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The Hong Kong Polytechnic University

Department of Building Services Engineering

A Critical Study on the Fire Safety for Big Hotels in Hong Kong

WU HOI HUNG

A thesis submitted in partial fulfilment of

the requirements for the degree of Doctor of Philosophy

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CERTIFICATE OF ORIGINALITY

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WU Hoi Hung (Name of student)

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ABSTRACT

The abstract for the thesis titled "A Critical Study on the Fire Safety for Big Hotels in Hong Kong" submitted by WU HOI HUNG in 2006 for the degree of Doctor of Philosophy at The Hong Kong Polytechnic University.

Fire safety is always a major concern in hotel operations and guest services. A critical study on the fire safety in big hotels in Hong Kong was carried out in this thesis. A detailed review on all the fire safety codes and requirements relating to hotel accommodation was carried out. Local codes on the fire services installations (FSI) required issued by the Fire Services Department were reviewed and the codes from the Buildings Department were studied. Hotel licensing requirements by the local Home Affairs Department were introduced. Fire safety requirements in the Mainland China code on high-rise buildings, the National Fire Protection Association safety code and other fire safety guidelines in USA were also discussed.

The total fire safety concept was found to be very important to hotel staff and guests. On the hardware side, the active fire protection systems commonly adopted by firemen in fire fighting against fires in hotel were examined and analyzed critically. These systems are also essential to the fire fighting team of the hotel itself. Another hardware component, the passive fire protection systems including fire resisting constructions, means of escape and areas of access were studied. To most of the hotel operations, the software component, namely a proper fire safety management scheme, is often regarded as more important in international chain

hotels. Housekeeping and maintenance of the passive protection installations play a major role in the overall fire fighting strategy.

A critical hazard area in the hotel, i.e. the kitchen, was then focused on. Safety concerns and problems usually encountered in kitchens were surveyed and analyzed. Full-scale burning tests in part of a sample kitchen were performed. Fire scenarios and the action of active fire systems such as sprinkler and water mist systems were assessed. In addition to the heat release rate, maximum temperature and fire extinction time were examined and analyzed. It was found that the temperature could reach the flashover temperature of 600 ^{o}C in some cases, and the heat release rate could be as high as 1.4 MW. No splashing or spilling of fuel was found for the test arrangements in the model kitchen. The sprinkler and water mist system were shown to be effective in extinguishing kitchen fires but less extinguishing time was required in using the sprinkler system. These experimental results provide valuable guidelines for the design of fire safety provisions in hotel kitchens. This refers not only to hardware fire safety systems, but also software fire safety management to achieve total fire safety.

Experimental studies were carried out for studying thermal sensitivity of fusible links at fire dampers normally installed in hotel guestrooms. Two groups of experiments were carried out to examine the thermal response of fusible links with a heated wind tunnel. The first group of experiments involved testing 50 fusible links following common standards used in the USA, i.e., Underwriters' Laboratories 33 on heat responsive links at constant temperature and air speed. All the fusible links fulfilled the operating time as recommended. The second group of

experiments involved the testing of fusible links at various temperatures and air speeds. Recording the operating time of the fusible links would give the response time index by plotting a suitable graph.

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NOMENCLATURE

A_e	Surface area of the sensing element (m^2)
A_{ef}	Surface area of the sprinkler frame (m^2)
A_f	Surface area of the frame (m^2)
A_{f_p}	Surface area of the pipework (m^2)
A_v	$H_v W_v$ (m^2)
A_T	$2 (L + W) H + 2 L W - A_v$ (m^2)
B	Constant (-)
C	Orifice plate coefficient ($kg^{\frac{1}{2}}\, m^{\frac{1}{2}}\, {}^oC^{\frac{1}{2}}$)
c	Conductive heat transfer between the sensing element and the framework
c_e	Specific heat capacity of the sensing element ($Jkg^{-1}\, {}^oC^{-1}$)
c_f	Specific heat capacity of the frame ($J\, kg^{-1}\, {}^oC^{-1}$)
H	Height of the compartment (m)
H_v	Height of the ventilation opening (m)
h_e	Convective heat transfer coefficient of the sensing element ($W\, m^{-2}\, {}^oC^{-1}$)
h_{ef}	Convective heat transfer coefficient of the sprinkler frame ($W\, m^{-2}\, {}^oC^{-1}$)
h_f	Convective heat transfer coefficient of the frame ($W\, m^{-2}\, {}^oC^{-1}$)
h_{f_p}	Convective heat transfer coefficient of the pipework ($W\, m^{-2}\, {}^oC^{-1}$)
k	Thermal conductivity of air ($W\, m^{-1}\, {}^oC^{-1}$)
k_c	Factor related to the conductive heat loss c (-)
L	Length of the compartment (m)
l	Characteristic dimension of the sensing element (m)
$\dot{m}$	Mass flow rate in the duct ($kg\, s^{-1}$)

m_e	Mass of the sensing element (kg)
m_f	Mass of the flame (kg)
Nu	Nusselt number (-)
n	Exponent (-)
ΔP	Pressure drop across the orifice plate (Pa)
$\dot{Q}_{mf}$	Minimum heat release rate for flashover (kW)
Re	Reynolds number (-)
RTI	Response time index ($\mathrm{m}^{\frac{1}{2}}\ \mathrm{s}^{\frac{1}{2}}$)
RTI_v	Virtual response time index ($\mathrm{m}^{\frac{1}{2}}\ \mathrm{s}^{\frac{1}{2}}$)
T_e	Gas temperature at the orifice plate (^{o}C)
T_g	Nominal gas temperature in test section (^{o}C)
T_m	Marked temperature rating of the link (^{o}C)
T_u	Nominal ambient air temperature (24 ^{o}C)
t	Time (s)
t_o	Operating time of the link (s)
t_{op}	Operation time of the sprinkler (s)
u	Speed of air (m s^{-1})
V_{ef}	Ventilation factor ($\mathrm{m}^{2\frac{1}{2}}$)
V_g	Air speed in wind tunnel section (m s^{-1})
W	Width of the compartment (m)
W_v	Width of the ventilation opening (m)
X	$1-\dfrac{T_m - T_u}{T_g - T_u}$ (-)
β	constant (-)
ν	Kinematic viscosity of air ($\mathrm{m}^2\ \mathrm{s}^{-1}$)

θ_E	Effective operating temperature (^{o}C)
θ_e	Temperature of the sensing element (^{o}C)
θ_e (0)	Initial temperature of the sensing element (^{o}C)
θ_{nom}	Nominal release temperature (^{o}C)
$\Delta\theta_e$	Increase in temperature of the sensing element (^{o}C)
$\Delta\theta_f$	Increased temperature of the frame (^{o}C)
$\Delta\theta_g$	Increase in gas temperature (^{o}C)
τ_e'	Time constant of the sensing element (s)
τ_f'	Isolated time constants (s)
τ'	Long-term time constant (s)
τ''	Short-term time constants (s)

CHAPTER 1 INTRODUCTION

Modern hotels nowadays have many new construction features such as double skin facade and use a lot of glass features and new materials [Chow 2001a]. It is also equipped in its internal areas with lots of state-of-the-art technology and equipment. The fire safety concern that may be brought forward by all these installations will be studied very carefully. In particular, all the electrical and mechanical installations inside the hotel building itself are of great concern. The air-conditioning and ventilation system is not just provided for the proper internal environment to the guests and hotel employees but is also a major factor to be considered in fire safety aspect. The running of the air ducts [ASHRAE 1997] through fire resisting construction and proper fire dampers and stop details to be installed are critical. The material used in the ventilation system is a major fire safety concern both locally and abroad and must be considered carefully. Of critical importance, the smoke control mechanism in the ventilation system in hotels is both a practical and academic focal point to the operators. On the other hand, the electrical building services systems, including the lighting system, are also a major concern to fire safety in hotels. In the author's hotel operating experience, most of the fires in hotel guestrooms are caused by faulty electrical equipment or the improper usage of these electrical installations. Training to hotel staff is important, particularly on strict adherence to electrical ordinances and standards upon using all these electrical equipment.

Furthermore, in this thesis, the fire safety and risks in particular functional areas in a hotel, such as the kitchens and laundries, will also be emphasized. There are lots of electrical and mechanical equipment and installations in the kitchens and laundries. The installations involve various kinds of fuel and large amount of oil, and dust will be generated during the operational processes. In this study, the fire risk in kitchens will be focused on as nearly all the hotels, no matter its ranking and service standard, will have kitchens servicing the guests and employees. The risk and fire load [Chow 1999] in kitchens are high and an extensive study on the safety aspects in kitchens will be conducted. Experiments will also be carried out to find out the heat release rate for a possible oil fire in the kitchen.

1.1 Objectives of the Research Work

The objectives and key items in this thesis:

To investigate the fire safety concerns and problems in hotels, in particular the high risk area — kitchens. Fire codes were reviewed for hotel accommodation. The local fire codes involve those from the Fire Services Department [FSD 1998] and Buildings Department [BD 1995, 1996a, 1996b]. Mainland fire codes [Ma 1995, 1997; MPS China 1997] and National Fire Protection Association (NFPA) fire standards and guidelines [NFPA 1993, 1994, 1995] were also compared and considered.

To study the total fire safety concept [Chow 2004b; Hui 2004] and its application in the practical hotel operation. The importance of fire safety management [Chow, 2001a; Dailey, 2000] in hotels will be focused on.

To carry out full-scale burning tests [Babrauskas 1992, 2003; Chow 2001b, 2002, 2004a] and investigate the fire scenarios and heat release rate for kitchen fires. The effects on operation of sprinkler [Gupta 2001; Watts 2003] and water mist system [Mawhinney 1993, 1994; Yao and Chow, 2001] on kitchen fires will be studied.

To carry out experiments [Chow and Ho 1992; Heskestad and Bill 1984, 1988, 1989] in rating fusible links installed in fire dampers for hotel guestrooms. This is critical to the passive fire protection systems and the correct rating [UL33 2005] of the fusible link is important to the damper operations.

1.2 Methodology

Local and international chain hotels in Hong Kong were surveyed to investigate the fire safety concerns and problems in big hotels. Local fire codes and those from the Mainland and the US were compared and reviewed. Hotel licensing requirements [CNTA 2005] were particularly dealt with.

To understand the importance and application of total fire safety concept in Hong Kong, particularly the practice and program of fire safety management [Della 1999] were reviewed.

Very few experimental data are available from systematic full-scale burning tests [Chow 2002], especially for certain building configurations such as the hotel kitchens. Full-scale burning tests [Chow et al 2003d] on a model kitchen in a remote area of China were carried out to determine the heat release rate and also the effects of sprinkler and water mist system on the kitchen fire. Full-scale burning tests are important to determine the actual fire environment and material behaviour under fire condition.

The operation and performance of fusible links in smoke curtains and fire dampers were reviewed. The empirical equations [Chow and Ho 1990] and models involved for sprinkler heads were studied. Simulation experiments were carried out to verify the performance of the fusible links currently used in one of the local hotel projects. Response time index [Chin 2002] of the fusible link was evaluated. The experiments are critical for ensuring that correct rating and performance of these fusible links are achieved in actual operating conditions.

1.3 Outline of the Thesis

Chapter 1 is an introduction to hotels nowadays. Fire safety is of critical importance to hotel operations. The various mechanical and electrical installations are discussed and their importance towards fire safety is outlined.

Chapter 2 is a detailed investigation on hotel fires. The fire safety concerns and issues related to fires in hotels will be outlined. Electrical and mechanical installations in the hotel building services system will be studied and its operation on fire safety concern will be investigated. Particular fire risks in certain functional areas will be studied, for example, laundries and kitchens. Local [FSD 1998] and foreign fire codes [NFPA 1993, 1994, 1995] will be studied, particularly those codes directly related to hotel and guesthouse accommodation will be reviewed. These codes are implemented in Hong Kong in early 1990s and are under continuous revision to achieve both fire and building safety standard. The importance of fire safety concern in international chain hotels is specially discussed. This relates to the hotel image and reputation if a correct fire management scheme has been successfully implemented.

Chapter 3 is an in-depth study on the total fire safety concept and its application in daily hotel operations and activities planning. The hardware and software components and also the fire safety management strategy [Shipp 1998] and planning in hotels will be studied. To the hotel operators, fire safety management may be the most important aspect relating to the asset and life in the hotel. The various components and attributes in the passive fire protection systems and installations will be outlined. This passive system [Tsui and Cheung 2004] may be the first defence and protection against fire spread. The correct selection and rating of the materials and installations will be critical to the success of these passive fire protection systems.

Chapter 4 will focus on the active fire protection systems [NFPA 1997], which comprise all the dry and wet fire fighting systems. Various codes related to these systems, their operation, characteristics and suitability on their usage in various hotel functional areas will be reviewed. Just like passive fire protection systems as described in Chapter 3, the importance and implementation of engineering performance-based fire codes to replace the traditional prescriptive codes will be discussed. More advanced systems such as the water mist system and chemical system will be examined.

Chapter 5 is to discuss and investigate fire safety management in hotels. This software component which is of paramount importance to the hotel will be studied in depth. For the hospitality service industry, a proper strategy and training plan should be established in order to cater for the changing service environment and different guests' expectations nowadays. The various components [BSI 1994] in a fire safety management scheme will be explored further.

Chapter 6 is on the methods used for this study [Wilson 1990]. Basically, fire safety concerns and theories for hotels will be reviewed. This forms a basis for further research. Of critical importance, experiments were carried out to investigate various fire scenarios of kitchen oil fire and the operation of sprinkler and water mist system. A remote site in China was selected to perform the experiments in part of the actual kitchen setup.

Chapter 7 is a review on the site selection and its characteristics. The environmental concerns on these experiments [Chow et al 2003d] are particularly dealt with and the necessary expertise in setting up the experiments is outlined. The actual experiments carried out for kitchen oil fire are outlined. All the results will be recorded and analyzed. The most important parameters, such as heat release rate, maximum temperature recorded and the fire extinction time will be reported.

In Chapter 8, empirical equations for heat transfer [Heskestad and Smith 1976, 1980] at sprinkler heads will be studied. Heated wind tunnel tests on sprinkler heads were simulated for testing the actuation of fusible links. Experiments were carried out on rating the fusible links for fire dampers installed in hotel guestrooms. The data obtained in the experiments will be reported and analyzed.

Finally, in Chapter 9, conclusions for the whole study will be given and further studies recommended.

CHAPTER 2 HOTEL FIRES

Hotel buildings are very complex on its functional use and also change with time for its major clienteles. The familiarity of various types of guests coming from different countries with the hotel configurations is usually a question mark. On fire safety concern, as only the hotel employees are familiar with the hotel layout, fire exits and safety installations, etc., a proper training plan to staff [Malhotra 1987] is of paramount importance. Since usually the hotel guests cannot easily find the locations of the fire fighting installations and the exits or staircases, in accordance with the local or international fire code, proper lists of fire service installations must be provided.

In this chapter, some past experience of fire examples in hotels will be listed. The fire safety concerns on the electrical and mechanical installations in a hotel building will be discussed. International chain hotels will have their particular focus on fire safety and installations required. The requirements and the special installations that these chain hotels in Hong Kong may have on fire safety concern will be outlined. Furthermore, particular risks in a hotel building, such as the kitchen, will be discussed. The particular problems and issues related to fire safety in kitchens will be reported. Besides the fixed fire fighting systems and the fire resisting construction [England et al. 2000] provided, the software component such as the fire safety management scheme provided by the hotel operator is equally important to guests on fire safety aspects [Bickerdike Allen Partners 1996].

2.1 Review on Parameters Related to Fire Safety and Problems in Hotels

Before embarking on the fire safety problems often encountered in hotels, some examples of past fire incidents in hotels will be described. These fire occurrences were actual happenings although the fire size was not large and did not cause any casualties.

2.1.1 Examples of fires in hotels

- Fire in guestrooms

A lot of electrical and mechanical facilities are installed in a typical guestroom. Their characteristics and effects on fire safety will be discussed in more detail later in this section. Besides, the guestrooms are usually fitted out with a lot of fabric and finishing. Guests smoking in guestrooms are a primary source of fire happening in guestrooms. Some of the guests are heavy smokers and they do not handle the cigarettes ends well which leads to the fire outbreak. Although these fires are usually extinguished by the sprinkler system [Cheung and Chan 2003] inside each guestroom, the water damage and the panic caused may be very significant.

Moreover, in modern hotels, there are also some service apartments that serve a certain amount of long-staying guests residing for years or months. Quite often, some pantry or kitchenette equipment will be provided for minor cooking in the guestrooms. This will pose a high fire risk to both the guests and hotel employees. If the cooking process is unattended in the guestroom, it may lead to a fire accident. Furthermore, the guestrooms are also equipped with many electrical appliances or heaters. If these equipments were not correctly used and properly maintained, a fire would occur and this actually happened in the past. For example, water boiled in kettles and equipment malfunctioned without electrically cut off when boiling temperature was reached. This concerns the quality and reliability of the equipment. Similarly, some guests misused the hairdryer as a clothes dryer and that caused a fire. In winter, clothes or fabrics in the guestroom would be ignited by a heater if unattended or heating surface being too close to the finishing.

- Fire during hotel renovation

Again, this concerns the quality of project management and the attitude of hotel management towards the contractors. A lot of these fire examples happened in the past, though the fire was put out by the contractor at the very initial stage. Most of the construction workers are smokers and they break the rules to smoke on the site even when they are forbidden to do so. This is a fire risk to the hotel because the lighted cigarette ends in the site can lead to a big fire.

Careless welding is another source leading to fire during the hotel renovation. For electrical and mechanical installations in modern buildings and certain steel or metal framework construction for the structure and window installation, these works involve lots of welding work. The poor and careless attitude of the workers during welding will leave lots of lighted or high temperature soot on site. If not properly cleaned or removed, this soot will be a fire source on site. There are several examples in the past hotel renovation projects such as the removal of old escalators in the lobby in order to create an atrium [Morgan and Marshall 1975], intense welding will be needed and actually the author had seen a fire due to such welding process. Same as in another upgrade project on installation of a new air handling unit for the laundry room, intense welding was needed and the sparks actually lighted the dust and lint accumulated inside the equipment. This is an example of poor welding technique and inefficient maintenance and cleaning procedures implemented in the past on the equipment. Both of these two examples of fire due to careless welding did not cause any casualties but the damages to the hotel building were significant. In both cases, hotel evacuation was required and that caused panic to hotel guests and employees.

- Fires in kitchens

Typical fire examples in kitchens will be described in later chapters.

- Fires in laundries

Laundry in a hotel is equipped with many large electrical and mechanical installations. It is a factory and indeed a very labour intensive operation in the hotel. There are also a lot of equipment in the hotel laundry, including folding machines, flatwork ironers, pressers, compressors, dry cleaning machines, washers and form finishers, etc. High rating motors, chemicals and large exhaust volumes are typically involved in daily laundry operation. Detailed and efficient maintenance and cleaning programs and operation are necessary to keep the equipment in a safe condition. All the heated surfaces or motors should be kept away from linen or clothes. All lint and dust on the equipment interior or surface should be properly removed. Several fires had happened in the past in the laundry, though most of them were put out by the hotel internal fire team and did not cause any casualties. One example involved the 50 HP motor of the washer while it was washing about 100 kg of laundries. Due to poor maintenance and carelessness, the dust or lint on the motor surfaces was ignited from the motor heat. The fire was put out by portable extinguisher but the washer was damaged as the motor and washer body itself was seriously burnt.

- Fire due to lighting installation

Lighting provides the suitable visual environment in the hotel lobby, restaurants, conference halls and guestrooms, etc. Lighting is understood to generate heat, in particular for those high power rating fittings usually adopted such as halide lamps or floodlights. Lighting systems are usually not regarded as a high fire risk and not so many concerns are given to minimize the chance of fire occurrence. In particular, the electrical characteristics, circuitry and power rating need to be checked in order to prevent the occurrence of a fire.

The focus effect of some halide fittings might also lead to fire. There had been several such fire cases in hotels, such as the reading lamp installed at the bedside panel and the focus heat actually burnt the duvet on the bed. Similarly in the restaurant, when the guests’ clothes were accidentally placed too near to the column light fitting [Canter 1980], the focus heat from the light fitting burnt the clothes and the hotel had to compensate for this damage to the guest. Moreover, the hotel management also needs to install a lot of lighting stripes on the decorations and finishing at the front of the house areas, especially during festival seasons. The electrical quality of the whole installation has to be checked by qualified electrician so as to prevent fire due to overheating or electrical failure.

2.1.2 Problems and concerns for fire safety in hotels

From aesthetic point of view, hotel buildings are similar to other types of buildings when viewed from outside. Hence, there is a thinking to provide a global solution in the design of hotels on the provisions for visual, thermal and safety aspects [Buchanan 1999] so that hotels can be operated similar to offices, hospitals or government buildings. This concept however may cause confusion and in most of the cases do not tally with the operation needs of the hotel management.

According to the local fire code [FSD 1998], whether the prescriptive code or the engineering performance-based fire code is adopted, it is still required to provide the fire protection and suppression systems for the hotel building itself. Similarly, other electrical and mechanical systems are also provided in the hotel for the comfort and safety of the guests. Moreover, the fire safety system is usually incorporated into the hotel central building management system. This system will manage the operation, status and commands the fire safety system operation in the hotel.

On the contrary, the operational characteristics and service needed to be provided to guests pose additional difficulties and problems on fire safety in the hotel premises. First of all, the needs for hotel guests differ significantly from those of office staff or clients to a theatre. Basically, guests will sleep in the guestrooms and dine in the restaurants. Because of the accommodation provided inside an unfamiliar hotel configuration and guestrooms, added concerns should be placed on fire safety to safeguard the life and assets inside the hotel. In some of the hotels nowadays, it is a usual client segment to have long-staying guests or service apartments. To better cater the needs of the guests, warming or even simple cooking equipments are provided in the guestrooms. This means that the type and profile of guests inside a hotel really is a concern on fire safety.

Secondly, the daytime and night-time requirements of a hotel guest will be very different from other building users. This relates to the specific and so many services that the hotel will offer to the guests. During daytime, the guestroom may not be occupied as the guests will go out for site scenery if they are tourists or attend meetings or conferences for corporate guests. On the contrary, some corporate guests may also use the guestroom as an office for all the business function requirements and meetings, as a work station or a lounge, etc.

Thirdly, a main outstanding difference is that a hotel will operate 24 hours daily for the year round. This definitely will pose additional concerns on the design, installation and maintenance [Della 1999] on the fire service installation to be provided. Seemingly, there is no downtime for nearly all the installations provided in the hotel. Whenever a maintenance program is needed for the fire service installation, alternative systems have to be considered in order to provide an equivalent fire safety level to the hotel. The hotel management also needs to face challenges by having a team of qualified engineers that would handle any situations without undermining the fire safety standard.

Fourthly, modern hotels also host various types of activities and functions in its lobbies, convention centre and conference halls. The functions range from simple pleasurable events to major business meetings, product launching and even leisure and sport activities. Recently, the Hong Kong Special Administrative Region government also hosted some World Trade Organization (WTO) meetings in hotels. There may be a sudden gathering of large crowd of people inside and outside the hotel. This will be a big challenge to the hotel management and they often need assistance from the local fire brigade on how to deal with this kind of emergency situation. In the recent WTO event in Hong Kong, the Fire Services Department basically tested again all the fire services installation for all the hotels hosting any WTO delegations. All the internal hotel fire teams were on full alert during the whole WTO event, together with the full support from the local Fire Services Department. The various functions which might include fireworks, pyrotechnics and cooking demonstration added the fire risks although the function lasted for only a very short period inside the hotel. The hotel management needed to think very carefully in each function on how to provide safe environments for these functions.

In the last decade and in modern hotels, the hotel management needs to provide “personal service” to the guests. The guests will pay for the hotel in order to have the equivalent service provided for them to feel like their own home. This “personal service” or individualization of comfort [ASHRAE 1997] will surely pose additional concerns on fire safety.

2.1.3 Hotel functional areas

To the hotel operator, there are three essential elements in the hotel as far as the space allocations are concerned. They are the private zones, the front of the house areas and the back of the house areas. Private zones are basically the hotel guestrooms, suites and service apartments where fire safety in these areas is our top concern. For the front of the house areas, they include the restaurants, hotel lobby, health clubs, conference halls, meeting rooms, shopping malls and lounges, etc. These areas also serve the hotel guests and usually will have large crowd of people. In the back of the house areas are the laundry, kitchens, hotel in-house offices, storerooms, plant room and loading bay. Particular focus will be placed on the fire safety in these areas as they may not be occupied sometimes, for example, the plant room. Hence, serious considerations on fire safety in the following areas in a hotel must be raised:

- Guestrooms, suites and service apartments

As related in previous sections, fire safety in these areas is of top concern to the guests as they are residing in the room particularly during the night-time. Various activities may be conducted in the guestroom, for example, smoking, cooking and the improper use of electricity may all increase the fire risk in the guestroom.

- Plant rooms

In the local fire code, a special license, such as the dangerous goods license, has to be applied for certain special plant rooms. The E & M plant rooms may include main A/C plant room, boiler room, main switch rooms and swimming pool filtration room, etc. Special and even individual fire protection systems are provided for these plant rooms.

- Food and beverage areas - restaurants and convention halls

Cooking activities and smoking are major concerns in these food and beverage outlets. Moreover, the gathering of large group of guests in these areas creates additional concerns on fire exit and evacuation. In trendy hotel restaurant design, the open kitchen concept is often adopted and actual cooking being done in the restaurant and this must be a challenge to the fire system designer and the hotel management.

- Laundry plant

It is both a factory and a plant room to the hotel. As a factory, it is labour intensive with many hotel employees working at the same time in an area, typically densely installed with large electrical and mechanical systems. As a plant room, it houses many laundry equipments and the handling of a lot of detergents and chemicals.

- Back of the house areas

They consist of all the supporting areas for servicing the hotel guests and employees. In particular, fire may occur in the loading and unloading bay and car parks. Flammable vapour is involved if the petrol is not properly handled. All the main electrical and mechanical systems serving the hotel building are basically located in the back of the house areas. Hence, proper and detailed program on maintenance of the installations must be implemented. For international chain hotels, usually the corporate office will have periodic visits by senior management personnel to carry out audit on the quality and standard of all these back of the house areas.

- Kitchens

Details will be discussed in the subsequent sections.

2.1.4 Electrical and mechanical systems in a hotel

To the architects, hotel is a prestigious building and the guestrooms usually occupy about 60 to 70 % of the total gross floor areas approved for the hotel project. For the success of the hotel building, the architect needs to consider not just the layout of the guestroom but also the structure [Buchanan 2001], the construction and finishing materials and the coordination of all the electrical and mechanical systems. To the hotel operators and owners, they have to maintain the profitability and competitiveness of the hotel building. This cannot and should not be in conflict with their primary objective to provide a safe, clean and comfortable environment for the guest.

It is the prime responsibility of the hotel management to maintain properly the following installations:

- Electrical installation and appliances

Proper use of electricity and strict adherence to electrical codes and ordinance must be enforced by the hotel operator. A proper selection of electrical devices and appliances are essential and should be carefully considered during the purchasing stage.

- Air-conditioning and mechanical ventilation system

Such system not just provides a comfort environment to the guests and hotel employees but it is needed to provide a clean and hygiene environment also. All the fusible links, dampers and fire devices installed in the ventilating system must be checked and maintained properly.

- Fire protection system

Active fire protection systems include the sprinkler system, hosereel and hydrant system, fire alarm system and portable extinguishers, etc. Passive fire protection systems include the building construction with proper fire rating, fire doors or walls, dampers, seals and smoke lobbies, etc.

- Extra-low voltage systems

They are essential systems to the proper execution of the fire evacuation procedures, including the public announcement systems with overriding features.

- Laundry and kitchen equipment installations

Care and proper maintenance must be implemented to remove the oil deposit, or dust or lint collected in the kitchen and laundry equipment respectively.

- Cold and hot water system

Proper maintenance and care are required for the fire protection system for the boiler and calorifier room.

2.2 International Chain Hotels – Fire Safety Considerations

Every guest has its own expectation towards a hotel. To most of the guests or chain hotel management group, a hotel is an area designated for guests to have a pleasant stay and safety environment under a quality and effective infrastructure. The International Hotel and Restaurant Association (IHRA) defines a hotel as “an environment which always delivers overnight accommodation” and which is licensed to market its business as a hotel.

International hotel chains with their main objectives to fully satisfy customers’ needs, always try to offer a wide and varied range of guest services. These hotel chains bring in more spacious rooms and offer a wide range of refined food and beverage services. This is particularly obvious in the 1980s with China adopting an open-door policy that attracted even these international hotel experts to develop their management expertise in the Far East. Nowadays, hotel industry becomes more and more competitive. The international hotel chains push for more of their expansion plans of corporate and business people in the Far East, Europe and the Middle East. All these hotel chains, not just talk about luxury of bedrooms, state-of-the-art facilities, friendly surroundings and high quality environment, but they also must focus on the basic concept for a hotel, i.e. the safety provided to guests.

2.2.1 General fire safety requirements for an international chain hotel

In this section and in accordance with the author's experience, the general fire safety requirements will be outlined in an international chain hotel. The areas included are public areas, guestrooms and back of the house areas. Credits are allowed for sprinkler protection, recommendations for fire safety for existing finishing and fire alarm procedures. These requirements lay down the minimum standards that are acceptable in a chain hotel in order to protect the human life and asset in a hotel.

- Fire warning system

In a chain hotel, there should be a means for giving warnings [Canter 1980], in case of fire, to people in the building.

A fire warning system consists of detectors and manual call points strategically situated throughout a building, which are connected to a control indicator panel. Depending on the fire warning system installed, information will be displayed at the control panel. In the case of addressable system nowadays, the location of the actuated detector or breakglass unit will be given on an automatic liquid crystal display (LCD) at the control panel.

In the event of a fire, the control panel will identify which zone, detector or manual call point has been actuated and therefore the location of the fire. It will also actuate the fire alarm for evacuation, etc. Some fire warning system may also be connected to fixed extinguisher systems and have a direct communication route to the local fire brigade (like the Chubbs link in Hong Kong).

In addition, the fire warning system may also include the connection of relay contacts which may be regarded as the interface between the warning system and the main building services, such as lifts, air conditioning systems, dampers, etc. Operation of the warning system will prevent these services from working, or will change their mode of operation, i.e. lifts will home down automatically to the lobby floor. Air-conditioning system will be switched off and dampers will close down all open ducts or orifices in order to prevent the spread of fire or smoke throughout the hotel [Cherry 1986]. The aim of a fire warning system is to ensure early evacuation of the building and to reduce the physical losses caused by fire damage.

