generator	Identify people at significant risk in case of fire	Existing fire safety measures; Control of ignition; fire detection; means of escape; system maintenance; Training; evacuation plan.	Emergency plan; Instruction; recommendati on,	Revise if situation changed
Evacuation Index						

*Hazard: A hazard is something that has the potential to cause harm.
**Risk: A risk is the chance, high, or low, of that harm occurring

Table 8.5: Fire safety audit and risks analysis procedure

Profession	A	%A	B	%B
1	10	38.5	7	36.9
2	4	15.4	2	10.5
3	2	7.7	2	10.5
4	4	15.4	3	15.8
5	5	19.2	5	26.3
6	1	3.8	0	0
Total	26	100%	19	100%

Table 8.6: Response to the validation exercise for the studied models

Note: Profession:

1=Architect, 2=Engineer, 3=QS, 4=Contractor, 5=Fire Brigade Officer, 6=Developer.

A = Frequency of respondents responded to the questionnaire.

B = Frequency of respondents validated the model.

Elements / Items	Easy to understand	Originality	Reliability	Workability	Integrity
Model 8.2	✓	✓	✓	✓	✓
Model 8.4	✓	✓	✓	✓	✓
Model 8.5	✓	✓	✓	✓	✓
Table 8.3	✓	✓	✓	✓	✓
Form 8.1	✓	✓	✓	✓	✓

Table 8.7: Validation table

CHAPTER 9

CONCLUSIONS AND RECOMMENDATION

9.1 Introduction

Research on fire safety for high-rise residential buildings ranges across several disciplines i.e. integration between the fire safety engineering field, building design and social sciences. This study investigated the integration between human behaviour and structural design, particularly escape route design and specification, the aim is being to produce a fire safety model to assess and improve fire safety standards in high-rise residential buildings.

In order to achieve this aim, mixed methodologies are used throughout the research i.e. a combination of both quantitative and qualitative data collection and analysis. There are three mains components of the research carried out i.e. observation, computer simulation and questionnaire survey.

This research has explored the current state of escape route conditions in high-rise residential buildings and investigated the requirement for upgrading fire safety and design specification for staircase, corridor, fire door, etc. It has also considered the behaviour of occupants of high-rise residential buildings in case of fire, perceptions of behaviour and looked at the factors that most motivate them to evacuate the building.

9.2 Conclusion

From the observations of the research finding, it is evident that improvements in fire safety standards in high-rise residential buildings in Malaysia are needed. Provision for escape route, i.e. corridors, fire doors and staircase design and specification, should be improved, along with the occupant's awareness of evacuation procedures in an emergency situation and how to use fire suppression systems. Also, regularly checking and auditing of fire safety aspects in building and strict enforcement of regulations to ensure that escape routes are safe for use at all times should be carried out. This suggestion is to ensure that the standard of fire safety in high-rise residential buildings can be achieved. From the simulation studies, it is recognised that the escape routes specification proposed are reflected to the number of people simulated. The result may be different if the number of people used in the simulation is different.

The issues with which this work is consent are what are the current states of the escape routes in high-rise residential buildings in Malaysia?; Does the escape route design and construction comply with the current regulation?; What are the optimum dimension of escape routes that can permitting all occupants to evacuate the building safely and fast?; What are the actions that the occupants of high-rise residential buildings would do if a fire breaks out in their residential building?; What people perceptions when fire alarm goes off?; What factors that most motivating people to evacuate the building once the alarm sounded? What factors that most influencing the human behaviour when they are in emergency situation e.g. in building fire? To answer these questions, investigations have been carried out and the outcomes are discussed in the relevant chapters. Summarise of the findings can be found in the following sub-sections.

9.2.1 Building observation

There are 438 staircases in five high-rise residential buildings in Kuala Lumpur observed and overall 38.84% staircases steps inspected and an average of the staircase steps per stair was 9 steps. In terms of compliance to the UBBL, 73.6% treads complied with the regulation and only 1.16% complied at the minimum requirements i.e. treads depth designed slightly about the minimum requirement i.e. 255mm wide. The majority of the treads depths i.e. 35.33% are designed between 275mm to 284mm and the tread depth mode was 280mm (11 inches).

