A FEW ISSUES ON DEVELOPING PERFORMANCE BASED FIRE SAFETY CODES

L. Zhao
Ove Arup and Partners Hong Kong Limited
Level 5 Festival Walk, 80 Tat Chee Avenue, Kowloon Tong, Hong Kong

(Received 27 December 2000; Accepted 2 November 2001)

ABSTRACT

In the past decades, significant progress has been made in both fire science and human behaviour science. This together with the advance of computer technology and the development of computer tools for fire, smoke and human simulation lead to the creation of a new engineering field "Fire Engineering". It is now recognised in many countries by the authorities to use a fire engineering approach for building designs, especially for large complex buildings. However, in many cities and/or countries there is no legislation or building code to endorse the use of fire engineering.

It is generally recognised that a fire engineering approach can provide, but not limited to, the following benefit:

- Better functionality and layout of buildings
- Improve architectural appearance
- Encourage technology innovation
- Enhance competitiveness of local industry
- Ensure fire safety of large and complex buildings
- Reduce overall building cost

A building code to endorse the use of a fire engineering approach will have to be performance-based as performance is the first principle in a fire engineered design. Such a code is often called a performance-based fire safety code. This paper will present and analyze a few issues in the existing fire safety codes in Hong Kong and give some insights to the development of new performance based fire safety codes.

1. INTRODUCTION

Fire engineering is a relatively new engineering field which has attracted significant interest in the past few years. It is based on fundamentals of material science, combustion science, fluid mechanics and human behaviour science etc. for practical engineering designs. The modern computer technology has also provided much needed support for the easier use and understanding of fire engineering principles and for engineering designs.

Benefits of using a fire engineering approach include:

- Better functionality and layout of buildings
- Improve architectural appearance
- Encourage technology innovation
- Enhance competitiveness of local industry
- Ensure fire safety of large and complex buildings
- Reduce overall building cost including both initial investment and future maintenance cost

Whilst the benefit of fire engineering approach has been very well recognised, the use of such an approach has not yet been standardised and there are no regulations endorsing such a use in many countries. Often it is entirely to the discretion of the local authority as to whether they wish to accept such an approach and the judgement used may vary from person to person and from city to city even though the building code is the same. The aim of developing performance based codes is to overcome this problem by providing a uniform regulatory framework as the basis for fire engineering practice.

In the past decade, performance based codes have been developed in a few countries such as Australia [1] and New Zealand [2]. Performance based codes set out performance requirements and usually do not pose restrictions on how these requirements can be met although such a code may give examples of code compliant and alternative solutions to provide guidance for the use of the code. Alternative solutions are also called fire engineering solutions.

Performance requirements therefore form an important part of a performance based code. It has been recognised that performance fire safety requirement is best determined based on fire risk [3]. It is therefore important to understand different categories of risk and then to determine appropriate risk criteria for various building types. It is also necessary to review the existing prescriptive codes to find out the underlying principles and to make them explicit, and further to examine closely whether these underlying principles are appropriate. This paper will therefore focus on risk classifications and examination of existing building fire safety codes in Hong Kong. It is not the intention of this paper to examine all the details of the Hong Kong building fire safety codes, instead it is intended to only point out the types of problems which may need to be resolved.

2. RISK CLASSIFICATIONS

2.1 Introduction

Risk can be classified into many different ways. The following risk classifications or concepts are useful in the understanding of risk:

- Voluntary risk and involuntary risk
- Generic risk and specific risk
- Absolute risk and comparative risk
- Accepted risk and acceptable risk
- Individual acceptable risk and societal acceptable risk
- Potential risk and actual risk
- Public risk and private risk

2.2 Voluntary Risk and Involuntary Risk

For people who go for certain type of activities which may have a higher than normal risk, if they are well informed of the associated risk, and their decision to carry out such an activity is purely based on their own personal interest, then they are voluntarily exposed to the risk. For instance, people engage in rock climbing, boxing and horse racing are often voluntarily exposed to the associated high risk. If people are not aware of the risk or they have the obligation to take the risk, then they may be exposed to the risk involuntarily. An example of fire risk is that people who work in a petrol station can be regarded as being exposed to an involuntary risk, while people who visit the petrol station for their own interest excluding commercial activities are voluntarily exposed to the fire risk of the petrol station.

2.3 Generic Risk and Specific Risk

Risk can be classified into many different categories, such as financial risk, traffic accident risk, fire risk and health risk. In each of these categories, it may be further classified into smaller and more specific risk, for instance, risk of having heart disease, prostate cancer and high blood pressure. For fire risk, it can also be classified into different categories, such as fatality risk, injury risk, property risk, environmental risk, business continuity risk and business image risk. For different buildings, different risks have different importance. For instance, for residential buildings, fatality risk and injury risk (i.e. life safety) is often the primary concern; for oil production facility, environmental risk is often a significant, if not the primary, concern; for power stations, business continuity is often an important issue. A performance based code needs to address these different risks properly for different types of buildings.

