USING RISK-BASED TIME METHOD TO DETERMINE THE MAXIMUM TRAVEL DISTANCE FOR BUILDING DESIGNS

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ABSTRACT

Maximum travel distance is one of the most important design parameters which have significant impact on building designs. The prescriptive design approach is simply to comply with the maximum limits given in the codes. These maximum limits vary from one code to another where the rationale for the difference is not clearly spelled out. This is not the only shortfall related to this important design parameter. It is noted that different types of occupancies have the same maximum travel distance in most of the existing codes and that distance is independent to whatever fire safety measures in the building.

A Risk Based Time (RBT) method is proposed to provide a simple approach for the determination of the maximum travel distance. Such a method can be used in a fire engineering approach in the evaluation of a new design, and it can also be used to provide rationale and specify new values in the prescriptive codes.

1. INTRODUCTION

Prescriptive building codes have been developed in the past primarily based on experience than fire sciences. During the last 10 years or so, more rationale has been sought for the prescriptive requirements. An alternative to the prescriptive codes is so called performance based codes which have been used in practice in some countries such as Australia. By its name of "performance based", such a building code sets out the performance requirement and usually a set of guidelines are also given, often in a separate document, for the determination of the performance either qualitatively or quantitatively.

Maximum travel distance is one of the most important design parameters which have significant impact on building designs. The prescriptive approach is simply to comply with the code permitted maximum limit where this distance may vary from country to country. It is also common in any one building code that different types of occupancies have the same maximum travel distance and that distance is independent of the fire safety systems installed in the building. One of the exceptions is the NFPA Life Safety Code [1] which has different maximum travel distances for different types of occupancies and for buildings with and without sprinklers. It does not explain how these values have been derived and why only sprinklers have been considered to be beneficial in terms of relaxing the requirement of the travel distance, however, there is at least some rationale behind these values.

In those countries where a fire engineering approach is permitted, there are three methods that are commonly used for evaluating the performance of the travel distance. One method is to compare the evacuation time to a specified time limit such as 2.5 mins for unsprinklered buildings and 5 mins for sprinklered buildings. No rationale is given as to why 2.5 mins or 5 mins, or given that unsprinklered buildings can have 2.5 mins, sprinklered buildings should have 5 mins. Another method is to compare evacuation time with untenable time which can be predicted based on fire dynamics and smoke calculation. In this second method, it is usually assumed that all fire safety systems provided are reliable, that is, failure of systems is not taken into account. Thus an excessively long distance may be considered as appropriate using this method.

A third option is to conduct a full risk assessment such as CESARE-Risk [2]. However, due to the complexity of this method, it is not often used. A full risk assessment may include fire growth, smoke spread, detection, and human response and evacuation. Comparative risk results are used for instance, to compare with the same type of buildings using the same calculation methodology for one (a code compliant design) with travel distance of 30 m, and the other 50 m (e.g. a proposed new design). If the proposed design has a risk which is equivalent to or lower than a code compliant building, then such a design is considered to be acceptable.

This paper will propose a new approach called Risk-Based Time method (RBT). It recognises that risk is a preferred judgement criterion, and by converting risk into time, some design parameters can be determined. The principle of this approach is to establish a bridge between risk and time. Once the link-bridge between risk and time is established, the time equivalence of various fire safety measures can also be established. It should be noted that this method is a comparative method in that the base case must be known, that is, there must be a code compliant solution or an accepted base solution. This method is not intended to define what the absolute level of risk should be achieved, but rather to compare a design which is different and/or deviated from the building code and to determine whether it can achieve the same fire safety level. This paper will present the methodology of this RBT method together with various examples.

2. METHODOLOGY

2.1 Introduction

As stated before, the RBT method is intended to be used on a comparative basis. Typical applications of comparisons of designs are:

- a design which is deviated from the building code is compared with a code compliant design,
- both designs A and B are code compliant designs. Which design has a higher level of fire safety or what parameter should be used such that the two designs will have an equivalent level of fire safety. For instance, design A has means of escape open to air (balcony approach), and design B has enclosed means of escape.
- a building is not covered by the building code. Thus it is intended to compare this category of buildings with a similar type of buildings where requirements are specified by the building code.