In terms of the step riser high, 99.99% complied with the regulation. Majority of the rises i.e. 39.22% are design between 151mm to 160mm and the riser high mode was 153mm (6 inches) (maximum requirement is 180mm).

From the observations of a number of high-rise residential buildings in Malaysia, there are eight scenarios of staircases orientation and layout in terms of people moving direction i.e.; Opposite directions with fire door; Opposite directions without fire door, L-Shape direction with fire door; Straight direction with fire door; Opposite direction horizontal staircase with fire door; Opposite direction horizontal staircase without fire door; One direction horizontal staircase with fire door; and Cluster types with one staircase. From the eight scenarios, 260 study models had been developed for further analysis of the staircase specifications i.e. staircase width, fire door width and corridor width.

9.2.2 Escape Routes condition in high-rise residential buildings

The current state of escape routes in high-rise residential buildings in Malaysia needs an immediate attention from the building authorities or Management Corporation (MC) to reinstate its conditions for the safety of occupants. From the observations, there are five main categories of issues and problem encountered i.e. Structural Design and Construction, Facilities for Fire Safety in Buildings, Maintenance, Attitude of People, and Management.

Most of the problems arose mainly due to the lack of checking, inspection and enforcement by the building management i.e. Management Corporation. If a regular checking and inspection was made and action was taken against those who have committed offences e.g. locked the fire door, left personal items in corridors or stairwells, dumped rubbish in stairwell, etc. some of the problems arose could be solved, the safety of people could be assured, the risk of injury or fatality could be reduced and the management integrity could be trusted. As a result, fire safety objectives in high-rise buildings could be achieved.

It is proposed that fire safety assessment which is currently applicable to the factory buildings should be extended to the high-rise residential buildings too. Appropriate amendments to the related rules and regulations should be made to impose a fire risk assessment at least once every two years for all high-rise residential buildings in Malaysia. Currently, every year assessment is needed for the factory buildings and a fire safety certificate will only be issued by the fire department if fire safety aspects in factory buildings are in place.

9.2.3 Questionnaire surveys on occupants of high-rise residential buildings

From the questionnaire surveys, a number of people occupy the flat ranges from 2 to 15 people. The majority of the flats are occupied by 6 people (20.9%), follow by 4 or 8 people (17.4%), 5 people (13.0%), 12 people (9.6%), etc. The highest occupancy was 15 people (only one flat). This case assumed as special case, therefore it was not considered in further analysis. The second highest was 12 people per flat (11 flats in this case). Therefore it considers as a high occupancy and considered for further analysis in simulation processes. There are 56.5% males and 43.5% females participated in this survey and their ages range from 15 to 70 years old. 53.0% of them have at least diploma or highest. In terms of fire safety knowledge, only 32.2% had attended at least one day fire safety course and in terms of experience fire drill, 57.4% had an experience of fire drill but majority of them (41.7%) had fire drill at their office.

From the opinion surveys, 40.9% occupants said that they will immediately evacuate the building if a fire alarm goes off but 59.9% of occupants will do something else before evacuating the building. Among the important points to highlight are the occupants wish to evacuate the building using the staircase instead of the elevator. Majority of them will evacuate the building after calling 999, help other occupants and try to save as many as possible of their effects. Among the gender, 64.6% males would do something else before evacuate and 52.0% of females would do the same before evacuating the building. In terms of age groups, people age between 31 to 40 years old (51.3%) more lightly to evacuate rather than to do something else but people above 40 years old (86.7%) more likely to do something else before evacuating the building in fire emergency. Meanwhile among the respondents who have attended a fire safety courses, 64.9% would do something else before evacuating the building. In contrast, 56.4% who never attended fire safety course will do the same. Analysis on the education level shows that those with high education (57.4%) more likely to do something else but among those with low education (61.7%) more likely to do something else before evacuating the building. There is an evident that gender, age, knowledge and education level will influent the human behaviour in terms of action to be taken during a fire emergency.