Fire detectors detect one of the three characteristics of fire: heat, smoke or flames [Morgan and Gardener 1990]. Heat detectors are suitable for most buildings and show a bigger resistance to adverse environmental factors. They are good for detecting fires with very rapid heat evolution but little or no smoke. Due to the lack of response to smoke, heat detectors are not suitable for most areas in a hotel and are only installed in areas where smoke detector could give unwanted alarms, e.g. kitchens.

Ionization smoke detector works by detecting a change in electrical current within the detector as the smoke particles interfere with the system and equilibrium of charged ions.

Generally, ionization smoke detector will respond quickly to smoke containing small particles but have a less rapid response to smouldering fires.

On the other hand, manual call points [Della 1999] are the square “breakglass” appliances strategically located around the hotel building. Generally, no point in a building should be further than 30 m from a call point, although this distance should be reduced where there are specific fire hazards.

Detectors and call points are arranged in zones, which may be considered as unit fire compartments. Besides showing the location of a fire, the control and indicator panel should also provide information on power supply fault and wiring faults, etc.

Where intercommunication or public address equipment is used in lieu of conventional sounders to transmit a general alarm, the signal should take priority and override other facilities of the equipment. The alarm signal, which may be followed by a voice transmission of essential information for safe evacuation should be distinct from other signals which may be in general use on the system. In the event of a false alarm, it is important that the cause and extent of the problem is determined as quickly as possible. Installations which are the subject of a series of false alarms should be referred to the designer. The provision of a two-stage alarm system may need to be considered in some nuisance case.

- Portable fire fighting equipment

The sitting of portable extinguishers should always be as close as practicable to the fire risk, adjacent to exits, on escape routes and away from extremes of temperature. Portable fire fighting equipment should be securely fixed to wall with the carrying handles approximately 1 m from floor level. Fire blankets should be provided in high or special risk areas, for example, in all kitchens and workshops. It is most important that portable fire appliances are kept in their allocated positions and not misplaced or misused.

Extinguishers are made in a number of sizes. If the allocation of water extinguishers is to be based on the criterion floor area, then one 9 litre extinguisher should be provided for every 200 m^2 of floor area [BSI 1988]. In deciding what will constitute appropriate means for fighting fire within the hotel, it is necessary to consider the nature of the materials in each area and thus the class of fire likely to be involved.

On the contrary, hosereels are strongly recommended particularly where the floor areas are in excess of 800 m^2 [BSI 1988]. They are the most effective extinguisher, depending on the class of fire. Once they are in action, a substantial volume of water can be provided and the water supply can also be controlled. For ease of handling, it is normally convenient to restrict the length of hose on one reel to 30 m of 19 mm diameter internal bore hose.

- Fixed fire fighting equipment

Water sprinklers, due to the effective extinguishing ability and accessibility of water, provide good general protection when installed in hotels. However, in situations where the use of water could be hazardous or when it is essential to avoid or at least minimize water damage, of which special risks are present, the installation of alternative systems, such as carbon dioxide, foam, halon or dry powder should be considered. In many cases in hotels, the extinguishing systems will operate automatically and may also be connected to the detection and alarm systems to provide complete protection.

Water sprinklers comprise a system of pipework, pumps, control valves and heat sensitive valves in the sprinkler heads which release water onto the seat of a fire. The rate at which the water is released will depend on the severity of the fire, given the nature of any combustible materials present. It is the flow of water which actuates any connected alarm systems. A clear space of at least 0.3 m should always be maintained below the level of the sprinkler head throughout the room.

Besides water sprinkler system, foam installation can also be used in special cases. Foam installation is a self-contained system capable of making, conveying and releasing foam. The foam may be low, medium or high expansion foam.

For carbon dioxide (CO_2) installation, the gas is usually stored in a cylinder or refrigerated tank and is connected to the outlet nozzles by a system of pipework. Such system may be designed to operate automatically or manually. Carbon dioxide systems provide good protection for hazardous plants in a hotel, e.g. transformer areas, electrical equipment and computer facilities, etc. One disadvantage of this system is the reduction of oxygen in the protected area on actuation, which necessitates built-in warning and time delays to allow evacuation of the area.

On the other hand, the components of halon systems are similar to those in carbon dioxide installation, although less storage is required for the same level of protection, due to differences in the extinguishing action. There are two types of halon systems: “Halon 1301” and “Halon 1211” [NFPA 1997]. Generally, halons are used for protection in the same sort of area and situation as carbon dioxide system. Like carbon dioxide system, the operation of halon system has health and safety implications due to the toxic effect of the halons themselves. In addition, halons are known to affect the atmospheric ozone layer and are now only used when no suitable alternatives exist.

Similarly, the dry powder is kept in a pressurized container, or is connected to a gas cylinder with a system of pipework leading to the outlets. On actuation, the powder become fluidized in the expellant gas and is conveyed to the outlets. These systems are suitable for fires involving flammable liquids, electrical equipments or where water damage must be kept to a minimum. They are not suitable in situations where re-ignition may occur.

- Emergency lighting system

Adequate lighting, whether natural or artificial, is important in enabling hotel guests to locate an escape route and move quickly along it to a place of safety. Hotel emergency lighting is required not only on complete failure of the normal power supply but also on a localized failure if such a failure would present a hazard. Any new emergency lighting system should conform to the local codes. The normal standards require that emergency lighting should maintain an adequate level of illumination for two hours in accordance with the hotel licensing requirements [CNTA 2005]. The greatest need of emergency lighting is those areas where there are guestrooms, corridors and escape routes.

There are several types of emergency lighting systems. Emergency light fittings are classified according to the type of power supply they use. The electrical power needed to operate them may come from one of the three sources:

a. Individual batteries in each light fitting
b. A central battery system which powers all the luminaries
c. An electrical generator which powers all the luminaries

Luminaries in which power is supplied from a central source, i.e. the central battery system or a central generator, are referred to as “slave” luminaries. This is in contrast to “self-contained” luminaries where the power source is contained within the luminaries.

In addition to the relative positioning of the power sources to the luminaries unit, it is also possible to have “maintained” and “non-maintained” emergency lighting systems. “Maintained” systems refer to those where the luminaries are operational at all times. “Non-maintained” systems only become operational when the normal power supply fails.

- Means of escape in case of fire

The basic principle of satisfactory means of escape [Tsui and Cheung 2004] in a hotel is that persons should be able to walk unaided to a place of safety, regardless of where a fire might break out in the hotel building. Satisfactory means of escape should be an integral part of the hotel building construction. This excludes portable ladders and self-rescue devices.

Hotel guests or employees should be made aware of the escape route from their particular location. The escape route should be easy to follow and adequately signposted. The following factors should be considered:

a. The routes should be sufficiently wide, and of sufficiently short distances to allow speedy and safe evacuation.
b. Ideally there should be alternative routes leading in different directions to that all persons should be able to turn their backs on a fire. However, a single exit may be permissible when the travel distance is limited and where the fire risk is low.
c. The route should enable everyone to escape unaided.
d. The route should lead directly to the open air or via a protected route to the open air.
e. The distance between work stations and the nearest fire exits, should be minimized.

The travel distance should be kept as short as possible. It is necessary to know the number of people likely to be inside the building when examining means of escape. Except where a single exit is sufficient, one of the exits should be assumed to be obstructed by fire. Therefore, in the case of two exits, each should be capable of letting all the occupants through. When more than two exits are provided, the largest should be discounted in accessing the aggregate widths of the others. Exits should not be narrower than other parts of the escape routes. Lift and escalators are not usually acceptable as part of an escape route.

- Fire resisting doors

Fire resisting doors are provided to prevent the spread of heat and smoke and to protect escape routes. The resistance of a fire door is determined using tests approved by the local fire or building authority. Two aspects of fire resistance are measured, namely the stability and integrity. All fire doors provided for the protection of escape routes should be fitted with smoke seals.

All fire doors, except those to cupboards and service dusts, should be fitted with self-closing devices to ensure the positive latching of the door. Examples of suitable devices are weights, floor or overhead springs and overhead door closers. Self-closing doors should be permanently marked on both sides, at about eye level, with the words “Fire door – Keep closed”. Fire resisting door to cupboards and stores on escape routes, which are not provided with self-closing devices, should be permanently marked on the outside at about eye level, “Fire door- Keep locked closed”.

- Fire exit doors

Exit doors on escape routes which are not the normal route of travel from the hotel should be indicated by notices bearing the words “Fire exit”. If such an exit door is not visible from any point on the escape route, a notice in the same white and green coloring should be provided at such a point, reading “To Fire Exit” and accompanied by directional access if necessary. Illumination of exit and directional signs should be provided by an emergency service, e.g. an emergency generator or batteries, independent of the main supply.

2.3 Critical Fire Hazard Area in a Hotel – Kitchen

As mentioned in the above sections, kitchen is a high fire risk area. Complex and intense application of various building services systems and MVAC system are installed in the kitchen. In this section, various systems in the kitchen and the concerns and problems on fire safety will be mentioned. Also, training for kitchen staff and maintenance management of various systems are equally important to prevent the occurrence of fire.

2.3.1 Introduction

The fire loading and risk in a kitchen are high, not just because of the flammable grease deposited in the MVAC system but also there are various types of fuel used in the kitchen, such as towngas, electricity, solid fuel or even LPG. Particularly at night, when the number of employees in the kitchen is low with the steward staff doing the cleaning operation, the outbreak of a fire will be a surprise to everyone. Most of the fires that happen in the kitchen relate to the poor maintenance of the building services system or the carelessness in the operation of the kitchen equipment.

First of all, in international chain hotels, chefs of various nationalities are employed to run the kitchen operation. Also, during festive seasons, a lot of casual or short-term workers will be working in the food and beverage outlets and hence adequate training is considered for them to handle a fire outbreak.

Secondly, in case of peak business seasons, good kitchen management is important to avoid carelessness in handling kitchen equipment and the procedures in the kitchen for preventing fire. Moreover, as discussed before, the fire loading in the kitchen is high and any reckless operation will cause a fire. Furthermore, there are very complex electrical and mechanical systems in the kitchen and the correct maintenance program is usually neglected because these maintenance works are usually carried out at night where the supervision is poor.

2.3.2 Electrical and mechanical systems in a kitchen

Kitchen equipment and their proper cleaning and maintenance are critical.

Electrical Installation – Electrical system reliability is important in this damp, oily and hot environment. It is required to focus on the correct procedure to handle electrical equipment and the safety aspect raised.

Steward Cleaning Equipment – Again, this is critical for the electrical safety and the maintenance operation required.

Fresh Air and Exhaust System – This is required as per local hygiene code and operational needs. As conveyed before, proper maintenance to guarantee its performance is the top priority.

Fuels – In local license code, only towngas and electricity are allowed and extra fire protection measures are needed for other fuel, e.g. solid fuel.

Dumbwaiters and Food Conveyor – This is critical for the passive fire protection system as fire or smoke can spread to other parts of the hotel if the wall or floor openings are not sealed properly.

Fire Protection System – special fire protection systems, such as FM 200 or fast response sprinkler heads may be adopted.

2.3.3 Fire protection systems in a kitchen

Fire protection systems in a kitchen include:

a. Water sprinkler or water mist system [Andersson and Holmetedt 1999] is required by local code and the correct fitting and rating of the sprinkler heads are critical to the extinguishment of the fire. Correct rating of the sprinkler heads [BSI 1990] is crucial to avoid false alarm and the improper burst of sprinkler head that cause significant operational difficulties and financial losses.

b. Hosereels are also required as per local fire code. All the kitchen employees must be trained on how to operate this portable equipment.

c. Fire extinguisher and fire blanket are usually the first defence again any fire outbreak. A lot of minor kitchen fires are put out by the CO_2 or water extinguishers, and the damage to the kitchen equipment and related facilities will be minimized. Proper training on their usage is important, particularly when there are a lot of casual and temporal workers in the kitchen.

d. Detectors and manual pull stations are required as per the local fire code and licensing requirements. They are the first alarm and any defects must be cleared as a priority. Correct sitting of these detectors are important to avoid false alarms which will be a nuisance to the operation.

e. BTM system and FM 200 [NFPA 1997] are usually used in Chinese cooking range and teppanyaki cooker respectively. They are expensive and delicate systems and must be handled and designed with care.

f. Emergency lighting & battery luminaries are required as per the local fire code and licensing requirements. Usually, these back-up lighting are needed to maintain for two to three hours.

CHAPTER 3 TOTAL FIRE SAFETY CONCEPT APPLIED TO HOTELS

3.1 Introduction

Total fire safety concept should be implemented in hotels and basically four major factors will be considered [Chow 2004b]:

- Risk factor, such as the occupancy load factor (OLF) and the fire load density (FLD)
- Fire services installation (FSI)
- Passive building construction (PBC)
- Fire safety management (FSM)

In subsequent sections, each of the above factors will be discussed in more detail. To the hotel management team, all these four factors are important and critical to fire safety [Building Regulations 1985] in the hotel. However, with changing guests' needs and hotel building usage, fire safety management strategy, the software component of the total fire safety concept, is considered even more important and should be focused so that all the hotel staff are familiar with all the necessary procedures, strategies and measures [NFPA 550 1995] on fire safety. In this section, the total fire safety concept in hotels and its development will be outlined. The passive building construction in a hotel will be discussed in detail.

3.2 Total Fire Safety Concept in Hotels

Fire engineering is quite a new subject and being developed rapidly in recent years. It is a multi-disciplinary subject, involving physics, chemistry, fluid mechanics, computer application, electrical and mechanical engineering and instrumentation. With the recent big fires in Hong Kong, Korea, USA, China and Europe and the current trend of boom economy, all academics and practitioners are facing escalating challenges on how to solve all these complicated fire safety problems. The related fire science issue becomes more and more complex and hence the subject of fire engineering always is an integral part of public safety science concern [Mckinnon 2003] and gradually receiving much more attention. To the hotel management team, total fire safety concept includes and relates to nearly most of the contents of the subject “fire engineering” and actually reflects the key rationales behind the subject “fire engineering”.

Normal operational mode of the building often has to be maintained and the fire safety inside the hotel premise to be kept. To better protect the hotel building itself and minimize the damages due to possible fire outbreak, not only the active fire measures should be provided during the building design stage. The active fire measures basically directly prevent the outbreak of fire and also are technical designs to control and restrict the fire growth and development to other hotel areas. These active fire measures include the fire alarm and detection at the initial fire stage, water sprinkler or water mist system and the smoke management system. Besides the active fire measures, passive fire measures are also needed. The passive measures include the study on fire resistance of building materials, compartmentation, refuge floors and fire exits and escape routes, etc. These passive measures are to improve or increase the ability of the structure and building construction or finishing to withstand the effects of fire. From the point of view of maintaining the fire safety in the hotel building, the combined successful operation of both the active and passive fire measures is necessary. With the operation of these measures, the protection of the structure against the fire outbreak can be achieved and at the same time evacuate the guests and hotel employees to emergency escape routes.

However, from the fire prevention and protection perspectives, these active and passive measures are complimenting each other and function as a whole and complete technical infrastructure. Hence, establishing the total fire safety concept [Shields and Silcock 1987] helps to theoretically and philosophically unite fire safety with both these active and passive fire measures together. Total fire safety concept is used to guide and educate hotel employees and guests on the correct behavior during outbreak of a fire. This will improve the quality for all related personnel participating in the building management and the fire safety scheme in the hotel and will strengthen the fire safety management system in the hotel. In other words, total fire safety concept is used to formulate the software component for the hotel building fire safety scheme so as to control the hardware and technical components, i.e. the active and passive fire measures. Moreover, establishing the total fire safety concept will on one hand help to raise the design level to another prospective while fully understand the complete picture of fire safety. On the other hand, the concept not just improves the fire management system but also strengthens and reinforces the quality of all management personnel involved. By properly implementing the total fire safety concept, the technical components and functions of both the active and passive fire measures are united together. Meanwhile, the scientific management for these active and passive systems can always be kept in the proper operational mode.

3.3 Development of Total Fire Safety Concept

Total fire safety concept has been gradually developed and implemented over the past 30 years. Although there are significant achievements and progress in fire science and fire safety engineering [Fire Safety Symposium 1989] with plenty of experimental data and model tools being set up, more research works are needed so that all the fire engineering designs are based on fundamental fire engineering principles and in a scientific manner. With total fire safety concept in mind, fire safety design, installation and management can be dealt with as a whole. The concept can be applied to any building types with all the fire engineering design and measures [Fire Safety Engineering 1989] being interactive and harmonized together. The total fire safety concept actually considers the influence between various fire safety measures and also formulates a proper fire safety strategy for the hotel building environment.

There are quite a number of countries researching or practicing the implementation of engineering performance-based fire design. They do not just rely on traditional prescriptive building and fire codes but also establish functional terms in their requirements of the building regulation. The UK has been doing this since 1985 but there is no guidance or recommended solution on how these alternative solutions to fire safety design can be assessed or established. How various fire safety measures interact with one and other still cannot be known. Detailed in the NFPA 550 standard [NFPA

1995], the first systematic development on total fire safety concept and the adoption of the fire safety concepts tree can be seen. This concept tree outlines the relationship between fire protection, fire precaution and fire prevention measures. Documented development on the total fire safety concept is from Australia, led by Vanghan Beck. They focused on their total fire safety concept in the following six areas [Eaton 1991]:

- Nature of occupancy
- Occupant avoidance
- Active fire measures
- Passive fire measures
- Fire growth and development
- Fire fighting strategy

The interaction of these areas later evolved into the first edition of fire engineering guidelines [SFPE 2002; BSI 1994, 1997] which later became the subsequent BS7974 [BSI 2001].

3.4 Application of Total Fire Safety Concept in Fire Safety Design

The fire safety design can be considered in two different stages. One is the early fire development stage and the other is the post-flashover stage.

For the early fire development phase, smouldering fires will be managed [Ohlemiller 2002] which may not be disastrous to occupants or cause building damage. The critical factor for this stage is to protect the occupants and the building itself against the fire effect. The occupants are needed to be alerted by public announcement or fire alarm system [Shields and Proulx 2000] to bring them safely to the exit or escape route. Additional fire safety measures such as emergency lighting or smoke extraction system may be needed in case occupant evacuation is initiated. The fire safety strategy in this stage requires the interaction between the occupants, fire alarm system, escape route and possibly the smoke management system [Alpert 2002; Kung et al 1991; Klote and Milke 2002].

For the post-flashover stage [Bryan 2002], the passive fire measure will possibly be subjected or challenged by the heat from the fully developed fire. The fire developed fully as there may be a delay in informing both the in-house fire fighting team or local fire brigade and that the water sprinkler system may be non-existent or inoperative. The primary purpose at this stage is to prevent fire spread to other parts of the hotel, causing further hotel damage and human life loss. The fire safety strategy basically concerns three points, namely, the building characteristics and material properties, building usage or fire load and if any internal or ventilation openings are involved.

A number of parameters [Schifiliti et al 2002] must be considered concerning the above two stages of fire. Firstly, “How big is the fire?” has to be considered. Design fire is important and specified by the relationship between the release rate and time, and with heat release rate being viewed as the most important parameter in any fire hazard assessment. Hence, full-scale burning tests are critical as there are basically insufficient data on how various combustible materials behave and burn under different ventilated environment. Certain full-scale burning tests in a sample kitchen will be outlined and reported in later sections.

The behavior of the hotel occupants [Proulx 2002] toward a fire alarm, the time required for them to recognize the alarm or take action or to arrive at the fire exit [Nelson and Mowrer 2002] are both important and crucial to human lives. This is a psychological or sociological issue but we still lack exact and complete knowledge [Hall 2000; Zukoski 1994] on the above problems and the time required.

Fires have to be reported to the local fire brigade so that appropriate action and rescue can be arranged without any delay. There are particular design data or model developed so far for fire brigade operation. In Hong Kong, the operation and response time from the local fire brigade always receive good comments. However, there are still rooms for improvements such as the response to fire at ultra-high hotel buildings, arson fires, terrorist attacks and chemical fires.

Numerous tests have been carried out by various international bodies on the building materials, structure and finishing, such as BSI, ASME, ISO and NFPA. However, whether these tests and rating reflect the actual behavior of the building material in a fire is still questionable. Hence, more sophisticated and refined material tests on fire should be conducted to reflect the actual material behavior under a real fire, whether it is a t^2 fire or a quick and severe fire [CIBSE 1995] that has major disastrous effects on the fire resistance of a door [England et al. 2000].

3.5 Review on Passive Fire Protection Systems in Hotels

Passive fire measures form a major part of the hotel construction and structure against the effect of fire. These passive measures are also a significant and major section in the standard licensing requirements on building safety conditions issued by the Home Affairs Department for purposely built hotels. In this section, the aims of these passive fire measures in a hotel; their major components; ideas from the various codes [BD 1995, 1996a, 1996b] such as the local codes on means of escape (MoE), fire resisting construction (FRC), and means of access for fire brigade (MoA) will be reviewed. Life safety code NFPA-101 and standard licensing requirements from the Home Affairs Department for the issue of operating license to local hotels will be discussed. How these passive fire measures integrate with the previously discussed 'Total Fire Safety' concept will be outlined.

3.5.1 Aims to be achieved by passive fire protection systems

In the past decades, modern hotels have adopted new architectural designs and concepts in response to changing guests' needs and hotel corporate image. For hotel industry in the 1980s, nearly all hotels were built simply with simple concrete structure, connected with floors of guestrooms and facilities. With the incorporation of advanced electrical and mechanical systems into the hotel infrastructure, more and more complex hotel configurations have emerged. The use of more daylighting design, ventilation and air-conditioning system and better fire protection system all contribute to the appearance of new architectural features, such as the use of large atrium spaces in the hotel lobby, open corridor design for resort hotels with all part of the hotel being connected horizontally and vertically. All these modern hotel buildings are symbols of economic growth of the country, like China in the past 20 years. However, it seems that the current building or fire codes, based on the existing prescriptive rules, are not so well organized or arranged to confront the challenges of all these new architectural designs. Besides those new architectural features, a lot of new finishing materials are used and the characteristics of these materials under fire are sometimes unknown. All these new architectural features, building complexity that may involve groups of buildings, ultra-tall hotels and advanced materials used cause problems on design for new hotels, in particular on fire and smoke hazard concern. These new features and materials are concerns to fire prevention and also fire fighting for the local fire brigade.

The main aim of the passive fire measures [Tsui and Cheung 2004], of course, is to maintain the safety of the occupants inside the building and also the life safety of the fire fighting or emergency teams. Based on this main aim, the measures must lead or educate the hotel building owner or management the necessary fire protection and prevention in the building itself and its surrounding buildings and also to protect the assets within the hotel. Passive fire measures must comply with the local code on building and fire safety. Also, in many cases for international chain hotels or multinational building owners, they must satisfy the insurance requirements laid down by these major management and multinational companies or owners. Not just international chain hotels but also local hotels need to maintain the hotel or their corporate image and most importantly, to maintain the hotel business and minimize the financial loss in case of a fire. That is why the passive fire measures play a significant part in the hotel on fire strategy and indeed is an environmental protection concern also. In some hotel buildings that are converted from heritage or historic buildings in China, Singapore or

Hong Kong, the passive measures must be seriously considered because it is both our obligation and moral to conserve these buildings.

To summarize, passive fire measures aim to provide fire prevention, building protection and human life safety for the hotel building. The local building codes or standard hotel licensing conditions have actually laid down the minimum requirements for the building itself in satisfying the safety and health needs anticipated by the society. Those fire measures represent the expectation of the community toward fire safety required in the hotel buildings.

3.5.2 Essential parts of the passive fire protection systems

The first essential part is the fire resistance in the passive fire protection systems. The fire resistance of the structure, finishing or materials will limit fire spread and avoid structural collapse in case of fire. The requirements are laid down in the code of practice on Fire Resisting Construction, 1996, and a major part in the whole fire safety strategy. For the initial fire stage or pre-flashover stage, it is important to lay down proper fire resistance for the building materials or finishing so as to restrict flame spread at this fire developing period. In the following stage or when the fire has developed to a post-flashover fire, the fire resistance in the structure or finishing basically resists the fire spread and avoids total building or structural collapse. The general building elements involved are the fire partition walls, floor slabs, smoke and intuminent seals, fire rating doors and glazing, staircases, emergency signage such as exit signs. During each hotel licensing inspection by Buildings Department, the building surveyor will inspect most of the sealing or fire stopping around the ducts or building services installation through the walls or slabs to ensure that they are properly sealed without any gaps or openings.

Passive fire protection systems [White 2002], in particular the fire resisting construction, are important and cannot be traded off by other active fire systems provided. For modern hotels with so many floors, duct spaces and connected air-conditioning systems, it is critical to seal all the gaps and holes at all fire rated partitions so as to prevent and limit fire or smoke spread to other parts of the hotel building. Hence, good housekeeping practices have to be implemented by relevant hotel engineering and maintenance department to ensure that scheduled inspection, repair and maintenance have been carried out to maintain the fire resistance in the building structure, partitions and finishing.

The other essential element of the passive fire protection systems is the escape routes or exits. The requirements are laid down in the local code of practice on means of escape in case of fire, 1996. Advanced developments and designs in local hotels bring in more fire safety considerations and problems, particularly on egress and exit aspects. As compared with old and traditional buildings, some of these new hotels are unique as several fire safety issues are needed to consider at the same time. These include the building height for ultra-tall buildings, change of functional use inside the hotel and possibly the increase in hotel occupancy loading as many of them adopt the service apartment concept. High occupancy loading in the hotel implies a potentially larger number of causalities and damage to the building in case of a fire occurs. Large group of people are anticipated to search or run to the escape route, resulting in possible longer escape time due to queuing and chaos and pre-movement time issue. The hotel management needs to accommodate this issue carefully by revising all their safety measures, especially on the fire safety management implementation. Furthermore, upon the various advanced and complicated layouts adopted in modern hotel building design, the occupant age has to be considered when planning the whole fire evacuation strategy. Children and kids are considered as a high risk group that needs more care and help during fire evacuation.

The aim of the escape route is to enable the occupants to reach a safe place via an escape path which is free from smoke and fire [Butcher and Parnell 1979]. This principle must be accomplished during the whole evacuation stage so as to minimize death and injury of occupants. For either prescriptive codes or engineering performance-based fire codes, serious considerations on the capacity of the escape routes are requested so that the maximum occupant density in the hotel will not be exceeded.

Good housekeeping and maintenance practice should be implemented and supervised by senior hotel management. Often happening in hotels is that obstructions and storages are placed at lift lobbies, staircases or even the escape routes. These are totally unacceptable and senior hotel management must instruct that all the exit routes are to be kept free from any obstructions at all times and all exit doors are maintained operable from inside without using a key. No storage of dangerous goods along the escape route or lobby is allowed and all the fire doors should not be wedged with wooden blocks.

The third essential element of the passive fire protection systems is the access for fire-fighters or emergency personnel. The requirements are laid down locally in the code of practice on the provision of means of access on fire fighting and rescue, 1995.

This is sometimes a problem in Hong Kong and it can be seen from the media concerning the difficulties in some fire cases for fire-fighters to access the building. Serious considerations must be followed up on the design of these access routes for the fire brigade so that they can access the building which is on fire. Misunderstanding on the various requirements between various statutory departments must be sorted out at the design stage so that sufficient space is allowed for the fire-fighters to approval and extinguish any fire incident.

On the fire safety management or the software component practiced by the hotel management team, it will be more important whether there is a team of trained hotel staff who can lead the fire brigade or fire-fighters to the fireman’s lift or access route. The fireman’s lift must be well maintained so that it can be used in case of fire or other emergency situations such as electrical power suspension. The hotel team must inform the firemen exactly the location of fire and if there are any guests or employees being trapped at the fire location. Good housekeeping practice is of paramount importance at this stage as all the fireman’s lift lobbies or access routes must be free from any obstructions or blockage. Time is very important for any rescue operation and the hotel management team must coordinate fully and assist the fire brigade team in any hotel fire incident. The correct sitting of the smoke vents at the hotel exterior, the fire alarm panel, fire sprinkler pump room, street hydrant and hosereel pump room should all be clearly shown to the fire brigade so as to organize the rescue.

3.5.3 Fire resisting construction – main characteristics and requirements

Hotel [CNTA 2005] should be separated from any adjoining buildings by an external wall having a fire resisting period of not less than two hours. Also, no openings should be made in such external walls that are within a distance of 900 mm of any part of any building on the same site or within 450 mm of the boundary with an adjoining site. Openings may however be made on external walls within a distance of 1.8 m of any part of any building on the same site or within 900 mm of the boundary with an adjoining site provided that these openings are protected by fixed lights with fire resisting glazing.

Elements of construction [Fitzgerald 1997] in any hotel basement and the separation between the basement and any hotel adjoining storey should have a fire resisting period of not less than 4 hours. Where different occupancies are happening within the same use of a hotel, separation should be made between them by walls and floors capable of resisting the action of fire for a period of not less than that required for the elements of construction of the compartment in which it is situated, subject to a maximum of 2 hours. The local FRC code needs to concern the fire resistance of any element of construction e.g. compartment wall, floor, roof, fire separation at internal and external openings and adjoining buildings and also fire separation at any bridges or tunnels connected. Hence, approval of the fire resisting construction table, methodology or smoke vent disposition, adjoining building protection and fire damper or smoke lobbies at bridges or tunnels connected are necessary.

A hotel should be divided into compartments by walls and floors such that no compartment exceeds 28,000 m^3. Compartment walls, floors, separations and lobbies should be constructed with all joints completely filled with non-combustible material to prevent the passage of smoke or flame. Any opening in a compartment wall or floor for the passage of electrical and mechanical service installation or holes left after the hotel construction should be protected with fire dampers or other suitable forms of fire stop to maintain the required fire resisting period of the compartments. Where ducts, pipes, wires and any insulation passing through the wall are of combustible material, such material should be contained within an enclosure having an FRP corresponding to that of the surrounding structure [Fleischmann and Buchanan 2002]. Where access openings are provided to the enclosure, such openings should be provided with self-closing doors having an FRP of not less than half that of the structure.

At any internal unprotected opening such as at escalators and circulation staircases, a barrier of not less than 450 mm measured vertically downwards from the underside of the floor should be provided to surround the opening. The barrier should be constructed of material having an FRP of not less than 1 hour. The barrier shall extend not less than 450 mm below any false ceiling hung in the vicinity of the opening.

For special hazard areas like kitchens, special requirements are necessary. They should be enclosed by non-combustible construction having an FRP of not less than 1 hour and openings should be provided with doors having an FRP of not less than half an hour. Kitchens should also be provided with protected lobbies between each door and any escape route from the main hotel building portion.

All fire resisting doors having an FRP should be arranged to be self-closing with notices for them to be always kept closed. All such doors should be closely fitted around their edges to impede the passage of smoke or flame. Doors including frames should be tested in accordance with BS 476: Part 20 and 22 : 1987 and certified as being capable of resisting the action of fire for the specified period.