The requirement for the compared design must be known and used as the criterion. The parameter for the comparison is fire risk. In the RBT method, design parameters are converted into time, then converted to risk. Such an approach is considered to be more appropriate than a simple time average approach or other alternative approaches. The derivation of the Risk-Based Time is given below.

2.2 Derivation of the RBT Equations

Assuming that there are two designs, one complies with the code, the other deviates from the code but has additional fire safety measures. In a simple time average approach, it can be derived that a new design should have the equivalent travel time of:

$$t_3 \propto (1-\alpha)t_1 + \alpha t_2 \qquad (1)$$

where t_3 is the travel time of the new design which typically has additional fire safety measure/s, t_1 is the travel time of the compared design, t_2 is the additional travel time for the new design and under the assumption that the additional fire safety feature/s are reliable. Hence t_2 is an additional component to reflect the additional safety measures. α is the weighting factor to reflect the impact of the additional fire safety measures. An arithmetic simple mean would suggest α to be the same as the effectiveness of the additional system or the mean value of the effectiveness of systems if more than one additional systems are added. Such an approach disregards the impact of the number of people in the building which is not considered to be most appropriate.

There are various different forms to express fire risk. One way is to use "number of fatalities/injuries per year", and another is the likelihood of fatality/injury per year which has a unit of "per year" for an individual person. These two are related to each other by:

$$R_1 = NR_2 \qquad (2)$$

where R_1 is the number if fatalities/injuries per year, R_2 is the likelihood of fatality/injury per year, and N is the number of people exposed to the fire. Obviously, the longer the available time, the less likely that a person who is exposed to the fire will be in fatality, hence R_2 is directly related to time. The proposed RBT approach uses R_1 which takes into consideration of the number of people who are exposed to the fire.

After considering the number of people exposed to the fire, equation (1) becomes:

$$N_3 t_3 = N \times f[(1-\alpha)t_1 + \alpha t_2] \qquad (3)$$

where N is the number of people in the code compliant design, N_3 is the number of people in the non-code compliant design, and f represents a function which will be determined later.

In most codes, the design population of the building is related to the floor area. Thus for designs shown in Fig. 1, N_3 is related to N by:

$$\frac{N_3}{N} \approx \frac{L_3}{L_1} \qquad (4)$$

where L_1 is the maximum travel distance for the code compliant design, and L_3 is that for the new design.

If the designs are as shown in Fig. 2, N_3 is related to N by:

$$\frac{N_3}{N} \approx (\frac{L_3}{L_1})^2 \qquad (5)$$

For the purpose of illustrating the Risk-Based Time method, the designs shown in Fig. 1 will be used. As travel distance is proportional to travel time in a non-congested situation, that is, L_3/L_1 is proportional to t_3/t_1, equation (3) can be modified as:

$$\frac{t_3}{t_1} t_3 = f\left[(1-\alpha)t_1 + \alpha t_2\right] \qquad (6)$$

It is further recognised that the society is far more reluctant to accept multiple fatalities than single fatality. The extended distance, particularly a very long distance, may lead to multiple fatalities. The above equations should be modified to reflect the society's concern. Logarithm is used as a convenient way to reflect such a concern:

$$\ln(\frac{t_3}{t_1} t_3) = (1-\alpha)\ln(t_1) + \alpha \ln(t_2) \qquad (7)$$

Rearranging the above equation yields,

$$2\ln(t_3) = (2-\alpha)\ln(t_1) + \alpha \ln(t_2) \qquad (8)$$

or

$$t_3 = \exp\{[(2-\alpha)\ln(t_1) + \alpha \ln(t_2)]/2\} \qquad (9)$$

It should be noted that these derived RBT equations have their limitations, that is, the building designs should be similar to those shown in Fig. 1 and congestion is not expected or negligible.