2.4 Absolute Risk and Comparative Risk

Statistics can give a good indication of the risk level. Such a risk is often called an absolute risk level. In many risk assessment analysis, conservative assumptions are made for various reasons, thus the obtained risk level from such a risk assessment will not be the same as the absolute risk level. Such a risk result is however useful in comparative terms, that is, if the same assumptions are used for all the designs, then the obtained risks can be compared and the best design can be chosen.

The debate between absolute risk and comparative risk has been existed for some years. The supporter of using absolute risk as the criterion for design purpose stresses that "comparison method does not force regulators or politicians to analyze risk in a more societal sense" [4], that is, analysis of risk reduction and its associated cost is a difficult task as the risk is not a "real" risk. This gives difficulty to the regulators in the decision making process.

The supporters for using comparative risk as the risk criterion for design purpose believes that the lack of specific data and often prohibitive task of analysing a very large number of scenarios makes reasonable determination of absolute risk difficult [5], and hence relative risk is the only viable option.

It is believed that both methods will co-exist for some time as part of natural development process. Two principles should also be used in the decision making process, namely, ALARP (as low as reasonably practical) and ARAP (as realistic as possible). The ALARP principle has been widely used, as to how low is reasonable is subject to a broad societal view. The ARAP principle aims to overcome the disadvantages of both absolute risk analysis and comparative risk analysis. The principle requires that any assumption must be conservative, however it must be realistic and as close to the reality as possible. Many assumptions used in the practice of fire engineering worldwide are overly conservative. Such assumptions maybe appropriate in many cases for deterministic analysis, but they should not be used for probabilistic risk assessment.

With the ARAP principle, the final risk result will be reasonably conservative, both absolute risk criterion and comparative criterion will be meaningful.

2.5 Acceptable Risk and Accepted Risk

The term "acceptable" is more debatable than "accepted". A question which is often raised in relation to "acceptable" is acceptable to whom? As fire risk or any other type of risk is only part of the life problem, the acceptable criterion can be widely different from person to person. Even on social group basis, the acceptable risk is different from one group to another. The term "accepted" is different, one may believe that the risk is not acceptable, but he or she has to accept the risk.

Fig. 1 shows the British Standard DD240 [6] individual fatality risk and the region where the ALARP principle should apply. Other criterion such as multi-fatality criterion should also be included. According to DD 240 Part 1, individual fire risk at home is 1.5×10^{-5} and elsewhere is 1.5×10^{-6}, the risk for more than 10 fatalities is 5×10^{-7} and for more than 100 fatalities is 5×10^{-8}. Since there is no outrageous outcry in the community regarding the existing fire safety for most of the buildings, it may be concluded that the community generally accept the current fire risk level. However, are the current risk levels the same as what published in DD240? A conservative estimate of the actual fire fatality risk to metro rail passengers shows that the overall risk to life for metro rail is in the region of 10^{-9} to 10^{-10} per year [7]. A study by Scott and Zhao [8] also found that individual passenger fire fatality risk is predicted to be approximately 2.3×10^{-9} per trip for a trip of around 10 km on a Hong Kong Mass Transit Railway (MTR) where most of the line is underground tunnels. However public transport facilities are considered to be special facilities where the general requirement is far much higher than that for ordinary building. Accordingly, the DD240 risk criteria should only be used as risk criteria for ordinary buildings. A risk level of less than 1% of the minimum accepted risk for ordinary buildings other than homes ($\sim 10^{-6}$), i.e. $< 10^{-8}$, may be considered as a reasonable criterion for special facilities such as transport facilities, and an even higher criterion should be used for distinguishably important facilities such as nuclear power plant.

For any building and particularly special facilities, the consideration for risk criteria should include a principle which refer to "as low as reasonably practical" (ALARP). The so called reasonably practical often means cost effectiveness. For instance, a study of cost effectiveness of automatic door closers for aged care accommodation by Zhao et. al [9] concluded that each door closer has a cost per life saved of over \$US10 million. Cost per life saved is defined as the cost for installation plus the maintenance cost divided by the number of lives which can be saved as a result of the installation. Cost per life saved for single stationed smoke alarms, i.e., smoke detector plus an alarm in a single unit, was found [9] at between \$A0.95m and \$A3m (\$US0.5m – 1.5m). This is compared with \$A1m (~US\$0.5m) for Australian Radiation Laboratory and \$A0.625m (~\$US0.32m) for the Federal Office of Road Safety and National Road Transport Commission in circumstances that involve placing a value on per life saved [10].

2.6 Individual Acceptable Risk and Societal Acceptable Risk

Since individual acceptable risk can be vastly different from one another, how to determine the societal acceptable risk? Who should determine such a risk level? Can regulators represent the best interest of the society and define the acceptable criterion properly? What factors should the regulators take into account? What is the impact of unable to define a proper criterion? Will it cause social unrest? These questions must be answered before making a final decision.

