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Assessing the reliance of sprinklers for active protection of structures

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Abstract

Fire protection in buildings is required to achieve the overall objectives of providing protection to occupants for safe egress, safeguard fire fighting personnel during their intervention activities and to prevent the spread of fire to other property. The form of fire protection in buildings is classified into active and passive types. For structures, conventional codes require passive protection to be provided. Active protection afforded by sprinklers is required in buildings with a higher fire hazard category, such as high rises and industrial occupancies, but they are not considered to replace passive protection. However, many codes allow some relaxation of the passive protection when sprinklers are installed. The ability of sprinklers to control the development of fire has been well demonstrated statistically and in many fire tests. However, unlike passive fire protection, active systems such as sprinklers are mechanisms requiring a certain degree of motion and response in order to work. Hence the reliability of active systems to perform when required is perceived to be lower than passive protection. Using a risk assessment approach, this paper explores the means by which sprinklers may be relied upon in providing protection to structures in order to achieve the desired objectives for fire safety in buildings.

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Keywords: Sprinklers; Passive protection; Active protection; Structures; Risk assessment

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1. Introduction

Based on a 2005 study in US [1], 32% of all fires occur in buildings, but deaths from fires in buildings accounted for 84.5% of all deaths due to fire. Of these, 83.1% of building deaths occurred in residential properties, where there is hardly any fire protection provided. Hence one may deduce that fire protection measures in non-residential properties are effective in keeping the fatality rate low. However, a recent study in Australia [2] has concluded that fire protection is over invested and is non optimal, such that is no clear relationship between any increase in investment into the fire system and outcomes in terms of fire fatalities and property losses. Nonetheless, building regulations have developed and evolved to provide the expected level of safety for occupants as well as property. This is achieved through the provision of a variety of fire and life safety systems, primarily comprising of various active and passive protection systems. In higher hazard categories, such as high-rise buildings where access is reduced and industrial properties where the fire load hazard may be higher, both active and passive protection systems are required.

The prescribed requirement for the provision of both active and passive protection in buildings has been in the building regulations for many years. One may consider the primary role of passive protection is to contain the fire within the compartment of fire origin and not allow the fire to spread outside of it, whereas active protection serves to reduce the level of hazard by controlling the development and size of the fire.

In recent years, the study into the benefits of sprinklers, particularly in consideration of its high level of efficiency in controlling fires, has encouraged the prospect of considering whether sprinklers may be used to trade off the requirements

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for passive protection. One of the more well demonstrated effectiveness of sprinklers is the 1991 fire of One Meridian Plaza in Philadelphia [3], where the fire which began on the 22nd floor and raged out of control for hours, was only brought under control when it reached the 30th floor which had automatic sprinklers installed. The fire was held back by seven sprinklers until it burnt itself out and brought under control 19 hours after it started.

The effectiveness of sprinklers is generally well recognized in terms of its ability to control a fire, and there has also been much experimental studies undertaken to demonstrate the effectiveness of sprinkler performance. Most notably is the series of sprinklered and unsprinklered full scale office fire tests for 140 William Street [4]. Although this series of tests were intended to demonstrate the ability of unprotected steel beams to withstand the effects of a fully developed fire in a non-sprinkler protected environment, the effectiveness of sprinklers in controlling the fire size was also well demonstrated.

Studies into the performance of sprinklers, however, showed that much of the causes of sprinkler ineffectiveness lie on the operational side, *i.e.* where the desired water discharge rate from the sprinklers was either inadequate or unavailable [5].

Fire protection of structures is part of the requirements for fire safety in buildings that are required to achieve the overall objectives of providing protection to occupants for safe egress, safeguard fire fighting personnel during their intervention activities and to prevent the spread of fire to other property. The corresponding objectives for fire protection of structures is to assure that the overall objectives are not compromised due to the inability of the structure to perform adequately during a fire.

For structures, conventional codes require passive protection to be provided. Active protection afforded by sprinklers is not normally considered to replace the passive protection. However, certain codes allow some relaxation of the passive protection when sprinklers are installed. Although the ability of sprinklers to control the development of fire has been well demonstrated statistically and in many fire tests, sprinklers, unlike passive fire protection, are an active system with mechanisms requiring a certain degree of motion and response in order to work. Hence the reliability of active systems to perform when required is generally perceived to be lower than passive protection. Using a risk assessment approach, this paper explores the reliance of sprinklers in contributing to the overall fire safety of buildings and how its performance in association with providing active protection to structures may be assessed to achieve the desired objectives for fire safety in buildings.