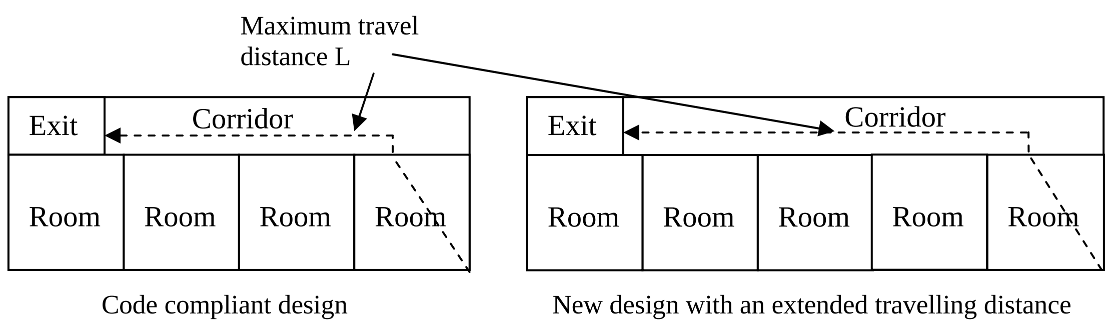

Fig. 1: Schematic layout of a code compliant design and a new design

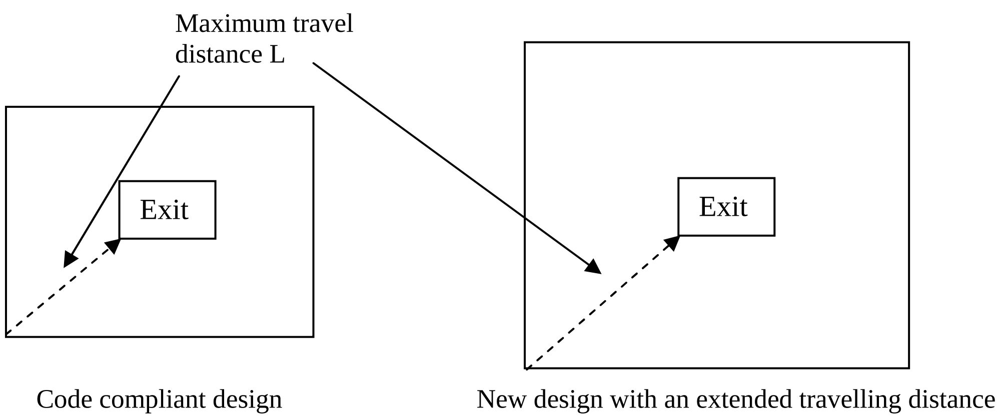

Fig. 2: Schematic layout of a code compliant design and a new design

2.3 Comparison of Equation (6) and Equation (9)

Equation (6) does not distinguish the difference between the aggregation of single fatality incidents and single incident of multiple fatalities. This is accepted in a broad scale, for instance, if a country with a population of 100 million with the number of fire fatalities per year of 100 is regarded to have the same level of fire risk as a country of population of 10 million with the number of fire fatalities of 10. The case is however different for a building due to public perception. It has been found that the society has a far greater concern for multiple fatalities than for single fatality. Litai and Rasmussen [3] have suggested that an ordinary risk is 30 times more acceptable than a catastrophic risk. In a recent publication by Wolski et al. [4], it was suggested to use mathematical means to accommodate human attitudes towards risk as 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 [5], that is, to use human risk attitudes (risk factors) to classify buildings. In this RBT method, this risk perception is addressed by equation (9) using a convenient logarithm. It should be noted that this logarithm addresses issues of single fatalities versus multiple fatalities (ordinary versus catastrophic to some degree). When this RBT method is used for different categories of buildings, risk factors as suggested by Litai and Rasmussen [3] may need to be considered on top of the logarithm.