A bridge, like the one at Wanchai Century Novotel Hotel, uniting a hotel to an adjoining office building should be provided with a fire shutter having an FRP of not less than 2 hours and no openings should be provided in the hotel within a distance of 900 mm from the junction of the bridge and the walls of the hotel within this distance should be of non-combustible construction having an FRP of not less than 2 hours. Underground tunnels uniting a hotel (like the one at Kowloon Hotel) to an adjoining building or facility should be provided with a fire shutter having an FRP of not less than 4 hours.

It is the basic aim of FRC in any design to restrict the effect from fire, through conduction, radiation or convection. Usually, a two-layer model is formed in a compartment fire. A fire plume is gradually formed until it reaches the ceiling where it will be deflected to form a horizontal ceiling jet. If the compartment wall or floor is not of the specified fire resisting period, the fire will spread to other parts of the hotel. However, depending on the fire size and compartment, in some cases it may be feasible for the fire plume to be too large that it will not be contained in the room compartment. Under the fire safety design concept, FRC is to limit the spread of fire and the collapse of the hotel building [Milke 2002] so as to reduce the damaging effects of smoke, heat and flames on the hotel guests and employees. The design has to cater for the fire separation within the hotel building and between adjoining buildings and the structural integrity of the hotel.

3.5.4 Means of escape – main characteristics and requirements

Every exit route shall lead directly to a street or to an open area having unobstructed access. Such access to a street shall not be closed with doors or gates unless such doors or gates are fitted with panic bolt. The enclosing walls of every staircase shall be so continued at ground floor level as to separate from the remainder of the hotel any passage or corridor leading from the stair to any ground level exit doorway to which the stair gives access. Every hotel shall be so constructed that there are available from each storey not less than two exit routes.

The maximum travel distances that will be permitted from any part of hotel shall be 36 m of which not more than 24 m may be along a corridor or not more than 30 m may be along a balcony approach. If the exit route is in one direction only, the maximum travel distance shall not be greater than twice the length of the exit route between the entrances to the enclosures of the required staircases. Every hotel should be so constructed that there are available from each storey not less than two exit routes.

Every required stairway in a building shall be separated from the hotel by a wall having an FRP of not less than half an hour. Any opening in the wall separating a staircase from the hotel shall be protected by a self-closing door having an FRP of not less than half an hour provided that no such door shall be required between a balcony approach and any stairway leading from there.

The exit door of any hotel or storey with direct access to a protected stair shall be self-closing with an FRP of not less than half an hour. Every internal corridor giving access to rooms shall be enclosed by partitions having an FRP of not less than half an hour; the doors to rooms from the corridor shall be self-closing with an FRP of not less than half an hour. A lobby between the internal corridor and the staircase will not normally be required in a hotel in which the highest storey is not more than 30 m above ground level. The exit route from any room or storey to any part of a staircase which serves a storey more than 30 m above the level of the ground shall be through a lobby. Such lobby shall be designed as an integral part of the staircase so that it could not be readily incorporated as part of the accommodation, and shall be a protected lobby. The means of escape from any part of the hotel shall be so arranged that it is not necessary to pass through one staircase enclosure in order to reach an alternative stair.

When a fire occurs, hotel occupants are not expected to take a very long distance to reach the safe exit [Joyeux 2002] and the ground level is often considered as the most appropriate place of safety. Hence, alternative routes must be provided for immediate access to the place of safety in order to avoid occupants being trapped at the fire scene. Under the MoE design, a structural means has to be provided with safe routing of travel from any point of the building to the place of safety. The design has to cater for both the horizontal and vertical evacuation of occupants via the staircase, lobby and exits provided.

The MoE code concerns critically the exit width, number of exits from room or individual stores, maximum distance travel, staircase capacity loading, refuge floor, lighting and access to staircase and finally the exit to the place of safety usually at ground level.

3.5.5 Means of access for fire fighting and rescue – characteristics and requirements

The basic aim of the code for means of access is to provide fire-fighters the necessary safe and unobstructed access to the fire scene to perform their rescue and fire extinguishment operation.

At least one fireman's lift [Buckley and Bradborn 2000] has to be provided. Where more than one lift is installed in a hotel, the lift which is to be the fireman's lift shall be designated by the local fire brigade. Fireman's lift shall be provided to enable fire services personnel to reach any floor that may be on fire in the hotel without having to traverse more than two floors. Separate liftwell must be provided for the fireman's lift and up to three lifts may share the same well provided all these lifts are designated as fireman's lift. A notice shall be displayed outside the liftwell indicating which one will be the fireman's lift. The lift car shall be of a minimum size of 1.35 m^2 net floor area with a rated minimum loading of 680 kg.

Time is essential in any fire fighting operation [Klaene and Sanders 2003] in order to save lives. The emergency vehicles from the fire brigade should be able to reach the fire scene without any obstruction and in a reasonable time under a safe environment. Hence, the code of means of access for fire-fighters lays down requirements that the building should have emergency vehicular access so that fire appliances can reach the fire site safely.

Internal means of access would be more efficient for the fire-fighters although current advanced equipment like aerial devices may provide external access to individual fire incident floor of the hotel. To protect fire-fighters from the exposure to heat, flame and smoke from the fire, it is necessary to have protected routes inside the hotel building so as to minimize their travel distance in the fire environment. These protected routes also serve as the refuge places for the rescue personnel.

From the design point of view, means of access provide the safe route of access from the hotel exterior to any point of the building. It is important to concern and plan the emergency vehicular access from the hotel exterior to the building. The vertical access, via fireman's lift or protected vertical shaft, must be planned for fire-fighters to carry out rescue operations. For horizontal access at each floor, protected lobby should be established for travel from the vertical access.

In brief, the code for means of access for fire-fighters and rescue outlines the requirements for emergency vehicular access, the access at ground level and the provision and requirements for firemen's lifts. It also lists out the requirements for the number of access staircases and the provisions for rescue staircases.

3.5.6 Passive fire measure – alternative fire engineering approach

Nowadays, many countries are practicing the performance-based fire safety design [Custer and Meacham 1997]. Fire safety goals and design objectives have to be identified in performance-based design. However, the advantages are that there is flexibility to have a range of technical solutions for the same design problem or issue. By doing so, it will help to bring in innovations to the design, new materials, advanced technology which assist in making the whole design process more efficient. This is particularly obvious for buildings with special features like hotels or with special hazards due to their height, proposed use, site location and construction which specially may need particular fire safety objectives and standards to be established. It is laid down in the building code that “the Building Authority recognizes that fire safety may be approached in a number of ways, the best of which is not necessarily prescriptive”.

The code also mentions that “the Building Authority assesses the acceptability of any alternative or complimentary approach to fire safety in a building by reference to such criteria on the means of escape, the means of access, the fire services installation, the fire resisting construction, the size, the height, the use, location and the management of the building”. Hence, besides the passive fire protection systems, the code also brings in components like fire safety management and active fire protection systems.

As an alternative to prescriptive codes for the fire safety provision, currently the fire safety engineering approach [Tubbs 1999] is also adopted. The approach includes basic engineering principles, models and scientific methodology in order to provide a design solution and framework to achieve the performance requirements and objectives as outlined in the building laws. In brief, the fire safety engineering approach formulates the performance-based codes and requirements which will be a flexible approach to reach a more efficient and cost-effective design.

3.5.7 Passive fire protection systems – integration with total fire safety concept

For the fire safety engineering approach [Chow 1999], it allows the designer to determine their own methodology to achieve the specified goals and objectives which will be in very clear and precise terms. However, there may be disadvantages in adopting the performance-based design. First of all, the local building authority, which has the obligation to approve any building design, may be reluctant to approve design as they may not be familiar with the goals, objectives and methodology used. Moreover, the engineering approach may be more academic as it needs the application of engineering principles and scientific methodology [Hadjisophocleous and Tamim 1998] which most designers or government officials may not get acquainted. This concerns the quality and education of the designer and reviewer and also the necessary quality control measures to assure the adequacy of the design by engineering approach.

It is understood that once the occupancy or building use is changed, the fire protection needs will be revised in prescriptive codes. That is why the establishment of the key assumptions, goals and objectives are so important in performance-based fire safety design. It also states the importance of the components of fire safety management in the whole building design and operation. The subsequent inspection, testing, repair and maintenance of all the fire protection systems provided (whether it is active or passive) are important to upkeep the goals and objectives originally set in the design stage and assumptions.

In the past, MoE, MoA, FRC, FSI and FSM will be considered separately in prescriptive fire safety design. Now, a more comprehensive fire safety strategy can be focused on so that the software fire safety management (FSM component) can be used to control the building hardware provisions (MoE, MoA, FSI and FRC component). The design goals and objectives originally set and planned will not be forgotten even after the issue of the necessary occupation permit if a fire safety management scheme is implemented [SFPE 2001].

CHAPTER 4 ACTIVE FIRE PROTECTION SYSTEMS

4.1 Introduction

Before an effective and cost conscious fire safety strategy is finalized, a clear picture on the fire safety objectives is needed so as to satisfy the client's need and project specification [Chow and Wong 1998]. These fire safety objectives must be related to human life safety, protection of asset and environment and the conservation of cultural heritage.

Fire safety measures must be formulated, whether passive or active, communication systems or egress systems, in the design of a building. However, as related in the previous chapter on total fire safety concept, the synergistic effect and integrating together of all these measures and systems will make a building safe. These integrated measures and systems include, on the passive fire protection side, the proper fire rating or resistance of the building constructions and fire stops at the floor and walls penetrations. On the active fire protection side, they include the fire suppression system, smoke management system, fire detection system and the egress system.

The active fire protection systems [FSD 1998; CNTA 2005] are designed and installed to meet the requirements in the building and fire code so as to function as designed in case of fire. The active fire protection systems, usually powered by electricity, standby power or UPS, are operated under automatic devices action to control and suppress the action and effects of fire.

In recent years of research and developments [Chin 2002], a wide range of active fire protection systems are available for use in actual fire fighting operations. The first active system in fire safety operation is the detection devices which will sound the alarm to inform the occupants on the possible fire outbreak. These include the smoke or heat detectors, breakglass points, and public announcement emergency system. Then, the fire suppression systems which include the fire hydrants, hosereel, portable extinguisher, sprinkler or water mist systems and possibly chemical systems will operate to control the fire and limit the spread of the fire and smoke to other parts of the hotel. Finally, the emergency illuminating system is to provide the necessary luminance for evacuation of the hotel occupants to the place of assembly.

The operation of active fire protection system is believed to raise the alarm or concern of the occupancy to any possible fire outbreak or growth, limit the smoke spread, suppress the fire and control or restrict the fire or smoke spread to within or outside the fire compartment, make possible the fire-fighters' operation to happen, avoid building collapse, minimize life and asset loss and to permit most rapid egress to the safe place. However, in real situations and due to environment or other restraints, some of these active fire protection systems do not perform in accordance with their design expectations. More intensive and detailed research must be carried out to provide more valuable data. These supportive data will avoid initial design assumptions or judgments being drawn up blindly during the design stage when the suitable systems are being proposed for the particular hotel building. In this chapter, local and international fire codes for hotel concerning active fire protection systems will be discussed. The operation and characteristics of active systems will be outlined, such as fire detection, sprinkler, water mist, hydrant and chemical systems.

4.2 Local and International Fire Codes for Active Fire Fighting Systems

In this section, the requirements for active fire fighting systems from various local and international fire codes will be discussed. Locally, for the application of hotel operation license, the fire safety requirements as listed in the Hotel and Guesthouse Ordinance [CNTA 2005] have to be followed. Basically, the requirements laid down in the "Code of practice for minimum fire service installations and equipment and inspection and testing of installation and equipment" have to be complied with. In China, the requirements in the China fire code issued by the State Council and the Ministry of Public Security and also the fire code for high-rise buildings are referred to. In the US, there is a particular section in the NFPA life safety code-101 [NFPA 1994, 1995] for hotels and guesthouses.

From the local code of practice, audio or visual alarm system should be provided for any part of the hotel where the area occupied by the occupancy on any one floor exceeds 2000 m^2 and the hotel occupants, due to their risk exposure by transient presence either as visitors or shoppers, will require such system or advice. Such system will include the alarm bell system, visual advisory system and public announcement emergency system, etc.

If water supply [Cheung and Chan 2003] is undesirable for the fire suppression system in the hotel, then automatic fixed installations other than water shall be provided. The automatic system or devices should be supplied also with essential power and an independently powered electrical generator shall be installed to provide the necessary electrical capacity for the essential services in the hotel. Portable fire extinguishers, fire blankets or sand buckets are provided whenever necessary in accordance with the code, for various locations in the hotel. The locations are primarily the pantry, switch rooms, plant rooms and also restaurants and kitchens as per the local restaurant licensing requirements from the Food and Environmental Hygiene Department. Usually a 2 kg dry powder or a 4.5 kg CO_2 gas fire extinguisher will be provided for the pantry or switch room location.

It is important to detect the outbreak of fire and alert the hotel occupants in the shortest duration possible. Hence, it is required to install an automatic smoke detection system, in accordance with the Fire Offices' Committee for automatic fire alarm installation 12th edition, for the entire floor if the guest floor is used for sleeping accommodation. On current changing use of the guestrooms to other similar function, like service apartments for long-staying guests, heat detector at some locations inside the guestrooms may be accepted to avoid false alarms. The alarm of such system shall be transmitted to the fire services emergency centre by direct telephone line, which is also linked up with the hotel fire alarm system. Regular testing, inspection, maintenance and repair should be carried out for the automatic fire alarm system as this is the first line of defence of the building against fire. The main automatic fire alarm system control [Tamura 1994] is usually installed in the fire control centre of the hotel. This control centre is located at the ground floor of the building for easy access and checks by the local fire brigade.

In case a fire is detected by the occupants, such as the kitchen chef or in-house guests, they can alert the whole hotel by sounding the manual fire alarm system. This system is installed with one actuating point (e.g. breakglass unit) and one audio warning device at each hosereel point, usually near the exits. It is in the fire code requirement that the actuating point shall initiate a series of automatic devices action for the fire pump to start and audio warning device actuation.

For fire suppression systems, a number of related systems have to be provided to control and limit fire and smoke spread. A fire hydrant and hose reel system should be installed to ensure that every part of the hotel is reached by a length of not more than 30 m of the fire services hose or hose reel tubing. Daily service, checking and repair of the system are necessary to reconfirm that all these hydrants and hose reels provided are in operating manner and working properly. With past experience on site or upon daily hotel operations, this simple housekeeping and maintenance procedure is usually neglected or treated in a very poor manner.

Another fire suppression system that should be provided is the water sprinkler system. Automatic sprinkler system shall be installed for the entire hotel building including staircases, common corridors in accordance with the Loss Prevention Council Rules for automatic sprinkler installations. Except for areas with special risk, such as in kitchen with cooking woks, computer rooms or switch rooms, sprinkler system is proved to be a very effective system in limiting fire spread or fire extinguishment in a hotel. Several past fire incidents happened in local hotels and the fires were basically extinguished by the operation of fire sprinkler before the action of the in-house fire team and local fire brigade.

It is important that all exits should be indicated by illuminated exit signs bearing the word "EXIT" in block letters and characters of not less than 125 mm high with 15 mm wide strokes [NFPA 2005]. Color contrast for translucent surrounds to lettering shall be complied. If an exit sign is not visible in any location in the hotel, say due to turns at corridor or blockage by other architectural features, suitable directional signs conforming to BS5499-4 [BSI 2000] shall be erected with an exit sign and shall be provided at conspicuous locations to assist hotel occupants to identify the exit routes in case of an emergency. Emergency lighting should be installed in the whole hotel and all exit routes leading to ground level. A self-contained secondary lighting system will be accepted if the illumination level of not less than 2 lux for duration of 3 hours in the event of power failure is provided.

Staircase pressurization or static/dynamic smoke extraction system shall be installed with the local code of practice for minimum fire service installations and equipment. Whenever ventilation or air-conditioning control system is installed in a hotel, it should stop mechanically induced air movement within a fire compartment. All ventilation systems should comply with the building (ventilation system) regulation and a letter of compliance should be obtained from the Fire Services Department.

4.3 Automatic Fire Detection System

For fire protection and safety, time is the most important parameter. The alarm response time, evacuation time and suppression time should be reduced. The prime objective of any fire detection and alarm system is to reduce human life loss from fire and secondly to protect the asset property. An advanced and early warning performance of the detection system is expected, particularly when designing and installing the system in accordance with performance-based codes. In the following sections, various fire detection systems and their applications will be outlined.

4.3.1 Introduction

Fire alarm systems are the first defence and feature among the protection elements of the hotel building. If the systems are properly designed, installed and maintained, the systems can surely reduce life loss and property damage due to fire. By adhering to the requirements specified in the local code of practice for minimum fire services installation, NFPA 72 national fire alarm code or FOC guidelines, a qualified fire detection and alarm system can be ensured.

Several characteristics of the hotel building have to be finalized before selecting the appropriate fire detection system. A holistic approach should be taken that the effects of the combination of all the fire protection features must be greater than individual operational effects of each component. Therefore, effective protection level must be a combination, interlocking and interrelated functioning of each fire protection system. Hence, designers or owners for the hotel building should not just provide a fire alarm system or sprinkler system but they also have to think of all other passive fire protection features or other valuable protection systems as a whole in order to achieve the safety of the hotel building.

4.3.2 Fire alarm system - components

A normal fire alarm system may provide several signals. The alarm signal, whether it is true or false, should be attended immediately in a hotel [NFPA 2005]. The trouble signal, which indicates a failure or fault in the alarm circuit, should be attended immediately. The other critical signal is the supervisory signal, which indicates the activation of the fire protection systems that are connected to the fire alarm system, e.g. sprinkler system, dry chemical and gaseous system, etc. The components in a fire alarm system can be classified as the central system control unit, the main or secondary electrical supply, and the initiation device circuits such as the detectors, the visible or audible devices. In many of the local and foreign applications, there must be a direct link connection to the local fire brigade where immediate response to any fire alarm can be activated. The secondary power system has to be properly selected for the fire alarm system. The secondary power system must be operating to supply energy to the fire alarm system within 15 s and followed by 3 hours of emergency operation. The main and secondary power must be properly maintained and tested to ensure that the fire alarm system will function during an emergency.

4.3.3 Automatic fire detectors

In any occurrence of fire, certain environmental changes are involved like heat, smoke and radiant energy. Of course, human beings are the best fire detectors but their detection can be distracted by many other factors that make these early detections ineffective. Several space and fire characteristics should be considered before any detector selection. Firstly, different types of fires may have different environmental emissions, for example, some fire may have no smoke or even flameless. Secondly, the environmental emission being detected must reach the detectors and exceed a certain minimum threshold for the detector activation. Thirdly, the environmental emission from other non-fire situation that may lead to false alarm, for example, boiling water that activates the detector in the kitchen or guestrooms. Hence, all the fire codes will indicate the requirements leading to the proper selection and location of these fire detectors in order to accomplish the fire protection objectives. Fire alarm system designers need to consider the amount of environment emission from any potential effects on the proposed detector options. Finally, the designer has to select the automatic fire detector that can offer the fastest response time and minimum disruption due to false alarm or detection.

4.3.3.1 Heat detectors

Fixed temperature heat detectors will initiate an alarm if the space air temperature near the ceiling reaches the pre-determined temperature setting. However, there may be a rapid increase in the space air temperature by a fire which the fixed temperature detector cannot raise the alarm. Therefore, the rate of rise detector is usually designed to function when the rate of temperature rise exceeds a preset value, say 7 to 8 ^{o}C per minute. This rate of temperature rise is normally expected under a potential fire condition. However, care should be taken when locating and selecting the rate of temperature detectors in order to avoid false alarms. Usually, these detectors will not be installed in the hotel kitchens, laundries, near heaters or air diffusers, etc. There are also several types of rate of rise temperature heat detectors, namely line type and spot type.

4.3.3.2 Smoke detectors

Ionization smoke detectors normally contain a small amount of radioactive material that polarizes the air in the detector chamber leading to a small current flow though the air between the two electrodes in the detector. The smoke particles, possibly due to the fire emission, will decrease the conductivity of the air in the sensing chamber and activate the detector if the conductance falls to a pre-determined level.

Photoelectric smoke detectors work on two principles, either by obscuration of the light intensity over the light beam path or by scattering of the light beam.

4.3.3.3 Selection of detectors

A wrong selection of detectors will definitely lower the detection efficiency or cause too many pre-matured false alarms. In the choice of detectors, the fire protection goals and objectives have to be firstly identified. The fire protection objectives can be life safety, property protection or simply to satisfy local fire codes. Then, general design objectives should be formulated that will outline how these fire protection goals are satisfied. Thirdly, the occupancy pattern should be considered, say the possible fire threat in a hotel building and examine if any dangerous goods storage or other fire suppression system are available. Then, the potential environmental emission from the probable fire will be considered and the ambient situation in the space. Finally, detectors are selected based on its sensitivity towards the ambient condition to avoid unexpected false alarms.

After selecting the detectors, the installation and the proper spacing of the detectors should be considered. In some cases, smoke or heat detectors are used to control other active fire protection systems, for example the gaseous system or pre-action sprinkler system. Comprehensive preventive maintenance and regular testing are required for all the selected and installed automatic fire detectors. In hotels, bi-weekly tests on all these fire detectors should be arranged to ensure that they are functioning and operating safely in their areas.

4.3.3.4 Audio and visual devices

These devices are part of the fire alarm detection system. They give warnings to the hotel occupants and indicate to them the necessity to evacuate to a safe place. A fire alarm system can send a single bit of information by sounding an audible signal with strobe light flashing or multiple bit of information by a public announcement system. Usually when provided with more detailed information, people tend to evacuate rapidly and effectively to the safe place. The audibility and intelligibility of the audible devices are both important to provide a clear message for evacuation of the occupants.

Visual devices are usually to supplement the function of the audible devices. The local hotel licensing requirements, NFPA 72 and life safety code NFPA 101 [NFPA 1994; 1995] all specify the necessity of visual alarm devices in the hotel building. For visual devices, the source intensity and also the illumination at a distance from the source have to be considered in particular.

4.4 Automatic Sprinkler System

Automatic sprinkler system is designed and each sprinkler head will respond to the heat from the fire and distribute water over the fire source. Sprinkler system may be considered in several aspects, namely its thermal response, the distribution of water, ability to suppress the fire and its control capability. A number of recent researches are available [Chow and Wong 1998] on quantifying the sensitivity of sprinkler system. These research works had come up with some terms, like the time constant or response time index [Chow and Ho 1990] as a measure of the sensitivity of the sprinkler system.

On the other hand, the distribution pattern of most sprinkler systems is tested only for overall coverage under specific geometric conditions. Little can be achieved from an engineering design point of view on the specific spray patterns from sprinkler operation. Currently, the total amount of water actually delivered to the fire source per unit floor area still cannot be predicted since the spray patterns will change with the water discharge pressure. It can be expected that the total heat absorption rate of the sprinkler spray will be proportional to the total water droplets surface area and the temperature difference between the water droplet and the ceiling smoke layer. The total cooling capacity produced by the sprinkler system will depend on the depth of the ceiling jet and the distance through which the water droplets travel through the smoke layer.

Sprinklers function in a number of ways to control or suppress fire [Cheung 1995]. Firstly, the operation of sprinkler system will be most efficient to distribute water in producing the cooling effect by the water spray. Particularly, the radioactive heat reflects back to the fire for sustaining combustion will be significantly reduced if fine water droplets are produced that will generate further cooling effect. From the fire triangle in a combustion process, oxygen is crucial to sustaining fire growth. When the sprinkler system operates, the water droplets produced will evaporate to steam which will be more than 1700 times in volume in comparing with the water ejected. The steam generated will deprive the fire from the needed oxygen to sustain the fire growth. The sprinkler system will work well in an unventilated enclosure because the fire is contained and under the combined effect of the above mentioned “spray cooling” and “oxygen deprivation” effect. Moreover, in ventilated spaces, the strong updraft due to the fire will blow away the small water droplets and hence critically reducing the sprinkler system efficiency. Hence, designer will specify sprinkler system based on distributing a variety of water droplet sizes over the fire source ground and to maintain a low ceiling temperature and control or suppress the fire.

During the outbreak of a fire, traditionally it is expected that a number of sprinklers would be operating at or around the fire source. The operation of the sprinkler above the fire source may not be able to extinguish the fire but they can work together with other newly activated sprinklers to cool the atmosphere and to prevent other sprinklers outside the fire scene from operating. In particular, the newly operating sprinklers will cool and wet the surrounding areas including the probable stored combustibles and further assist in preventing the spread of fire. At the burning fuel level, the water droplets reaching the burning fuel will reduce the burning rate to such a stage that the fire will not spread to nearby additional fuel, together also with the water droplet pre-wetting effect on the nearby fuel. However, at the ceiling level, the sprinkler operation will absorb the heat from the rising fire phase to prevent operation of additional nearby sprinklers and also avoid the building structural damage due to excessive heat from the fire source. Usually, the area upon which sprinklers are operating will be greater than the fire source area. Finally, the fuel in the fire source is burnt out and the fire is extinguished. It is also believed that walls or compartments will assist the sprinkler system by reducing the number of sprinklers operating. As fewer sprinklers are operating, the higher water pressure will increase the flow which in turn increases the cooling effect of the water droplets. Also, a thicker smoke layer will enable the droplets to go through longer distance and hence improve also the cooling effect of the sprinklers.

In normal situations, the water discharge from a sprinkler is restrained by a cap holding against the orifice by a system of lever pressing down on the cap and anchored to the sprinkler. There are several types of sprinklers, namely the fusible sprinkler, bulb sprinkler and thermo sensitive elements, etc. Automatic sprinklers have several temperature ratings. Usually, the sprinkler temperature rating can be distinguished by viewing the color codes on the glass bulbs of the sprinkler. Sprinkler of higher temperature rating [Yao 1988] will be installed where high heat release rates are expected. This is to prevent and reduce the sprinkler operation outside the fire area. To suit various ceiling or fitting out requirements, various sprinkler types are available, namely pendant sprinkler, recessed sprinkler, flush-type sprinkler and concealed sprinkler, etc.

For designing sprinkler system [Cheung 1997; LPC 1990], designer will need to satisfy the local code of practice for minimum fire service installation, FOC and UL requirements and NFPA 13 fire code. In general, several sprinkler system types are available such as the wet-pipe system, dry-pipe system, precaution system and deluge system, etc. The design of sprinkler system is based primarily on the fire hazard classification of the occupancy. The fire hazard classification may be light hazard, ordinary hazard or extra hazard groups.

4.5 Fire Hydrant and Hosereel System

Fire hydrant and hosereel system are fixed piping system that brings water from a reliable water source to the hotel building where hoses can be used for fire fighting by the firemen or occupants. These systems must be provided in tall and large area buildings. The hydrant and hosereel system increase the fire fighting efficiency by eliminating the need to lay hose from the fire engine to the fire site. Even when the buildings are fully sprinkled, the hydrant system will serve as a back up and support the sprinkler operations. Designers will design the fire hydrant system based on the requirements from the local codes of practice for minimum fire service installation, NFPA 14, NFPA 101 life safety code and the FOC rule.

The common purpose of the hydrant and hosereel system is to deliver water for manual fire fighting. However, the system design may vary to achieve this purpose. Whereas one system may have water connecting from the fire engine to the hose in the building, while others may have fully automatic connected hoses with automatic water supply. Again, like sprinkler system, the design process of hydrant system starts with the confirmation on intended use of the system. The hydrant system may be designed for full-scale fire fighting, first aid fire fighting or both. The three uses mentioned correspond with the three classes of hydrant system in NFPA 14 [NFPA 1993], that is class I, class II and class III.

In accordance with NFPA 14, there are several limitations on the selection of the hydrant system. Manual hydrant systems should not be used in high-rise building design. Surely, sprinkler and pump system [Cheung and Chan 1997] will be required in accordance with the fire code and hence it is reasonable to install also pumps for the hydrant system to achieve an increased safety level in the hotel building. Moreover, manual systems are not approved to be used in class II and class III system. This is because pre-connected hose system obviously must have an available water supply ready for fire fighting. Furthermore, dry systems are not allowed in class II or class III buildings because of the potential risk of untrained occupants that may delay the water availability in fire fighting.

The required numbers of hydrant and hose connections depend on the building layout and design. Two methods are recommended. One is the “actual length” method in which the hose connection is sufficient to reach all portions of the area served with a 30 m hose and with a nozzle reach of 9 m. The second method is the “exit location method”. By this method, 64 mm hose connections are located in exit stairs, as required in the building code. As building exits are distributed within the building to provide enough egress and hence hose connections will also be considered distributing adequately upon this principle.

There are also several system components in the hydrant and hosereel system. The steel pipe and fittings selected must withstand maximum system pressure from 175 to 300 psi. The hose, hose racks, nozzles and hose cabinets should also be selected very carefully. Hoses are usually kept on compatible racks and should always be positioned in a readily accessible location with convenient reach of the standing occupant. Moreover, hoses must be clearly visible and located in places not easily to be obstructed. If the hoses are kept in a cabinet in most of the modern building design, the doors should have a glass panel or other means for easy identification. The valves or pressure reducing devices must be durable and able to withstand the maximum system operating pressure. Throughout the whole hydrant and hosereel operations, a detailed preventive maintenance program, inspection and testing must be implemented to ensure its proper functioning.

4.6 Water Mist System

In the past decade, the use of water mist fire suppression systems has become more frequent in Hong Kong. First of all, the general extinguishing principles of water mist system are examined [Knoxville 1994; NFPA 1997]. The extinguishing action of water mist system is believed to be due to the dilution of the air supply at the fire scene when the water droplets evaporate to vapor and surround the heated areas. The cooling effect of the water droplets is also a dominant factor. The water droplets in the water mist system must be relatively fine and the amount of water must be sufficient relatively to the fire size.

The basic extinguishing mechanisms [Mawhinney and Kim 1994] involved are heat removal, oxygen displacement, elimination of radiant heat, vapor/air dilution and the kinetic effects. It may not be difficult to understand the engineering principle in extinguishing fires for the first three mentioned extinguishing mechanisms. However, computational fluid dynamics may be involved to further investigate the vapor/air dilution and kinetic effects extinguishing principle.

On heat removal or cooling effect, it is understood that when water mist system operates and water droplets are applied to the fire, heat will be removed from the fire scene. Heat is absorbed from the hot gases, the burning fuel and also from the surrounding objects and surfaces. The cooling of the surrounding surfaces and objects contributes to reduce the speed of fire spread. The use of water mist systems and fine droplets will increase the speed of extracting heat from the burning fuel as the rate of heat transfer will be increased due to the increase of surface area of the water mass. The conversion of water droplets to steam needs latent heat of vaporization extracting from the fire. If enough heat is extracted from the fire, the flame temperature may drop to a level below that necessary for sustaining the combustion reaction. At the same time, the effect of oxygen depletion will also mean the fire might be extinguished with only a portion of the theoretical minimum required for flame cooling.

