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Risk Index Method–A Tool for Sustainable, Holistic Building Fire Strategies

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Abstract: Modern fire safety engineering seeks to ensure buildings are safe from fire by applying optimum levels of fire safety and protection resources without the need to *overprotect*. Similarly, the principles of sustainability aim to ensure resources are suitably applied to meet social, economic, and environmental objectives. However, there is a mismatch between the actual application of fire safety and the sustainability objectives for buildings, typically caused by the highly prescriptive historical approaches still largely adopted and legislated for in many countries. One solution that is increasingly adopted is the more flexible, "performance-based" fire engineering approach that bases fire safety and protection provisions on the development of key performance objectives, some of which could be influenced by sustainability engineering propositions for buildings, but very often this does not appear to be enough. The proposed new concept prompts separate assessment and scoring of the eight most important fire safety factors, allowing for calculation of the fire strategy risk index (FSRI). By comparing the FSRI of the actual submitted strategy against the baseline strategy, enforcement agencies or other interested stakeholders will have a methodology to determine optimal fire safety solutions for buildings.

Keywords: fire strategy; risk index; fire risk assessment; fire protection; cost simulation; fire safety simulation; holistic fire strategy

1. Introduction

1.1. The Mismatch between Sustainability and Fire Engineering

The primary aim of fire safety engineering is to assess the building, including its processes and occupancy profiles, and to determine the most effective strategy to limit the consequences of a fire, both directly and indirectly. Typically, a key consideration is the protection of life, although in more recent times the scope has widened to encompass issues such as the protection of assets, business interests and the environment. Collins English Dictionary (2020) [1] defines sustainability as the ability (for a scenario) to be maintained at a steady level without exhausting natural resources or causing severe ecological damage. Given that damage control is also a primary objective of fire safety and protection, it could be argued that the objectives of both the sustainability and fire safety industries are aligned. However, this is not always the case. Some of the methods used to fight fires have been found to be harmful to the environment. Halons (halogenated hydrocarbons), once prominently used to extinguish fires, were found to be extremely harmful to the ozone layer and were banned for general use in the 1990s. Run-off water from the action of firefighting can typically contain chemical biproducts of combustion, leading to contaminated land, rivers, etc. [2].

There are other issues that also show a mismatch between the two disciplines. One example is the extensive requirement of fire compartmentation in building fire strategies, whilst sustainable building design tends to favour more open building layouts. Consequently, the way fire safety engineering is applied to building design must be reviewed. If sustainability is to become a natural feature of our built environment, then the methods used to apply fire safety need to incorporate features that consider issues such as the environment. This must start with reflection on how we prepare fire strategies and how we can evaluate them. Troisi et al. refer to enforcement authorities as one agent in improving a systemic approach to safety systems, with a shift in perspective from single bodies involved with safety performance to interdependence with all agents [3].

To understand where we need to change, it is important to understand how fire safety is currently applied. Most nations make use of the application of fire safety regulations to ensure that minimum standards are applied. These laws are often supported by national or international codes or standards, which provide specific details to be followed and are backed up by the law of the land [4–9].

Despite advancement of the use of fire engineered solutions, most buildings are still required to meet with the prescriptive national building regulations. Historically, these have been supported by national fire codes, which have also been largely prescriptive in nature. Such rules are often seen as restricting advances in building design. The whole focus is on rigid designs that help protect building occupants against the ravages of fire, with little concern for other aspects such as the internal and external environment of the building. This is naturally at odds with the objectives of sustainability. The Society of Fire Protection Engineers [10] stated that performance-based fire engineering design will become increasingly important in ensuring sustainable building design. They recognised the mismatch between fire safety prescription and sustainability issues and pointed out that, in order to quantifiably reduce a building's resource use, fire engineers need to take into account the resource demands of products necessary to achieve the required fire safety performance. The fire protection industry needs to recognize new materials and products and adapt the fire safety solutions accordingly [11,12] (Snyder, 2010, Vecchiarelli, 2014).