A comparison of equations (6) and (9) is given in Fig. 3. It can be seen that if t_2 is not significantly different from t_1 and α is large, then these two equations will give a similar result. If α is small, then the results from equation (6) and equation (9) will be very different, as shown in Fig. 4.

Various examples will be given below to illustrate the use of RBT method in the determination of the maximum travel distance for various building designs.

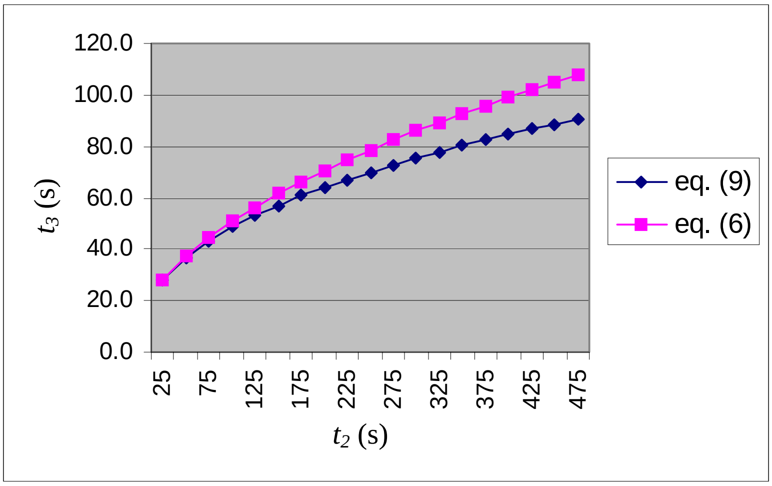

Fig. 3: Comparison of equations (6) and (9) for t_1 = 30 s and α = 0.8

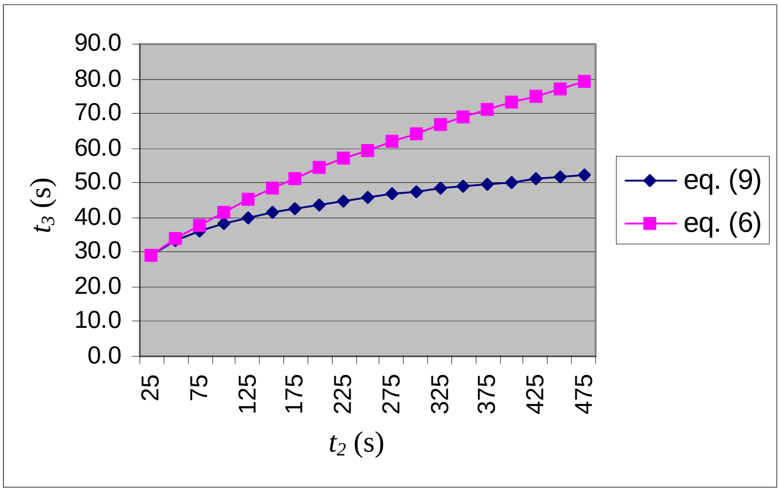

Fig. 4: Comparison of equations (6) and (9) for t_1 = 30 s and α = 0.4

3. EXAMPLES

Example 1: Assuming that a low rise apartment building without smoke detectors is allowed by a building code to have a maximum travel distance of 30 m, what is the maximum distance allowed for the same building with smoke detectors?

The criterion is to achieve the same level of fire safety standard. Therefore, the key is the difference that smoke detectors can make in such a building. According to studies conducted by Brian [6], the means of awareness of fire incidents are as given in Table 1.