Consultation process is one of the commonly accepted approaches for making a regulation. Views from different groups can be often reasonably reflected during the consultation process. The process should include the following elements:

- examine the impact of any new regulation or change of regulation on the existing buildings and future buildings
- examine the appropriateness of the objective and acceptance criterion

Agreement from majority if not all parties have to be secured before a new regulation can be put in place.

2.7 Potential Risk and Actual Risk

Perceived high risk is not necessarily actual high risk. Petrol stations are often perceived to have a higher risk than traffic accident risk. However the actual risk of petrol stations is in fact lower than traffic accident risk. This is because extra measures and technology innovations have substantially improved the situation. Nowadays explosion in a petrol station is an extremely rare event due to explosion prevention technology. Extra measures including public awareness, reducing ignition sources etc. have significantly reduced the chance of having such an incident. Therefore any actual risk should not be isolated from the actual safety and security measures that have already been put in place. Any variation to the existing fire safety measures may dramatically increase the fire risk if the potential risk is high.

Another example is a comparison between liquor and sofa. Obviously liquor is more likely to catch fire and cause fire to spread. However when they are packed in bottles, which is usually the case in a shop, and placed in a shopping complex, the chance of having a bottle being broken and at the same time catching a fire is very unlikely. Any arsonist is unlikely to choose this form of fire as it is too obvious and the tight security means that the arsonist is very likely to be caught. Perhaps then the more likely chance but with an extremely low probability is to have a terrorist attack. It should be noted that terrorists are also unlikely to choose such a form of attack as the damage is unlikely to be significant enough. For sofa, however, it is perhaps more likely to attract arsonist as a smouldering material can be relatively easily placed in a hidden matter and the arsonist can run away without being identified. This indicates that the same material in a different form or package and in a difference place may have a different fire risk. Hence things perceived to have a high risk because of its material property may not be valid.

Various countries have their own regulations regarding materials such as Hong Kong FSD Notice Dangerous Goods General [11]. These ordinances classified materials according to their material properties, and not related to how the materials are packed or where they are placed.

A recent publication by Wolski et al. [12] discussed how to accommodate perceptions of risk in the development of performance based building code.

2.8 Public Risk and Private Risk

Public risk and private risk are easier to distinguish in certain types of risk such as health risk. If someone has a risk of having high blood pressure due to obesity, then such a risk is solely a private risk. On the other hand, if someone has a disease which may transmit to the public, then it is a public risk. In a fire situation, if someone commits suicide using a fire, and if the fire and smoke does not spread to other areas, then such a fire risk can be classified as a private risk; otherwise it is a public risk. Another commonly accepted definition is that any risk in a private property is considered to be a private risk, and that in a public place is a public risk. If a private property is within a public place, such as a flat, then the risk inside the flat is private risk, and that in the public corridors, stairs etc. is a public risk. However in such a case, a private risk may result in a public risk, for instance, fire or smoke spread from a flat into other public areas or other flats.