1.2. The Development of Performance-Based Fire Engineering

Even though performance-based approaches to fire engineering design have been around for decades, some nations have sought an interim step to gain full acceptance. The British Standards Institution determined that the restrictive nature of prescriptive standards should be replaced by a standard that allowed for some flexibility in applying fire safety, even if it did not apply the methodologies adopted by performance-based standards. British Standard BS 9999 [13] was first published in 2008. This allowed variation in the specification of aspects of fire safety, such as travel distances for evacuating persons, based upon the building's risk profile. The risk profile was made up of two factors: the potential rate of fire growth, and the occupancy profile (e.g., occupants' knowledge of the building, the potential for not being awake during a fire, etc.).

The concepts behind a performance-based approach were introduced from the 1970's onwards to allow greater flexibility in the design and application of fire safety and protection systems. From the 1990s, standards were published to provide guidance regarding the application of a performance-based approach. The UK is acknowledged as an early pioneer in standardising this more flexible approach. In later years, many other countries have followed up with their own ideas and codes.

British Standard BS 7974 [14] was published to provide guidance for the preparation of fire engineered solutions. This standard superseded DD 240-1 [15], which was the earliest attempt to standardise such an approach by providing a "rational methodology for the design of buildings". The standard was intended to apply to the design of new buildings and the appraisal of existing buildings. The key benefits highlighted by the British Standard were that;

a. It provided the designer with a disciplined approach to fire safety design;
b. It allowed the safety levels of alternative designs to be compared;
c. Iit provided a basis for selection of appropriate fire protection systems;
d. It provided opportunities for innovative design;

e. It provided information on the management of fire safety for a building.

The main standard was supported by several guidance documents published as “Public Documents” or PDs. These documents were designed to provide fire safety engineers with additional information to allow them to formulate effective and relevant performance-based fire strategies [16–24].

It is not just the UK that has standardised the use of fire engineering [25,26]. The USA’s National Fire Protection Association have published NFPA 101A: A guide on alternative approaches to life safety [27]. The NFPA 101A document itself was originally found as an appendix to the main life safety standard NFPA 101 (the original and more prescriptive Code) [28]. The standard follows on from NFPA 101 by allocating self-contained sections to various types of building use, from healthcare to correctional facilities and so on.

Today, many countries, for example New Zealand [29] or the United Arab Emirates [30], have explicit codes covering recommendations for performance-based approaches, or they point towards either, or both, of the BS and NFPA referenced standards. There are also specific codes dedicated to especially risky buildings [31].

1.3. The Sustainability Issue in Fire Safety Standardisation

A major manufacturer of fire-resistant glazing [32] highlights that fire can have a major impact on the sustainability of communities and the built environment since a building that burns down is fundamentally unsustainable. They point out that the fire protection of buildings therefore has an increasing role on the sustainability agenda. Yet, most fire standards and codes rarely explicitly highlight the issue of sustainability. It is only by promoting an innovative approach that the subject and objectives of sustainability can be specifically incorporated.

Figure 1 illustrates a model depicting how sustainability relates to the key factors of social equity, economics and the environment. By balancing all three aspects, it is suggested that true sustainability can be achieved. Could this relate to the aims of fire engineering?

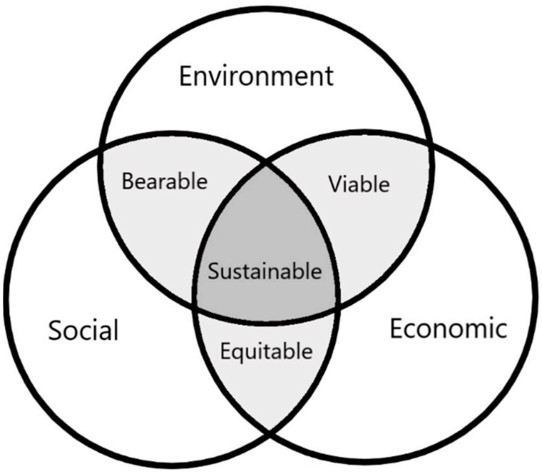

Figure 1. A sustainability model [33].