In terms of perceptions when fire alarm goes off, from the questionnaires survey, it found that, people perception it was a genuine fire alarm and they will alert all people in their flat to immediately evacuating the building to the safe designated area. On the perception of exit choices to evacuate, they knew where escape stairs are, will use the staircase to evacuate and will follow the exit signage when evacuating the building.

In terms of motivation factors to evacuate the building, the factors that most motivate are command from a person with authority e.g. fire brigade officer, police or building security. Other factors are fire cues, fire alarm and people start moving out from the building. These factors are among the high priority factors that will motivate them to evacuate the building.

In terms of the evacuation behaviour, the main factors that will influence the occupants' behaviour are crowds i.e. traffic congestion in the escape stair, havoc situation, the number of people in the building and smell of burning materials.

9.2.4 Computer simulation studies

Analyses were done on five high-rise residential buildings of different internal layouts. The staircases and fire doors designed for the simulations were as specified in UBBL to compare with the specifications suggest from the finding of the studies. There are four stages of simulation done i.e. analysis of the effect of staircase intermediate landing floor, the effects of different internal layout and staircase orientations, escape routes specifications analysis, and the effect of fire door and staircase width on the total evacuation time.

i. The effect of intermediate landing floor

From the simulation studies, it found that the intermediate landing floor has an effect on the total evacuation time recorded. There was a significant evident that the intermediate landing floor will increase the total evacuation time about 15% to 24% longer than the staircase designed without the intermediate landing floor.

ii. The effect of internal layout and staircase orientation

The simulation results show that building B recorded the best total evacuation time and floor clearance time for the low, normal and high occupancy (see tables 7.6, 7.7, and 7.8). Building B is a 'U' shape building designed with four escape stairs. In terms of the number of occupancy in the building, if the number of occupant increases i.e. doubling the number e.g. from low occupancy (1 person per room) to normal occupancy (2 persons per room), the floor clearance time would increase between 5 seconds to 90 seconds and the total evacuation time would increase between 30 seconds to 90 seconds. If the number of occupant increases to the high occupancy (i.e. 4 persons per room) the total evacuation time would increase between 3½ minutes to 5½ minutes compare to the normal occupancy. In the high occupancy tested, the result shows that people who stay in the third floor to the ninth floor level might be at risk because the floor clearance times recorded were more than 150 seconds. Therefore, increasing the number of people above than the normal occupancy will pose a high risk to the occupants. In addition, the simulation results show that for some building layouts certain staircases may not be chosen as exits because of the distance from the flats, and they are therefore ineffective for evacuation. Also, some staircases are more likely to be chosen by the evacuating occupants and therefore become congested, causing floor clearance times to increase.

iii. Escape routes specification analysis

The optimum width of the staircase, fire door and corridor is 1220mm to 1372mm, 990mm to 1220mm, and 1220mm to 1524mm respectively. The optimum means that the consideration was not only be given to the minimum evacuation time recorded but how many of these elements i.e. staircase, fire door and corridor widths recorded the evacuation time within 30 seconds differences. The more these elements recorded close together within 30 seconds differences the most optimum it was.

In terms of the study models with the fire door, model 5 and model 8 have the best total evacuation time recorded. The total evacuation times recorded were within 3 minutes to 3½ minutes of all fire door widths for the staircases 1067mm, 1220mm and 1372mm. Meanwhile, model 6 is the best model with the corridor i.e. the total evacuation time recorded for the staircase, 1220mm, 1372mm and 1524mm was within 3 minutes to 3½ minutes.

iv the effect of fire door and staircase width on the evacuation time

When tested the effect of fire door and staircase width on the ten storeys building upon the dynamic flows of high occupancy of people, i.e. assumed 4 people per room, simulation results suggested that enlarging the fire door width alone without enlarging the staircase width will not improve the evacuation time. However when enlarging the staircase width without enlarging the fire door width, the evacuation time improved from 11 minutes 53.8 seconds to 10 minutes 27.9 seconds. However, if the fire door width enlarged to 1067mm and staircase width as well enlarged to 1220mm, the evacuation time was further improved by about 14.2%.