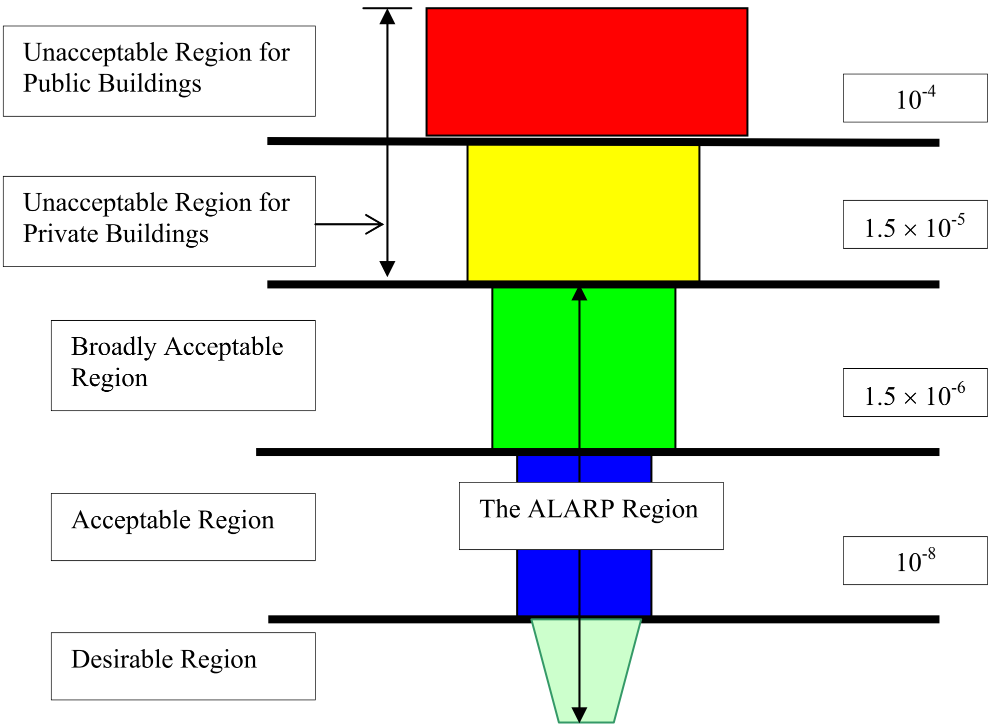

Fig. 1: Fire risk criteria in accordance with DD240 and the ALARP principle

It is important to distinguish private risk and public risk as people often have different risk criteria and hence different expectations for these two types of risk. It is commonly accepted, for instance, sprinklers are not required for high-rise flats in Hong Kong, but sprinklers are required to be installed in high-rise offices and even low-rise offices. This is in part because at home, accidents including fire accidents are often related to the occupants' activities. Thus ultimately if any accident occurs, they are suffered from their own activities. On the other hand, if fire and smoke are spread from other areas, people may be innocently exposed to the risk. Hence people have a higher expectation for public risk, that is, public risk should be lower than private risk.

Similarly when people come to office to work, they have a high expectation that any risk in the work environment is low unless they are involved in high risk jobs for which they must be well informed.

3. REVIEW OF EXISTING REGULATIONS

3.1 Issues Related to Existing Codes

Review of existing codes/regulations is an important part of developing any new codes/regulations. The areas for improvement need to be identified during the review. The following gives typical deficiency of the existing codes/regulations:

- Conflict between the fire safety codes and building regulations
- Undefined terminology in existing codes
- Ambiguous or unclear explanation
- Qualitative terms versus quantitative terms
- Design fire and design person
- Single risk criterion or multiple risk criteria

3.2 Conflict between the Fire Safety Codes and Building Regulations

For instance, the Hong Kong Building Construction Ordinance requires that each corridor to have the same width as the staircase. However the Hong Kong Means of Escape (MoE) code [13] minimum requirement is different for corridors and staircases. A design satisfying the MoE may not necessarily satisfy the building construction ordinance, and vice versa. This may create a potential conflict between the fire safety codes and building regulations. To avoid the potential conflict, and strictly follow the building regulation, then there should be only one minimum requirement for corridors and staircases. However this may not be the best solution from fire safety point of view as, for instance in this case, the MoE code requirement has a better fundamental support, that is, the requirement for corridors and staircases should be different.

For a low-rise building, for instance a two-storey building with one corridor and one staircase only, the staircase only serves the people on the first floor. The corridor width needs to be the same as that of the staircase. Using a performance criterion for the purpose of evacuation, the corridor width may be slightly narrower than that of the staircase as the travelling speed in the staircase is slower. Any difference in width will make the narrow passage a bottle-neck in the evacuation. For high-rise buildings, the number of corridors and the number of staircases in the building will be very different. Usually the number of corridors is far greater than the number of staircases. Using the flow concept to illustrate the movement of people, if the width of each staircase is the same as each of the corridor width, then the flow in the staircase must travel faster than that in the corridor to maintain the balance of inflow and outflow. This is practically not possible as the travelling speed in the staircase is often slower than that in the corridor because of the difficulty in moving downwards. NFPA 130 [14] recommends a vertical descending speed of 0.3 ms^{-1} for travelling on stairs, this compares a horizontal travelling speed of 1.02 ms^{-1}.

This situation may be different for large complex buildings where phased evacuation is used. The principle of a phased evacuation is to evacuate people on the fire floor and the adjacent floors, usually the floor above first, and then evacuate the other floors progressively if required. In such a case, the congestion in the staircases can be significantly reduced. However it should be noted that phased evacuation is not practical for residential flats and hotels.

3.3 Undefined Terminology

To avoid undefined technical terms in the code. For instance, the term "noncombustible" is not defined in the Hong Kong Fire Resistance Construction code [15]. If it is understood as a non-technical term, then a combustible is defined as being able to "catching fire and burn easily" by the Oxford Dictionary. Noncombustibles can then be understood as "not able to catch fire or cannot burn easily". Such a definition cannot be used as a technical definition as whether a material will catch fire depends on various factors, such as temperature of the ignition source, pressure and exposure time. In the 1920 edition of the National Building Code (US) promulgated by the National Board of Fire Underwriters (NBFU), it was defined as "will not ignite or burn when subjected to fire". In the 1943 edition it redefined noncombustible as "assemblies which do not involve materials of such kind or quantity or so contained as to burn during exposure in a test fire or continue flaming or ignite after the furnace is shut off". Up till that time this technical term has not be well defined.

The first edition of the BOCA Basic Building Code (1950) define a noncombustible material as "any material which will neither ignite or actively support combustion in air at a temperature of 649 °C (1200 °F) during an exposure of five minutes in a vented tube or vented crucible furnace". By then, this technical term is technically well defined.