Let us start with social considerations. This closely relates to the ethical need to protect life and is largely considered a fundamental part of all building legislation by national fire safety regulations. The environmental issue is less touched upon by prescriptive fire standards but can be a key consideration and performance objective for modern fire safety engineering. Economics is a factor that is relevant in both approaches. The added flexibility of fire engineering has also delivered benefits by avoiding “overprotection” [34] and applying systems as specifically required. The obvious conclusion is that the adoption of performance-based techniques for the specification of fire safety and protection will assist in developing “sustainable buildings”. However, there are some issues that may prevent the techniques from being globally approved [35].

1.4. Issues Surrounding the Reality of the Application of A Performance-Based Approach

If sustainable building design dictates that fire safety engineered performance-based approaches are necessary, then it is vital that the approach is accepted by all. Enforcement Agencies around the world are entrusted to approve fire safety designs for new or modified building projects. To this day, many do not have absolute confidence in submitted designs, especially those using a performance-based approach. This was confirmed in 2016 via discussions between the authors and the London Fire Brigade [36]. The brigade can employ their own team of fire professionals to, as far as possible, check the submitted fire strategies. This obviously has time, resource, and cost implications, especially when there are increasingly tight budgets imposed on them. Their other choice is to restrict the validation process with the potential for missing aspects that may not subsequently be proved to be acceptable.

The problem of approving fire strategies is further exacerbated by the fact that fire engineering organizations, big and small, all have their own styles and methodologies. There is little in the way of consistency of approach. Other than detailed analysis on a case by case basis, there is currently no means of measuring if a fire strategy is fit for purpose; is it designed to provide baseline levels of fire safety or is it deficient in one or more areas? The effectiveness of a fire strategy relies on the skills and experience of fire strategists—those tasked with preparing the fire strategy. However, with the increased flexibility of performance-based designs, even when subject to the controls of standards such as British Standards [5,16–24], there is a danger that the strategy will miss key features.

1.5. An Introduction to Holistic Fire Strategies

Holistic Fire Strategies (HFS) is an idea first developed in 2013 [36] to cater to all the above concerns simultaneously, as well as improve industry acceptance [9,37–39]. HFS does not seek to change fire science or the application of fire engineering principles. What it does seek to do is:

(a) Provide a highly auditable framework. The key beneficiaries of this will be enforcement agencies around the world, which will enjoy increased confidence in HFS-based fire strategies. They will also benefit by reducing the currently high levels of resource and time commitment required to evaluate each submitted strategy.

(b) Provide a consistent approach and format, whether the building design is based in London, Stockholm, Chicago, Dubai, Sydney, etc. The idea here is to introduce a fire strategy framework for each building and occupancy type. This is referred to as a metric template. The concept is that a metric template is prepared for each building type such as airport, hospital, office block, etc. This template would formalize the approach taken and guide the person preparing the strategy to consider premises related issues. The template would be peer reviewed by local authorities in the field for each type of metric template.

(c) Widen the scope of fire strategies to include threat assessment and objectives setting. This will be part of the metric template process.

The control process will be made available via a specially designed website (www.igni.online). This website will allow every project to be registered by the appropriate project team. They would then download the relevant metric template and follow the instructions. Note that this metric template will incorporate features such as objectives assessment and threat analysis which can be used to promote sustainability objectives as an integral part of every fire strategy. As the template gets completed, this can be monitored, also via the website, by the relevant enforcement authorities. Note that the template will not take the place of the fire strategy itself but will support the development of the strategy in a clear and consistent format. It will also ensure that all relevant points have been considered as identified by leading fire engineering experts. This will allow enforcement agencies to quickly identify what assumptions have been made and how the strategy has been approached.

Section 2 covers the development of one aspect of this concept: how to better formulate and evaluate fire strategies, particularly those that use a performance-based approach.