Some researchers believed that the fire suppression effect by oxygen depletion will be more dominant than flame cooling. Water droplets expand about 1900 times upon vaporization. If evaporation takes place immediately, the water vapor will displace the air in the vicinity of the droplet. Rapid evaporation, expansion and air displacement happened in the fire compartment by steam generating from the water droplets injecting to the fire scene. If the oxygen level is reduced to below a certain critical level, the fire will be burning inefficiently and easier for extinguishing by the cooling effect.

However, the dilution of oxygen by water vapor during suppression process [Liu et al. 2001] will be limited by the average temperature of the gases in the fire compartment. This will explain why water mist system is more efficient in large fire extinguishment than small fires in a fire compartment. When the fire compartment temperature is higher, more water vapor dilutes the oxygen in the air. This also explains why turning the water mist system on and off will reduce the extinguishing time in a given compartment. More water will be evaporated because of the higher compartment temperature during the off stage of the cycle.

Another extinguishing mechanism, the elimination of radiant heat, reduces the spread of fire to unignited fuel surfaces and the vaporization at the fuel surfaces. In other words, radiant heat elimination protects the occupants and assets in the space from direct radiant heat damage. The efficiency of radiant heat elimination depends on the droplet diameter and its mass density. Water mist system with higher concentration of very fine drops has been proved to be more efficient in reducing the radiant heat transfer. Actually, the reduction in heat transfer to the fuel surface will reduce the rate of generation of volatile vapor.

The extinguishing mechanism by vapor/air mixture dilution should also be considered in detail. The water vapor and air entrained in a water mist system operation will dilute the vapor/air mixture to below the flammability limit. This extinguishing effect is referred to as a secondary mechanism because it is hard to see that dilution alone can extinguish the fire. In designing water mist system, it is still infeasible to quantity the relationship among the flammability limits of different fuels, the fuel vaporization rates, spray evaporation rate and finally the mass flow rates of water mist and entrained air.

The kinetic effects of mist on burning fuel also have to be considered. To fire-fighters, a general flare-up at the instant of application of water spray on liquid fuel fires may not be unfamiliar. The sudden intensification of the fire has been commented by some researchers to the effect of droplets striking the fuel surface and causing increased vaporization rate. Moreover, enclosure effects also will improve the water mist system performance. The performance improvement may be due to restricted ventilation and heat entrapment. Hence, it is easier to extinguish an under-ventilated fire in an enclosure than a well-ventilated unenclosed fire.

It is understood that ‘water mist’ is a very fine water spray [Yao et al. 1999] that will remain suspending in the air for a period of time. Four characteristics of water mist are considered which will influence its efficiency as a fire suppression system. They are the drop size distribution, flux density, spray momentum and additives needed.

The relationship between drop size distribution and extinguishing capacity [Downie and Polyneropoulus 1995] of water mist is complex. Moreover, drop size distribution also does not determine the ability of a spray to extinguish a given fire. There are other factors such as enclosure effect, flux density and fuel properties involved in determining whether a fire can be extinguished.

Whether a water mist system will extinguish a fire depends only partially on the drop size and spray velocity. This surely needs the mass of water spray that interacts with the fire be enough to absorb a critical portion of the heat from the fire. Spray flux density is therefore an important characteristic of the water mist fire suppression system.

The success and failure of a fire suppression system depends on the variations in the spray momentum [Andersson and Holmetedt 1999]. The three factors forming the spray momentum are the spray velocity, its direction relative to the fire plume and the mass of the water droplets transported onto the fuel surface. The more control on spray momentum exercised, the greater will be the control on total water requirements, time to extinguishment and overall system reliability. In addition, water mist systems with additives, such as sodium chlorine or alkaline salt, are of interest for application in machinery spaces and engine compartments.

There are some practiced applications of water mist system in machinery spaces, turbine enclosures, marine accommodation, hotels, computer rooms, tunnels and aircraft passenger compartments, etc. For hotels, the prime objective is life safety although hotel property protection is also critical. For remote heritage churches, parks building and galleries, the objective is mainly to protect the property and heritage preservation. Water mist [Putorti and Twilley 1995] is currently viewed as a possible alternative to halon 1301 for use in electrical equipment rooms. Potential applications include use in telecommunication central office buildings, control rooms and computer rooms.

4.7 Non-water Fire Suppression Systems

Halogenated systems or agents, such as halon 1211, halon 1301 and halon 2402, are used in portable fire extinguishers and central extinguishing systems. The extinguishing mechanism of halogenated agents is not very well known. It seems that a chemical reaction appears to interfere with the combustion process. The agents act by breaking the chemical species involved in the flame chain reaction. While all the halogens are active in this way, bromine is much more effective than chlorine or fluorine. Moreover, the toxicity of halon 1301, halon 1211 and halon 2402 should be considered. There are two types of application systems, namely the total flooding system and the local application system. It is understood that halons are potential ozone-depleting substances and should not be released to the atmosphere except to extinguish the fire.

Due to the ozone depletion potential of halon systems, currently halon replacement agents and systems are sought for. There are some practical applications, such as the FM200, Argon and Inergen system, etc.

The use of foam [NFPA 1997] as extinguishing agents and systems can be considered. Foam is produced by mixing a foam concentrate with water at the appropriate concentration, and than aerating and agitating the solution to form the bubble structure. Low expansion foam is used to extinguish flammable or tank fires by the application to develop a cooling, coherent blanket. Foam can also be used to diminish or halt the generation of flammable vapor from non-burning solids or liquids. It is also important where aircrafts are fuelled and operated. Currently, warehouses and buildings storing large quantities of combustible and flammable liquids are protected by foam-water sprinkler systems. The protection required is a function of the type and quantity of liquid stored, building height, and storage configuration. Foam breaks down and vaporizes its water content under attack by heat and flame. It therefore must be applied to a burning liquid surface in sufficient volume and rate to compensate for this loss, with an additional amount applied to guarantee a residual foam layer over the extinguished liquid.

CHAPTER 5 FIRE SAFETY MANAGEMENT IN A HOTEL – SOFTWARE COMPONENT

Fire safety management is a very important software component to the hotel operation. It is also a basic concept in providing total safety to the building itself. In the following sections, various views and discussions on the application of fire safety management will be outlined. Fire safety management should be started by using an engineering approach at the design stage, on the design of fire provisions for new hotel building projects. In the fire safety manual, all the fire safety objectives should be listed out. On the other hand, a ranking system is used for the fire provisions, in comparing with the new fire codes, on the passive fire protection and active fire protection systems installed in existing hotel buildings. From the comparison, the fire safety management program is planned to supplement the inadequacy in the existing hardware components. Based on the fire safety objectives and assumptions originally planned, a fire safety plan can be worked out for the hotel. Control legislation by the government department is recommended on the implementation of these fire safety management plans. The hotel fire safety management program and the implementation of the hotel fire evacuation plans will be examined in the following sections.

5.1 Introduction

Fire safety management is very critical in the concept of providing total safety in a hotel building. Various views from the literature towards fire safety management are available. Malhotra [1987] had a very detailed review on fire safety management and the fire grading report [HMSO 1952] prepared in 1952 in the UK is regarded as the first document on fire safety management. In this report, it mentions the maintenance of the provisions for means of escape, regular inspection of all doors, passages and staircases and also about external facilities which might become unsafe due to external exposures.

Next, the BS5588 [BSI 1983, 1985] “Fire precautions on the design and construction of buildings” Parts 2, 1983 & Part 3, 1985 are available on advices concerning the management and evacuation procedures in case of fire. The appendices of these two parts focus on giving valuable guidance to the management on using staff for fire safety, training and function, keeping records, preparing notices and calling the fire brigade. At the same time, these appendices also advise on the defined actions in case of fire and evacuation procedures. The hotel management or owner must work out a fire safety plan by referring to the size of the building and its occupancy. In using engineering approach [BSI 1997, 1999] in hotel design, qualified fire engineers should be involved to formulate the design objectives and the fire safety plan and design. In working out the fire safety management program, the fire safety engineers must familiarize with all the fire safety design assumptions and objectives.

Following the introduction of BS5588 Part 11 in 1997 [BSI 1997] on “Code of practice for design offices, industrial storage and other similar buildings”, it focused on the effective management combined with appropriate staff training to be important in taking correct actions and having the occupants evacuated safely. Genuine and coordinated advices should be sought from the local fire brigade and the hotel management should be aware of the statutory requirements regarding the maintenance of means of escape, fire warning systems, portable fire extinguishers, escape lighting and fire safety instructions to staff.

At least two points should be considered carefully in the recommendations from the above document concerning the commissioning and handover of fire safety installation and fire safety manual. One important point is that a fire safety manager should be appointed to take overall control of the premises and day-to-day safety management of the building. In a hotel, the fire safety manager is usually the safety and security manager or the Director of Engineering. Moreover, it is also necessary to prepare a fire safety manual which should be kept in a safe place inside the hotel and maintained by a competent person.

The fire safety manual should explain the fire safety planning, constructions and systems designed; and their relationship to overall safety and evacuation management. It refers to the documentation produced at the hotel design stage for using different types of fire protection system in different incidents and the responsibility of staff. The manual should also include drawings of the hotel building identifying the different smoke control zones and fire detection zones. Finally, the manual should record all the routine fire maintenance activities and the drawings of the basic fire precaution measures.

Recent views [HMSO 1996] on fire safety management focus on the hazard both to the people inside the hotel and the building content itself. In BSI-DD240: Part I : 1997 “Fire Safety Engineering – Part I : Guide to the application of fire safety emergency principles”, fire safety management is important to the success of the safety engineering design. People involved in the fire safety management program are represented in the Qualitative Design Review team.

In BS ISO/TR 13387-1 : 1999 “Fire Safety Engineering – Part I : Application of fire performance concepts to design objectives”, the prevention and control of fires, the evacuation of occupants and the maintenance of fire safety system are critical parts of the fire safety management programs. Malhotra in 1987 specified that fire code to be added in supplementing the building code and maintenance of fire protective measure was mentioned.

System approach to fire safety management was considered in the National Fire Protection Association and Fire Safety Concepts Tree. How the fire safety goals and objectives are affected will be examined together on all the fire safety features provided. Following this approach, a Fire Safety Management Handbook was published by the American Society of Safety Engineers, USA.

The implementation of a fire safety management program [Della 1999] can help to reduce the hotel insurance premium, business interruptions and create an efficient working environment. The program will also improve the hotel reputation to the public, customer service and even realize quality gains. In formulating the fire safety plan, needs and capabilities should be first assessed, and the hotel facilities and any fire hazard should be analyzed. Moreover, it is necessary to develop and implement fire prevention and fire protection control and evaluate the overall effectiveness. There are several critical components in forming a fire safety management program, namely, inspections, education and training, fire suppression, emergency service, evaluation of fire possibility, fire prevention, reports and records keeping and most importantly, the communication between all relevant parties involved.

5.2 Main Objectives of Fire Safety Management in a Hotel

In case of a fire, the main objectives [Malhorta 1987] of the fire safety management program are to ensure:

- All the fire safety measures provided will be available for use.
- Hotel occupants will be able to use all the fire safety measures.
- Hotel occupants will be assisted to escape to a safe place.

Failing to implement the above management program and guidelines would lead to heavy casualties during fire outbreaks. Hence, fire safety management in a hotel at least has to focus on the following three aspects:

a. The hotel management has to ensure that all the fire safety measures provided are maintained, serviced and kept in a proper functional order.

b. The hotel management has to initiate appropriate actions during fire outbreaks which would assist occupants to reach a safe place.

c. There may be renovations or refurbishments in the hotel. Hence, the hotel management has to review the adequacy of current fire safety measures in case there is a change of building, building use and new technology on fire services installation.

The hotel management has the obligation to ensure that all fire safety provisions are maintained properly. The management should also train their staff on the available fire protection systems so as to assist the local fire brigade or even deal with smaller fire incidents.

5.3 Main Objectives of a Fire Safety Plan

A fire safety plan should be prepared in fire safety management, there may be three essential components [Malhorta 1987]: A maintenance plan for proper service and maintenance of the hotel passive and active fire protection systems; a proper and organized staff training plan which will include major training schemes for all hotel employees; and a proper and organized fire action plan that will list out all required and detailed actions to be implemented by each staff in case of a fire.

In the hotel fire maintenance plan, basically the following should be included to maintain all the passive fire protection systems (such as escape routes and fire doors), to maintain all the active fire protection systems (such as fire detection system, sprinklers, portable extinguisher, hydrants and hosereels and special systems), to verify the system performance and the system integrity interfaces at regular intervals, to include information and plans on layout, escape routes and egress signs for hotel occupants and to have good housekeeping such as proper disposal of rubbish and the use of heat sources like gas cookers. This is particularly important when the hotel guestrooms nowadays are very often used as service apartments where usual residential cooking or life styles will be happening inside.

A proper hotel staff training plan should include detailed descriptions of the duties of each staff, nomination of the fire warden, training on the use of hotel equipment, particularly safety in handling electrical and gas equipment in kitchens and laundries, proper procedures and guidelines to guide guests and staff to the safe place.

The hotel fire action plan should include proper guidelines and procedures on reporting to the local fire brigade, proper guidelines to assemble hotel guests and staff and bring them safely to the assembly places, guidelines, procedure and techniques to attack fire in the case of a small fire incident, procedures and proper routing to assist the local fire brigade and to conduct a proper roll call at the assembly place for all hotel guests and staff reported to be inside the building.

A fire safety manager should be appointed and responsible to the hotel top management. It is recommended to have a permanent staff for a hotel with more than 100 staff; or the expected hotel occupancy loading is more than 500. Other than that, some members of the hotel staff can be appointed as fire safety officers. Hotel staff recruited as ‘fire-fighters’ in large hotels should be trained, for example, in a local fireman training school in Pat Heung in the New Territories.

In addition to the above three plans mentioned, a fire prevention plan is also required. This plan will identify the use and maintenance of hotel items which could be ignition sources, or combustibles which can lead to rapid fire spreading upon ignition. Examples are taking care of all electrical appliances in the guestrooms, kitchens and laundries; and waste materials and rubbish handling. In other words, good housekeeping in a hotel should be done properly.

5.4 Integration with Fire Safety Engineering in New and Existing Hotel Buildings

Recent advance on the role of fire safety management in fire safety engineering was discussed below [BD 1998; Chow 1999]. It was reported that safety systems might not be properly maintained and proper management of the building should be implemented. The importance of integrating fire safety management into fire safety engineering during the concept and design stages was pointed out. Advanced techniques such as fire models [Forney and Moss 1994; Yang 1999] should be used at the design stage with an awareness of the management impact. It is essential that a fire safety engineer understands how the effectiveness of the safety systems design will be influenced by fire safety management. The duties of a fire safety engineer are proposed.

In passive fire protection system, they include structural fire protection measures including compartmentation, fire doors, fire stops and protected means of escape. In active fire protection system, they include hosereel / fire hydrants system, emergency lighting and exit-way guidance, smoke management system, fire detection system, fire suppression system and fire alarm system.

The work of the fire safety manager is important and the major tasks supposed are in Appendix A.

In addition, a fire safety engineer can direct the work of the fire safety manager in three aspects: to assist and ensure that the active fire protection systems are properly maintained and tested, to ensure that passive fire safety systems are not made ineffective. For example, the removal of lift doors while replacing lifts in a big old highrise building that had led to a big fire in Hong Kong [Chow 1998] and to manage the hotel building in conforming to the assumptions made on fire safety design, such as controlling the fire load and occupancy loading.

However, in Hong Kong, hotels are constructed at different times and it is difficult for them to satisfy all the new fire codes [FSD 1998] and regulations. As mentioned previously, in any building design, the means of access code, means of escape code, fire resisting construction code and the fire services installation code should all be satisfied.

Before 1972 [Chow and Wong 1998], the fire codes were not detailed and even the types of building occupancies were not clearly defined. Commercial buildings could not be distinguished from residential buildings during this period and they were usually regarded as old buildings. However, there were major improvements by 1987 and a lot of the fire safety provisions, for example, minimum corridor width, were incorporated in the code. Since 1987, sprinkler system has been required nearly for all non-residential highrise buildings and the fire safety provisions have significantly been enhanced.

For those existing buildings, a fire safety ranking system is suggested to be adopted and based on current code in order to assess the fire safety aspects on the passive building design and active fire protection system. If there are any deviations between the existing fire safety provision and those in the new codes, then a fire safety management scheme needs to be worked out to compensate for the shortfall. It is difficult for the existing buildings to satisfy the new codes. However, an alternative solution may be adopted in applying engineering performance-based fire codes upon fire safety provisions design. Nevertheless, it will take certain time to develop the necessary codes and the cost might be high.

To give total safety to hotel buildings, fire safety management must be properly implemented. Fire safety management might not be controlled by building regulations. It is noted that the fire codes for dealing with fire safety provision for new hotels are not yet in use. In Hong Kong [Effective building management, 1998], the Buildings Department, Fire Services Department, and the licensing section of the Food, Environment and Hygiene Bureau and even the Health and Safety Officer of the Labour Department should take care of the fire safety management. In other words, an overall fire safety system, or a total safety system, including design, construction and management of the fire safety system should be worked out. However, there are still not yet any codes related to this topic. The fire safety management program in a hotel is described in Appendix B.

5.5 Development of an Effective Fire Safety Management Program

Understanding the fire safety organizations and having basic knowledge of the available resources are important in fire safety management. In Hong Kong, the government departments, such as Buildings Department, Fire Services Department and relevant academic and professional institutions can provide most of the information for this fire safety management program. Knowing where to go, what facilities and equipment they process and their ability to respond would be of great assistance in organizing a plan of actions. First-hand knowledge of fire fighting resources at one’s command is one of the keys in determining whether a fire of a certain size can be controlled with a minimum of damage.

Then, the fire chemistry and its relationship with the particular hotel involved must be understood. Whether it is the fire triangle or fire tetrahedron, it is important for the hotel management team to prevent the combination of fuel, oxygen or heat that can initiate a fire.

In previous sections, essential elements have been mentioned that make up the fire safety management and also the fire prevention plan and control of hazardous materials in a hotel. Care and maintenance of active and passive fire protection systems in a hotel are considered. In particular, various legal aspects, legislation and organizations involved in forming an effective hotel fire management program are discussed.

CHAPTER 6 METHODS OF STUDY

Throughout the whole study, a practical research methodology has been applied in order to investigate various fire safety aspects [CIBSE 2003] in big hotels. First of all, it is understood from previous chapters that hotels are complex building constructions. Fire safety codes in Hong Kong, USA and China have been reviewed. This is essential so that we can know the differences in the statutory fire codes in various countries and their applications in big hotel projects.

For special risks in the hotels, the fire safety aspects in kitchens will be studied. Hazard assessment in hotel kitchens will be carried out by full-scale burning tests [Chow 2001b] in a model kitchen in a remote town in Northern China. This will give the heat release rate [Babrauskas and Peacock 1992] and air temperature distribution when a model kitchen is burnt. Experiments will also be conducted for burning kitchen, under the operation of a sprinkler system and water mist system respectively to study the fire extinguishing time.

To maintain the integrity of the passive building construction, the operation of heat response links at fire damper is important during the breakout of a fire. Heated wind tunnel tests at fusible link samples will be conducted, in accordance with the setup and requirements specified in UL33 [UL 2005] concerning heat response links for fire protection service. The tests are important to understand the performance and integrity for locally made fusible links.

6.1 Fire Safety Codes Review

In previous chapters, the concept of total fire safety in hotels has been studied. Building codes have been studied that concern the passive fire protection systems and the fire service installation codes that relate to the active fire protection system in Hong Kong. Furthermore, the main licensing requirements on fire and building safety are listed out as specified in the local Hotel and Guesthouse Ordinance. These local codes and ordinances must be fully satisfied for any hotel buildings in Hong Kong. In comparison, the NFPA 101 [NFPA 1994] life safety code will be listed and reviewed.

It is understood that hotels or guesthouses are mainly used for stays of a relatively short duration. The accommodation of sleeping hotel guests is a main characteristic in the provisions of the life safety code because occupants who are asleep are unaware of a developing fire. The guests when awakened to be alerted to the fire outbreak might also be confused. The possibility of being asleep and familiarity with the surroundings during a fire are main factors that endanger the hotel guests' safety. Hotels lead to additional safety issue, because escaping guests need to transverse smoky and hot interior corridors in typical hotel configurations before searching the exits.

The content of a hotel is classified as light hazard and designed in accordance with NFPA 13 standard for the installation of sprinkler systems. The difference in classification in the code is based on the human life threat when comparing with the extinguishing effects of the automatic sprinkler system. The occupant load calculations for areas of hotels used for non-residential purposes should be based on the occupants load factors applicable to the use of the area.

In hotel buildings protected by automatic sprinkler system, exit enclosures shall have a fire resistance rating of not less than one hour, and the protection rating of doors shall be not less than one hour.

Hotels are not allowed to have any door locked against escape while the hotel building is occupied. This requirement [NFPA 1997] allows the door to be equipped with a locking service that permits the door to be opened from within the building. The safety code requires a minimum of two separate exits from each floor. A third exit is required when the hotel guests loading of a floor exceeds 500 and a forth exit when it exceeds 1000. This requirement will probably have little effect on modern hotel design practices because hotel guest floor large enough to accommodate more than 500 guests would probably be provided with more than two exits based on travel distance limit consideration.

If the hotel building is protected through by an automatic sprinkler system, the common path of travel is permitted to be 15 m, which is the same distance permitted for the length of existing dead-end corridors, regardless of sprinkler system considerations. Travel distance within a guestroom or suite to a corridor door shall not exceed 23 m. However, travel distance from the corridor door of any guest room to the nearest exit shall not exceed 30 m. The distance of travel from the termination of the exit enclosure to an exterior door leading to a public way shall not exceed 30 m.

Emergency lighting must be provided in all hotel buildings with more than 25 rooms. Any vertical opening must be enclosed or protected. All hazardous rooms in a hotel, subject to possible explosion, must be effectively cut off from other parts of the building.

Particular attention must be paid to new draperies, curtains and other similar loosely hung furniture and decorations in a hotel regarding their fire resistance characteristics and compliance testing.

Detection, alarm and communications systems must be installed in hotels. Guest rooms and suites specifically required and equipped to accommodate hearing impaired individuals shall be provided with a visible notification appliance. The code requires that, in additional to the normal distribution of manual fire alarm stations, the front desk, telephone operator's location or similar location must also be equipped with a manual pull station. The intent is that a pull station is to be available at the location where guest phone is an emergency. The smoke alarms installed in sleeping rooms are usually single-station alarms that are provided for the sole purpose of notifying the occupants of a smoky condition within that room. Thus, the alarms are not part of a required automatic detection system and are not required to initiate the building alarm system.

Hotel buildings must be protected throughout by an approved automatic sprinkler system. In some cases, hotels are required to use quick-response sprinkler throughout guestrooms. The technology associated with quick response sprinklers help to maintain tenability within the room of fire origin.

Tables 6.1, 6.2 and 6.3 also summarize some of the differences in China code [MPS China, 16-87; MPS China, 45-82] and NFPA requirements [NFPA 1994, 1995], particularly on escape routes and travel distance limits.

6.2 Hazard Assessment

There are certain risky areas in a big hotel, particularly the kitchen, which has been mentioned in previous chapters. Hazard assessment has to be carried out for the kitchen in a big hotel. Material burning must be understood, whether it is solid, gas or liquid. Burning involves oxidation which is also accompanied by the release of energy as heat or light. The first parameter of hazard assessment [Babrauskas 2003] of a material might be the amount of heat it produces when it burns, i.e. the heat of combustion. The chemical composition of the material will almost determine the amount of heat produced, which depends on the physical form of the material.

Methane and propane, the simplest organic compounds, are common gaseous fuels. The richest variety of materials is organic solid, like wood, paper, textiles and plastics, commonly encountered in hotel fires. The molecules that form most organic materials comprise of many thousands of atoms linked together to form chains and networks necessary for its useful mechanical properties. Polymerization is the process and the origin of almost all plastics and synthetic polymers. Nearly all organic materials burn readily with the release of water vapour and carbon dioxide upon complete combustion. It is found that the heat produced per unit weight of oxygen consumed is the same within about 10 percent. This is another important parameter and allows us to use oxygen consumption as a reasonable measure of the heat produced by a burning organic material. Organic materials fall into two classes, namely hydrocarbon or cellulose. From energy point of point, oil or natural gas is a better fuel than wood, which consists mainly of cellulose.

Hazard assessment concerns the production of heat, smoke or toxic gases produced during burning and the rate at which these fire products are produced. Some factors contributing to the burning rate will be examined. Burning is in general a vapour phase phenomenon when the fuel and oxygen are brought into contact at a molecular level. The rate of burning depends on how fast the chemical reaction of oxidation occurs. At the preliminary stage or in premixed flames, the burning rate depends on the inherent rate at which the substances combine. The rate is quite fast and hence it will be very dangerous to contact the air and combustible vapour and the burning process is difficult to be interrupted.

The burning behaviour of materials may differ greatly. They may vary from the fast end of the spectrum as explosion to the slow end side like auto-oxidation and smouldering. Auto-oxidation is the combination of a material with oxygen at a rate far too slow to produce the heat and light normally associated with fire. Self-heating can occur if the heat produced by the auto-oxidation is not removed. On the other hand, smouldering is a burning process quite different from flaming. Only a small fraction of combustible materials, those which can produce porous char during the course of combustion, will smoulder. Most smoulders are organic which can yield both volatile fuel species and a rigid, porous char structure.

Different burning behaviour and characteristics of gases, liquids and solids pose different types of hazards. The methods for measuring and controlling them are also different. It may be better to consider fire hazard control relating firstly to the likelihood of ignition, then the control of fire spread and lastly the management of the fire if ignition and spread cannot be prevented.

Flammable gases usually burn quickly once ignited. The main action to avoid ignition is firstly the determination of the flammability limit, and secondly to operate so that the concentration is kept beyond those limits. Moreover, the possibility of ignition can also be reduced by the addition of chemical inhibitor to raise the lower flammability limits. In practice, ignition control is done by stringent storage and handling safeguards. For example, dangerous goods licence is needed to be obtained for the hotel for storage of matches or fireworks materials. Alternatively, it may be possible to reduce the oxygen available in closed environment and therefore raise the effective flammability limit without a major breakthrough in the prevention and suppression of large flammable gas fires. The most effective means of minimizing the fire impact is advanced planning, preparedness and response of trained emergency personnel.

Oil in kitchen is a major fire hazard. Burning actually occurs in the vapour phase and the most hazardous combustible liquids are those with a high vapour pressure. Serious measures exist to minimize the escape of flammable vapours in the handling of volatile liquids. If a fire of such kind is initiated, means are also available to prevent the supply of additional combustible fuel to the fire. These include designs for the venting of storage tanks and flame arresters, etc.

For fires involving solid materials, there is a variety of tests to determine their susceptibility to ignition. The fire hazards posed by inorganic structural materials are most likely to be passive. For example, structural steel may lose its strength, concrete can crack and spall, and glass can break or melt. Such materials are therefore rated on the ability to withstand such high temperature effects. Improvements in ignition control of materials have come about as a result of flame resistant developed for both natural and man-made materials.

6.3 Necessity of Experiments in the Study

Very few experimental studies on heat release rate measurement for combustibles had been carried out [Chow 2001b]. Hence, carrying out experiments for this heat release rate study is important so that fire safety problems can be addressed properly. Moreover, experiments [Chow et al 2003c] had not been carried out before to verify the performance and operation of fusible links used in fire services systems. In designing a fire services installation for a big hotel, an engineer requires to choose the most economical design which satisfies all the specifications, including the aesthetic requirements and owner's needs. In designing an experiment [Chow 2002] to measure the heat release rate when burning a model kitchen, questions on cost are too frequently focused. The main reason may be because of the difficulty in deciding a good estimator on the time necessary for the experiment. Also, it is partly a traditional consideration that science is above monetary considerations. Economic factors must be taken into account in view of the increasing cost of experiments in research. Needless to say, experiments must be carried out in a cheaper way when it can be done equally effectively with less expenditure. It will be difficult to decide whether a given release rate measuring experiment should be carried out, considering its probable cost involved. Budget cost estimates [Bright 1990] must include direct expenditures for materials, salaries and overheads. When the experiment is conducted, sometimes we will be shocked by the magnitude of overhead costs. In general, the overhead costs include laboratory rent, electricity, heat and administrative expenses of the laboratory. Usually, these costs amount to nearly 40 percent of the total direct salaries and wages.

A usual source of waste is the misuse of the time of salaried personnel with scientific and proper training in handling all the heat release rate experimental apparatuses and procedures. There are many jobs which less highly trained assistants could carry out equally well. One main reason for this misuse of talent is the low salary scale so often paid for scientists in China.

Costs will also be a serious consideration on whether to buy a piece of apparatus for the experiment or to build it, like the Chinese calorimetry in Lanxi [Chow et al 2003d] in Northern China. If it is true that this is available commercially just what is needed, it is usually cheaper to buy it. In considering the cost of building an apparatus, it makes a difference whether a salaried machinist has time not needed for other work or whether he is occupied for his full capacities. The former situation is practically a pure hypothetical one in most laboratories. It is necessary to add the cost of the supervising and designing scientists’ time and also the cost involved in making changes and adjustments in an untested design.

In planning actual experiments for measuring heat release rate in kitchen, it is necessary to have a good basic understanding of the nature of the problem and any relevant theory associated with it. Moreover, an experiment usually will be designed on the basis of one or more preliminary hypotheses. These can be constructed more effectively if good knowledge of the theory and background of the situation is available. It is sensible if the problem is analysed and is thereby enabled to cast it into the simplest form. It will also be possible to divide the problems into parts when they can be much more easily answered separately than together. Moreover, it will be desirable or even necessary to approach the answers in stages, starting with the most idealized and simplified version possible. In certain cases, it is possible to construct a single experiment whose outcome largely determines the fate of a given hypothesis in theory. Nevertheless, it is important to design the experiments that are as far as possible crucial with respect to the hypothesis under consideration. This may not be easy as it sounds because there are alternative interpretations for the results of most experiments. It will be bad to carry out an experiment without a clear-cut idea in advance of just what is being tested. Usually, however, a certain objective is the reason for undertaking a research, and yet when the experiments are over, it becomes apparent that the questions asked were not the ones whose answers were really needed. It will be safe to go right back to the origin of the inquiry and ask at every stage on why doing this experiment, why testing the fire scenarios under the operation of water mist and sprinkler system.