2. Sprinkler concessions in fire codes

Historically, sprinklers were installed in buildings solely for property protection, largely due to the influence of insurers who offered significant reductions in fire insurance premiums, particularly in storage and industrial facilities. In the last few decades, the benefits of sprinklers were also seen to be able to provide protection to building occupants by controlling the fire before it could become fully developed. Typically, an effectively operating sprinkler is able to limit the fire area involved to less than 10 m^2 and bring temperatures down to less than 100 °C [6]. As a result, the action of sprinklers may be considered to perform similarly to compartmentation and structural fire protection to limit fire spread. In addition, sprinklers are also capable of preventing the fire from becoming fully developed, which neither compartmentation nor structural fire protection is able to.

The benefit of reduced insurance premiums for sprinkled light-hazard occupancies, such as office and apartment buildings, was less significant because of the relatively lower value of property losses in fire. In order to encourage the wider use of sprinklers for these types of premises, trade-offs or reductions in the requirements for compartmentation and structural fire resistance were permitted when sprinkler protection is provided throughout a building. Hence in US, many building and fire codes recognize the installation of sprinklers as equivalent to one-hour rated structural fire protection [7, 8]. However, this concession only appears to apply to separation elements such as walls and floors that are provided between occupancies. There is no concession for structural line elements such as beams and columns.

Although Performance-Based Design offers a method to gain acceptance for additional concessions beyond those permitted, the appropriateness of such concessions based on a performance-based approach is often questioned. Regulatory authorities are also often concerned about the lack of uniformity for input data and in the consistency of such designs [9].

In UK, the Approved Document B (Table A2) [10] permits reduction in the fire resistance period of up to 30 minutes when the building is sprinkler protected, and does not differentiate between separating barriers or structural members.

In New Zealand, the design fire for performance-based design can be assumed to be controlled (*i.e.*, with a constant heat release rate) after the sprinkler activates. Hence the fire, when controlled by sprinklers, is considered not to develop further to flashover [11]. When sprinklers are provided, the code also allows a 25% relaxation in the assessment of the fire resistance of primary structural elements:

- which are unable to develop dependable deformation capacity, and
- whose failure would consequently lead to disproportionate extent of collapse

Other structural or non-structural elements may be relaxed by 50% when sprinklers are installed.

3. The sprinkler system

3.1. Sprinkler provisions

Sprinkler provisions are generally categorized into light hazard, ordinary hazard and high hazard. The determination of the required hazard category is normally a function of the building occupancy type. This is a reflection of the type of fire load that would be expected within that building category.

In Hong Kong, use of sprinklers is only exempted for residential buildings, or buildings with a total floor area of less than 230 m².

In Australia all buildings over 25 m are required to be sprinkler protected. Sprinkler systems are installed to AS2118.1 and maintained to AS1851 to form a very reliable means of fire protection. Estimates of sprinkler reliability range from 95% to 99% within Australia [5, 12].

Sprinkler protection is required in many countries when the building height reaches a high-rise category. This is usually between 20-30 m. For residential buildings, however, Singapore, Hong Kong and Japan do not require sprinklers, although statistically, civilian fatalities recorded in Western countries such as Australia [13] show about 20 times higher in residential occupancies than non-residential occupancies.

3.2. Experimental data

In order to compare the impact of sprinklers on fire, a number of full scale tests which compared sprinklered and unsprinklered scenarios for the same fire enclosure conditions were referred [14]. These are summarized below (Fig. 1 and Fig. 2):

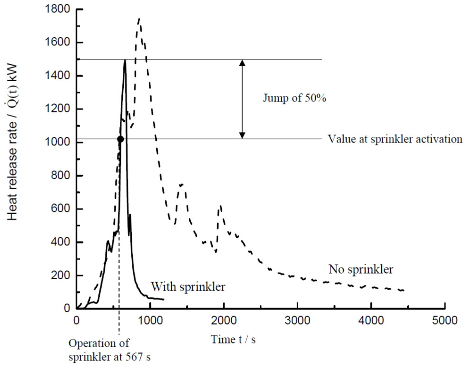

Fig. 1. Office fire test at Harbin engineering university [15].