2. Fire Strategy Evaluation Methodology

2.1. Introduction

To improve the auditability of fire strategies using performance-based techniques and thus assist in creating "sustainable" fire strategies, a novel framework and method is proposed. The method for fire strategy evaluation is originally based on a British fire strategies methodology, composed by combining methods presented by PAS 911 [34] and Bryant [36] with a risk-based method that was developed by Swiss engineer Max Gretener [40] and a fire risk indexing idea [41].

It is the Gretener Method [40] that was chosen as a basis for the wider assessment of fire strategies as this method promotes the calculation of potential hazard and protective measures values, which are used in the final fire hazard index calculation. The method uses empirical figures, estimated individually for the building, based on the level of its fire protection in comparison with solutions either generic or required by national legislation. This idea follows most probability type risk assessments, where fire risk is assumed as a product of hazard severity and loss expectation represented by the fire's frequency of ignition. In 2018 the method was published in Poland [42]. The evaluation assumes the:

- Scoring of eight separate fire safety factors;
- Presentation of the results at the fire strategy value grid;
- Calculation of the fire strategy risk index (FRI), which is used as the final factor for evaluation.

For each evaluated building (or part thereof, such as a fire zone), the method assumes comparison of two fire strategies: the baseline strategy (default, based on the building's risk profile or determined individually) and the actual strategy (real, realized for a new build project or for an existing building).

2.2. Preparation of an Eight-Part Questionnaire

A questionnaire has been prepared to allow the separate scoring of each of the fire strategy elements (Figure 1). It is a derivative of the format prepared and originally trialled in Poland at three power stations [43,44]. Both the baseline fire strategy and the actual fire strategy should be independently assessed using the same questionnaire, presented in Table 1. The baseline will be scored against the base requirements of the national fire safety standards for the building risk profile and other factors such as height. Note that the baseline, if based upon performance-based objectives, could incorporate features to improve sustainability objectives.

The questionnaire incorporates a series of features that can be summed together to come to a final score. In some cases, there is an "OR" option. Furthermore, it should be noted that individual features may typically score up to a value of 5 or 10. If it is believed that the feature is required (for baseline cases) or provided (for actual cases) but is not complete or is a variation of that feature, then the feature may be scored between zero and the maximum score.

The actual fire strategy will be scored based on the fire strategy proposed for a specific building or where a retrospective assessment of an existing building's fire strategy is undertaken.

Clearly, if the building is designed exactly to the national standards, the baseline and actual fire strategies should match. In other cases, the evaluation can show where adjustments have been made such as providing a sprinkler system to allow for reductions in other elements.

Once completed, a diagram referred to as a "fire strategy value grid" can be produced showing the results. An uncompleted version of the diagram is shown in Figure 2.

The pattern made up by the joined node scores can be quite revealing. The area within the pattern provides an idea of the resources and costs associated with the provisions required by the strategy. For instance, if each element is scored as twenty-five, the pattern will form the whole outer core of the diagram, with the maximum area taken up. Consequently, the fire safety and protection provisions are likely to be costly to implement and extremely resource hungry. Conversely, a shape with a much smaller footprint will be much more affordable. It must still be effective and answer all the issues from the earlier objectives setting.

Table 1. Holistic fire strategy questionnaire [42].