Table 1: Means of awareness of fire
(Extracted from Table 3-12.2 by Bryan [7])

See flame	15%
Smell or see smoke	34%
Noise	9%
Shouts and told	33%
Alarm	7%
Other	2%

The data is for the US and it is rather general. For this application, more specific data such as means of awareness in apartment buildings is preferred. However, for the purpose of illustrating the proposed methodology, these data will be used. In an ordinary building where ceiling height is not more than 4 m, smoke detectors can be often activated at a relatively quick time. It can be reasonably assumed that people will receive alarm before shouts provided that the alarm type is appropriate too. Seeing flame, smelling smoke may occur earlier than hearing the alarm particularly in the room of fire origin. For people in the rest of the buildings, alarm is most likely the first cue. However, according to fire statistics for apartment buildings, most fatalities occurred in the apartment of fire origin. Thus, the cue sequence in the apartment of fire origin should be used for conservative reasons. It is therefore assumed that alarm will make a difference in α = (7% + 33% x R) of the cases where R is the reliability of the alarm system. The probability of people response to noise is also ignored for conservative reasons. A reliability value of 70% seems to be reasonable and conservative for alarms in an apartment building, thus the probability is α = 7% + 33% x 70% = 30.1%.

Other probabilities such as probability of people who will response to alarm should also be taken into account. If people choose to ignore the alarm, then alarm will have no benefit. Research studies in this area have been carried out by Proulx [8], Brennan [9] etc. In this example, this probability will not be considered as the probability of hearing alarm is conservative hence having already taken the impact into account.

It should also be noted that there are various alarm systems and reliability of such systems may vary significantly. If a system is quite different from an ordinary one, generic statistics is not a best option. Specific analysis of the reliability of the system may be required.

If the fire is not detected, people in the fire room may get other fire cues. The recommended recognition time for people in the building is greater than 3 mins [10]. However for the room of fire origin, or the apartment of fire origin, this time may be shorter. More study is required in this area. For the purpose of this example, 3 mins is used.

If the code permitted distance in the apartment building without alarms is 30 m, then t_1 = 30/1.2 = 25 s using a travel speed of 1.2 ms^{-1} [11] assuming no occurrence of congestion. The total evacuation time, that is, the sum of response time and the travel time, for the building with no detectors is 3 mins plus 25 s which equals to 205 s.

The time for detection can be obtained by using computer software such as FPETool [12]. A typical time of smoke detector activation time in an ordinary building of a ceiling height of 3 to 4 m is in the order of 30 s for a medium to fast growing fire. If the alarm system is 100% reliable, and people will respond to the alarm with a probability of 100%, then the travel time allowed is t_2 = 205 - 30 = 175 s. This is equivalent to a travel distance of 216 m. However, it is recognised that the reliability of the system is not 100%, and neither is the probability of response to the alarm, hence this distance must be adjusted accordingly. Using equation (9), t_1 = 25 s, t_2 = 175 s, and α = 30.1%, t_3 can be obtained which is 33.5 s. Thus, the risk based time difference is 33.5 - 25 = 8.5 s, and the maximum travel distance in a building installed with smoke detectors is 40 m.

It should be recognised that statistics indicate that the means of awareness of fire is different for different countries, such as the UK statistics by Woods [13]. This difference can be caused by various reasons including detector coverage. In this regard, local statistics is always preferred. Detectors in some countries have become a mandatory requirement for newly constructed residential high-rise buildings [14], thus the coverage will be approaching to 100%.

In this example, the collected statistics is assumed to have been obtained from buildings having a detector coverage of 100%. Such an assumption will result in a conservative result for the maximum permitted travel distance when detectors are installed. If statistics are taken from buildings where the detector coverage is less than 100%, then the probability of response to alarm given that detectors are installed will be higher.

Assuming that the overall response to alarm is 50%, t_1 = 25 s, then using equation (9), t_3 = 41 s. Thus, the maximum permitted travel distance should be 49 m. This is compared with 40 m when the response to alarm is 30.1%. A summary of the results is given in Table 2.

Table 2: Comparison of the maximum permitted travel distance for detectors

No detector	30 m
Detector with a response probability to alarm of 30%	40 m
Detector with a response probability to alarm of 50%	49 m

Example 2: For the building above, if the reliability of the alarm system improved from 70% to 80%, what is the implication on the maximum permitted travel distance (to maintain the same level of fire risk)?