The 1955 edition of the NBFU National Building Code established a definition for noncombustible material that was subsequently adopted by other model code and most local codes in the US. The adopted definition is that a noncombustible falls in one of the following groups:

a) materials no part of which will ignite and burn when subjected to fire. Any material that liberates flammable gas when heated to a temperature of 750 °C for 5 minutes shall not be considered noncombutible.

b) Materials having a structure base of noncombustible material, as defined in a), with a surfacing not over 1/8 in (1 in = 2.54 cm) thick that has a flame spread rating not high than 50.

c) Materials, other than as described in a) and b), having a surface flame spread rating not higher than 25 without evidence of continued progressive combustion and of such composition that surfaces that would not have a flame spread rating higher than 25 without evidence of continued progressive combustion.

Details of surface flame spread is given by Quintiere [16]. The definition of noncombustible in the British Standard is quite different. BS476: Part 4 is the test standard used to determine whether a material is combustible or not. The exposure temperature is the same as that in many of the US codes, 750 °C, however the exposure time is 20 minutes. The material is deemed to be noncombustible if

1) causes the temperature reading from either of the two thermocouples to rise by 50 °C or more above the initial furnace temperature, or

2) is observed to flame continuously for 10 s or more inside the furnace.

3.4 Ambiguous or Unclear Explanation

The Hong Kong MoE Code [13] explains that a refuge floor is intended to accommodate "10 floors above and 10 floors below". What if there are less than 10 floors above the refuge floor? Should this also be applied to office buildings where the requirement is one refuge floor for every 25 storeys? What it really means is perhaps "half of the total number of floors above the refuge floor and half below". This has to be clearly defined to avoid confusion.

3.5 Inconsistency between Requirement and Underlying Principle

The design of building escape routes is one of the most important design aspects to ensure the life safety of occupants in the building. Alternative means of escape is required for any large room where the maximum travel distance exceeds the code prescribed limit. Definition of alternative escape routes given by the UK Approved Document B [17] is "escape routes sufficiently separated by either direction and space, or by fire resisting construction, to ensure that one is still available should the other be affected by fire". Whilst this is probably universally adopted in principle, the criterion to be satisfied as alternative means of escape varies from code to code. In the US, NFPA code [18] uses a rule referred as the one-half diagonal rule to check the compliance for the alternative escape routes as shown in Fig. 2a. In UK, Approved Document B uses a separation angle between the escape routes of 45^o as shown in Fig. 2b. In Hong Kong (HK), the requirement is defined in the MoE Code [13], which is the same to the UK approach, however, the separation angle is 30^o as shown in Fig. 2c. The underlying principle of the HK code is in fact the separation distance between the escape routes rather than the separation angle between the exit routes. This is explained by the HK code commentaries "when a secondary exit door is required to be provided to a room, it should not be too close to the other exit door, otherwise it will lose its effect as an alternative exit". Thus the one-half diagonal rule and the separation angle requirement have the same underlying principle, i.e., separation distance between the exit routes. But this underlying principle is not the most appropriate criterion for determining alternative means of escape. Detailed discussion will be given in the following section.

3.6 Appropriateness of the Code Requirement

Using the code requirement of alternative means of escape as an example. A close examination indicates that this requirement of having a

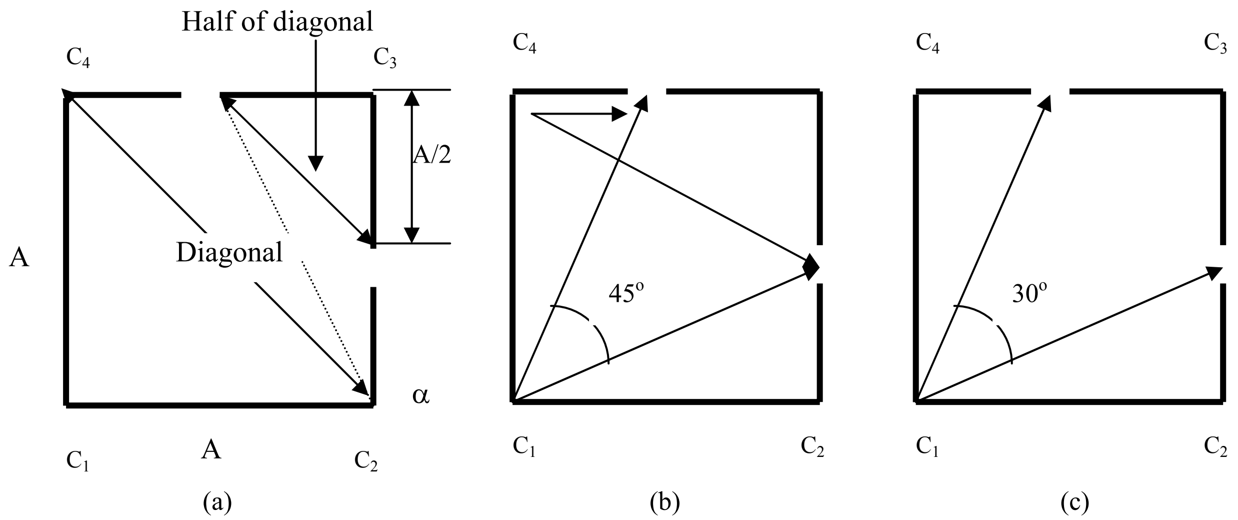

Fig. 2: (a) NFPA diagonal rule (b) UK Approved Document B and (c) Hong Kong MoE Code

separation angle or alike for all three codes mentioned above is not most appropriate. Whether or not an escape route is appropriate to be regarded as an alternative route should depend on whether its tenability condition will be affected when there is a fire blocking the other escape route. Tenability conditions include both smoke condition and heat radiation condition should be considered for defining an alternative means of escape such as "an escape route which can maintain a tenable condition should the other means of escape affected by fire".