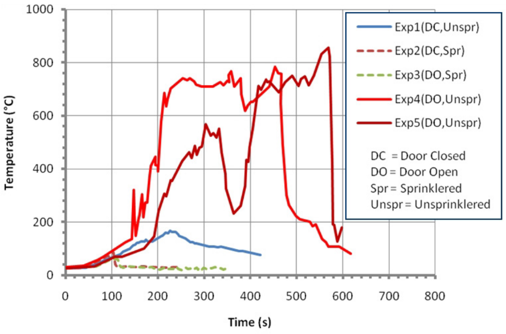

Fig. 2. Temperature *vs*. time data comparing sprinklered and unsprinklered fires in dormitories at 1.5m from floor [16].

In Harbin University, a full-scale burning facility was used to study flashover office fire test [15] in 2004, which comprised of a chair, a desk with paper and books on top, a computer box and a cupboard in the burn room. The peak heat release rate was about 1.8 MW at 800 s without sprinklers. When repeated with sprinklers, the heads were activated when the heat release rate reached 1 MW, but moved up to 1.5 MW. However, the intensity of the fire as measured by the energy released (area under the curve) has been significantly reduced to about 17% of the unsprinklered fire.

A number of full scale fire experiments in abandoned dormitory buildings were conducted by the National Institute of Standards and Technology (NIST) to study the impact of sprinklers in the room of fire origin, with and without the door opened [16]. The sprinklers activated within 2 minutes and clearly controlled the fire before it could reach flashover, such that the temperatures did not exceed 100 °C. Without sprinklers, the fire burned for about ten minutes with peak temperatures ranging between 800-850 °C. An exception occurred for the case with the enclosure door closed where, due to lack of ventilation, the fire was not sustainable and the temperature only reached up to about 150 °C.

A series of full scale fire tests on residential buildings were undertaken as part of the Fire Code Reform Centre (FCRC) Research Project in Melbourne, Australia to study flashover fires (Fig. 3) [17]. Included in the series was a sprinkler controlled fire test where the temperature peaked momentarily at about 250 °C, whilst the average temperature did not exceed 100 °C. The temperatures in the unsprinklered case remain high at about 1000 °C and the duration, if taken at temperatures exceeding 500 °C would be approximately 20 minutes.

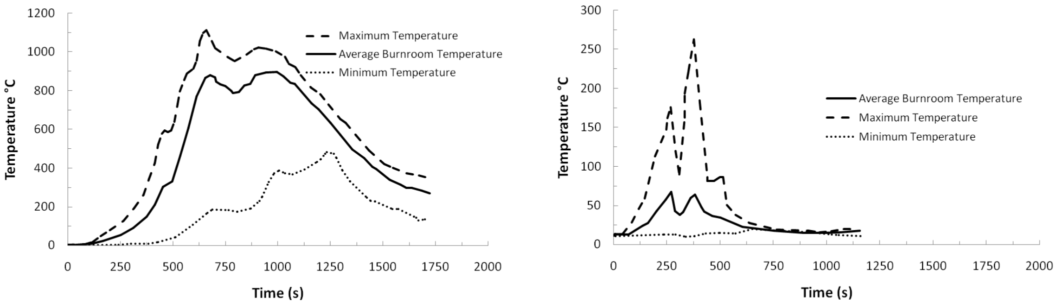

Fig. 3. Flashover fires without sprinkler and with sprinklers [17].

There are many other full scale fire tests available in the literature demonstrating the overwhelming effectiveness of sprinklers in controlling a fire. However, as these tests are preplanned, they are only able to demonstrate the ability of sprinklers in controlling a fire when it is in operation. The overall sprinkler performance needs to include the ability of the sprinkler to be operable in the first place.

3.3. Sprinkler failure

The sprinkler system, as an active system, relies upon a number of components to operate in order to perform effectively. Essentially, starting from the activation of the sprinkler head, water must be available (requiring filled water tank) and able to flow unimpeded (valve turned on and no blockage in pipes) at a pressurized rate (requiring pumps) to discharge onto the fire (which can be controlled by water). Hence the loss of any of these components will lead to the inability of the sprinkler to perform effectively. If the installed sprinkler system fails to deliver water to the fire, the benefits of providing sprinkler protection would be effectively lost completely.