Node	Questionnaire	Max Score
1 Control of ignition sources (CI)	Basic management documented controls (≤5) + regular testing of electrical systems (≤5) + restriction of all forms of ignition to protected and fire separated areas (≤10) + specialised ignition control methods (≤5)	25
2 Control of combustibles (CC)	Basic management documented controls (≤5) + strict controls on specification of internal and external building fascia's and linings (≤5) + strict controls on the specification of fixtures, fittings and equipment (≤5) + restricted allowances on size, location and/or type of combustible materials in common spaces (≤5) + creation of sterile areas in escape routes by locating combustible materials in controlled and contained environments (≤5)	25
3 Fire Compart-mentation (FC)	Requirements for structural integrity of the building against fire (≤5) + fire separation of escape routes from risk areas (≤5) + enhanced fire separation to allow for firefighting operations (≤5) + enhanced fire separations to maintain specific occupied areas of the building until firefighting operations have been completed (≤5) + enhanced fire separations to allow for protection of assets (≤5)	25
4 Smoke Control Systems (SC)	Use of simple methods to vent key areas (e.g., opening of windows in escape stairs and lobbies) (≤5) OR automatically operating proprietary venting arrangements (≤10) + mechanical smoke extract or pressurization systems in escape staircases (≤5) + mechanical smoke extract systems to enable variations of other elements of the fire strategy (e.g., extended travel distances) (≤5) + use of smoke control systems to allow continuance of critical operations during a fire incident (≤5)	25
5 Fire Detection (FD)	An automatic fire alarm system using manual activation only (≤5) + monitoring escape routes by fire detectors (≤5) + monitoring of hazard areas (≤5) + monitoring all remaining areas (≤5) + enhanced specialist monitoring methods (≤5)	25
6 Fire Suppression (FS)	Suppression systems to protect high hazard equipment (≤5) + systems to protect hazard rooms or areas (≤5) + systems to protect key parts of the building (≤5) + systems to protect all remaining areas of the building (≤10)	25
7 Fire service intervention (FI)	Manual method only for contacting fire service (≤5) OR automatic or 24/7 trained manual contact (≤10) + response time to be within national guidance (≤5) + proprietary facilities for access to all parts of the building (≤5) + facilities for firefighting water supplies (≤5)	25
8 First aid Firefighting (FA)	Provision of portable fire extinguishers (≤5) + personnel trained in their use (≤5) + specialist firefighting systems for specific risks (≤5) + trained professional firefighters on-site for rapid attendance to a fire (≤10)	25

The way the pattern sits on the diagram can also reveal the type of strategy being used. For a pattern predominantly in the upper quadrant, the strategy will place greater reliance on fire safety management, whilst a pattern towards the lower quadrant will place greater reliance on active fire protection.

A shape on the left-hand side indicates that the strategy will rely on suppression of a fire, whilst a shape to the right places greater reliance on containment and control of a fire, and the products of combustion, by structural means. An item scoring highly in the diagram is likely to be an important feature of the final written strategy.

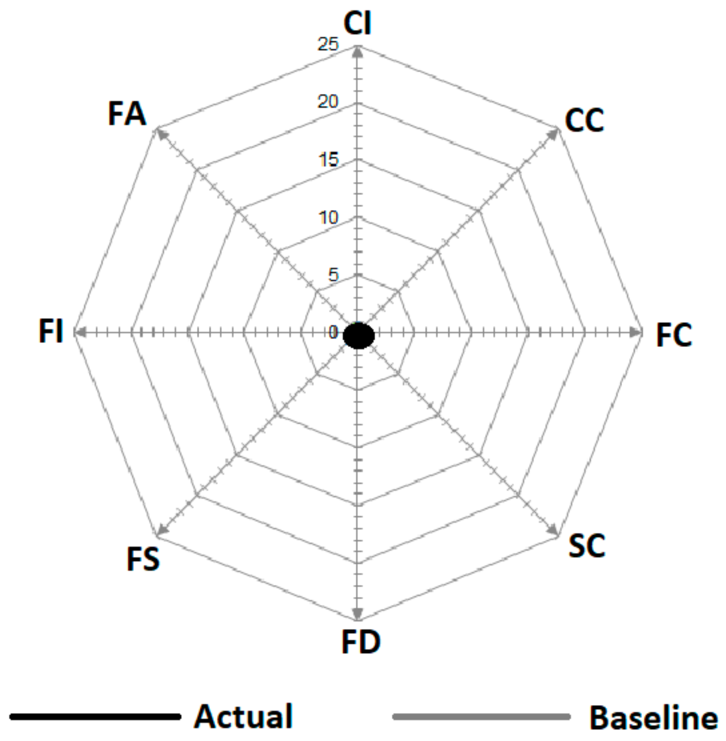

Figure 2. Fire strategy value grid.