The simulation results suggest that with the proposed specification i.e. staircase length, tread, riser and fire door as proposed in appendix 8.3, the floor clearance time could be reduced by about 20% to 50% for some floor levels e.g. for building D at floors 3 to 9. According to the simulation results, floor 10 appears to be the safest as the floor clearance time was below 150 seconds even with high occupancy.

9.2.5 Fire safety model

Fire safety conceptual model of how fire safety standards in high-rise residential buildings can be achieved was developed after prudently analysed all research data from the mixed methodologies discussed earlier. There are two main sub-models integrated to the model developed i.e. human behaviour model and structural design model. Table 8.3 and figure 6.6 show the fire safety specifications for escape routes and a human behaviour model respectively. The factors from these two models have been integrated into five fire safety components to form a fire safety conceptual model of how fire safety standards can be achieved in high-rise residential building as in figure 8.4. The five fire safety components are:

- i Fire safety awareness,
- ii Fire safety design,
- iii Fire safety equipment and evacuation skill,
- iv Fire safety audit, and
- v Fire safety enforcement.

It is proposed that to achieve the fire safety standards in high-rise residential buildings, those five fire safety components need to be put in place together. It is proposed that a fire safety audit form as in appendix 8.1 could be used to audit the fire safety aspects in high-rise residential buildings. A fire safety audit should be carried out once every two years and fire safety certificate issue by the fire brigade should be introduced to all high-rise residential buildings. From the observations, it can be concluded that the conditions of escape routes need some significant improvement if the safety of people is to be assured.

9.3 Recommendations for further research

Although the work documented in this thesis represents a contribution towards achieving the objective set and to answer the research questions, a number of issues were identified for further research. Further research and investigation of these issues would provide a better understanding in measuring the effectiveness of the implementation of the fire safety programme in high-rise buildings. These will provide the policy maker, building managers, designers, etc with additional knowledge and information to be used in determining appropriate decision making strategies and planning for fire safety implementation in future high-rise buildings inclusive high-rise residential buildings. Some potential issues include:

- Field study on evacuation time taken of unannounced fire drill of high-rise residential buildings with fire cue fabricated i.e. smoke compare with the time taken of announced fire drill on the same building. The study should cover recording the movement of people within the building i.e. in corridor and staircase, the location where people will gather after evacuated the building, to determine whether lift or staircase is mainly chosen for evacuation, and the factors that would have caused the evacuation delay.

- Investigation on the effectiveness of fire safety awareness programmes introduced into a selected high-rise residential building, as a pilot study, can be measured by conducting an unannounced fire drill after a certain period of the programme being introduced. This information is very useful before a full scale of programme introduction nationwide. By measuring the effectiveness of those programme's implementation, all uncertainties can be identified and continued improvement can be made.

- Deeper evaluation on various orientation and layout of internal circulation areas i.e. corridor designed, the location of staircases and lifts, the location of flats, and final exits using simulation software package can be conducted to evaluate the safest internal layout design for future high-rise residential buildings. Consideration should be given to more internal circulation layouts of different building shapes. This investigation can provide invaluable information to the designers and the policy makers for the safety of people in the future high-rise buildings. The study should include but not be limited to the construction technology and construction cost for those design proposed.

- Among the problems encountered in high-rise residential buildings are related with the provision of facilities for fire safety in building i.e. smoke control, illumination, emergency lighting and exit signage. Those problems will have consequences of smoke penetration into escape stairs, concentration of fume and smoke in the corridor and stairwell, limited range of vision, difficulty in walking, risks of slipping on staircase, slowing down the evacuation process, etc. Research on optimum cost, energy consumptions and alternative solutions for providing effective facilities for fire safety in high-rise buildings is important. The finding will be of benefit to the building designers, building occupants, local authority, etc.

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