Using the same procedure given in example 1, installing alarm will have a difference of α = 7% + 33% x 80% = 33.4% of the cases. This estimate is quite conservative as pointed out before. Using t_1 = 25 s and equation (9), t_3 can be obtained, that is 34.8 s. Thus, the maximum allowed travel distance is 42 m. Compared with 40 m for alarms with reliability of 70%, the increase of 10% in reliability has a benefit of increasing the travel distance by 2 m. This calculation is conservative because α is conservative. If α is increased, then the benefit will also be increased; and vice versa.

If equation (6) is used, that is, without considering the risk perception difference for single fatality and multiple fatalities, then t_3 is 42.3 s for alarms with reliability of 70%, 43.8 s for alarms with reliability of 80%. This is equivalent to a maximum travel distance of 51 m and 53 m for alarms with reliability of 70% and 80% respectively. A comparison of the results is given in Table 3.

Example 3: If in the same building, smoke detectors are replaced with sprinklers, what is the maximum travel distance such that the fire safety standard is not reduced? All other fire safety systems are the same in the building.

Table 3: Maximum travel distances for buildings with and without alarms

No alarm	Alarm with reliability of 70%		Alarm with reliability of 80%	
30 m	40 m	51 m	42 m	53 m
-	Eq. (9)	Eq. (6)	Eq.(9)	Eq.(6)

Most sprinkler systems have a reliability of 95 - 99% [15]. If the system is wet pipe type, reliability is relatively higher, 98-99% is considered to be reasonable. Statistics show that majority of the fires is not large enough to cause sprinkler activation, in other words, only a small proportion of the fires will require sprinkler activation. Thus, sprinklers will have no effect if all fires are small. However, the reality is that most hazard conditions and hence majority of fatalities occurred in a small proportions of fires, that is, those large fires. Small fires usually do not create untenable conditions. It should be cautious that for certain type of buildings, such as aged care accommodations, small fires (eg. smouldering fires) can be a major fatality contributor. For the fires do not create untenable conditions, fire safety measures, travel distance etc. do not apply as people are safe in any case. The sprinkler system is always connected to an alarm system which is a common practice.

The time of sprinkler activation can be predicted using computer software such as FPETool. For medium to fast growing fires which are common such as furniture fires and kitchen fires in a typical building (ceiling height of 2.4 - 3 m), fast response sprinklers activation time is typically at 60 s to 120 s. For the purpose of this exercise, the time of activation is taken to be 90 s.

Assuming that sprinklers are connected to the building alarm system, the benefit of the sprinkler system may be considered together with the building alarm system. Consider the benefit of alarm first. The benefit of having alarm can be represented by risk based time. Since α is taken as 98% x 33% = 32.3%, t_1 = 25 s, t_2 = 205 - 90 = 115 s, using equation (9), t_3 = 32 s. This indicates that if sprinklers give alarm only, even though its reliability is significantly higher than detectors (for detector reliability of 70%), the benefit of sprinkler is less than that of detectors because the alarm time is delayed. This example shows that the Risk Based Time method can be used to compare two different systems.

Sprinklers can also reduce the fire size. Typically, a sprinkler can reduce the fire size by a factor of 2 to 4. For a shopping complex, the design fire size is usually greater than 10 MW for the case of no sprinkler, 5 MW for standard sprinklers and 2.5 MW for fast response sprinklers [16]. Thus, for a 1000 m^2 ceiling area and 3.5 m ceiling height (false ceiling), the smoke reservoir volume is 1000 x (3.5 - 2) = 1500 m^3 assuming that smoke clear height of less than 2 m will cause smoke hazard to people. At smoke clear height of 2 m, the smoke production rate is 26.9 m^3s^{-1} for a 10 MW fire; at 3.5 m, it is 37.4 m^3s^{-1}. The smoke generation rate is higher at initial stage. Using an average smoke generation rate as an approximation, smoke can fill the reservoir in about 47 s.