2.3. Fire Strategy Risk Index Calculation

The last step of fire strategy evaluation is a Fire Strategy Risk Index (FSRI) calculation. The purpose of this calculation is to amalgamate each of the individual scores for both the baseline and actual conditions.

Various methods could be used with the information obtained for the fire strategy value grid [45,46]. It is the Gretener Method, which was developed by Swiss engineer Max Gretener [40], that was chosen as a basis for the wider assessment of fire strategies. The reason for this is that this method promotes the calculation of potential hazard and protective measures values, which are used in the final fire hazard index calculation. The method uses empirical figures, estimated individually for the building based on the level of its fire protection, in comparison with solutions either generic or required by national legislation. This idea follows most probability type risk assessments, where fire risk is assumed as a product of hazard severity and loss expectation represented by the fire frequency of ignition. It is presented in Equation (1).

The purpose of the Fire Strategy Risk Index (FSRI) is to provide a single score for both the baseline and actual fire strategies based upon the product of the Fire Hazard Index (FHI) and the Frequency of Ignition (Fi), both of which are found through analysis and existing codes as described below. By comparing the two scores, the overall efficacy of the fire strategy can be evaluated. The fire strategy risk index assesses the residual risk for a fire strategy. Ideally, the actual risk index score is equal to or lower than the score for the baseline. Where it is higher, then the fire strategy should be re-evaluated.

$$\mathrm{FSRI} = \mathrm{FHI} \cdot \mathrm{Fi} \quad (1)$$

The Frequency of Ignition is one of the key parameters of most probabilistic risk assessments and is specifically covered in British Standard PD 7974-7 [23]. It is usually the initiating event in most event trees and can be a base event in fault trees. Offices typically have a frequency of ignition per year of around 0.4×10^{-2}, whilst this increases to 4.6×10^{-2} for hotels and restaurants. For our examples presented later, schools are rated at 1.4×10^{-2}, and public buildings and services (which includes metro stations) are rated at 1.8×10^{-2}.

The fire hazard severity, as represented by the Fire Hazard Index from Equation (1) is proportional to the Potential Hazard (PH), reduced by the Protective Measures (PM) applied, as shown in Equation (2).

$$\mathrm{FHI} = \frac{\mathrm{PH}}{\mathrm{PM}} \cdot 100 \quad (2)$$

The original Gretener formula (1973) [40], expressed empirically, derived numerical factors for fire initiation and spread from factors for fire protection. The idea used in the method presented here is based on values achieved by scoring each fire safety factor in accordance with the calculations for the baseline and actual strategies. The FHI is clearly a ratio.

2.4. Introducing a Weighting System

When creating a scoring index for a fire strategy using both baseline and actual conditions, it could be assumed that each of the nodes is equally important. The opportunity to allow stakeholders to adjust the criticality of each node may be based upon the following:

- The requirements and guidance of national legislation and codes.
- The results of objectives setting and threat analysis.
- Building-specific issues that one or more stakeholders deem important.

Clearly, the weighting (W) should be such that each of the eight nodes are separately scored with the total coming to unity. Consequently, in the case of each node being equally valued, the value of W for each node will be 0.125.

A total score for protective measures (PM) is obtained from the formula (Equation (3)) by aggregating the points obtained from the assessment of each fire safety factor adjusted by the appropriate weighting factors.

$$\begin{aligned} PM = {} & W_{CI} \cdot A_{CI} + W_{CC} \cdot A_{CC} + W_{FC} \cdot A_{FC} + W_{SC} \cdot A_{SC} + \\ & + W_{FD} \cdot A_{FD} + W_{FS} \cdot A_{FS} + W_{FI} \cdot A_{FI} + W_{FA} \cdot A_{FA} \end{aligned} \quad (3)$$

In an optimal fire strategy, the Potential Hazard (PH) can be determined by assuming that, for the case where baseline conditions are exactly met, PH = PM, and therefore the FHI will have exact unity. Therefore, by using Equation (2), PH = PM/100.