Equipment or apparatus is needed in the heat release rate measurement tests. The apparatus may serve to hold certain variables constant and to change other variables in a prescribed way. It often but not always involves measurement. Apparatus may also provide appropriate conditions for changing objects or materials as a preliminary to observation. In designing the heat release rate tests in a kitchen, specifications must be made up for every part, no matter small, based on the duty that part is to perform The design questions can be qualitative or quantitative. If the qualitative possibilities are not known, it is unlikely to make decisions correctly. Here, experience is of great help, but the experience of others is used by the wise. However, quantitative decisions are usually harder and may require calculations, sometimes based on difficult theories. It is needed to minimize the cost of the design by close calculations, or to calculate a lower or upper limit for some specification which may affect for the design. Misunderstood or incomplete instructions are a serious source of waste and delay. The more the technician is told about the uses of the part, the more likely he is to produce what is needed. It is important to be able to tell at all times that the different parts of an apparatus are in proper adjustment and working conditions since instruments are expensive in the heat release rate measurements. They should be used where they will do the most good. Expense can also be reduced by using the same instrument for several tests, provided that this can be conveniently arranged, or by switching. To facilitate test operation, all adjustments should carry at least a rough scale. It will be harder to tune up a complicated system if it is not possible to go back to a previously attained setting. The more precise is the given adjustment needs to be made, the finer the scale should be.

The basic purpose of our experiment [Chow and Meng 2004d] is to test the effect of a certain selected variable, the heat release rate, when a model kitchen is burnt. To do this successfully, other variables which may influence the result need to be kept constant. As a result, one of the principal problems is apparatus design on how to keep these variables from disturbing the situation.

6.4 Heat Release Rate

In this study, heat release rate measurements were carried in a model kitchen with the operational effects of water mist and sprinkler systems. Heat release rate (HRR) study [Babrauskas and Grayson 1992] was developed in 1980s and is an important aspect of fire protection engineering. In practical fire engineering and safety design, the question "How big is the fire?" should be answered. With the heat release rate measurement, the necessary quantifying answer to the above question and the very cornerstone of fire protection engineering are provided. The knowledge of heat release rate becomes necessary for all trades, including fire protection design engineers, building officials, chemists and all other technical specialists. When going into the 1990s, the focus on heat release rate becomes obvious in most of the fire research and problems.

Heat release rate is a major fire parameter in any fire safety engineering design because it defines the size of the fire. With this quantification, it also indicates a lot other fire parameters, such as smoke and toxic gas production. It is important in fire engineering for having the accurate heat release rate on items like building contents furniture, wall linings and industrial storages, etc.

To successfully measure heat release rate from burning materials, early research works [Krasuy and Babrauskas 2001] were usually interrupted by difficulties in constructing an efficient small-scale adiabatic systems used for materials testing. For testing building products or furniture under large-scale apparatus, this will involve great costs and difficulties which hamper these tests from practical applications. The use of oxygen depletion calorimetry as the methodology to measure heat release rate has overcome the above difficulty. Currently, it will be comparatively cheap and easy to carry out both bench and full-scale heat release rate tests on materials in fire environment.

It is believed that heat release rate measurements were initially carried out on systems that monitored temperature rises in flue of furnaces and reproduced the same temperature rise from metered control burners. The first FM construction materials calorimeter was built in 1959 but it is a very bulky apparatus. Actual bench-scale work on materials was done on insulated box systems which used calibrated thermocouples in the flues of smaller apparatus. However, poor insulation and thermal feedback between the sample and the radiator are some of the problems with the instrument. The International Organization for Standardization both examined this apparatus and also started to develop their own insulated box test. Both were eventually rejected as oxygen consumption calorimetry became available.

Oxygen consumption calorimetry is based on the theory that for a large number of liquids and gases, a constant net amount of heat is released per unit mass of oxygen consumed in combustion. The heat release can be readily measured if all combustion products from a burning test are collected in an extraction system and the flow and oxygen concentration in that duct is accurately measured. Such a technique has considerable advantages for large-scale reaction to fire tests as it does not limit the burning tests by carrying them out unnecessarily in compartments. This technique has gained considerable support and there is now a list of the laboratories working with large-scale oxygen depletion calorimeters.

On the other hand, bench-scale oxygen depletion calorimeter [Babrauskas 2003] has been designed with a number of geometries, such as the cone calorimeter. This has become the standard bench-scale test method for measurement of heat release rate. The cone calorimeter has also made heat release measurement viable to the researchers with standard laboratory facilities.

Room fire test in full scale for surface products, ISO9705 [ISO 1993], was published in 1992. This standard provides for measuring heat release from wall lining materials when attached to the surfaces of a standard room rig. It is similar to a test method also being developed by ASTM.

6.5 Fusible Links at Fire Dampers

Fusible links are installed in fire dampers and smoke curtains, and will be activated to operate the damper in order to maintain the integrity of the fire rating for air-ducts passing through fire walls. Simulation tests, using the heated wind tunnel, will be conducted in accordance with UL33 [UL 2005] to measure the performance of fusible links commonly used in Hong Kong. The results will be reported in later sections.

Hotels are usually equipped with very advanced and modern air-conditioning and ventilation systems for the comfort of guests. If ducts need to penetrate fire rated walls, floors or partitions, fire dampers with equivalent fire-resistance ratings must be provided to maintain the integrity of the fire areas. Damper will also be used to prevent back draft in duct systems to keep unpleasant smell from being sucked upstream and spread in the guestrooms.

Fire damper is installed in an exhaust hood [ASHRAE 1997] at the duct connection to the exhaust system hood in a kitchen. Its main objective is to prevent fire from getting into the ductwork. Fire dampers are useful in the hotel kitchen exhaust system because they will help to keep fire out of the existing ducts that may not be able to contain the fire.

They also assist to prevent the spread of fire to other parts of the hotel building and provide safety in case the duct fire suppression system does not function.

However, fire dampers are considered not necessary as the installed duct system if properly designed can exhaust the fire and smoke out of the hotel building in a safe manner. Moreover, closing the fire damper will turn the fire and smoke back into the kitchen and spread more quickly. The smoke will make it more difficult for the fire service personnel to even see to fight the fire. Furthermore, a fire kept out of the duct system and in the hotel kitchen space can spread quickly to combustible surrounding greasy surfaces, increasing the hazard to other guests and other hotel functional areas. The exhaust system may be so dirty and greasy that the damper cannot close properly and so the damper only provides a false signal of safety and makes it more difficult to access the fire in the duct. It is clear that much of the concern with dampers has to do with the proper condition of the ductwork beyond the damper, including its integrity and clearance to combustibles.

Fire dampers in kitchen exhaust systems should only be installed in listed hoods at the hood to duct connection, or they may be a component of a listed grease extraction system that is installed downstream of the hood. Exhaust hoods with integral makeup air supplies usually have fire dampers installed in the supply duct to hood connection, or at one or more of the makeup air register openings. Their fusible links have the same inspection and replacement schedule.

Fire dampers and its associated fusible links also need to be checked for proper and full operations. The links should be able to break rapidly in accordance with its temperature setting. If it does not break fully, its surface must be properly cleaned to remove grease and impurities. If the fire damper cannot close quickly and completely, it cannot be effective as designed.

For local hotel building projects, many fire dampers will be used in guestrooms along the primary air or exhaust duct systems. The local Fire Services Department currently is using the sampling test procedures on fusible links for use in fire dampers of ventilating systems. The purpose of the sample test is a site acceptance test where applicable for locally made fusible links which are approved by local Fire Services Department. A batch of samples will be drawn randomly from the hotel building ventilation system. Ten percent of the total quantity of fusible links of the same product or a maximum up to 10 will be drawn by the fire services officer on site with the representative of the registered ventilation contractor for the test.

The operating temperature (bath) test will be carried out as follows:

a. The operation temperature (bath) test is a check on the absolute operating temperature of the links. It shall operate within 74 ^{o}C.

b. The vessel is to be prepared with a source for heating the water bath with means for heating the liquid at a prescribed rate. An agitator is to be used as an aid in obtaining uniformity in temperature of the bath liquid and measuring the temperature of the liquid.

c. Water should be used in the bath test of the fusible links

d. Mercury thermometers or other types of thermometers with valid calibration certificate shall be used to determine the temperature of the liquids employed in the bath test. The bulbs of thermometers should be held level with the fusible link by a support member.

e. Place the fusible links in an upright position, completely immersed in the water bath and independently apply a load of not more than 0.4 kg to the end link, using a suitable weight or adjustable spring balance.

f. Raise the temperature of the bath liquid at a convenient rate until the liquid is at 60 ^{o}C.

g. Control the rate of temperature rise at a rate not exceeding 1 ^{o}C in 2 minutes until operation of the fusible link, or until a temperature is reached at which the link fails the test.

h. Record the temperature of the liquid and the time of operation, as each heat responsive fusible link operates.

All samples shall pass the test in principle. Otherwise, all links installed on site must be replaced. Acceptance of site test may vary on individual project basis, due consideration will be given to the total quantity and the lots of production being installed In a later section, tests on fusible link samples will be conducted in accordance with the conditions specified in UL33.

Empirical equations, as described in Appendix C, concerning heat transfer at sprinkler are also reviewed to indicate the sprinkler performance between air speeds and temperatures. Large samples of local fusible links were tested under various air temperatures and speeds using the heated wind tunnel with the actuation time recorded. Graphs are also plotted to verify the fusible link performance, such as response time index and time constant, etc.

CHAPTER 7 FULL-SCALE BURNING TESTS FOR KITCHENS AND CALORIMETRY

In this chapter, the principles of calorimetry and its development will be discussed. The oxygen consumption calorimetry and cone calorimetry [Babrauskas and Grayson 1992] will also be investigated and outlined. The Chinese assembly calorimeter [Chow et al 2003d] will then be described and the experimental site mentioned and explained. The necessity of carrying out full-scale burning tests and related issues will be discussed. Full-scale burning tests in a sample kitchen will be reported and results analysed.

7.1 Calorimetry

The fire performance of hotel buildings itself and other occupied spaces can be considered as having two main characteristics: flammability and its stability to fire. Flammability refers to the heat release rate, flame spread and also its ignitability. On the other hand, stability refers to the performance of the building structure itself against fire and whether the partitions or compartments can withstand the effect of fire.

Actually, standard testing methods for flammability [Babrauskas 2003] does not have a long historical basis. Tests for the flammability of textiles were not standardized until the first version of the current NFPA 701 Bunsen-burner test proposed by the National Fire Protection Association in 1938. With most other articles of greater weight and thickness, the heat release rate, flame spread, and ignitability may all need to be considered. In many applications, it is found that these three variables may be highly correlated.

On measuring heat release rate tests at a small scale, the earliest test method [Babrauskas and Grayson 1992] was the FM Construction Materials Calorimeter, developed by Thompson and co-workers in 1959. The apparatus, with a specimen size of 1.22 m by 1.22 m, was tested in the horizontal and face-down orientation. The principle of apparatus might best be described as a ‘substitution test’. A specimen was placed into the apparatus and subjected to a prescribed exposure from an oil burner fire. The exhaust temperature was recorded as a function of time. A second test was then made, with a non-combustible blank substituted for the specimen. The principle of measuring was by metering the amount of propane flowing into the evaluating burner and the combustion energy represented by the metered propane was then taken to correspond to the heat release rate of the specimen.

Improved design principle was available in 1972 which in present-day terminology could be called an ‘isothermal’ design. In this design, a control section is established in the stack, where thermocouples are used to monitor the temperature of the exhaust gases. The heat release rate is determined by including a mass flow measuring device in the propane supply line. The specimen’s heat release rate is equal to the decrease in the propane flow expressed in heat units. This instrument significantly simplified testing, since it no longer required extensive calibrating runs for each test. However, there are some limitations on its use. These included the very high apparatus complexity, the sensitivity to exhaust pressure fluctuations and the need for a long equilibrium time prior to the test. This NBS-I calorimeter was finally replaced by the NBS-II instrument and was removed from service.

While the NBS-I calorimeter was not of much practical use, the SRI calorimeter accommodated vertical specimens 457 x 610 mm in size and with a usable flux range of 15 to 70 Wm^{-2}. This apparatus was also not much used.

For the NBS-II calorimeter, the origins of this apparatus were similar to those of the SRI calorimeter. The apparatus was intended to be more rugged, and to be less susceptible to certain sources of error identified on the NBS-I unit. A maximum heat release rate measuring capability of 1000 kWm^{-2} was provided for vertically oriented samples, with twice that for horizontal ones. A major feature of the new apparatus was that provisions for a load cell were made from the very start, so that there would be a continuous record of the specimen mass loss. The apparatus, as constructed, worked generally to specification. Problem areas included the inability to test single-sided vertical specimens and the sensitivity of the response to barometric pressure variations propagating down the exhaust system. A more serious obstacle to adoption by other laboratories was the fact that the apparatus required a high pressure natural gas supply, a very large air compressor, and several other difficulties of construction and installation. Thus, its users were restricted to exploratory research studies.

The Cone Calorimeter [Babrauskas 2003] was designed at NBS after experience had been gained with the desirable and undesirable features of a number of previous devices. The calorimeters routinely operated at NBS included the NBS-I, NBS-II, and OSU apparatus. In pursuit of the best implementation of the oxygen consumption principle, a number of other purely-developmental calorimeter was also constructed. Different heating arrangements and various concepts for oxygen consumption gas trains were explored in these units. The FMRC small-scale flammability apparatus and the SRI calorimeter were also studied in detail in this design process, although they were never installed or operated at the NBS laboratories. The instrument that resulted has been called the Cone Calorimeter, due to the truncated cone shape of the heater.

7.2 Oxygen Consumption Calorimetry

Thornton showed that for a large number of organic liquids and gases, a more or less constant net amount of heat is released per unit mass of oxygen consumed for complete combustion [Huggett 1980]. Huggett found this to be true for all organic matters also and obtained an average value for this constant to be 13.1 MJ kg^{-1} of oxygen consumed. This value may be used for practical applications and is accurate to within ± 5%.

Thornton's rule implies that it is sufficient to measure the oxygen consumed in a combustion system in order to determine the net heat released. This is particularly useful for full-scale fire test applications as what had been done in the Chinese calorimetry for kitchen heat release rate tests. Thus, for example, for compartment fires, the oxygen consumption technique is much more accurate and easier to implement than methods based on measuring all the terms in a heat balance of the compartment. The technique is now used extensively in many laboratories all over the world, both in bench-scale and full-scale fire test applications.

The basic measuring principle is by collecting all the combustion products removed through the exhaust duct. At a distance downstream with sufficient and adequate mixing, both flow rate and composition of the gases are measured. For open systems like the room fire test, the furniture calorimeter and the standard cone calorimeter, a hood is used to collect the combustion products and it is not possible to measure the air flow rate into the system directly. The volume flow rate is measured downstream after the gases have undergone expansion due to chemical reactions. For closed systems, the mass flow rate of the air into the system can be measured directly. The following describe the main simplifying assumptions made:

a. The amount of energy released by complete combustion per unit mass of oxygen consumed is taken as a constant, i.e. 13.1 MJ kg^{-1} of oxygen.

b. All gases are considered to behave as ideal gases, i.e. one mole of any gas is assumed to occupy a constant volume at the same pressure and temperature.

c. Incoming air consists of oxygen, carbon dioxide, water and nitrogen. All “inert” gases, which do not take part in the combustion processes, are lumped into the nitrogen.

d. Oxygen, carbon dioxide and carbon monoxide are measured on a dry basis, i.e. water vapour is removed from the sample before analysis measurements are made.

Usually, there are two techniques to measure mass flow rate in the exhaust duct in the kitchen fire test. The first technique measures mass flow rate $\dot{m}$ (in kg s^{-1}) in term of the pressure drop ΔP (in Pa) across and temperature at an orifice plate T_e (in ^{o}C) through orifice plate coefficient C (in kg$^{\frac{1}{2}}$ m$^{\frac{1}{2}}$ ^{o}C$^{\frac{1}{2}}$):

$$\dot{m} = C\sqrt{\frac{\Delta P}{T_e}} \tag{7.1}$$

If the test is operated within a narrow range of conditions, C is approximately constant. Its value can be determined via a gas burner calibration. However, if flow rates are varied during a test or if temperature changes considerably, the effect on C of the Reynolds number and pressure at the downstream side of the orifice plate must be taken into account. The other option is to measure velocity at one point in the duct, usually along the centerline.

Oxygen consumption calorimetry [Peacock and Babrauskas 1991] is primarily addressed to measuring the heat release rate and the heat of combustion [Babrauskas and Peacock 1992]. However, with some additional instrumentation, it can also be used to measure smoke and toxic gas yields and the overall chemical composition of the volatile pyrolysis products from the fuel using the above measuring principle. For open systems, such as the room fire test, the furniture calorimeter and the standard cone calorimeter, a hood is used to collect all of the combustion products. In a closed system, the burning takes place in an enclosure. A closed system allows for the burning of the specimen in controlled atmospheres. It allows for a more precise measurement of the mass flow rate of the incoming oxygen.

It is essential that the hood and the exhaust system be designed to collect all of the combustion products. Thus, the standard flow rate 0.024 m^3 s^{-1} in the cone calorimeter has been established to allow about a safety factor of 2 against spillage of combustion products. In applications such as the furniture calorimeter, the hood must not become so hot to influence the burning rate of the specimen due to thermal radiation feedback. This may require the use of water-cooled shields. A constriction at the entrance to the duct serves to promote the mixing of the combustion gases and the entrained air before the measurement section is reached; without such forced mixing, highly inaccurate measurements could result due to stratification. The measuring points should be downstream of the entrance to the horizontal section in order to establish a reasonably developed flow profile. There must be another length of straight duct beyond the measuring point.

The exhaust blower must be able to withstand high temperatures of the order of 350 ^{o}C, or more, depending on the fire size, the details of duct layout, and the consequent heat losses achieved prior to the blower location. It is especially important to note that most simple blowers obey a ‘fan law’, which states that, as the temperature is raised, the volume flow rate remains constant. This means that the mass flow rate drops inversely to absolute temperature. This diminution does not occur if the blower is located in a constant-temperature section or if a feedback loop is arranged to monitor the mass flow rate and control the blower speed accordingly. The latter type of constant-mass-flow-rate operation is provided as an option on the cone calorimeter. For closed systems, the air is normally supplied under pressure, so that the use of the fan in the elevated temperature gas stream is avoided.

One of the advances made during the last decade of heat release rate studies was the incorporation of load cells into the apparatuses for measuring heat release rate. This is now done routinely in bench-scale and furniture calorimeter studies. Room fire tests have also been equipped with load cells, although this may be much more difficult to do successfully. One of the major reasons why load cell measurements are essential is that they allow scale-independent data to be derived. Load cells used in heat release rate instruments have to be resistant to drift induced by temperature changes. Burning objects often tend to shift or fall as they burn. Thus, the load cell must also be mechanically robust and stable against jamming due to off-center load or torques.

A heat flux meter is used to set the intensity of the thermal radiation field [Babrauskas and Grayson 1992]. The meter may be either the Gardon or the Schmidt-Boelter type. The Gardon type is a thin foil with the hot junction comprising a single wire brazed onto the center of the foil. The Schmidt-Boelter type consists of a multi-layered thermopile assembly. For fire test purposes, both are normally used in a configuration where the sensing element is mounted on a water-cooled body. The meters may be configured as radiometers or as total heat flux meters, depending upon whether they have windows.

Heat flux meters are normally used to monitor heat fluxes which are predominantly convective. While incident radiation can be defined and monitored properly, there is no such thing as ‘incident convection’. Convection heating can only be defined once the temperature conditions of both bodies have been defined. In a real fire, the heating is usually to certain material which, as a minimum, will rise in temperature over time and at worst may ignite. A small, water-cooled body does not represent this type of convective interchange at all well. If accurate measurements under such conditions are needed, the normal procedure is to instrument with thermocouples the actual specimen exposed.

The total absorbed heat flux can then be computed by inverting the solution of the Fourier heat flow equation.

7.3 Cone Calorimeter

For much of the bench-scale work carried out over the past decades [Babrauskas 2003], the cone calorimeter has been found by numerous laboratories to be the best tool for heat release rate measurement. It has been designed to include a number of functions, including measuring effective heat of combustion, ignitability and smoke and soot, etc.

It is emphasized that the cone calorimeter has been designed to use only oxygen consumption calorimetry as its measurement principle. Other calorimeters which on occasion use oxygen consumption principles, for example, the FMRC Flammability Apparatus, may adopt other measuring technique. The convective fraction is dependent on the details of the apparatus design, and also the scale of the specimen.

A kitchen fire burning near it maximum rate can give gas temperature over 1000 ^{o}C, producing corresponding irradiances to walls and contents of 150 kWm^{-2}. Testing under such extreme conditions may not be required; nonetheless, if post-flashover fires are to be simulated, irradiances of over 75 kWm^{-2} should be available, and preferably closer to 100 kWm^{-2}. A significant convective component would negate the purpose of having a radiant ignition test. Rather low convective fluxes can be achieved for specimens oriented horizontally, face up, and with the prevailing air flow being upwards.

The cone calorimeter derives its name from the conical shape of the heater. Once the decision had been made to use an electric resistance heater, running at a realistic maximum temperature of about 950 ^{o}C, its material and shape still had to be determined. The material was simply decided, based on poor experiences with exposed-wire resistance heaters and with silicon carbide rod-type heaters. That left the tube heater, which consists of a resistive wire element inside a protective tube, swaged ever a packing of inorganic insulation. The tube is made of Incoloy and can be bent to a desired shape. To determine the best shape, the conical heater used in ISO 5657 ignitability apparatus was examined. This was run to be promising from the point of view of the shape. The proper shape had to have a hole in the middle, since otherwise a hot spot would occur at the sample center, where the radiation view factor is the highest. The same heater had to serve in both horizontal and vertical orientations. In the horizontal orientation, it was essential that all the products of combustion flow out the hole in the middle, and not splash on the header coil, or escape from the underside.

When measured with respect to a water-cooled heat flux meter, the results showed that in the horizontal specimen orientation, the convective contribution was immeasurably small. In the vertical orientation, the fraction was typically 8 to 12%. Thus, it can be said that the objective of having a test method where the heating is primarily radiant was successfully met. For modelling of test results, however, one may be more interested in the possibility of convective heat transfer to a specimen which is heated up, or even burning, not to a calibration meter constrained by its water cooling jacket to be a near-room temperature. The direction of the heat flow was such as to represent a heat loss from the specimen in all cases. The experimental data, however, shows a surprisingly high variation of the coefficient with irradiance, and thus some further studies should be warranted.

The air flow rate through the system which is feasible must be bounded by certain limits. The air velocity must not be so fast that ignition results are improperly affected. It must also be not so slow that products of combustion spill out of the hood. If it is a closed system, it should also be concerned about not being slow enough that the air/fuel ratio drops into the fuel-rich regime; the standard cone calorimeter, however, has been designed for ambient air testing, and so this consideration does not apply. The exhaust system uses a high temperature cast iron blower to exhaust the gases and an orifice plate flow meter. The orifice plate flow meter is instrumented with a differential pressure transducer and a thermocouple. For specialized studies, where the entire combustion system is glass-enclosed, it is possible to go to flow rates below 12 ls^{-1}. Within such enclosed systems, accurate measurements can be made down to about 9 ls^{-1} using the standard orifice place; for lower flow rates, down to about 5 ls^{-1}, the standard orifice plate is replaced by one having a smaller opening.

In most cases, however, an external ignition source is desirable. This ignition source should, in general, not impose an additional localized heating flux on the specimen. The ignitor should reliably ignite a combustible gas mixture in its vicinity. The ignitor has to be designed so as not to be extinguished by fire-retardant compounds from the specimen or by air flows within the test apparatus.

The specimen thickness should be, as much as possible, the thickness of the finished product. There are limitations at both ends of the scale, however. The instrument is restricted to testing specimens not thicker than 50 mm. As a practical guide for testing unknown commercial samples, it is desirable to specify that any specimens less than 6 mm thick should always be considered as needing to be tested over their in-use substrate. Both horizontal and vertical specimen orientation are provided; however, it is considered that the horizontal orientation is standard, while the vertical orientation is reserved for special-purpose testing only. With proper precautions, the horizontal orientation can be used for testing liquids and melting materials. For the cone calorimeter, a commercial-design load cell was found which permits only up-and-down axial motion, while being insensitive to torques or forces from other directions. The load cell has to accommodate two different orientation specimen holders, and may need to hold additional fixtures. Some categories of specimens, however, present special problems. These are specimens which either have a propensity to ignite first along the outside edge, or when ignited, burn disproportionately vigorously near the edges.

7.4 Necessity of Full-scale Burning Tests

Consequent to so many disastrous fires in Hong Kong, there are big concerns on building fire safety. Of all the fire risk parameters considered, heat release rate [Peacock and Bukowski 1994] is the most important one affecting the development of a fire. Nevertheless, data on heat release rate for combustible products are not yet available [Chow 2002]. It is of paramount importance to study the probable heat release rate by burning those combustibles, such as the cooking oil burning in the hotel kitchen. Fire models [Cox 1995; BSI 2002] should be considered.

Full-scale burning tests should be performed to measure the heat release rate. The results can be applied to investigate how the fire safety provisions can be improved. These include providing better passive building design such as the structural elements; and the appropriate active fire protection systems. The information will be important for implementing the new building fire safety codes.

7.4.1 Developments in Full-scale Burning Tests

Before 1970, there was little need to conduct experimental studies of the details of room fires. Room fire experiments were typically conducted as an adjunct to studying fire endurance [Babrauskas and Grayson 1992]. For such purposes, it was necessary to track the average room temperature, since this temperature was viewed as the boundary condition determining what the wall, floor, column, etc., was exposed to. Neither the heat release rate nor other aspects of the room fire such as gas production rates were of major interest. In conducting full-scale house burns, it was tried before 1950 to study gas production rates as a means of determining how early untenable environments might exist.

During the 1970s, however, empirical room fire tests were regularly being conducted at many fire research and testing facilities throughout the world. Instrumentation typically comprised a multiplicity of thermocouples; several probes where gas samples were extracted; smoke meters; typically located at different heights along an open burn room doorway; heat flux meters located on the walls of the burn room; and possibly, a load platform. The load platform might register the weight of a single burning item, but was of little use when fully-furnished rooms were tested. Despite the fundamental role of heat release rate in the room fire, there was no technique available to measure that. Since neither the burning item’s mass loss rate nor the air and gas flow rates could, in most instances, be determined, the measurements of gas and smoke concentrations at isolated measuring stations were not of much use in tracking extraction rates.

Two developments needed to be become available before further progress could be made: a robust instrument for measuring flow rates of combustion products; and especially, a practical technique for measuring heat release rate. Conventional velocity measurement devices are normally precluded from use in fire applications due to several problems. These include clogging of small orifices and the inability to properly calibrate for high temperate use. The new bi-directional velocity probe solved these problems of measuring air flow rates in room, corridors, and in smoke extraction systems.

7.4.2 Room Calorimetry

The first attempt to develop some technique for measuring the rate of heat release in full scale was in 1978 by Warren Fitzgerald [Babrauskas and Grayson 1992]. A small room of size 2.7 m by 2.7 m by 2.7 m was instrumented with a large number of thermocouples, located in the gas space, the walls, and the exhaust duct. The room had a forced air supply of 0.16 m^3s^{-1}, from a small 0.15 m by 0.15 m supply duct, with another duct used to let out the combustion products. The room was also equipped with a load cell and a port for extracting gas samples. The facility was designed for measuring the burning rate of relatively small, free standing combustible items [Smith and Shaw 1999].

The most significant efforts in recent years in the area of full-scale test developments have gone into developing open-air calorimeters. The reasons have to do with the nature of a room fire during its early stages. It is intuitively obvious that a very small fire in a room will behave in the same way as if it were in the open air. Indeed, post-flashover fires can reach a state known as 'ventilation limited'. This means that so much combustible vapours are being liberated from the fuel items that, on the average, all of the available inflowing oxygen is still insufficient to meet the oxygen demands of the fire. This does not quite mean that the combustion gases, if measured, will show exactly zero oxygen. It is there because mixing is not perfect, and therefore, the oxygen is not available to the fire in those locations where it is actually needed.

The ability to make heat release rate measurement under open-air burning conditions is also rather recent. The current full-scale heat release rate methods date to two developments in the early 1980s, one at NBS and the other at FMRC. At NBS, an open-air full-scale calorimeter was built using the concepts of oxygen consumption. The device was termed the "furniture calorimeter", since its earliest applications were for the testing of upholstered furniture. The term has since become somewhat misleading, since numerous commodities have been tested in it. A calorimeter with a 2000 kW capacity could be used to test fast-burning chairs, but would typically not have enough capacity for a sofa. For testing items producing higher heat release rates, a 'large-hood' version of the calorimeter was implemented. The instrumentation and the measurements made are quite similar to the original furniture calorimeter.

7.5 An Assembly Calorimeter

In Hong Kong, it is difficult to select a site for full-scale burning tests as the land costs are far too high. More importantly, there are tight environmental protection regulations and real fire tests cannot be done. A site far from the urban area should be used for carrying out such studies. In this way, environmental impact of the burning tests can be minimized. Further, there should be water, electricity and heating supply in the remote areas which are cold.

An Assembly Calorimeter [Chow et al 2003d], has now been developed in a small town Lanxi in a remote area of Northern China, 200 km away from Harbin. There, a full-scale burning hall is designated (Figure 7.1 (c), (f), (g), (h) to (p)). This is a joint project supported by the Harbin Engineering University (HEU). The ‘duct section’ and the associated instruments including the oxygen analyzer, carbon monoxide analyzer and carbon dioxide analyzer at the Research Centre for Fire Engineering of The Hong Kong Polytechnic University were moved successfully to that site in June 2001 [Leung and Chow 2001]. Both field [Chow and Zhu 2003a] and zone models [Chow and Meng 2004d] can be used to study the kitchen fire with heat release rate measured.

The burning halls are shown in the photos (Figure 7.1 (b), (i), (j)). A bigger hall was used before in the first two years. A smaller one was used later on due to budget cut. The model kitchen arrangement was placed in a small room of size similar to the ISO 9705 room calorimeter. The room is of length 3.6 m, width 2.4 m and height 2.4 m with a door of height 2 m and width 0.8 m as in the photo. An exhaust hood was constructed outside to measure the heat release rate by oxygen consumption method.

7.6 Kitchen Fire

There are concerns in fire safety in public areas in the Far East. Hotel fire safety is also watched carefully as many tourists visiting big cities in there. There had been hotel fires but most of them were put out by the hotel staff. Some were controlled by discharging water from the sprinkler system. These fires occurred due to poor maintenance or low quality electrical installation and appliances in the guestrooms, kitchens and laundry areas.

Kitchens in hotels are rated as areas with higher fire risk because of cooking. Gas stoves with high thermal power used to be installed in Chinese restaurants. Some of them are even illegal installations but necessary to heat up the ‘woks’ (Chinese pans). Such high power cooking ‘woks’ might give kitchen fires when the cooking oil inside is heated up above the auto-ignition temperature.