Table 1. Reasons for unsatisfactory sprinkler performance [18]

Sprinkler failure reason cited in NFPA statistic [18]	Most likely reason in NFIRS [19]	Percentage of 2,693 incidents
Water to sprinklers shut off	System shut off	41%
Inadequate water supply	Not enough agent released	12%
Inadequate maintenance	Lack of maintenance	10%
Obstruction to distribution	Agent (water) did not reach fire	10%
Hazard of occupancy (excluding explosion damaged system)	Inappropriate system or Other	9%
Hazard of occupancy/explosion damaged system	Component damaged	7%
Dry pipe (e.g., defective valve, poor design through excessive heads)	Agent did not reach fire, Not enough agent released, or Other	3%
Antiquated system (particularly pipe sizes or sprinkler spacing to old standard)	Inappropriate system, Component damaged, or Other	2%
Miscellaneous or unknown	Unknown or Other	2%
Exposure fire	Excluded as sprinklers not in fire area	2%
System frozen	Agent did not reach fire, Not enough agent released, Component damaged or Other	
Other defective operation	Other	1%

Beside the issue that water may not be delivered upon activation of the sprinkler head, an operational sprinkler system may also be ineffective for a number of reasons. These include:

- effect of shielding (e.g. car bodies, steel cabinets)
- excessive height (reduced discharge density, delayed activation, too many heads open)
- fuel type (e.g. hydrocarbon fires)

The latter two, however, may be avoided if the sprinkler system has been correctly designed.

More detailed information on sprinkler failure may be found in the NFIRS database as shown in Table 1.

The top four categories (accounting for 73% of reported incidents) appear to translate fairly clearly and unambiguously to specific types of reasons identified in National Fire Incident Reporting System (NFIRS) 5.0.

3.4. Sprinkler reliability

Sprinkler reliability is a probabilistic measure of the sprinkler performance in controlling a fire as it is designed to. A simplistic measure of the probability of success is expressed as *P(success) = no of succesess/no of incidents*.

The successful operation of a sprinkler system however is better described in two components: the *operational* component and the *performance* component. The operational component defines the probability that the sprinkler will operate when required, i.e. when activated, water will be discharged at the designed rate and density from the activated sprinkler heads. The performance component is the measure that, given the sprinkler has correctly operated at its design specifications, the fire will be controlled as intended. The former is determined from testing and maintenance data whilst he latter depends upon the environment and fire conditions under which it is operating.

A summary of reported reliability estimates for automatic sprinkler systems, collected by Budnick [20] from various sources is shown in Table 2. However, many of those reported studies are more than 25 years old and hence exclude newer sprinkler technologies such as quick response and ESPR types. Nonetheless, they still represent a relative high level of reliability.

Table 2. Automatic sprinkler reliability studies [20]

Occupancy	Source	Reliability
Commercial	Milne	96.6/97.6/89.2
	NFPA	90.8-98.2
	Miller	86
	Maybee	99.5
	Kook*	87.6
	Taylor*	81.3
	Linder	96
General	Miller	95.8
	Miller	94.8
	Powers	96.2
	Richardson	96
	Finucane et al	96.9-97.9
	Marryat	99.5

4. Passive protection

Passive protection of enclosure barriers is required in buildings to provide fire compartmentation. Fire compartmentation is achieved by providing the wall and floor barriers enclosing the compartment with the required fire rating. Structural members which provide support to these barriers must also be fire rated to no less than these compartment elements. The fire rating of these members is assessed in terms of the ability to provide:

- *insulation* to keep the heat out,
- *integrity* so that gaps or cracks do not form and allow hot gases in, and
- *loadbearing* to provide structural support during fire.

4.1. Assessing structural behavior

The two main materials for structural elements are steel and concrete. However, much of the focus on concession for structural fire protection has been on steel structures as opposed to concrete structures, largely due to the costlier expense of providing insulation to the steel to achieve the required level of fire protection.