The tenability analysis should include both radiation and smoke conditions analysis. Under certain circumstances, it is generally accepted where the occupant response time in a fire room is short, hence the smoke condition is expected to be tenable, radiation heat may be the only performance criterion for examining the appropriateness for the alternative means of escape. This is more of the case when there is a smoke extract system installed which will maintain a smoke clear condition for the escape routes.

The existing code requirements need to be under close scrutiny as the requirements are based on traditional relatively small size and simple buildings. There is no doubt that the experience gained from these buildings over more than one century is very useful. However in order to suit the need of the society for large and complex buildings and incorporate more advanced fire safety systems, the requirements may need to be changed. For instance, the HK MoE Code [13] defines the maximum travel distance as a function of ventilation in the corridor. For ventilated corridor, the maximum travel distance can be extended. This is obviously correct from a fire engineering point of view. However how much the extension of travel distance should be needed to be closely examined as the fire engineering principles may not have been used when the existing MoE was written. In a performance based code, it is not necessary to define a single travel distance value. Instead it may define a performance criterion, for instance a risk-based equivalent time [19], to be achieved.

Another example of performance criterion is for smoke control. Often the prescriptive code requirement is based on volume exchange, such as 6 to 10 air exchange per hour. This requirement may be appropriate for relatively small compartments; for large compartments or high headroom compartments or rooms with special hazards or large quantity of combustibles, such an extraction rate may not be appropriate. This example also illustrates that performance criterion and code requirement are two different things.

3.7 Guidelines for the Compensatory Measures

It is generally accepted that when an additional fire safety installation is given to a building, the level of fire safety will be enhanced. Therefore to achieve the same level of fire safety as when the additional fire safety measure was not given, one or more other fire safety measures may be omitted or the requirement be reduced. For instance, if sprinklers are given to the building as an additional fire safety measure, smoke detectors can be omitted when the fire safety level is kept at the same level or better than before the introduction of the sprinklers. This compensatory approach is often used in practice, however, it is also controversial in many occasions. For instance, when sprinklers are introduced, how much reduction in fire resistance construction can be achieved? What is the impact when one fire service measure is taken out of the "integrated fire protection system" and replaced by another fire safety measure? Various methods are available to give an answer, however, many are subjective based on "expert opinions" or "consensus". Such a judgement or estimate is considered appropriate only when "all else fail …, there is no alternative but to make the best estimates possible" [20]. This can introduce biases depending on personal or institutional interest. For instance, a sprinkler manufacturer may argue that sprinkler reliability is extremely high, and a fire officer may focus on a few of worst fires. A panel of experts may balance the biases if the panel of experts come from different background. An alternative approach is to use a risk assessment model such as FiRECAM [21] and CESARE-Risk [22] which consider the integrated effect of fire growth, fire spread, performance of passive and active fire safety systems and people. Such a model can probably give a more rational answer.

In the existing prescriptive codes, many have already had some compensatory prescriptive measures, for instance, NFPA Life Safety Code [18] allows a longer travel distance for buildings with sprinkler protection, HK MoE Code [13] allows a longer travel distance for ventilated corridors. The rationale behind these prescriptive compensatory measures is quite clear, but these measures have however never been examined quantitatively. An attempt was made [19] to examine the appropriateness of the extended travel distance, and it was found that the NFPA Life Safety Code gives a reasonable agreement with the results obtained from the proposed risk-based time approach. The distances prescribed in the MoE Code were not all examined [19].

4. KEY ISSUES TO BE RESOLVED

4.1 Design Fire and Design Person

The concept of design fire/s has been used for many years. A design fire often is defined as a given heat release rate, either constant or as a function over time. The reason for choosing heat release rate is that heat release rate was found to be the single most important parameter for a fire [23]. Design fire is often the starting point of a fire engineering design where fire development and smoke generation are considered. But fire and smoke is only part of the overall fire safety design. One of the most important elements in the fire safety design is people. Can a similar concept to design fire be applied to people in order to facilitate the calculation of evacuation time? The concept of design person/s has either not been proposed or never been widely accepted. Why? Is it because that it has never been proposed or it has been proposed and quickly rejected? There is no doubt that response of a person is difficult to predict in the event of a fire. However to actually predict the development of an actual fire is also difficult, yet design fire/s has been widely accepted.