As reported in the literature [Edwards 1998], about 50% of all accidental fires in hotels, restaurants and fast food outlets started in the kitchen involving cooking oil or fat fires. The fuel temperature can reach up to 400 ^{o}C for a cooking oil or fat fire and the auto-ignition temperature varies from 285 to 385 ^{o}C. The fuel temperature of conventional test fires for Class B such as a heptane fire is only 50 ^{o}C. Therefore, the cooking oil or fat fires are difficult to extinguish and easy to re-ignite, different from conventional liquid fuel fires. A new fire classification, Class F, is defined by some standard institutions such as the National Fire Protection Association, the British Standards Institution and the International Standards Organization [Edwards 1998; Voelkert 1998].

Fire risk is usually specified by the fire load density (FLD), the total amount of combustibles stored in a kitchen. An upper limit of FLD is 1135 MJm^{-2} in local codes [FSD 1998]. As the kitchen is small with high FLD, flashover would occur rapidly. Large amount of heat and smoke would be produced and spread out to other areas. The space adjacent to the kitchen such as the dinning hall would be affected as investigated before by zone models [Chow 1995].

In fact, FLD itself is not sufficient to quantify fire risk. The fire scenarios in a kitchen have to be identified for hazard assessment. Heat release rate is the first parameter to assess consequences of the identified fire scenarios. There are not many such studies on heat release rate for kitchen fires in the literature [Liu et al 2004]. It is necessary to understand the probable heat release rates [Babrauskas and Grayson 1992] in an accidental fire of Chinese kitchen.

A series of full-scale burning test [Chow et al 2003d] were carried out to investigate the heat release rate on scenarios identified. Typical kitchen with ‘woks’ and cooking oil commonly arranged in hotels are studied. The experiments were conducted in the Assembly Calorimeter described as above. A model kitchen was constructed with an exhaust hood and fan-duct system. Heat release rate were measured by the oxygen consumption method. Two scenarios were identified in a typical Chinese kitchen setup for a staff canteen with two woks; and in a typical Chinese kitchen setup for a large banquet with six woks burning.

In following local fire regulations [FSD 1998] and subsequent hotel license requirements [CNTA 2005] for restaurants and kitchens, active fire engineering systems (known as fire services installation in Hong Kong) are required. Sprinkler systems with fast response or higher temperature response heads are required. In addition, water mist [Chow et al 2003b] and gas protection system with clean agent such as heptaflorouproppane are allowed. Effect of operating water system and the heat release rates will also be evaluated.

A sprinkler system [Grant and Drysdale 2000] and a water mist fire suppression system [Yao and Chow 2001] were installed. The cooking oil fires under the operation of sprinkler and water mist system were studied.

7.7 Full-Scale Burning Tests on Kitchen Fire

To assess how sprinkler and water mist would control a fire, full-scale burning tests [Wu et al 2005] were carried out. Kitchen fire scenarios with and without the operation of sprinkler and water mist system were considered. A model Chinese kitchen as in Figure 7.2 was constructed at the Assembly Calorimeter [Chow 2004c]. Flashover kitchen fires were studied in the autumn of 2005. Soyabean oil was used with chemical composition including iodine, moisture, peroxide and free fatty acid. The fatty acid composes of Palmatic acid, Stearic acid, Oleric acid, Linoleic acid, Linolenic acid, Arachidic acid, Gadoleic acid, Behinic acid, Erucic acid and Lignoceric acid.

Two groups of six kitchen fire tests were carried out as follows:

Group A arrangement on a hotel Chinese kitchen for staff canteen with two woks and the arrangement is shown in Figure 7.2 (a). Each wok was filled up with 1000 ml soyabean oil. Three scenarios were considered:

- Scenario A1:Fire only.
- Scenario A2: Fire with the operation of water sprinkler system.
- Scenario A3:Fire with the operation of water mist system.

Group B arrangement on a typical large banquet kitchen with six woks and each wok is filled up with 1000 ml of soyabean oil as in Figure 7.2 (b). Three scenarios were identified:

- Test B1: All six woks on fire.
- Test B2: All six woks on fire with the operation of water sprinkler system.
- Test B3: All six woks on fire with the operation of water mist system.

The model kitchen is of length 3.6 m, width 2.4 m and depth 2.4 m as shown in Figure 7.3 (a). Flue gas liberated would be extracted by a fan-duct system through the exhaust hood at a door opening of width 0.8 m and length 2 m. A stainless steel table long enough to set up six woks and two sinks was constructed as in Figure 7.3 (b). The woks filled with oil were ignited to give large amount of smoke. Tests were then repeated by operating the sprinkler system and the water mist fire suppression system. The operating pressures were 1.12 MPa and 1.26 MPa; and flow rates 5 ls^{-1} and 0.2 ls^{-1}

respectively for the two systems. Note that flow rate for the water mist system was only 4% of that for sprinkler.

7.8 Results on Group A Tests

Two woks filled with soyabean oil as in Figure 7.3 (c) were tested.

Test A1

Smoke was generated when the oil was heated. After about 7 min, the oil was ignited. A sharp increase in heat release rate is shown in Figure 7.4.

Test A2

After the gas stoves were lit, it took 4 min 55 s and 7 min 54 s respectively for the cooking oil to be lit at pan A and B. The sprinkler system was turned on after 9 min 50 s. No splashing nor spillage of oil was observed. The fire was extinguished after 10 min 1 s. The total burning time was 601 s. The heat release rate is also shown in Figure 7.4.

Test A3

After the gas stoves were lit, it took about 6 min 13 s for the oil to be ignited. The gas valve was then shut. After 2.5 min further, the water mist system was activated. It took 16 min 7 s for the water mist system to extinguish the fire. The total burning time was 25 min 20 s. The heat release rate curve is shown in Figure 7.4.

7.9 Results on Group B Tests

All six woks as in Figure 7.3 (d) were burnt.

Test B1

It took 6 min 20 s for fire to be ignited at wok A1, 6 min 35 s at wok A2, 4 min 45 s at wok A3, 5 min 34 s at wok B1, 5 min 10 s at wok B2 and 6 min 10 s at wok B3.

The fire was extinguished after 9 min 14 s at wok A1, 15 min 59 s at wok A2, 13 min 30 s at wok A3, 8 min 50 s at wok B1, 8 min at wok B2 and 16 min 10 s at wok B3.

The heat release rate is shown in Figure 7.5.

Test B2

It took 5 min 32 s for fire to be ignited at wok A1, 6 min 20 s at wok A2, 7 min 16 s at wok A3, 6 min 27 s at wok B1, 6 min 11 s at wok B2 and 6 min 37 s at wok B3.

The water sprinkler system was activated 8 min 7 s after the gas stove was lit. No splashing nor spillage of oil was observed as test A2. Water stopped discharging at 8 min 20 s. The oil was re-ignited and water was turned on again at 8 min 57 s. The cooking oil fire was completely extinguished at 10 min 50 s. The heat release rate is shown in Figure 7.5.

Test B3

It took 6 min 14 s for the fire to be ignited at wok A1, 7 min 5 s at wok A2, 7 min 9 s at wok A3, 6 min 27 s at wok B1, 6 min 35 s at wok B2 and 6 min 40 s at wok B3.

The water mist system was activated at 9 min 33 s after the gas stove was lighted. It took 19 min 3 s to extinguish the oil fire. The heat release rate is shown in Figure 7.5.

7.10 Discussion

Six tests were conducted in a sample kitchen with two or six woks burning.

On group A arrangement with two woks burning, the environment was quite smoky in test A1. The maximum heat release rate went up to 0.4 MW. In test A2, the sprinkler system needed less time, within 20 min, to extinguish the fire for the same setup. In test A3, the water mist system was effective in extinguishing the fire in about 25 min. It used only 4% of time as required by sprinkler.

On group B arrangement with six woks burning, the maximum heat release rate was up to 1.4 MW. In test B2, the sprinkler system took less time to extinguish the fire in comparing with test B3 with water mist system. It appears that water mist under the design condition is not so effective in suppressing bigger fires.

The operation effect of sprinkler system and water mist system were studied. Both water systems were effective in extinguishing the fire rapidly. From the above preliminary tests, it appears that the sprinkler system is efficient in extinguishing the fire. No splashing nor spillage of fuel was observed for the woks arrangement in the model kitchen. However, more water is required.

Calculation on the minimum heat release rate for flashover on our kitchen experimental set up was done as in Appendix D. In some of the cases in our experiment, the heat release rate reached 1.4 MW or 1,400 kW which was higher than the above calculated minimum heat release rate. Flame was also seen coming out from the test compartment. Hence, flashover fire was reached in the experimental fire in the model kitchen.

7.11 Conclusions

Six full-scale burning tests on two different groups of wok arrangements in a model kitchen were carried out in a facility in a remote area of Northeast China. The heat release rate was measured by the oxygen consumption calorimetry. The fire might reach the flashover stage in some cases. The sprinkler and water mist system are shown to be effective in extinguishing the fire.

CHAPTER 8 PERFORMANCE OF HEAT RESPONSIVE LINK IN ACTIVE AND PASSIVE FIRE SYSTEMS

Fusible links are temperature sensitive fire protection devices designed to be part of a fire protection system, such as sprinklers, smoke curtains and fire dampers, etc. The system is activated when the ambient temperature increases to the point that causes the fusible link to break apart. At the point of breakage, it releases the pre-load fire protection device, thus restricting the spread of fire. In this chapter, the application of fusible links in various fire protection systems and the theory involved will be discussed. Various test methods on the reliability and performance of fusible links will be outlined. Simulation tests will also be carried out on fusible links at various temperatures and air speeds and the results will be reported and analysed. The setup and equipment used in the heated tunnel tests [Chow and Ho 1990, 1992] were outlined and described.

8.1 Water Sprinklers - Heat Transfer and Empirical Equations

Fusible links [NFPA 1997] have been applied all over building services installations in such products as pressure tanks, damper doors, fire doors, parts washers, gas pumps, sprinkler systems, safes and chimneys. In this section, the application of fusible links in water sprinkler system and the thermal theory involved will be discussed [Theobald 1987; Theobald and Westley 1988].

The thermal response of a sprinkler head [Heskestad and Smith 1976, 1980] is usually described by the nominal release temperature θ_{nom}, the effective operating temperature θ_E, the sprinkler fire constant τ and the response time index ***RTI***.

The nominal release temperature θ_{nom} is commonly used in Hong Kong to rate a sprinkler head [Hartford 1998; Theobald 1987] and is also specified by the manufacturers for Fire Officers' Committee approval. This will be the maximum ambient temperature for the sprinkler head to withstand without opening and is measured by immersing the sprinkler head into a liquid bath which is heated at a rate of 0.5 ^{o}Cmin^{-1}.

The effective operating temperature θ_E is the minimum air-stream temperature required to activate the sprinkler. The value takes into account the heat loss from the element to the surroundings. θ_E can also be derived graphically from the results measured in the ramp test. Its value depends on the air velocity since the convective heat transfer coefficient between the sensing element and air is governed by the air speed [Melinek 1988].

The heat transfer empirical equations are listed in Appendix C.

8.2 Sprinkler Test and Response Time Index

In the above section, the thermal theory and the related empirical equations on sprinkler heads were reviewed. The principles of two common sprinkler tests, namely the plunge test and ramp test, will be introduced in this section. The sprinkler parameter, i.e. the response time index will be analysed and discussed.

The plunge test is to measure the thermal sensitivity of sprinkler heads. In this test, the test sprinkler is suddenly immersed into a flow of constant temperature and velocity. The results of these tests would be related to the expected performance in the field, and the test environment would be accurately reproduced by any interested party, which contrasts with the sprinkler sensitivity tests previously used by Underwriters' Laboratories and Factory Mutual.

In a real fire situation, the sensing element of the sprinkler will be heated by convection from the hot gases. The effects of radiation and free convection are insignificant. It will be acceptable to assume that the temperature is uniform throughout the body of the sensing element. It is based on (a) conductive heat exchange between the sensing element and supportive portions will be negligible and (b) heat required for sprinkler activation at the activation temperature will be small in comparing to the heat stored in the sensing element.

In Appendix C, the heat balance equation (C1) to (C7) for the heat sensing element and framework are reviewed. The plunge test describes the air temperature by a step function of time, i.e. $n = 0$ in equation (C17). From equation (C14) and (C15) [Chow and Ho 1990; 1992], the product $\tau_e' \, u^{\frac{1}{2}}$, which is a constant, is related to the thermal inertia of the sensing element which is independent on the gas velocity and temperature. This constant will be called the "response time index" of the sprinkler head. This response time index has included convective heat transfer and so will be a property of the sprinkler head itself. The values of the response time index varies from about 50 $\mathrm{m}^{\frac{1}{2}}\mathrm{s}^{\frac{1}{2}}$ for Early Suppression Fast Response (ESFR) sprinkler heads to about 300 $\mathrm{m}^{\frac{1}{2}}\mathrm{s}^{\frac{1}{2}}$ for ordinary ones. However, the plunge test is considered not so suitable in studying thermal responses of sprinkler heads since heated air at constant speed and temperature will be used [Chow and Ho 1990].

Another sprinkler test, the ramp test, describes a constantly increasing air temperature, i.e. $n = 1$ in equation (C17). Solving equation (C4) to (C7) and the equation for the ramp test will be shown in equation (C23). Developing the equations and from equation (C25), by plotting the graph of θ_e against $u^{-\frac{1}{2}}$, a straight line will be shown.

A number of points are needed to be considered in the above two tests. Firstly, the heat transfer to the sprinkler is mostly by convection instead of radiation during the early stages of fire. Secondly, conduction heat loss is needed to be considered as the pipework is taken as a large heat sink. Lastly, higher values of air speed are not recommended and air velocities between 1 to 4 ms^{-1} have been found in the ceiling jet during the early stages of fire.

8.3 Fire Dampers in Fire Protection Systems

Fusible links are used in fire protection devices [Cote 1997] locally in Hong Kong, including fire dampers, fire doors and sprinklers. Fire dampers and ceiling dampers will be installed to protect openings for ducts in walls and floors with appropriate fire resistance ratings. Air transfer openings should also be protected. All these dampers should be classified and labelled in accordance with UL standard 555.

A smoke damper can be used for either traditional smoke management or smoke control. For smoke management in a typical ventilation system in hotels, a smoke damper inhibits the passage of smoke under the forces of buoyancy, stack effect, and wind. However, smoke dampers are only one of many elements intended to inhibit smoke flow. In smoke management applications, the leakage characteristics of smoke dampers should be selected so that they may be functionally appropriate with the leakage of the other system elements.

In a typical smoke control system, a fire and smoke damper inhibits the passage of air that may or may not contain smoke. A damper does not need low leakage characteristics when outside air is on the high pressure side of the damper, as is the case for dampers that shut off supply air from a smoke zone or that shut off exhaust air from a non-smoke zone. In these cases, moderate leakage of smoke-free air through the damper does not adversely affect the control of smoke movement. It is the best to design smoke control system so that only smoke-free air is on the high-pressure side of a closed smoke damper.

Smoke dampers [ASHRAE 1997] should be classified and listed in accordance with UL standard 555S for temperature, leakage, and operating velocity. Many FSD approved type fire and smoke dampers are used in local hotels and site tested by the local the Fire Services Department. The velocity rating of a smoke damper is the velocity at which the actuator will open and close the damper.

At locations requiring both smoke and fire dampers, combination of dampers meeting the requirements of both UL standard 555 and UL standard 555S can be used. The combination of fire/smoke dampers must close when they reach their US standard 555S temperature rating to maintain the integrity of the firewall.

Fire, ceiling, and smoke dampers should be installed in accordance with the manufacturers' instructions. NFPA standard 90A gives general guidelines regarding the locations requiring these dampers.

The supply and return/smoke dampers should be a minimum of class II leakage at 120 ^{o}C. The return air damper should be a minimum of class I leakage at 120 ^{o}C to prevent recirculation of smoke exhaust. The operating velocity of the dampers should be evaluated when the dampers are in smoke control mode.

The exhaust ductwork and fan must be designed to handle the temperature of the exhaust smoke. The temperature of the exhaust smoke can be lowered by making the smoke control zones large or by pressurizing only the zones adjacent to the fire zone and leaving all the other zones operating normally.

The odour in the hotel is one of the first impressions the traveller has on arrival. The odour in the hotel entry hall, at the front desk while the check-in formalities are taking place, that of the guestroom and finally of the restaurant will strongly influence the guest's perception of well-being.

With well designed ventilation system, the odour occurrence can be minimized but maintaining fire system integrity is also important. Odour is at once associated with the cleanliness of one's surroundings and the corresponding feeling of well-being. The odours which float in the air may have numerous origins: they include cigarette smoke, body odours, cooking odours, paint odours, the odours of certain cleaning products, etc. These odours generally disappear when natural or artificial ventilation is used. In some cases, natural ventilation is not sufficient, e.g. in the kitchens and restaurants, and it is then necessary to resort to mechanical ventilation.

As soon as the volume of air necessary for the ventilation of the hotel is below 4 to 6 air change, the air is confined, odour settled, and the guest feels uncomfortable. The hotelier, conscious of the real danger of losing the guests, then takes steps to ventilate the premises. The danger of bad odour can be avoided by ensuring that the correct quantity of fresh air is distributed judiciously throughout the hotel. The hotelier may also consider that different parts of the hotel are not always occupied by a constant number of people. By definition, occupation is variable in hotels. What happens when there are fewer persons than anticipated? What if, for example, the “Grand ballroom” is occupied by 200 persons instead of 1200 which it can hold? It will then be necessary to adapt the volume of air to the number of people actually present, each of whom will require minimum quantity of air.

8.4 Heated Wind Tunnel – Experimental Setup

In order to carry out tests [Chow and Ho 1990, 1992] for studying thermal responses of fusible links under different heating conditions, a hot air tunnel, known as the heated wind tunnel (Figure 8.1) has been constructed and located at the ground floor laboratory of the Building Services Department of The Hong Kong Polytechnic University. With it, different values of hot air speed and temperature can be adjusted to simulate a fire-induced ceiling jet. The heated wind tunnel is constructed as shown in Figure 8.1. The appearance of the tunnel is similar to the one at the Fire Research Station [Chow and Ho 1992] but with a different heating and control design.

In the heated wind tunnel, air is blown by a fan positioned at the inlet. The inlet air stream passes through a heating section which is composed of finned air heater. The heated air then passes through a contraction and finally to the working section at the outlet duct. The tunnel is basically a constant-mass-flow open-ended device. The inlet air temperature remains in a limited range during the tests. For a particular fan speed, the mass flow remains practically constant in the heated section. The contraction before the working section would smoothen the air flow by reducing turbulence. An acceptable uniform condition of temperature and velocity can then be provided over the working cross-section.

The dimensions of the tunnel are 3 m long, 1.6 m high and 0.7 m wide. It is made from 1.2 mm mild steel sheet and its low thermal mass enables the tunnel air temperature to respond rapidly to any programmed changes. The working section is wooden made and without insulation. The relatively high thermal mass of wood allows the surface temperature of the working section to be cold with respect to the fusible link temperature. It also ensures that heat transfer to the fusible link is predominant by convection rather than radiation from the working section.

The equipment includes a belt-drive centrifugal fan (Figure 8.1) of which the speed is controlled by a frequency invertor. The air mass flow is determined by the speed of the fan and can be controlled manually by the invertor. Remote control is allowed if the invertor is connected to a source signal. The heating section consists of finned air heaters with a rating of 15 kW. The heat output is controlled by a PID controller which senses the air temperature in the working section. Manual override is also possible by a remote source signal.

The fusible link to be tested is fitted to a specially made metallic fitting as shown in the photo. Linear rates of rise of temperature varying between 10 to 60 $^{o}Cmin^{-1}$. may be maintained up to a maximum of 150 ^{o}C in the working section of the tunnel. Smaller rates of rises are also possible but linearity might not be maintained. At lower velocities (below $1ms^{-1}$), the maximum temperature can be increased to 200 ^{o}C but sustained operation at this temperature will activate a high temperature cut-out control. The time taken for getting a certain tunnel air temperature is about 10 s for medium air velocities. A longer time, about 30 s is required for lower velocities.

The air velocity in the working section may be varied from 1 to 15 ms^{-1} at 25 ^{o}C. Lower values can be achieved by reversing the polarity of the fan motor to obtain 0.2 to 1.5 ms^{-1}. The characteristic relationship between air velocity and the frequency output of the invertor can then be found. The tunnel air velocity can then be set to any required operating conditions.

There is a problem in controlling the air temperature at low air speed. A time delay is found and so giving a temperature fluctuation of 20 to 30 ^{o}C. The problem is solved by manual operation and the air temperature can then be set within ± 5 ^{o}C of the desired value. Calibration is necessary for every test in order to obtain the desired temperature.

Also, the rate of temperature has to be determined graphically by measuring the time required to get maximum heat output.

The heated wind tunnel is similar to the one constructed at the Fire Research Station (FRS) in the sense of getting controlled speed and temperature of hot air. But the equipments and their performances are different as shown in Table 8.1.

The air flow rate of the FRS wind tunnel is controlled by changing the iris diameter. The mass flow rate is determined using the pressure difference between the iris. Air velocity profile at the working section is measured using pitot static tube and checked by a vane-type anenometer. This design is applicable for test velocities 1 ms^{-1} or above. However, when the air velocity lies below 1 ms^{-1}, buoyancy effect of the hot gas may affect the uniform distribution of temperature and velocity in the working section. This would create a higher temperature at the upper part of the section. In this case, vane-type anenometer may not be a suitable device for measuring low air velocity.

For the heated wind tunnel, a frequency inverter is used to drive the fan. This variable speed device is possible to change the speed of the fan by 0.2% increments (0.1 Hz), thus providing an accurate air flow rate. The air velocity at the working section is measured using pitot static tube and a pressure transducer. This is similar to the one in the FRS tunnel. However, it is not applicable to choose the mean velocity of the working section as a reference value. This is because the air velocity at the top of the working section, where the sprinkler is located, may differ greatly from the mean value. The situation is especially obvious when the air temperature is high and the air velocity is low.

Therefore, a point velocity at the fusible link location, rather than a mean velocity, should be chosen.

As the frequency inverter can accept remote control signals, it is possible to use microcomputer control technique to create variable velocity profile during tests. This would provide greater flexibility, easier modifications, and higher accuracies.

A programmable controller was used to control air temperature in the FRS wind tunnel. In contrast to it, the one we used adopts a PID controller with step and current value output. Due to the heater and sensor time delays, difficulties are encountered in temperature control. But the problem can be overcome by switching to manual mode. Future modifications will increase the sensitivity and relate the relationships between air temperature, velocity and heater output by programmable controllers. The heated wind tunnel is a reliable instrument in testing fusible links under various temperatures and air speeds and is also adopted by the local Fire Services Department. First of all, the code UL33 on heat response link used in the fire protection device, was reviewed.

8.5 Heat Responsive Link for Fire-Protection Service – UL33

UL33 [UL 2005] cover the requirements for heat responsive link used for fire-protection service. These links consist of devices intended for installation under load conditions such as for use with automatic suppression systems; or automatic closure devices for doors, windows, dampers or smoke vents. Heat responsive links are categorized by temperature rating, type of coating and plating, minimum and maximum design load, and other factors which may have a bearing on their intended use.

Various types of heat responsive links:

- Bi-metallic type – Two different metals mechanically fastened together. Each metal has different expansion characteristics which act to release a load when exposed to sufficient heat. This type of device may be reused.

- Frangible bulb type – Liquid-filled glass bulb that features a load when exposed to sufficient heat. For example, water sprinkler system.

- Fusible type – Two or more metallic parts having a solder element that fuses to release a load when exposed to sufficient head. This is similar to the fusible links used at the fire dampers of ventilation system.

A heat responsive link shall be constructed for service where the maximum normal ambient air temperature at the part of installation does not exceed that in Table 8.2.

The operation characteristics of heat responsive link shall not be impaired by the application of any applied coating or plating when tested in accordance with these requirements. A corrosion resistant coating or plating shall be uniformly applied. A wax coating shall not be brittle when new nor become brittle with age. A wax coating shall not crack when tested at the maximum temperature for which the link assembly may be installed.

A link assembly shall support a load equal to five times the maximum design load for at least 150 hours. At least ten sample link assemblies of the lowest temperature rating in the Ordinary Temperature classification (or if ordinary temperature classification links are not produced, then those produced having the lowest temperature rating) are to be loaded to five times the manufacture's maximum design load for 150 hours at an ambient temperature of 70 ± 5 ^{o}F (21 ± 3 ^{o}C).

As an alternative, a heat responsive link assembly shall support a load for one minute when tested as below. At least ten sample links assemblies of the lowest temperature rating in the ordinary temperature classification are to be loaded to five times the manufacturer's maximum design load for one minute at an ambient temperature of 70 ± 5 ^{o}F (21 ± 3 ^{o}C). One attachment end of each sample is to be connected to the test supporting apparatus. The test load is to be applied to the other attachment end in the intended direction.

8.5.1 Operating temperature (bath) test

The operating temperature of heat responsive links [UL 2005], when bath tested, shall operate within the range having a maximum temperature not in excess of 5 ^{o}C or 107 percent of the minimum centigrade temperature of the range, whichever is greater. For the purpose of this determination, the marked temperature rating is to be included as one of the ranged values, making a total of 11 values in the range. The previous temperature ratings in Table 8.2 indicate all the link types.

Link operation for this test includes the intended functioning of the eutectic elements of any rupture of the frangible bulb heat responsive element. If partial fracture of the frangible bulb in the liquid environment occurs which does not result in link operation, the temperature at which the bulb fracture occurred shall be considered the operating temperature. Not less than ten heat responsive links of either coated or uncoated types of each temperature rating are to be subjected to this test. All ten samples shall comply with the requirements as specified above.

The fusible links are to be placed in an upright position under a load equal to the manufacturer’s minimum design load, but not less than 4 N, and completely immersed in the water or oil bath. The vessel is to be provided with a source for heating the liquid at the prescribed rate and with means to agitate the liquid and measure the temperature of the liquid bath. An agitator is to be used as an aid in obtaining uniformity in temperature of the liquid bath.

A laboratory mercury thermometer, calibrated in accordance with the specifications for, ASTM E1, is to be used to determine the temperatures of the liquids used in bath tests. The bulb of a thermometer is to be held level with the fusible link by a support member. The temperature of the bath liquid is to be raised until the liquid is within 11 ^{o}C of the temperature rating of the device for a device having a temperature rating of 149 ^{o}C or less, and within 17 ^{o}C for a device having a temperature rating of 163 ^{o}C and higher. The temperature rise then is to be controlled at a rate not exceeding 0.5 ^{o}C per minute until operation or until a temperature of 11 ^{o}C above the rated temperature is reached. The temperature of the liquid and the time of operation, as each heat responsive link operates, are to be recorded.

In previous chapter, the site test method by local Fire Services Department were described and outlined. Recently, there was one hotel project in Hong Kong where actually the FSD had carried out the site bath test on 20 sample links separately selected from two hotels. The test was satisfactory and FSD approved the use of the links in the two hotels.

8.5.2 Sensitivity-oven heat test

A fusible link shall have the following operating time characteristics [UL 2005] when tested in the sensitivity test oven in accordance with UL33. For a standard response link, each sample shall have a maximum operating time as specified in Table 8.3. If the link temperature rating is not shown in Table 8.3, the maximum operating time for each sample is to be determined by using the formula, based on a *RTI* value of 350 ($m^{\frac{1}{2}}s^{\frac{1}{2}}$) and the marked temperature rating of the link.

The mean operating time shall be equal to or less than a 1.3 times of the mean operating time of the link. Ten samples of fusible links of end type are to be placed in the sensitivity test over with the heat responsive element located at least 1 inch (25.4 mm) away from the inside surfaces of the oven and with the broadest part of the link, or with the heat responsive element of the link, facing toward the air flow. The samples are to be at the minimum load specified by the manufacturer.

The samples are to be conditioned at 24 ± 1 ^{o}C for at least 2 hours. The samples are then to be quickly plunged into the sensitivity test oven in the vertical position. Each link is to be observed to determine if operation occurs within the time as specified in the above table.

The sensitivity test oven is to consist of an 8 inches square stainless steel chamber. A constant air velocity of 2.54 ± 0.01 ms^{-1} and an air temperature as specified in Table 8.4 for each temperature rating are to be established.

The required link operating time values as specified in the above tables shall be calculated by using the following equation relating the response time index *RTI* (in $\mathrm{m}^{\frac{1}{2}}\,\mathrm{s}^{\frac{1}{2}}$), the gas temperature at the orifice plate T_e (in ^{o}C), the nominal gas temperature in test section T_g (in ^{o}C), the marked temperature rating of the link T_m (in ^{o}C), Nominal ambient air temperature T_u (24 ^{o}C) and air speed in wind tunnel section V_g(in $\mathrm{m\ s}^{-1}$) with operating time of the link t_o (s):

$$t_o = -\frac{RTI}{\sqrt{V_g}} \ln\left(1 - \frac{T_m - T_u}{T_g - T_u}\right) \tag{8.1}$$

where V_g is 2.54 ms^{-1}

Fusible links shall be marked with the temperature rating, a distinctive type or model designation, and the manufacturer’s or private labeller’s name or identifying symbol. The year of manufacture shall be stamped or cast on a visible area of the heat responsive link. Links produced in the last three months of a calendar day may be marked with the following year as the date of manufacture, and those produced in the first three months of a calendar year may be marked with the preceding year as the date of manufacture. If a manufacturer produces links at more than one factory, each unit shall have a distinctive marking to identify it as the product of a particular factory.

In the following section, several tests on local made fusible links were conducted to review their functional performance.

8.6 Local Fusible Links – Simulation Tests with Heated Wind Tunnel

Tests [Chow and Ho 1990; 1992] were also carried out on local fusible links currently used in local hotel projects. By setting up the heated wind tunnel in The Hong Kong Polytechnic University (Figure 8.1 (a) to (g)), the first batch of 50 fusible links (Figure 8.1 (h) to (k)) were tested in accordance with UL33 at gas temperature 2.54 ms^{-1} and 135 ^{o}C.

The fusible link actuation times were recorded as in Table 8.5 and plotted in Figure 8.2 by a bar chart.

For the 45 fusible link samples successful broken in the wind tunnel, they all satisfy Table 10.1 of UL33, for breakage time to be less than 86.1 s. The five fusible links, which did not break, might be defective or oxidized. This further confirmed the previous on site testing by FSD using the water bath method. The results show that the fusible links perform and operate in accordance with the requirements in UL33.

Moreover, tests on 180 fusible links were carried out using the Building Services Engineering heated wind tunnel, at air speed from 0.6 to 3 ms^{-1} and air temperature from 80 to 150 ^{o}C. The results are shown in Table 8.6. A graph, fusible link actuation time against $-\frac{\ln(X)}{\sqrt{V_g}}$ is plotted as shown in Figure 8.3. The slope, which is the response time index (*RTI*) for the fusible link, is found to be 343 m$^{\frac{1}{2}}$s$^{\frac{1}{2}}$ as in Figure 8.3. This result matches with the general ***RTI*** as measured for sprinkler heads.