For a 5 MW fire, the smoke generation rates are 14.8 and 21.8 m^3s^{-1}. The average is 18.3 m^3s^{-1}. Thus, the smoke filing time is 82 s. Hence, the time difference is 82 - 47 = 35 s. Given that the sprinkler reliability of 98% (wet-pipe type), the maximum distance may be extended by 42 m using travelling speed of 1.2 ms^{-1} on a nominal time basis. Using a risk based time method, if the code permitted maximum travel distance for a unsprinklered building is 30 m, using a normal travel speed of 1.2 ms^{-1}, t_1 = 25 s. Thus, t_2 = 25 + 35 = 60 s. For α = 0.98, using equation (9), t_3 = 38.4 s. Hence, the maximum permitted distance in the sprinklered building is 46 m. Hence, the extra distance is 46 - 30 = 16 m. This is significantly different from that on a nominal time basis which gives extra distance of 42 m. The effect of sprinklers on compartmentation has not been considered. Thus, the obtained result is only applicable to large compartments.

For a 2.5 MW fire, the smoke generation rates are 8.3 and 12.9 m^3s^{-1} at 2 m and 3.5 m smoke clear heights, and the average is 10.6 m^3s^{-1}. The smoke filling time for 1000 m^2 ceiling area is approximately 141.5 s. The time difference between smoke filling times for the case of no sprinkler and fast response sprinkler is 94.5 s. Hence, the maximum distance can be extended by 113.4 m on a nominal time basis. Using a risk based time method, t_3 = 53.8 s. Thus, the maximum travel distance is 64.6 m.

It should be noted that fast response sprinklers may not necessarily reduce the fire size compared with standard response sprinklers according to the research conducted by FM Research, for instance, in a warehouse which usually has a high ceiling. In such cases, other types of sprinklers such as large orifice sprinklers can do a better job in reducing the fire size.

The above analysis has not included the impact of the increase of smoke reservoir. Smoke reservoir may be increased as the result of the increase of the maximum travel distance. However, smoke reservoir cannot be increased excessively as smoke may be dropped as the result of losing buoyancy. The Hong Kong FSD Code of Practice [17] requires that each smoke zone (static smoke extraction systems) must be less than 500 m^2, and smoke reservoir size (for both static and dynamic smoke extraction systems) must be less than 2000 m^2. In the above analysis, 1000 m^2 has been used.

4. COMPARISON WITH NFPA LIFE SAFETY CODE

The maximum travel distance in the NFPA Life Safety Code [1] appears to have the support from the current theoretical study. According to the Life Safety Code, the maximum travel distance for an ordinary building is 45 m where the typical detection time is more than 3 mins [9]. For special buildings, that distance is 91 m. Both cases are for unsprinklered buildings. In a typical special building where there is a large pedestrian flow, fire is unlikely to occur and can be easily detected by people, CCTV and detectors are often installed. In such case, the detection time is typically within 30 s. Accordingly, t_1 = 45/1.2 = 37.5 s and t_2 = 180 - 30 + 37.5 = 187.5 s. Given the systems installed (CCTV, detectors) and high pedestrian flow, the probability of response will be very high. Therefore, the difference between the probability of response for the case of with and without sprinklers is minimal.

Assuming that the sprinkler reliability is 0.98, the maximum travel distance obtained using a risk based time is 99 m; if the sprinkler reliability is 0.9, then the maximum travel distance is 93 m. It should be noted that α is the product of system reliability and probability of usefulness/occupant-response given that the system is reliable. In this case, α is taken as the same as the system reliability by assuming that all fires causing untenable conditions are large fires and when sprinklers are reliable, sprinkler will have an impact on the fire size. Such an assumption is not conservative, therefore it should be used with care. In most cases, there is a certain proportion of fires which will create life threatening conditions but sprinklers will not be activated. Such a proportion varies with the design of buildings. A convenient approach is to relate this proportion to the building categories/class. Given this consideration, α = 0.9 appears to be more reasonable. A comparison of the results is given in Table 5.