4.2 Characteristics of a Design Person

For a fire, the single most important parameter is its heat release rate [23]. For a person in an emergency situation, there is no recognised or widely accepted single most important parameter. Looking into various factors which include response time, health condition, gender, fire fighting skills, familiarity with the building and mobility, it is difficult to determine which ones are the most important factors. However it can probably be concluded that response time and mobility are the most important factors in the vicinity of the fire.

Mobility is closely related to the physical condition of a person, the response time is however related to various factors, such as whether the person is awake or asleep, whether this is a means of detection, what the type of fire (smouldering or flaming) is, the age of the person (the young, adults or the elderly), and the role of the person. All these add complexity to the definition of a design person.

Whilst recognising its difficulty, it is however not impossible to define design person/s for various types of buildings. It is commonly known that in a specific type of building, many of the emergency characteristics are the same, for instance, in an office building, all people are expected to be awake, most if not all people are able to move unaided, all people are also expected to be adults. Thus design person/s can be defined.

It should be noted unlike design fire/s where in any one scenario, there is only one design fire, for design person/s, there may exist more than one type of design person in one fire scenario. Thus design persons may interact with one another. For instance, in a school, there can be teachers and students. In the case of emergency, these two types of design persons will act differently. The interaction between the teachers and students need to be taken into account in the assessment.

Although the term "design person" have not been used, some encouraging work have been done in research and the resulted computer software. One of the software having considered various types of persons in one scenario and interactions between different types of persons is CESARE-RISK [22] in which staff rescue and fire fighter rescue activities were considered. However the capability of handling interaction is still limited, and may not be sufficient for studying the effect of interaction on the overall fire risk. Nevertheless it is already far much better in this regard than many of the other software where the interaction of persons is totally ignored.

4.3 Setting the Performance Requirement Clearly

In the current fire engineering practice in Hong Kong, some factors are recognised and in some cases as reasons to give exemptions to certain requirement, but those factors are not clearly defined, neither quantitatively nor qualitatively, such as good fire safety management. What is the criterion or what are the criteria for a good fire safety management? Must it have a designated fire officer, experienced regular fire safety inspector, 24-hour manned fire control room? How should past fire records be taken into account? Without clearly setting the performance criterion for all related factors, fire engineering practice is a hybrid practice between performance based and prescriptive based practice.

4.4 Single Risk Criterion or Multiple Risk Criteria

In conducting risk assessment, either single risk criterion or multiple risk criteria are used. There appears to have no consensus as to what criterion should be used as well as how many criteria should be used. A single risk criterion is to define a single risk value as the determining limit, for instance, individual fatality risk of 10^{-6} per year. Multiple risk criteria can be a number of criteria, for instance, individual fatality risk of 10^{-6} per year, risk of more than 10 fatalities of 10^{-7} per year and risk of more than 100 fatalities of less than 10^{-8}. Risk criteria may also include injury risk, property risk, such as maximum damage risk, and other risks such as business continuity risk. Multiple risk criteria can also be a combination of different types of risk, for instance, one or more life safety criteria plus one or more property loss criteria.

A single risk criterion has its advantage of simplicity but the pitfall probably overweights the advantage. The main pitfall of a single risk criterion is that the risk value does not necessarily reflect the society's major concern. For instance, using a single risk criterion, 10 fatalities in one fire is considered to be the same as 10 fires where each fire having one fatality. The society tends to have a far greater concern for multiple fatalities than for single fatality. Litai and Rasmussen [24] have suggested that an ordinary risk is 30 times more acceptable than a catastrophic risk. In a recent publication by Wolski et al. [12], it was suggested to use mathematical means to accommodate human attitudes towards risk as a means to adjust maximum code prescribed expected risk-to-life depending on how the occupancy type or building risk is perceived, which is analogous to a proposal by the Nordic Committee on Building Regulations [25], that is, to use human risk attitudes (risk factors) to classify buildings.

One example of multiple risk criteria is a P-N curve shown in Fig. 3, where P is the probability of having the accident, and N is the number of fatalities, injuries, or property loss, loss of business etc. The zigzag line indicates the fatalities/injuries/property loss versus probabilities of occurrence for various different scenarios. (P_1, N_1) is the probability and consequence for scenario one respectively. The risk criteria in the P-N curve are the dark line which has infinite points representing the infinite number of criteria. Risk is represented by both the probability of occurrence and the consequence instead of the product of both. If there is any incident which has a risk level not within the area bounded by the dark line and the axes, then the design fails.

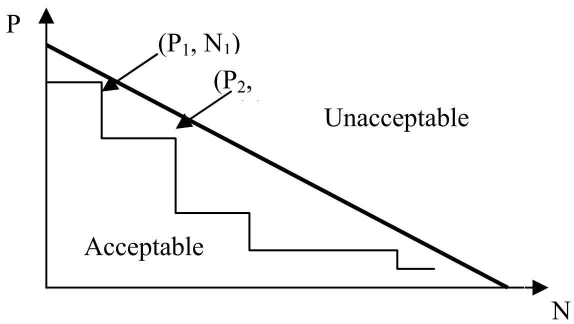

Fig. 3: P-N risk diagram

It is considered that multiple risk criteria such as a P-N diagram can better represent the society's concern, hence it is preferred to be used unless there is a justification that this is too complicate for the design concerned.