Furthermore, it can be seen that water bath tests adopted in UL33 or local fire services department, may not be appropriate for testing fusible links. The fusible links will be exposed to hot smoke or heated air, instead of heated water as used in the water bath test. Currently, water bath test on local fusible links is adopted by local fire services department and may not be suitable as water will have a much higher specific heat capacity than actual hot smoke. Hence, alternative method by using heated wind tunnel tests is proposed in this study for testing local fusible links. Simulation experiments carried out for rating sprinkler heads, involved in the testing of fusible links at various temperatures and air speeds were conducted in this study. The results in Figure 8.3 are concluded in the accurate and important evaluation on the *RTI*. The results of which can be easily used and widely applied in the local fire industry.

CHAPTER 9 CONCLUSION

Fire safety in hotel premises was focused on in this thesis. Critical areas, such as kitchens, will give safety problems. The importance of carrying out full-scale burning tests for kitchens was pointed out such that better fire protection strategies and systems might be worked out through evaluating the results. The performance of fusible links in active and passive fire systems was particularly pinpointed and tests to verify its reliability and operation were conducted.

Full-scale burning tests in a model kitchen were then carried out to investigate the heat release rate when a wok was burnt in the model kitchen. The operation of water sprinkler and water mist system were also investigated. The application of fusible links in local ventilating system of hotels has led to many safety concerns on its reliability and performance. Tests were also conducted in a heated wind funnel to find out the operation of these locally made fusible links under various air temperatures and speeds. The data are useful to local authorities and professionals in assessing the operation, performance and application of fusible links at fire dampers, sprinklers and smoke shutters in buildings. A conclusion summary on the thesis is as follows:

The profile of the study was described in Chapter 1 with the focus on fire safety in hotels. Hotel fires were studied and investigated in Chapter 2. The problems and all the parameters related to fire safety in a hotel were identified. In the mentioned examples of fires in hotels, large crowd of guests gathering, guests' being unfamiliar with the hotel configurations, and incorrect operation and misuse of facilities were the problems. The planning and proper maintenance of all the sophisticated building services installations in a hotel are critical as they nearly account for 50% of the total hotel construction project cost. Moreover, the importance of fire safety in international chain hotels in Hong Kong was outlined. These chain hotels have very detailed and planned fire safety strategies and management programs, both on prevention and implementation. They had also summarized in their fire safety plans all their experience and actual operations towards fire problems and correct management procedures during an actual fire. Furthermore, the kitchen was singled out as a critical area in the hotel. Fire safety issues and problems in kitchens were discussed by focusing on the type of utilities used and the complex applications of electrical and mechanical installations in the kitchen. By following recent local fire codes, proper fire safety and protection system could not be concluded and hence, this chapter actually leads us to the urgency of carrying out more intense study on kitchen fires by full-scale burning tests to understand the heat release rate when a model kitchen is burnt. Furthermore, with so many ventilation systems involved in the kitchen, the performance of fusible links are crucial to maintain the integrity of the passive fire provision or even the activation of the active fire systems.

The total fire safety concept was studied in depth in Chapter 3. The goals for fire safety are human life safety, protection of premises and fire prevention in a hotel. The MoE, FRC, MoA, FSI and FSM are needed to support the above three goals. It is concluded that the adoption of the total fire safety concept is important in the evaluation of the fire safety level of the hotel building. MoE, FRC, MoA, FSI and FSM components must not be assessed separately. All these key parts are related. A total fire safety strategy should be focused on so as to use fire safety management as the software component to control the hardware components, such as MoE, FRC, MoA and FSI, etc. Throughout this chapter and from the hotel operation experience of the author in recent years, fire safety management is concluded as a main contributing factor towards fire safety in a hotel.

Also in Chapter 3, the essential components of passive fire protection systems in Hong Kong were pointed out. These components, namely the MoE, FRC and MoA, are essential parts for building fire safety. Nowadays, prescriptive codes are used for implementing the design of these passive fire protection systems. However, as mentioned in the study that with so many new architectural building features, a more scientific method might be required and more research works are needed, particularly on the fire behaviour of materials and evacuation modelling. It is concluded that the adoption of performance-based fire codes and engineering approach towards fire protection design in buildings are highly advocated. The housekeeping and planned maintenance of all these passive protection systems in hotels are particularly pinpointed. The best passive fire protection system will not function to its design intent without proper care, repair and service follow-up.

The active fire protection systems for hotels were discussed in Chapter 4. Different active fire protection systems were reviewed, including sprinklers, water mist, hydrants and hosereels, detection systems and emergency lighting, etc. These active systems are essential to the building and its occupants by limiting the fire spread, suppressing the fire and preventing structural collapse of the building. Again, like passive fire protection systems, prescriptive fire codes cannot only be relied on in providing better design and safer buildings. It is concluded not to decide blindly on building design in choosing the suitable system, adequate supportive data and considerations must be provided to see whether the proposed active systems are feasible for the hotel building or not. More research works are required on studying the active fire system performance and characteristics towards controlling and limiting fire spread. Local fire codes and licensing requirements were reviewed and compared with those codes specified in foreign countries.

The concept of fire safety management and its application in hotels were studied in depth in Chapter 5. The fire safety plan, maintenance plan and the various normal and emergency mode of operation were reviewed. The importance of fire safety management was concluded as a very important software component in the daily operation or long-term fire safety planning in a hotel. On the other hand, the importance of engineering approach in the application of fire safety management was also pointed out. Various policies and procedures were listed for an emergency fire plan implemented in a local five-star hotel in Hong Kong. Hotel fire safety environment is comprised of and effected by a lot of parameters and simply the provision of all the hardware components may not effectively ensure the fire safety to guests without the simultaneous implementation of the fire safety management plan, the software component. From the various fire incidents mentioned in previous chapters, the importance of fire safety management in hotel operations and the critical need to provide full training on fire safety to all hotel employees are concluded.

Different developments in calorimetry and the establishment of the Chinese calorimetry for the actual full-scale burning tests for the model kitchen in this study were reviewed in Chapter 7. On cost and environmental concerns, it is difficult to perform the full-scale burning tests in Hong Kong and so a site was established in Northern China.

At the same time, the necessity of carrying out full-scale burning tests was concluded in fire safety engineering. Actually, heat release rate is a very important parameter in fire hazard assessment. By understanding it, information can be obtained on the possibility of flashover during fire and whether the items adjacent to the burning object will be ignited. Moreover, the smoke layer temperature, radiative heat flux and whether there is an upward spread of frame over walls can be found out. Furthermore, the heat release rate results will be useful in recommending the use of finishes combustibles and eventually the fire safety provisions in kitchens.

For the six burning tests carried out in the model kitchen, in some cases, the fire could reach a flashover temperature of 600 ^{o}C and the heat release rate of 1.4 MW. The operation of the sprinkler and water mist systems were effective in extinguishing the oil fire. It was found that the water sprinkler system extinguished the fire more rapidly in the burning tests. To provide better fire service protection and to arrive at a better suppression system, further full-scale burning tests under different kitchen setups and configurations are recommended. The results will surely tell more on what will happen in an actual kitchen fire incident.

The use of fusible links in both active and passive fire protection systems was studied in depth in Chapter 8. The theory behind the heat transfer for the operation of sprinkler heads or fusible links were reviewed. Comparing the use of water bath tests accepted by the local Fire Services Department on locally made fusible links, the testing requirements for fusible links in UL33 were also listed. Moreover, the heated wind tunnel was constructed in The Hong Kong Polytechnic University and used for carrying out the fusible link actuation simulation tests for a large sample (over 200) of fusible links at various air temperatures and speeds. For the initial test on 50 fusible links in accordance with UL33, it further concluded its compliance with the results of the local site tests on the 20 samples of fusible link selected randomly on site. In the second test on about 170 fusible links at various air temperatures and speeds, the response time index was calculated, and the graph for the fusible link performance was plotted. Further tests on fusible links are recommended for different ratings in order to suit its actual application in various uses in fire services installations. This area of tests is not receiving much attention in actual engineering field application.

To conclude for improving the fire safety for hotels, it is recommended to adopt the total fire safety concept on planning the fire safety provisions for hotels. By doing so, performance based fire code can be used which will be more appropriate and economical for providing the active and passive fire protection systems. In particular, fire models and full-scale burning tests can also be used for simulating the behaviour of hotel fire under various scenarios and the determination of the design fire size. The use of fire safety management concept is highly recommended as a useful tool on approaching the fire safety problem. It is concluded that the hotel management must have a proper fire safety management program, a software component to fully relate and combine the operational effects of both the active and passive fire protection system in any special fire problem in big hotels.

TABLES

Table 6.1: Requirements on escape routes in china codes

Type of occupancy	Maximum distance from room door to exit or stairs (m)					
	Rooms between two exits/stairs			Rooms on the side/end of the corridor		
	Fireproof class			Fireproof class		
	I, II	III	IV	I, II	III	IV
Child-care, nurseries	25	20	-	20	15	-
Hospitals, sanatoriums	35	30	20	15	-	-
Schools	35	30	-	22	20	-
Others	40	35	25	22	20	15

Table 6.2: Comparison on the egress capacity

China code					NFPA life safety code		
		Capacity requirements (m/100 person) (cm/person)			Uses	Stairways (cm/person)	Level components and ramps (cm/person)
Fireproof class		I, II	III	IV	Board and care	1.0	0.5
Stories	1, 2	0.65	0.75	1.00	Health care (sprinkler)	0.8	0.5
	3	0.75	1.00	-	High hazard contents	1.8	1.0
	4	1.00	1.25	-	All others	0.8	0.5

Table 6.3: Travel distance limits in NFPA life safety code

Type of occupancy		Travel distance limit	
		Unsprinklered (m)	Sprinklered (m)
Assembly		45	60
Educational		45	60
Health care		45	60
Detention and correctional		45	60
Residential		53	99
Mercantile		30	60
Business		60	91
Industrial		60	75
Storage	Low hazard	Not required	Not required
	Ordinary hazard	60	122
	High hazard	23	23

Table 8.1: Difference in heated wind tunnel setup

No.	Items	FRS wind tunnel	Heated wind tunnel in BSE of PolyU
1	Tunnel body	1.6 mm aluminium sheet with insulation.	1.2 mm mild steel with insulation.
2	Fan: • Type • Speed • Flow control mechanism	 Axial Constant Iris-type variable shutter	 Centrifugal Variable Frequency inverter
3	Heater	18 kW convection heater	15 kW finned air heaters
4	Temperature controller	Programmable digital controller	PID controller

Table 8.2: Heat responsive link - rating

Temperature classification	Temperature rating		Maximum ambient temperature	
	°F	°C	°F	°C
Low	125 – 130	51 – 54	90	32
Ordinary	135 – 170	57 – 77	100	38
Intermediate	170 – 225	79 – 107	150	66
High	250 – 300	121 – 149	225	107
Extra high	325 – 375	163 – 191	300	149
Very extra high	400 – 475	204 – 246	375	191
Ultra high	500 – 575	260 – 302	475	246

Table 8.3: Operating time for links in sensitivity-oven heat test

Operating time for links in sensitivity – oven heat test		
Temperature rating (^{o}C)	Oven temperature (^{o}C)	Standard response type (s)
57.2	135	78.0
60.0	135	86.1
68.3	135	86.1
71.1	135	121.3
73.9	135	131.1
79.4	197	84.8
93.3	197	112.4
100.0	197	127.1
104.4	197	137.3

Table 8.4: Sensitivity oven temperature in sensitivity-oven heat test

Sensitivity oven temperature			
Temperature rating		Oven temperature	
°F	°C	°F± 2	°C± 1
135 –170	57 – 77	275	135
175 – 225	79 – 107	386	197
250 – 300	121 – 149	555	290
325 – 375	163 – 191	765	407
400 – 475	204 – 246	765	407
500 – 575	260 – 302	765	407

Table 8.5: Fusible link test result (activation time) at air speed of 2.54ms^{-1} of 135 ^{o}C

Sample No.	Time for fusible link breakage (s)	Sample No.	Time for fusible link breakage (s)
1	45.9	26	29.1
2	41.5	27	28.7
3	42.2	28	34.1
4	28.8	29	29.6
5	35	30	34.5
6	33.2	31	34.3
7	39.6	32	28
8	37.8	33	30.3
9	31.5	34	31
10	34.8	35	29.9
11	33.4	36	36.3
12	35	37	32.4
13	35.8	38	33.6
14	33	39	32.4
15	33.4	40	360, did not break
16	30.8	51	25.5
17	31.9	42	26.1
18	31.4	43	30.8
19	30.6	44	28
20	33.8	45	30.4
21	29.2	46	30.3
22	31.6	47	360, did not break
23	31.3	48	360, did not break
24	32.1	49	360, did not break
25	35.6	50	360, did not break

Table 8.6: Fusible link test result (activation time) at various air speeds and temperatures

Velocity (m s^{-1})	Temperature (^{o}C)									
	80	85	90	95	100	110	120	130	140	150
0.6	NA	NA	NA	593.84	661.60	296.47	211.66	176.66	115.25	100.13
	NA	NA	NA	513.44	406.47	391.19	170.78	206.50	130.97	127.97
	NA	NA	NA	569.29	510.34	307.28	243.22	195.88	159.40	117.47
1.0	1223.66	831.00	707.00	322.82	277.31	204.44	141.72	106.19	94.06	86.63
	1206.69	578.47	677.00	307.84	385.88	142.90	136.69	74.69	132.03	76.53
	1001.16	623.31	563.00	356.28	290.35	183.97	133.75	117.22	90.78	92.85
1.5	682.72	548.13	408.81	233.94	253.28	120.78	105.03	60.72	66.72	71.44
	609.91	405.85	407.60	211.03	224.38	146.09	105.31	55.03	95.41	67.22
	924.37	431.82	334.84	291.37	193.63	154.31	127.04	50.78	101.19	66.41
2.0	419.18	241.87	200.41	184.63	163.72	110.82	118.32	66.00	54.35	53.43
	391.93	328.19	223.07	190.41	154.37	116.87	82.03	57.44	52.31	51.96
	265.56	256.13	207.93	170.59	144.44	110.69	132.63	67.47	54.37	46.43
2.5	335.47	221.72	188.41	114.36	136.25	88.50	98.62	49.97	44.42	37.31
	292.06	245.31	150.01	184.01	106.84	85.28	88.57	39.93	44.33	39.81
	285.41	211.00	146.32	120.31	106.75	82.12	75.03	40.41	53.37	36.91
3.0	123.25	92.94	70.57	64.91	54.88	44.53	40.75	33.25	29.62	31.09
	126.72	86.72	76.22	68.72	51.84	48.84	35.09	31.81	28.60	29.07
	138.78	84.59	64.34	59.25	47.06	42.65	34.15	29.75	25.72	19.00

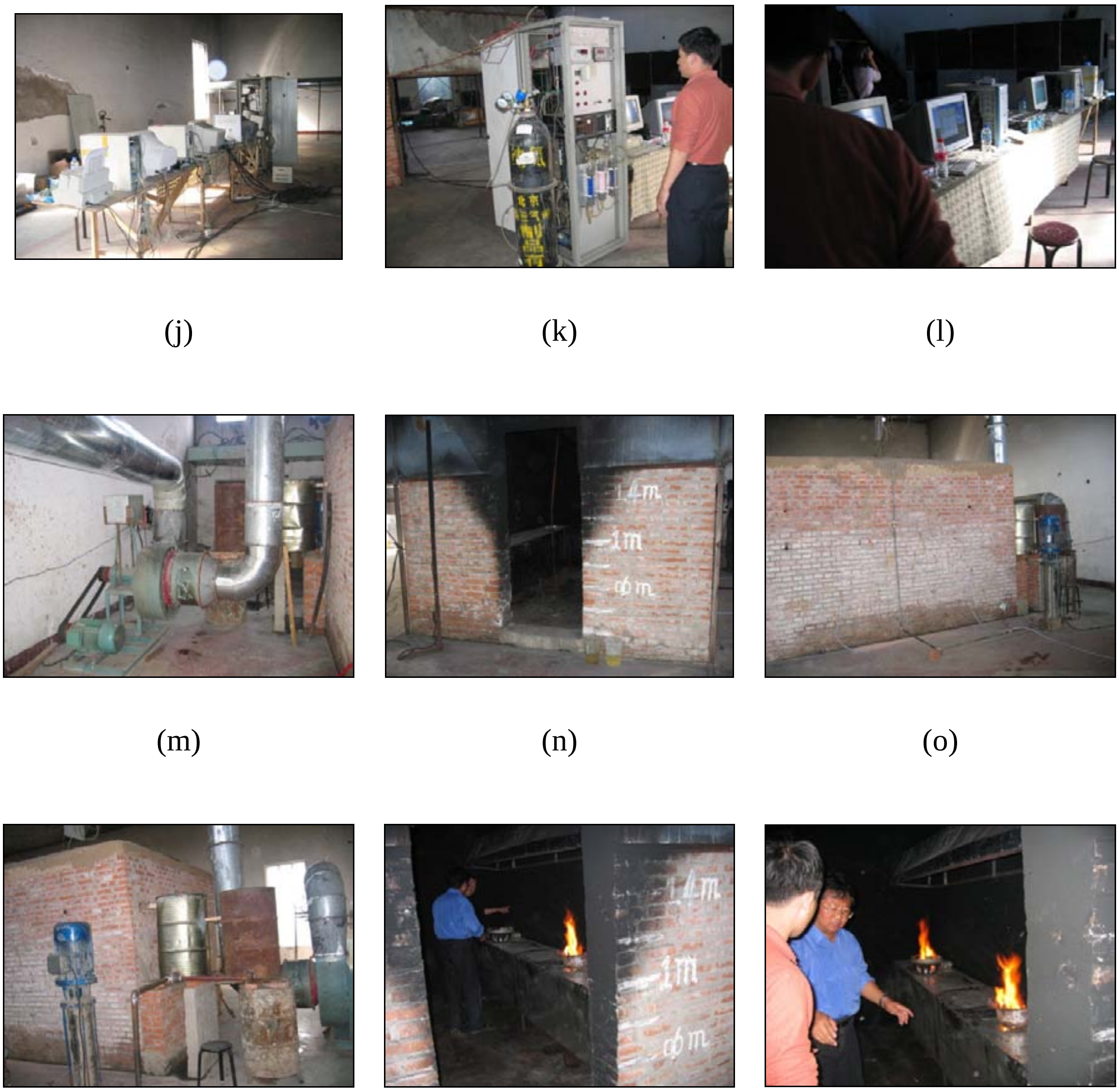
FIGURES

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 7.1: Burning tests of kitchen fires

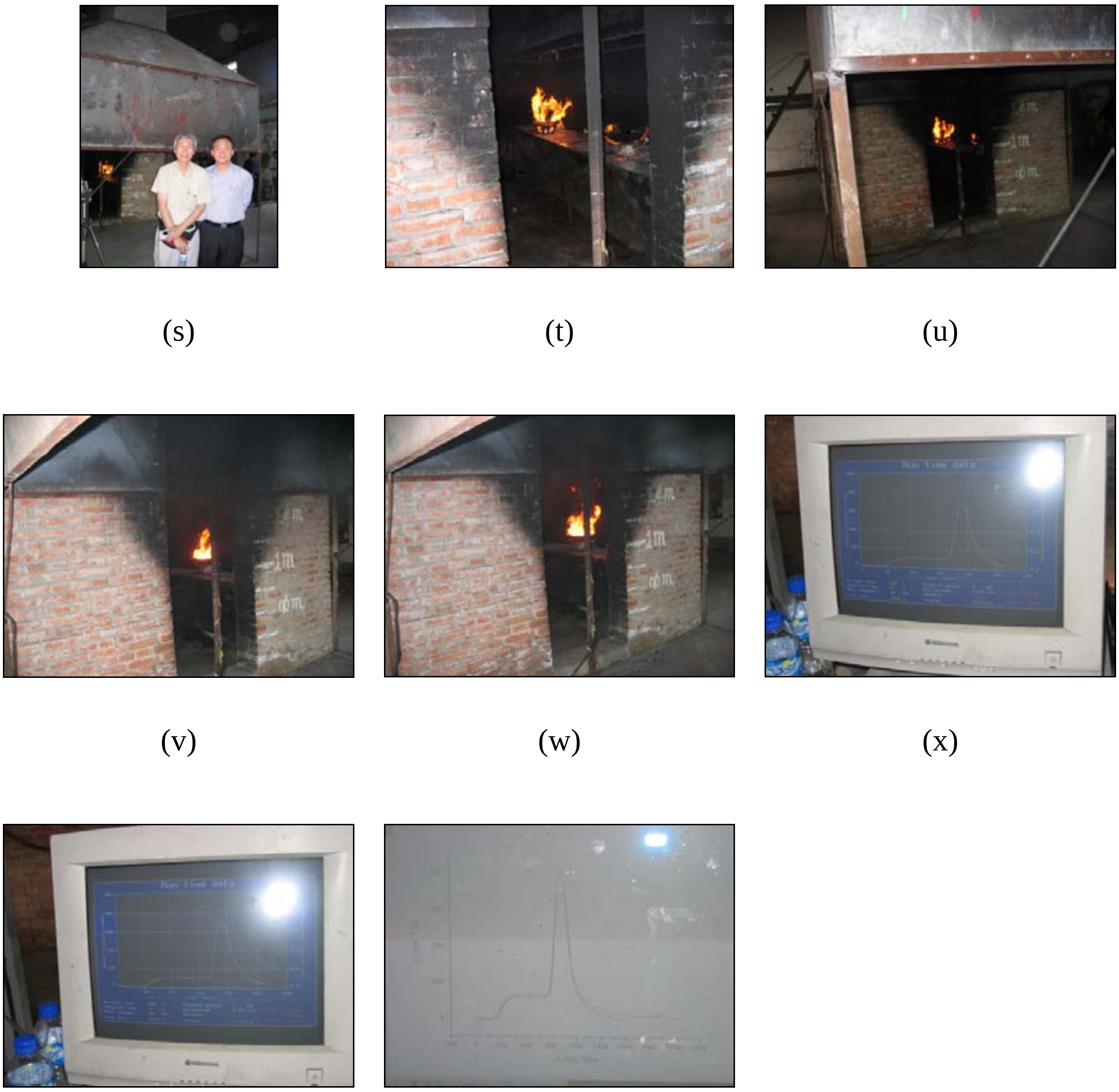


(j) (k) (l)

(m) (n) (o)

(p) (q) (r)

Figure 7.1: Burning tests of kitchen fires



(s) (t) (u)

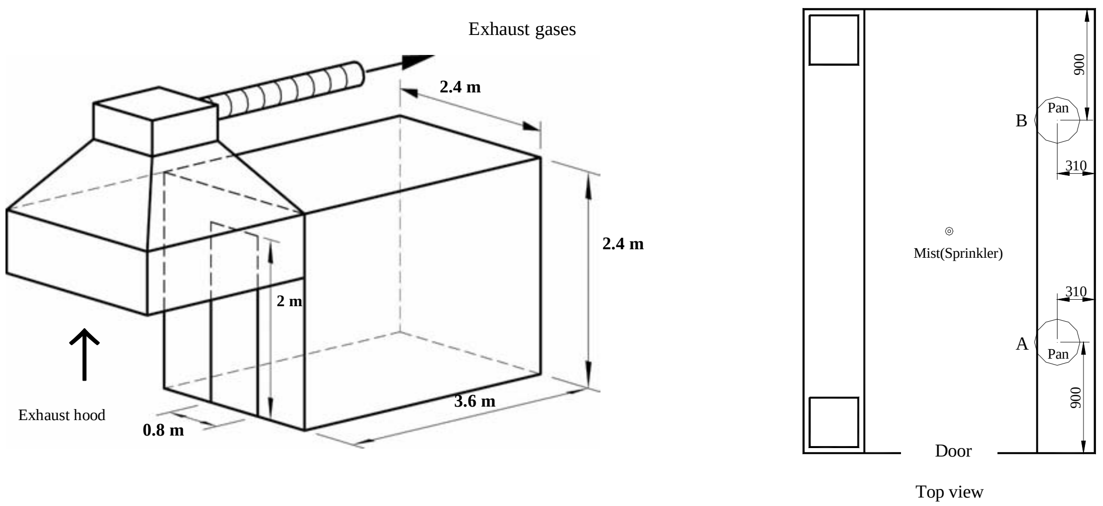
(v) (w) (x)

(y) (z)

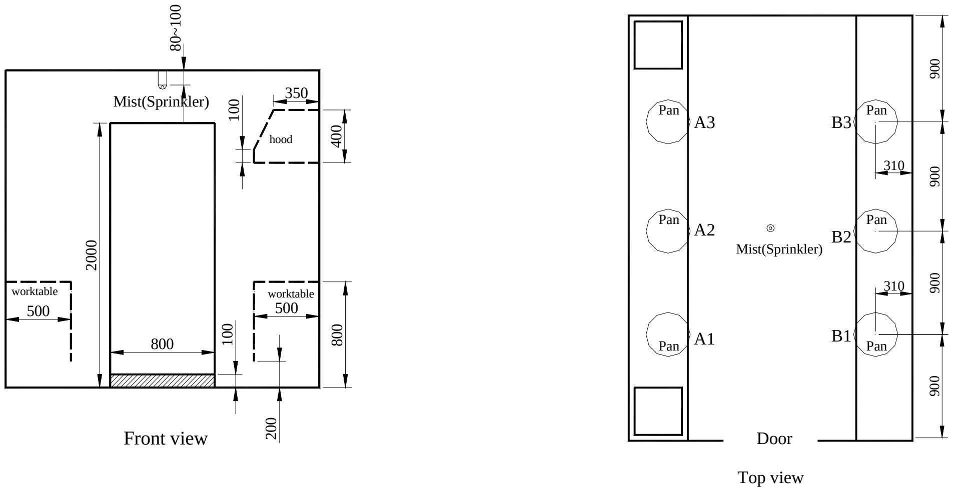
Figure 7.1: Burning tests of kitchen fires

(a) Staff canteen kitchen (b) Banquet kitchen with 6 woks

Figure 7.2: Hotel Chinese restaurant kitchens tested



(a) The room (c) Scenario A



(b) Front view (d) Scenario B

Figure 7.3: Model kitchen

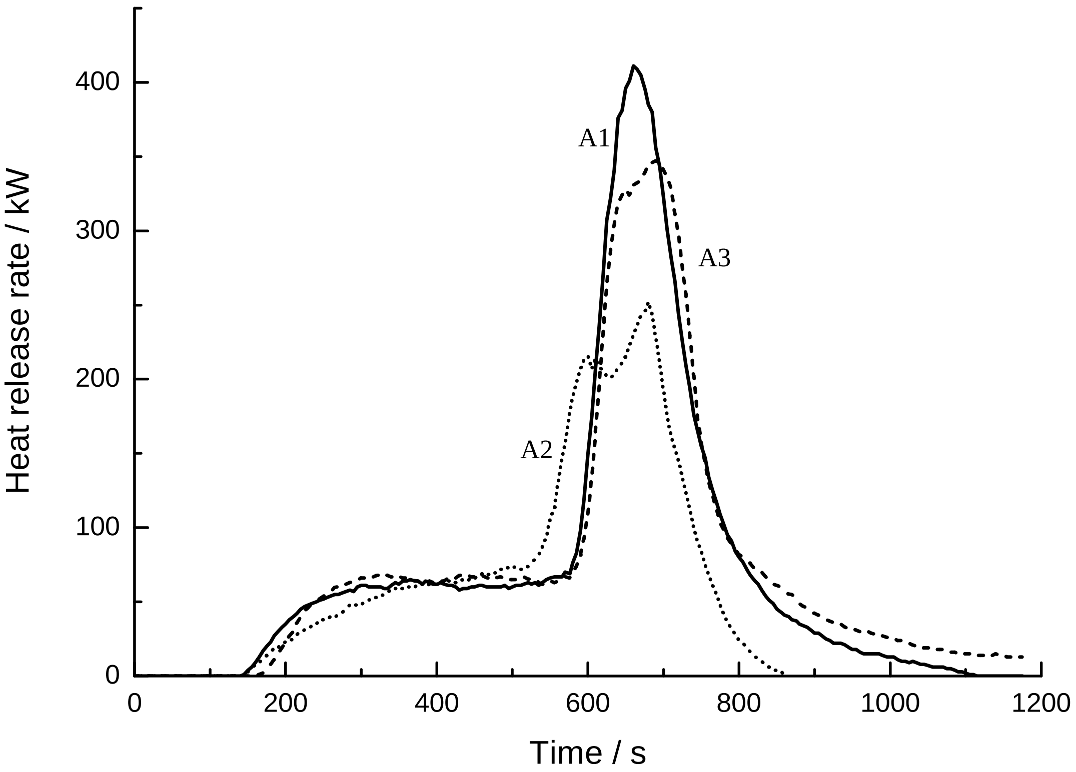


Figure 7.4: Heat release rates of testing group A on a staff canteen kitchen arrangement

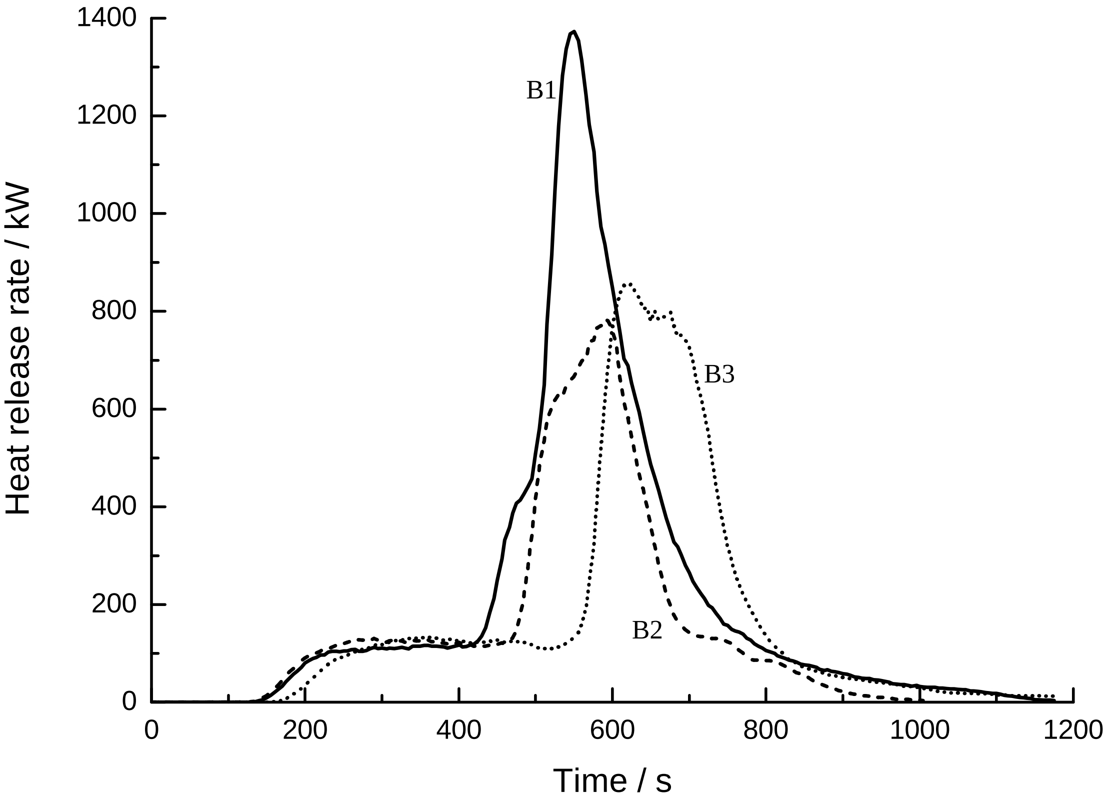


Figure 7.5: Heat release rates of testing group B on a banquet kitchen arrangement