The behavior of structures in fire is a complex phenomenon. This is mainly due to the dynamic nature of the fire behavior which varies with time and with a changing intensity, and which both are difficult to predict accurately. The behavior is complicated by the thermal response of the structural elements as their material properties change in response to the changing thermal environment. The behavior is further complicated by the localized impact of the effects of fire, such that each structural member will be affected differently to the effects of the fire.

For the purpose of this paper, a simplified approach to the thermal response of steel structures shall be adopted, based on the Australian Structural Steel Code [21] as a representative means of assessing compartment barriers and structural elements in general. This is the limiting temperature approach whereby the limiting steel temperature of steel (T_l) is given by the expression, $T_l = 905 - 690r_f$

where r_f is the ratio of the design action on the member under the design load for fire to the design capacity of the member at room temperature. The value of the load ratio r_f is typically of the order of 0.5, resulting in a limiting temperature of about 550 °C. This approach may also be applicable to concrete structures by applying the limiting temperature relationship to the steel reinforcement within the concrete.

4.2. Reliability of passive systems

Contrary to the belief that passive protection, because it does not involve a mechanism to perform its function, is inherently more reliable than active systems, may not necessarily always deliver a higher overall level of fire safety. Compartmentation requires that both smoke and fire are kept within the protected compartment and not spread. This requires that the compartment has no inherent openings or that openings do not develop during the fire.

One of the major weaknesses of compartment failure, as a result of a comprehensive risk assessment study conducted as part of the Warren Centre Fire Safety Engineering Project [22, 23], was found to be the use of door chocks to keep fire doors open in stairwells. This practice is particularly common in buildings where there is a convenience to access the adjacent floors using the exit stairs. Factors which encourage this would include inadequate lift service or had regular breakdowns or the tenant occupies several floors in the building.

Other causes of compartment failure may include the inadequacy of fire stopping penetrations, or penetrations being made in a fire rated wall for subsequent installations.

The doors to fire rated compartments are also required to be fire resistant. However, codes normally permit a lower rating than the walls they are fitted into [8]. In addition, because fire doors have movable components such as hinges and closers, they are possibly the weakest link in passive systems for compartments. Fire doors also have an inherent gap at its base which allows smoke and heat to escape.

The reliance of the material providing protection to the fire rated elements themselves has a number of limitations. For example, the depth of concrete cover provided to the steel reinforcement in concrete elements may not all be consistently at the design value. The concrete itself may spall during a fire and expose the steel reinforcement within. This similarly applies to the consistency and thickness of the insulation material provided for protecting the steel elements. Structural trusses are particularly vulnerable as it only requires one small member to be weakened to result in the failure of the entire truss system.

4.3. Trade-offs

Trade-offs normally refer to the reduction in the provision of code prescribed fire protection levels, and is usually in association with reliance on an alternative form of fire safety provision. However, as mentioned earlier, many code provisions recognize the benefit of sprinklers and allow some reduction in the fire rating requirements for passive protection, without the addition of an alternative provision. This would be considered to be in recognition that there is some form of doubling up in fire safety provision by having both sprinklers and the full requirements for passive protection.

With passive protection, the assessment of a fire rating lower than the prescribed requirement may be determined via a fire engineering approach whereby the performance of the protected element is assessed against the severity of the fire that may be expected to develop in that compartment (e.g. time-equivalent approach). Alternatively, trade-offs may also be assessed with the provision of automatic sprinkler systems in buildings in reducing the expected fire hazard, and hence significantly raise the level of fire safety. However, in any consideration of assessing the fire safety requirements, the performance objectives of providing for an adequate level of fire safety must not be compromised.

Table 3. Fatalities and property losses [13]

	Protected construction	Sprinklers
Apartments		
US Civilian fatalities per 1000 fires	7.4	2.6
Average estimated USD dollar loss per fire	5520	3613
Aus Civilian fatalities per 1000 fires	6.8	0
Average estimated AUD dollar loss per fire	13455	2636
Offices		
US Civilian fatalities per 1000 fires	0.5	0.0
Average estimated USD dollar loss per fire	16,388	8730

5. Statistics

The statistics on the impact of sprinklers as shown in Table 3 [13] indicate that sprinklers provide a substantial reduction in fatalities and property losses. The data shows that the fatality rate with no sprinklers installed within a building (all types of buildings) to be about 7 fatalities per 1000 fires and with sprinklers present ranges between 0-2 fatalities per 1000 fires. There has also been no fire related fatalities in sprinkler protected high-rise residential buildings in Australia.