Also for special buildings, if sprinklers are installed, the untenable time can be extended by 35 s for a smoke reservoir ceiling area of 1000 m^2 and depth of 1.5 m (see Example 3). Since the area of a special building is very large, the smoke reservoir is likely to be larger. Maximum smoke reservoir size is often taken to be 2000 m^2. Thus, the saved time is likely to be 70 s. The depth of the smoke reservoir could also be larger. A range of time saving has been analysed. Since t_1 = 91/1.2= 75.8 s, $t_2 = t_1$ + time saved, α = 0.9, t_3 can be obtained using equation (9). It was found that if the time saved is 60 s, then the maximum travel distance is 118 m, if the saved time is 100 s, the maximum travel distance is 133 m. It should be noted that these results are for design fire sizes of 10 MW and 5 MW for the cases of with and without sprinklers respectively. A comparison of the results is given in Table 6.

Table 5: Comparison of the maximum travel distances of ordinary and special buildings

Ordinary buildings	Special buildings	
	Life Safety Code	Risk-Based Time method
45 m	91 m	93 - 99 m

Table 6: Comparison of the maximum travel distances for special buildings

Unsprinklered buildings	Sprinkled buildings	
	Life Safety Code	Risk-Based Time method
91 m	122 m	118 - 133 m

It can be seen that the proposed Risk Based Time method provides a convenient approach (or a guide) to specify code limits which are often called "magic numbers". Implication of increase of maximum travel distance on other design parameters such as, exit routes and exit doors, should also be considered. This is however not within the scope of this study.

The Life Safety Code, same as many other building codes, does not distinguish the difference between fast response and standard response sprinklers. Sprinkler research indicates that these two types of sprinklers can have different performance, especially between Early Suppression Fast Response sprinklers (ESFR) and standard response sprinklers. The difference however varies with the sprinkler head height and other factors such as fire load. Further study in this area is required. Given that the impact of different sprinklers on fire size is known, the proposed Risk Based Time method can readily distinguish the sprinkler performance differences in building designs, hence permitting difference design parameters such as the maximum travel distance.

If a smoke extraction system is provided, then the difference between the sprinkler impacts on fire size is compensated by the different smoke extraction rates. Again most, if not all, building codes have not considered the impact of smoke extraction system on travel distance.

5. CONCLUSIONS

A Risk Based Time (RBT) method is proposed to compare the various fire safety measures, and convert the performances of different design into a risk-based time. This risk based time can be used to give an indication of relaxation of certain parameters such as the maximum travel distance for a specific design. This proposed RBT method also offers a convenient approach to produce code limits which are sometimes called "magic numbers" because of little rationale behind or no given explanation.

Examples are given to illustrate the use of such an approach for the determination of the maximum travel distance which is one of the key design criteria in building designs. This approach gives the quantitative means to extend or reduce the maximum travel distance for buildings with various types of fire safety measures and/or system reliabilities.

Various examples have been presented. It should be noted that the statistics and other values used in these examples are illustrative only. For a specific type of building and for a given city or country, more specific data is preferred. Particular attention is drawn to the statistical difference for different building categories/classes.

This proposed new approach is intended to be used on a comparative basis. Its applications may include but not limited to the following:

- comparison of a design which is deviated from the building code with a code compliant design,
- comparison of designs A and B where both are code compliant designs, and
- comparison of a building which is not covered by the building code with a similar type of buildings where requirements are specified by the building code.

This proposed RBT method can also be applied to the following areas:

- travel distance due to difference in travel speed, such as evacuation of disabled people,

- travel distance due to congestion, and
- travel distance due to response time difference.

It should be noted whilst the principle of the RBT method is the same for the above applications, the formulas may need to be modified to suit the specific conditions. Limitations for the current formulas have been presented when they are derived. The application of this proposed RBT method to other areas will be discussed elsewhere.

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