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

(j) (k)

Figure 8.1: Heated wind tunnel test for fusible links

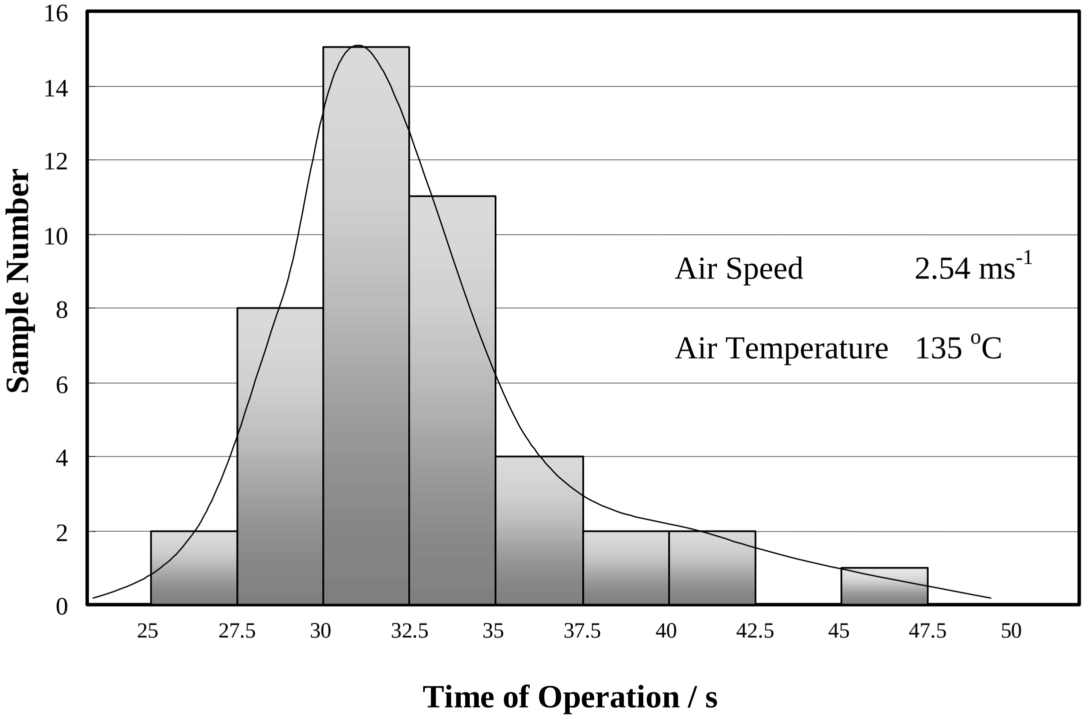


Figure 8.2: Activation times of fusible links

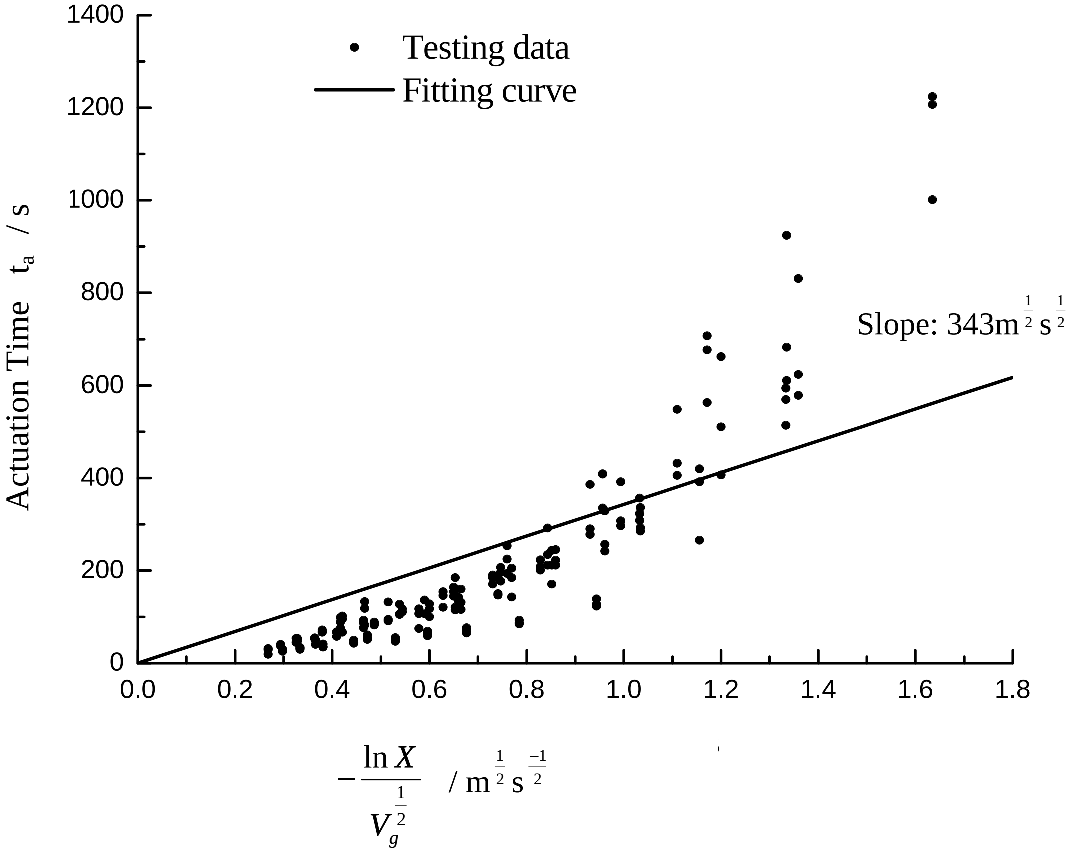


Figure 8.3: Activation times of fusible links at various air speeds and temperatures

APPENDIX A MAJOR TASKS OF THE FIRE SAFETY MANAGER

For daily task or normal mode of operation includes:

- To manage the maintenance and monitor the equipment performance;
- To carry out routine maintenance and testing of all emergency equipment;
- To ensure that all existing or new sets of codes or regulation are being satisfied;
- To control the building contents and keep dangerous good within licence limits;
- To maintain escape route and practice good housekeeping;
- To record all near miss fire incidents and happenings;
- To maintain and keep the emergency plan, in particular the evacuation plan;
- To communicate, liaise and have a working relationship with local and external fire brigade;
- To have plans on fire drills and train staff at all disciplines;
- To have continuous safety systems reviews and risk assessment, especially in case of renovations or refurbishment planned;
- To organize and plan independent safety audits and inspections;
- To maintain the access for the disabled and their escape during emergency;
- To have strict fire safety practices to be followed by contractor working in the hotel;
- To monitor and control the refurbishment in the hotel and its effect on fire safety;
- To record any building changes that may affect fire safety and evacuation; and
- To assess potential environmental impact of fire.

However, in case of fire and in emergency mode [Chow and Lui, 2001], the fire safety manager should:

- Initiate first aid fire fighting in case site conditions allow;
- Communicate and manage and assist local fire brigade in fire fighting;
- Manage all the control room operations, including fire, security and engineering, etc.;
- Initiate and ensure that all the active fire protection systems are working;
- Switch off non-essential equipment;
- Control the crowd, mastering occupants and assist in organizing evacuation;
- Take care of the disabled occupants in case of evacuation; and
- Record the whole emergency process and rectify any actions that might disrupt the efficiency during the emergency mode.

APPENDIX B FIRE SAFETY MANAGEMENT PROGRAM IN A HOTEL

In this section, the elements that will form an effective fire safety management program in a hotel will be outlined. Moreover, it will be stated in an organized and orderly way on how to develop an effective hotel fire safety management program so as to ensure human life and asset property safety. First of all, how a leading international chain hotel in Hong Kong develops and implements their fire emergency and fire safety management program will be outlined below.

The general fire instruction for all hotel staff is to keep calm and do not panic. Panic will certainly lead to disaster and remaining calm will certainly save lives. Any staff member discovering a fire or seeing any smoke or smelling burning should:

a. Raise the alarm immediately by breaking the glass of the nearest alarm. Telephone the hotel security control on the pre-assigned number and tell them the staff identification, and the exact location of the fire. If possible, the staff should also mention the nature of the fire, e.g. curtain on fire in a guestroom, cooker-hood on fire in the kitchen, computer short-circuit set light to paper on desk, etc.

b. Assist in fighting the fire if condition allows. Without putting oneself in danger, one quick attempt should be made to put out the fire by using the nearest available fire extinguisher or hosereel. In the kitchen area, at the same time all gas supply valves for ovens and stoves should be turned off, and electrical appliances should be switched off.

c. Close all doors and windows if the fire grows beyond control and leave the fire scene immediately; stand by at a safe distance and wait for the arrival of senior staff or fire fighting brigade and remain calm.

d. Keep all journalists and photographers away from the fire location, victims, and evacuees. There is always intense media interest in a fire at a five-star international chain hotel, whether or not there are any casualties.

It is the responsibility of the hotel management to avoid the occurrence of fire and the following prevention plan or guidelines for the hotel staff are proposed:

a. Never smoke in the hotel, particularly in non-smoking areas.

b. In areas where smoking is allowed, make sure that matches are extinguished before discarding them. Never throw cigarette ends or matches directly into waste paper baskets. Make sure that smouldering cigarettes and tobacco are not left unattended.

c. Keep heater to be at least two feet away from any furniture and curtains; and housekeeping or staff members to switch off heaters when leaving the room.

d. As previously mentioned, electrical safety is of prime importance. Do not overload any electrical circuits. If a multi-plug has to be used, consult the hotel technical department for technical advice.

e. When leaving the workplace, make sure that all electrical appliances are switched off.

f. In accordance with the Dangerous Goods licence requirement, excess material of a flammable nature should not be stored in the workplace, e.g. paraffin, solvents and gas cylinders.

g. Ensure that all electrical installations and wiring are properly connected and installed by a qualified electrician.

h. Conduct training to all hotel staff so that they know the locations of the nearest fire extinguisher, hosereel and breakglass alarm and also how to operate them.

i. Know the fire exits and escape routes to outside the building together with the assembly point in case of evacuation.

j. Ensure that all the fire exits in the hotel are not obstructed or jammed and the fire doors can all be opened.

In the following, recommended actions are outlined for each hotel department when a fire is confirmed:

a. At the telephone department and in the PABX room, the duty telephone supervisor will take charge of the role as the control communication centre. If the PABX room is evacuated, the front office will take over the job. If confirmed to be a real fire, hotel staff present will call at the operator to raise the fire alarm and then proceed to attempt to put out the fire with the nearest fire extinguisher. The operator in charge should call the general manager or resident manager and all main department heads to advise locations and seriousness of the fire. Upon receiving the confirmed fire alarm, the operator should group page "999" meaning Fire. The operator should also inform housekeeping to activate their own paging system (group calling "999"). This paging notifies all page carriers that there is a fire somewhere in the building and all page carriers are to report to their department heads.

b. For the hotel engineering department or the technical services division, the aim always is to locate and put out the fire as soon as possible, with minimal disturbance to the hotel guests or clients and to prevent panic and chaos.

The telephone operator in charge or security controller will immediately contact the duty engineer when a fire alarm is activated or when advised by an individual that there is a fire. The controller should give as much details as he has to hand about the fire to the Duty Engineer, who will immediately go to the fire scene carrying a walkie-talkie. As soon as he arrives at the fire scene, he will confirm the exact location and whether it is a false alarm, the fire is under control, or whether the fire appears to be out of control. If it is a false alarm or the fire is put out, the duty engineer will reset the alarm, advising the security controller or telephone operator when this has been done.

When the fire has been extinguished, he will complete a full written report on building and plant damage to be passed to the general manager.

The input from the security controller is also very critical. His responsibility is to locate and put out the fire as soon as possible, with minimal disturbance to the hotel guests or clients and to prevent panic and chaos. If a direct call by the hotel employee discovering the fire is made to security control, the controller will inform the exact location of the fire to the duty engineer and PABX supervisor.

The security controller will immediately dispatch the nearest patrolling guard to report on the state of the fire and if necessary, attempt to put out the fire while waiting for the arrival of the duty engineer. If the fire is confirmed and is still out of control, the security controller will call out the fire fighting team, advising them on the location and size of the fire. He should alert all guards that a fire emergency is in progress and the location of the fire. He will send a guard to the entrance of the hotel drive to show the emergency services the best approach and the location of the fire. Moreover, he should ensure that approach roads are kept clear and any access gates are opened and guarded where necessary. However, if the fire is in the guest floor areas, the security controller should call security guards to confirm floor attendants. Hotel guests on one floor below and two floors above the fire floor may be required to evacuate. The guards will then stay in the area of the guestroom that has been evacuated to ensure that no unauthorized person enters. They will also advise control if the fire breaks out in the guestroom and into the lift lobby prior to the arrival of the fire fighting team or fire department.

If the fire breaks out in the guestroom and into a lift lobby or smoke affects the lift shafts or public areas, they should advise the controller immediately by walkie-talkie, any movement in the building should then be by stairs only.

On the other hand, if the fire is in the hotel restaurants, if available, as many guards as possible should be sent to the restaurant concerned without detracting from other security requirements. Guards should maintain the security of the restaurant, ensuring no unauthorized entry of persons. Once the evacuation has been completed, no person is allowed into the restaurant until cleared by the fire fighting team, the fire department, the security manager or the general manager.

If the fire is in the hotel shopping arcades, shops on either side of the fire must be immediately advised on the possible danger. If these shops are closed, the key holders must be advised immediately. Two guards must be sent to the area of the fire to ensure no looting takes place following the sounding of the alarm. When the fire has been extinguished, a guard should remain in the area of the shop until relieved by the shop manager. At the same time, all guards are advised that the emergency is over. Where necessary, post guards over empty or damaged property if it cannot be secured from possible entry of unauthorized persons (including staff members, unless authorized by the security manager or the hotel manager).

The in-house hotel fire fighting team aims to locate and put out the fire as soon as possible, with minimal disturbance to the hotel guests and clients and to prevent panic and chaos. The fire fighting team will consist of the duty engineer (team leader) and three trained members of each shift duty. Three persons will be nominated as the fire fighting team at the beginning of each shift by their shift supervisor, one from the engineering department and two from the security department.

When a fire is discovered in the restaurant, any hotel staff members should raise the alarm immediately by breaking the glass of the nearest alarm. He should also telephone the PABX supervisor and tell the supervisor his name, the event location of the fire and the nature of the fire; curtains and furniture on fire or cooker hood on fire, etc.

Together with the nearest staff, he should make an attempt to put the fire out with the extinguishers or fire blankets on hand. However, do not endanger themselves is the basic principle in handling any fire outbreak.

If the fire is in the kitchen, all supply valves for ovens and stoves should be turned off and electrical equipment switched off. If one is not be able to extinguish the fire, evacuate the kitchen in an organized manner and close all the doors behind. The senior chef should ensure all staff are accounted for and report this to the manager.

The restaurant supervisor should then proceed immediately to the assembly point of food and beverage department and report to the F&B manager that evacuation is complete. He should then pass a list of hotel residents who had evacuated from the dinning rooms to the F&B manager for transmission to the front office manager.

The restaurant cashier with an escort of two restaurant staff should take all cash boxes until relieved by the manager. The last person to leave the restaurant should be the assistant manager and the head waiter who should check that all side rooms and toilets, etc. have been cleared of guests and staff. He should then report the completed evacuation of the restaurant to the manager.

When the fire is discovered in the hotel shopping arcade, the shop staff member discovering the fire should raise the alarm by shouting “Fire”. He should also break the glass of the nearest alarm. He should also telephone the PABX room and tell the telephone supervisor his name, the exact location of the fire and the nature of the fire. He should make one quick attempt to put out the fire with extinguishers on hand. If unsuccessful, close the windows and doors where possible. Turn off any gas supply and switch off electricity at the main, if applicable. He should remain calm and ensure all clients and staff have left the shop before finally closing the front door. He should also advise the neighbouring shops on either side that there is a fire and wait at a safe distance from the shop for the fire fighting team’s arrival. He should not re-enter the shop until he is advised that it is safe to do so by the fire fighting team or fire department or security officer.

If the fire is discovered in the hotel carpark, the hotel staff member should raise the alarm immediately by shouting “Fire”. He should break the alarm of the nearest alarm. He should also contact the PABX room and tell the supervisor his name, the exact location of the fire, and the nature of the fire, car on fire or wood and paper set on fire, etc.

If the fire involves petrol, use the foam fire extinguisher and try to put the fire out. If unsuccessful, move away from the fire. He should stop any carpark client moving closer than 50 m from the fire, explaining the possibility of the car exploding. “No entry” signs are to be placed at the carpark entrance, and a guard should be put on duty at the entrance to enforce this and also to allow the fire department vehicle access to the carpark. Vehicle owners should be persuaded that it may not be safe for them to attempt to get their own cars out of the carpark.

For kitchen staff, he should immediately turn off the gas supply valves for ovens, stoves and switch off all electrical equipment. Moreover, all air-conditioning and exhaust fans should be switched off. On leaving, all doors should be closed. He should report to the food and beverage manager to assist in evacuating diners.

For floor housekeepers, they should inform the room attendants of evacuation order in a calm manner; carry with the floor master key and sufficient chalk to mark crosses on guest room doors when the rooms are confirmed as empty. They should assign room attendants to call on guest room sections by sections. Further assistance will be provided by the room services staff, reception staff, reservation staff and stewards. They should also reassure guests that everything is under control. Furthermore, they have to ensure that guests do not attempt to take with the any bulky luggage. Also, they need to ensure that guests do not attempt to use the lift but proceed in an orderly manner to the designated fire exits. If they might have difficulty going downstairs, provide assistance where practicable. After all the guests have been evacuated, ensure the floor attendants check the end room again. When the check has been completed, chalk a large cross on the door to indicate the room is empty. Finally, make sure all the doors are closed. They have to ensure that they are the last one to leave the guest floor. They should assist and lead the guests to the assembly point via the fire exits; and report to the executive housekeeper that the evacuation is complete.

For room attendants, they should remain calm on receiving evacuation message from the floor housekeeper; carry with the section master key and proceed to knock loudly on guestrooms within their own section. If guests do not respond, they should open the door with the master key and tell the guests that: “There is an emergency. Please follow me to the exit”. Moreover, they have to persuade guests not to carry with them bulky luggage and that it is most likely they will be returning to their room in a short while. They should remember to call each guestroom and assist the floor housekeeper to ensure that all guests have been evacuated. They need to close the door after floor housekeeper has marked the door with a large chalk cross and assist in leading the guests to the assembly point.

For the front office cashier supervisor or outlet cashier, they should lock up records and documents; evacuate cash boxes to the location pre-assigned by the financial controller and report to the management accountant. Two persons maintain guard on the safe deposit room unless ordered to evacuate the lobby.

For stewarding staff, they should immediately report to the executive housekeeper to assist with the evacuation of hotel resident guests.

For front office supervisors, they should assign clerks to stand by at the fire exits to direct guests coming down from floors to the hotel lobby; and direct the guests to proceed to the predetermined assembly area. They have to also furnish the front office manager with an updated guests list by name and room. They have to lead the rest of the clerks to calm the evacuees and provide necessary assistance. They need to stand by for further instructions from the front office manager.

For baggage staff, they should guard the main door to prevent any unauthorized entry, then proceed to the stairwells on the first floor to direct guests to the ground floor level. For concierge clerks, they should assist the front office manager with evacuation of shops within the body of the hotel lobby.

For the contractor and their workmen, they should know exactly what actions to take in the event of a fire. The chief engineer should ensure that the contractors have been advised by their supervisor of the location of escape routes, fire points, fire extinguishing equipment, alarm call points. If appropriate, the instructor must know the telephones from which the fire brigade can be called. The contractor should have received instructions on how and when to inform the telephone operator. The contractor on site should understand the means of raising the alarm and the use of fire extinguishing equipment. Any damage to the fire protection equipment by contractors should be reported to the chief engineer immediately.

For cutting and welding job, the area must be checked by the duty engineer for fire immediately after the work has been finished and also some 30 minutes later. Portable extinguishers and hosereels should be ready.

APPENDIX C EQUATIONS FOR HEAT TRANSFER AT SPRINKLER HEADS

Since it takes time for the thermal sensing element of the sprinkler head to heat up and actuate, a time constant can be defined from the heat balance equation [Chow and Ho, 1990; 1992]:

$$m_e c_e \frac{d\theta_e}{dt} = h_e A_e \left(\Delta\theta_g - \Delta\theta_e \right) - h_{ef} A_{ef} \left(\Delta\theta_e - \Delta\theta_f \right) \tag{C1}$$

If there is no heat lost or gained from the element to the frame and the associated pipework, the heat balance equation can be simplified as:

$$m_e c_e \frac{d\theta_e}{dt} = h_e A_e \left(\Delta\theta_g - \Delta\theta_e \right) \tag{C2}$$

A fundamental time constant τ_e' of the sensing element (isolated time constant) can be defined by:

$$\frac{d\theta_e}{dt} = \frac{\left(\Delta\theta_g - \Delta\theta_e \right)}{\tau_e'} \tag{C3}$$

where $\tau_e' = \dfrac{m_e c_e}{h_e A_e}$

For an isolated thermal sensing element, the time constant depends only on the convective heat transfer coefficient h_e and should be independent of the rate of temperature increase.

If heat loss from the element to the frame is taken into account, Equation (C1) becomes:

$$\frac{d\theta_e}{dt} = \frac{\left(\Delta\theta_g - \Delta\theta_e\right)}{\tau_e'} - \frac{R_e}{R_{ef}}\frac{\left(\Delta\theta_e - \Delta\theta_f\right)}{\tau_e'} \qquad \text{(C4)}$$

$$\begin{cases} R_e = \dfrac{1}{h_e A_e} & \text{(C5a)} \\[2ex] R_{ef} = \dfrac{1}{h_{ef} A_{ef}} & \text{(C5b)} \end{cases}$$

Taking the pipework to be a large heat sink at a constant temperature and ignoring the heat gained from the element, a similar heat balance equation can be obtained:

$$m_f c_f \frac{d\theta_f}{dt} = h_f A_f \left(\Delta\theta_g - \Delta\theta_f\right) - h_{fp} A_{fp} \Delta\theta_f \qquad \text{(C5)}$$

Rearranging

$$\frac{d\theta_f}{dt} = \frac{\left(\Delta\theta_g - \Delta\theta_f\right)}{\tau_f'} - \frac{R_f}{R_{f_p}}\frac{\Delta\theta_f}{\tau_f'} \qquad \text{(C6)}$$

where $\tau_f' = \dfrac{m_f c_f}{h_f A_f}$, $R_f = \dfrac{1}{h_f A_f}$ and $R_{f_p} = \dfrac{1}{h_{f_p} A_{f_p}}$.

Two other time constants can be derived by taking the heat transfer to the frame and pipework into account. They are the collective time constant τ' and the apparent time constant τ''. The collective time constant τ' is a long-term time constant ($\tau >> \tau'$) while the apparent time constant τ'' describes a short-term phenomenon. Both values are useful in determining the characteristics of the sprinkler itself.

The relationship between the isolated time constant τ_e' with the heat transfer coefficient h_e is given by Equation (C3). In forced convective air flow, the Nusselt number Nu is related to the Reynolds number by:

$$Nu = f\,(\mathrm{Re}) \tag{C7}$$

where $f\,(x)$ is a function of any variable x.

Experimental data on the fire environment gives:

$$Nu = B\sqrt{\mathrm{Re}} \tag{C8}$$

where B is a constant related to the geometry of the sensing element.

The Reynolds number is given by:

$$\mathrm{Re} = \frac{lu}{\nu} \tag{C9}$$

Also, the heat transfer coefficient h_e is related to the Nusselt number Nu by:

$$Nu = \frac{h_e l}{k} \tag{C10}$$

Therefore, from Equations (C9) and (C10), the heat transfer coefficient is:

$$h_e = Bk\sqrt{\frac{u}{l\nu}} \tag{C11}$$

The quantity $\frac{k}{\sqrt{\nu}}$ is a property of air and is approximately independent of temperature. It follows from Equation (C11) that for a given sensing element (B and L taken to be constant):

$$h_e \propto \sqrt{u} \tag{C12}$$

since $\tau_e{}'$ is inversely proportional to h_e as shown in Equation (C3), a relationship between $\tau_e{}'$ and $\sqrt{u}$ can be derived:

$$\tau_e \propto \frac{1}{\sqrt{u}} \quad \text{or} \quad \tau_e{}' \sqrt{u} \quad = \text{constant} \tag{C13}$$

The product $\tau_e{}'\sqrt{u}$ is related to the thermal inertia of the heat sensing element which is independent of the gas velocity and temperature. The term ‘Response Time Index’ is defined for this equation:

$$RTI = \tau_e{}' \sqrt{u} \tag{C14}$$

Since the effect of air velocity is included in *RTI*, this quantity is better than the isolated time constant $\tau_e{}'$. However, conductive heat transfer between the element, the frame and the associated pipework has not been included. Therefore, a quantity known as the virtual *RTI* is derived to include the conductive heat transfer:

$$RTI_v = \frac{RTI}{1 + \frac{c}{\sqrt{u}}} \tag{C15}$$

The quantity RTI_v is related to the apparent time constant τ''. This is a parameter measured in the plunge test including conductive heat loss. It is a true measure of the real response time index of the sensing element. Taking the measured response time index to be RTI_v, the value of the real response time index *RTI* can be measured by plotting $\frac{1}{RTI_v}$ against $\frac{1}{\sqrt{u}}$.

Generally, the hot gas temperature increased $\Delta\theta_g$ is related to the time of heating t by:

$$\Delta\theta_g = \beta t^n \tag{C16}$$

Two specific cases are of direct interest. The first is the sprinkler head being immersed in a constant air heat bath (n = 0). The second one is the case with a constant rate of air temperature rise (n = 1). These are the physical principles of two well-known tests: the plunge test and the ramp test. From the two tests, the parameters θ_e and *RTI* can then be derived experimentally.

The plunge test [Heskestad and Smith, 1976, 1980] describes a step function of the air temperature (*n* = 0). Using Laplace transforms and neglecting the heat loss of the frame from the element, Equations (C4) to (C6) give:

$$\tau_e' = \frac{t}{\ln\left(1 - \frac{\Delta\theta_e}{\Delta\theta_g}\right)} \qquad \text{(C17)}$$

where $\Delta\theta_e = \theta_{nom} - \theta_e(0)$.

This can be calculated from $\Delta\theta_e$ and t which are measured in the plunge test, but it is not a true value of the isolated time constant since $\Delta\theta_e$ and t are measured with heat loss.

However, if the thermal losses from the element are considered, an apparent time constant can be derived:

$$\tau'' = \frac{-t_{op}}{\ln\left(1 - \frac{\Delta\theta_e}{k_c\left(\theta_g - \theta_e(0)\right)}\right)} \qquad \text{(C18)}$$

where k_c is related to the conductive heat loss c in view of Equation (C15):

$$k_c = \frac{1}{1+\frac{c}{\sqrt{u}}} \tag{C19}$$

Substituting into Equation (C18):

$$\tau'' = \frac{-t_{op}}{\ln\left(1-\frac{\left(\theta_e-\theta_g(0)\right)}{k_c\left(\theta_g-\theta_e(0)\right)}\right)} \tag{C20}$$

The virtual response time index ***RTI*** can be determined by this apparent time constant τ'':

$$RTI_v = \tau''\sqrt{u} \tag{C21}$$

Experimentally, initial temperature sprinklers are usually kept at the ambient temperature of the test laboratory. The time taken for the sprinkler to operate when it is plunged into a hot air-stream is taken as t_{op}. Combining with θ_e measured in the ramp test, τ'' can then be calculated from Equation (C20).

The ramp or rate-of-rise test describes a constantly increasing air temperature (i.e. $n = 1$). Solving Equations (C4) and (C6), the equation for the ramp test becomes:

$$t_{op} = \theta_E - \frac{\theta_g(o)}{\beta} + \tau' \tag{C22}$$

Rearranging the equation:

$$\theta_g = \beta\tau' + \theta_E \tag{C23}$$

The mathematical expressions for θ_E and τ' are very complicated but they can be determined by plotting Equations (C22) and (C23). Experimentally, a sprinkler is immersed in an air-stream with the temperature increasing at a constant rate of β ^{o}Cmin^{-1}, the temperature of the hot gas at the time of operation is θ_g.

The quantity θ_E appeared due to the conductive heat loss from the sensing element to the frame. In view of Equations (C18), (C19) and (C20), θ_E is related to the conductive heat loss constant c by:

$$\left(1+\frac{c}{\sqrt{u}}\right)\frac{\theta_{nom}-\theta_E(0)}{\theta_g-\theta_E(0)}=\frac{\theta_E-\theta_g(0)}{\theta_g-\theta_E(0)}$$

Hence

$$\theta_E=\left(1+\frac{c}{\sqrt{u}}\right)\left(\theta_{nom}-\theta_E(0)\right)+\theta_g(0) \tag{C24}$$

Therefore, plotting the graph of θ_E against $\frac{1}{\sqrt{u}}$ should give a straight line.

APPENDIX D CALCULATION FOR MINIMUM HEAT RELEASE RATE FOR FLASHOVER

Minimum heat release rate $\dot{Q}_{mf}$ (kW) for flashover with V_{ef} was proposed by Thomas [Chow et al, 2003c]:

$$\dot{Q}_{mf} = 378\ V_{ef} + 7.8\ A_T \tag{D1}$$

where V_{ef} is the ventilation factor and A_T is the effective area of the test chamber

Hence,

$$\dot{Q}_{mf} = 378\ (0.8)\ (2)\ (2^{\frac{1}{2}}) + [2\ (6)\ (2.4) + 2\ (3.6)\ (2.4) - (2)\ (0.8)]$$

$$= 1202.2\ \text{kW}$$

The heat release rate of test kitchen exceeds the minimum heat release rate calculated.

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