The extent of fire damage to show the impact of sprinklers at limiting the fire spread in shown in Fig. 4, and are summarized in Table 4.

Table 4. Impact of sprinklers at limiting the fire spread

Without sprinklers:	With sprinklers:
• 18.2% of fires spread beyond the room of fire origin • 17.4% of fires spread beyond the fire rated compartment of fire origin. • 14.7% of fires spread beyond the floor of fire origin.	• 3.7% of fires spread beyond the room of fire origin (5 × improvement). • 1.4% of fires spread beyond the fire rated compartment of fire origin (12 × improvement). • 0.7% of fires spread beyond the floor of fire origin (20 × improvement).

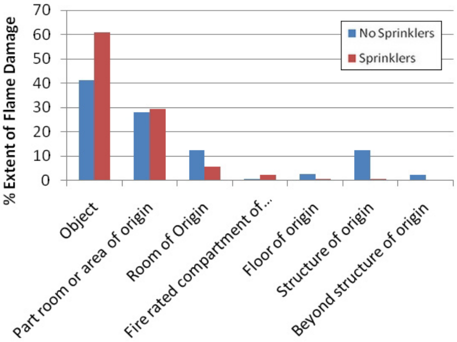

Fig. 4. Australian data on the impact of sprinklers in preventing fire.

US and Australian data indicated a similar fatality rate of approximately 1 fatality every 140 fires.

In US, home fire sprinklers help reduce the death rate per 1000 reported home fires to be 83 percent lower when wet pipe sprinkler systems were present, compared to reported home fires without automatic extinguishing equipment [24].

Sprinklers operated in 91% of all reported structure fires large enough to activate sprinklers, excluding buildings under construction and buildings without sprinklers in the fire area [18]. When sprinklers operated, they were effective 96% of the time, resulting in a combined performance of operating effectively in 88% of all reported fires where sprinklers were present in the fire area and fire was large enough to activate them. The more widely used wet pipe sprinklers operated effectively 89% of the time, while dry pipe sprinklers operated effectively in 76% of cases.

6. Risk assessment

Risk assessment is normally associated with the factors and events that would lead a particular system to failure. Hence, if the temperature of a structural member exceeds its limiting temperature, failure is deemed to have occurred. In the case of assessing the impact of sprinklers on the performance of structures in fire, there is adequate evidence that if the sprinklers operated and performed as intended, the resulting temperature in the enclosure is unlikely to exceed 100 °C. This is significantly below the typical limiting temperature of structural steel elements of about 550 °C and hence the thermal impact on the structure is negligible.

The risk associated with the use of sprinklers in trading-off fire resistance ratings is therefore largely associated with the probability of the sprinkler system failing.

6.1. Risk of sprinkler operational failure

For the purpose of this study, the risk of operational failure shall be limited to the probability of water at the sprinkler head being available at the design provisions, *i.e.* at the required flow rate and discharge density. The events that may contribute to this are described in the fault tree in Fig. 5. Details of the fault tree analysis are described in more detail in reference [5]. Only the yellow shaded input values to the fault tree events are required to determine the final operational failure of the sprinklers (refer Table 4). The input values shown in Fig. 5 are for the conditions that are representative of a compliant system that meets the Building Code of Australia (BCA) [25] at the time of the study for a high-rise office building.

The Failure Event of the sprinkler heads not issuing water is determined to be 0.0445. Hence sprinklers operated with a reliability of 95.5%. This is higher than the sprinkler statistics reported in US of 91% [18]. The higher reliability value may be attributed to a number of factors, but the most notably would be that the Australian data used in the Event Tree of Fig. 5 was limited to office buildings in particular. The referenced study [5] also included assessing the reliability for an upgraded sprinkler system which included the following improvements:

- Provision of a backup water tank for the sprinkler system (this is in addition to the BCA requirement for dual supply)
- Provision of a sprinkler valve alarm when turned off and flow monitoring alarm (to fire panel and fire brigade)
- Provision of subsidiary sprinkler valves serving each sprinkler zone
- Provision of end of line testing

The impact on the sprinkler performance as a result of the above improvements on an upgraded system is shown in Table 4 and Table 5. The individual improvements to the code compliant system are given in the last column. Note that the provision of a local subsidiary sprinkler valve for each sprinkler zone (item #3) reduced the sprinkler operational performance slightly but it was necessary to gain improvement to the overall system in item #2. With the above upgrades implemented, the overall improvement of the sprinkler operational reliability increased about 10 times to 99.5%.