5. CONCLUSION

Fire engineering approaches are becoming widely used due to the need of the modern society to build large and complex buildings, to reduce construction cost and to use modern building materials for better architectural appearance etc. Appropriate building regulations and fire codes need to be developed to endorse and guide the use of a fire engineering approach. Such a fire code is usually called a performance based code.

Various issues in relation with the development of a performance based fire code have been discussed in this paper. The discussion is concentrated on three areas, namely, risk classification, review of existing regulations and issues to be resolved for the development of performance criteria based on fire engineering principles. It is obviously not possible to cover all issues related to the development of a performance based fire safety code in one article. Much more work is required before a good performance based code can be written. It should also be noted that not all issues discussed here must be in a performance based code. Some can be in a separate guideline document to facilitate the use of performance based code for fire engineering designs.

REFERENCES

1. Building Code of Australia, Australian Building Code Board, Sydney, Australia (1996).
2. The Building Act 1991, The Building Regulations 1992, New Zealand Government, Wellington, New Zealand (1992).
3. Fire safety and engineering technical papers, The Warren Centre for Advanced Engineering, The University of Sydney (1989).
4. I. Moore, "A case study of fire risk assessment in Australia", SFPE Symposium on Risk, Uncertainty, and Reliability in Fire Protection Engineering, Baltimond, MD, USA, pp. 116-126 (1999).
5. J. Watts, "Index approach to quantifying fire risk", SFPE Symposium on Risk, Uncertainty, and Reliability in Fire Protection Engineering, Baltimond, MD, USA, pp. 39-45 (1999).
6. Fire safety engineering in buildings, Part 1: Guide to the application of fire safety application principle, British Standard DD240.
7. Metro fire risk, Tunnel Management International, April (1999).
8. P. Scott and L.D. Zhao, "Quantitative fire risk assessment", Report no. AFG-HK-042, Ove Arup & Partners Hong Kong Limited, March (2000).
9. L. Zhao, Y. He and V. Beck, "Cost-effectiveness of door closers in a sprinklered residential aged care building", InterFlam '99, Scotland, June (1999).
10. Office of Regulation Review, The analysis and regulation of safety risk, Australian Government Publication Services, Canberra (1994).
11. Hong Kong Fire Services Department, Fire protection notice no. 4, Dangerous goods general, July (1998).
12. A. Wolski, N.A. Dembsey and B.J. Meacham, "Accommodating perceptions of risk in performance-based building fire safety code development", Fire Safety Journal, Vol. 34, pp. 297-309 (2000).
13. Code of Practice for the Provision of Means of Escape in Case of Fire (MoE Code), Buildings Department, Hong Kong (1996).
14. NFPA 130, Standard for fixed guideway transit systems, 1995 edition, National Fire Protection Association, MA (1995).
15. Code of Practice for Fire Resisting Construction, Buildings Department, Hong Kong (1996).
16. J.G. Quintiere, Surface flame spread, The SFPE handbook of fire protection engineering, Section 2, Chapter 14, 2nd edition, NFPA and SFPE (1995).
17. Approved document B, Fire safety, The Building Regulation 1991, 2000 edition, Department of Environment Transport Regions (2000).
18. Life safety handbook, National Fire Protection Association, 7th edition (1995).
19. L. Zhao, "Using risk-based time method to determine the maximum travel distance for building designs", International Journal of Performance Based Fire Safety Codes, To be appeared (2001).
20. J.R. Jr Hall, Produce fire risk, The SFPE handbook of fire protection engineering, 2nd edition, Section 5, Chapter 10 (1995).
21. D. Yung and G.V. Hadjisophocleous, "Cost-effective fire safety retrofits for Canadian government office buildings", First International Symposium on Engineering Performance-Based Fire Codes, Hong Kong, pp. 58-66 (1998).
22. L. Zhao and V. Beck, "The definition of scenarios for the CESARE-Risk Model", Proceedings of the Fifth International Symposium on Fire Safety Science, Melbourne, Australia, International Association for Fire Safety Science, March 1997, pp. 655-666 (1997).
23. V.B. Babrauskas and R.D. Peacock, "Heat release rate: The single most important variable in fire hazard", Fire Safety Journal, Vol. 18, pp. 255-272 (1992).
24. D. Ritai and N. Rasmussen, The public perception of risk, The analysis of actual versus perceived risks, Oxford, Plenum, pp. 213-224 (1983).
25. NKB Fire Safety Committee, Performance requirements for fire safety and technical guide for verification by calculation, Nordic Committee on Building Regulations, Monila Oy, Helsinki, Finland (1995).