Table 5. Failure probability values of key events for sprinkler operational failure

#	Event	BCA Value	Upgraded Value	Improvement (× times)
1.	No auxiliary water supply from water tank	1	0.00013	23
2.	No external water supply from mains	0.04268	0.000102	22
3.	Water supply cutoff or local sprinkler valve turned off (at zone)	0.0019	0.00450	0.95
4.	Water supply line to riser damaged	1.0E-06	0	1.00
5.	Sprinkler heads faulty	1.0E-06	1.0E-06	1.00
6.	Sprinkler heads do not issue water	0.04450	0.00450	9.9

6.2. Risk of compartment failure with sprinklers

With the probability of the operational failure of a minimum compliant sprinkler system estimated at 95.5%, the overall impact on the reliability to the structure may be estimated with the following event tree [14] to be 92.1% (*i.e.* 1-0.0794).

For the upgraded system, the structural fire reliability is further improved to 95.9%.

6.3. Risk of compartment failure without sprinklers

In the case of sprinkler failure, or if the building is not sprinkler protected, failure of a structural member or compartment barrier would depend upon the fire resistance of the member when exposed to the effects of fire. Fire resistance levels of these members providing fire compartmentation are normally characterized into 30, 60, 90, 120, 180 and 240 minutes, assessed against exposure to a standard temperature-time curve in a furnace. Natural fires, as opposed to a furnace fires, do not normally sustain its fully-developed characteristics as long. Most natural fires do not endure for more than 20 minutes which is evidenced in many full scale fire tests.

With passive construction, areas of potential failure[†] lie in both events and mechanisms as follows:

- Likelihood of fire door left open ≈ 0.1
- Likelihood of inadequate protection to penetration to fire rated walls/floors ≈ 0.05
- Likelihood of fire door closer failure or other hardware ineffective ≈ 0.01
- Likelihood of fully developed fire overwhelming the fire compartment ≈ 0.01

As may be inferred from the above, the key components contributing to failure of compartment barriers has little to do with the fire resistance rating. Hence a crude estimate of the reliability of a fire rated compartment performance is 1-0.1-0.05-0.01-0.01 ≈ 0.83. This is also consistent with the statistics for fire spreading beyond the fire rated compartment of fire origin given above, 1-0.174[‡] = 0.826.

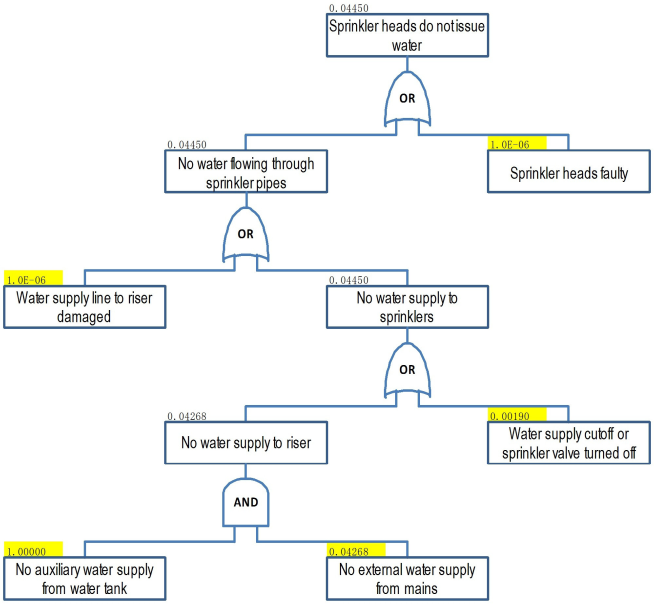

Fig. 5. Fault tree for operational failure of sprinkler system – compliant system.

6.4. Reliability of sprinklers in structural fire protection

Preliminary estimates of the assessment have indicated that providing minimum compliant sprinklers achieves about 92% reliability whilst fire rated compartment barriers has about 83% reliability, in terms of controlling or containing the fire. However, because the provision of sprinklers prescribed by codes are normally required to supplement the fire safety provisions already afforded by compartmentation, the inherent overall safety of sprinkler protected buildings is therefore much higher due to the combined protection provided. The above estimates of fire protection performance for sprinklers and

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[†] Taken from various sources but mainly inferred from references [22][23].

[‡] Refer to Statistics section, for the case without sprinklers, 17.4% of fires spread beyond the fire rated compartment of fire origin.

compartment barriers were determined independently, and not in combination. Hence, the effective performance levels with both sprinklers and fire compartmentation is 1-(1-0.92)×(1-0.83) = 0.986 (or 98.6%).

In an earlier paper [14], it was noted that if sprinklers are to be relied upon as a means of reducing the fire resistance rating of compartment barriers, then it should be considered by adhering to the concept of achieving an equivalent level of safety with the current fire safety provisions. This means that the sprinkler should have a level of reliability that is performing at least as good as the current combined reliability of both sprinklers and fire compartmentation at 98.6%.

The upgraded sprinkler system that was previously considered achieved a structural fire reliability of 95.9% (Table 4). This is approximately 50% or midway of the required improvement from 92.1% (Fig. 6) to 98.6%.

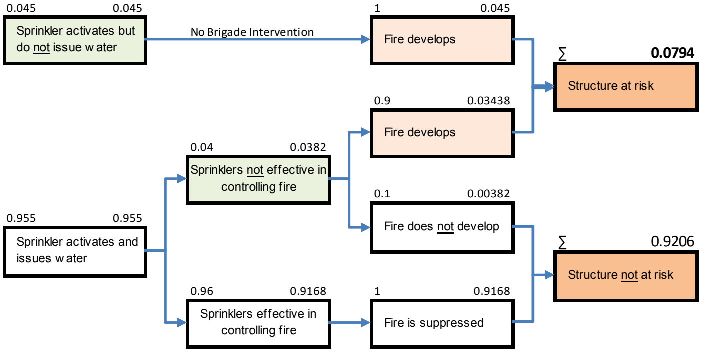

Fig. 6. Event tree for risk to structure due to sprinkler failure.

7. Discussion and conclusions

This paper has provided an assessment of the performance of both sprinklers and fire rated compartment in terms of deriving estimates of its probability of performance. Preliminary estimates of the assessment have indicated that both sprinklers and fire rated compartment barriers performed similarly in terms of controlling or containing the fire, with sprinklers performing slightly better. However, because the provision of sprinklers prescribed by codes normally does not supplement the fire safety provisions already afforded by compartmentation, the inherent safety of sprinkler protected buildings are therefore much higher due to the combined protection provided.

Whilst compartment barriers as a passive protection measure are often perceived to be more reliable, most of the components affecting compartment failure appear to lie with factors not related to the fire resistance rating. Hence, the performance of compartment barriers may be significantly improved if proper fire safety management (prevent chocking open of fire doors, proper protection of inadvertent openings or penetrations) and maintenance (door closers and other door hardware) are applied.

Overall, the performance of sprinkler protection offers the ability to control the fire before it becomes fully developed, a measure which passive protection is not able to provide. Reducing the potential development of a fire offers other advantages such as reducing potential damage and enabling a much easier access for fire rescue and intervention.

There is therefore potential to reduce the fire resistance rating of compartment barriers without compromising much of its safety, particularly in situations where sprinklers are also provided. However, if adhering to the principal of achieving an equivalent level of safety concept, then it would also be appropriate that the performance of sprinkler be further improved to at least a level consistent with the current estimates of the combined performance of a sprinkler protected fire rated compartment.

This study has shown that with the available means to improve the performance of sprinklers within practicable limits, the improvement in performance for sprinklers alone can only reach about half the combined performance of both sprinklers and compartmentation, and hence does not appear sufficient to completely replace the compartmentation requirements. It would therefore appear that the current recognition of some codes to reduce the fire rating provisions of structures when sprinklers are installed are not unreasonable and that the reductions should not exceed 50%, unless additional means of improving the sprinkler performance are provided to be at least equivalent to the current combined performance of a minimum compliant sprinkler protected compartment.

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