3. Worked Examples

Two examples are used to illustrate the fire strategy risk index methodology: a metro station and a school building.

3.1. Metro Station

The baseline fire strategy will be based on UK regulations for sub-surface railway stations. The scoring, assessed using the key requirements of the regulations, is presented in Table 2.

Table 2. Fire strategy scoring—baseline conditions for the metro station.

Node	W	Baseline	Actual
1 Control of ignition sources (CI)	0.1	20	20
2 Control of combustibles (CC)	0.1	25	25
3 Fire Compartmentation (FC)	0.1	20	16
4 Smoke Control Systems (SC)	0.1	10	6
5 Fire Detection (FD)	0.3	20	24
6 Fire Suppression (FS)	0.1	15	15
7 Fire service intervention (FI)	0.1	25	25
8 First aid firefighting (FA)	0.1	15	15

In this case, the actual strategy varies from the baseline strategy due to updated sustainability requirements in order to improve operational issues for the station. These changes are:

Fire compartmentation (FC) requirements were reduced in some internal office areas by removing subdivisions. This was chosen to improve local ambient working conditions and reduce the need to separately power ventilation systems. This improves all sustainability objectives of social working, economics, and environment. However, it was deduced that this lowered the score by four points.

Smoke control systems (SC) at this station are typically only used at ticket hall level and at platform level to cater for a train on fire scenario. A metro cooling project has replaced the need for mechanical extract at platform level in passive metro systems. This greatly reduced the need for intensive smoke extraction systems and the associated power requirements, which were replaced with bored ventilation systems up to surface level. The sustainability factor of economics was therefore improved, and the score was reduced to six.

Fire detection (FD) was additionally installed in public corridors although not on the platform. This was based upon a known scenario in another metro station where a fire was allowed to grow in passenger walkways and was not automatically detected in good time. This increased the scoring of these nodes to almost a full score, although one mark was deducted because of the platform levels.

The actual conditions are separately scored and presented in Table 2. It is suggested that the need for a detection system (FD) is of increased importance, with the weighting factor of W = 0.3, while all the other weighting factors stay at the level of W = 0.1.

Below, the FSRI method is used to arrive at this answer. Using the scores from Table 2, the fire strategy value grid can be completed as shown in Figure 3. In this case, the fire strategy is resource intensive, based on the overall area of both baseline and actual conditions. Furthermore, the dynamics of the fire strategy remain consistent given that the shape is not fundamentally different.

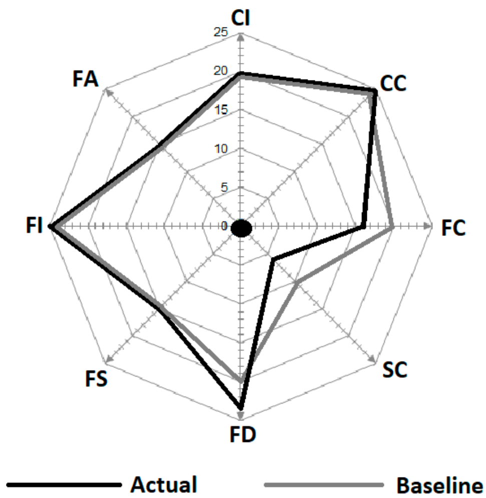

Figure 3. Strategy value grid for the metro station.

In the next step of the evaluation, the PM factors for the baseline and actual strategies are calculated with the weighting factors applied accordingly.

Baseline strategy: $PM = 0.1 \times (20 + 25 + 20 + 10 + 15 + 25 + 15) + 0.3 \times 20 = 18.0$

Actual strategy: $PM = 0.1 \times (20 + 25 + 16 + 6 + 15 + 25 + 15) + 0.3 \times 24 = 19.4$

The above values for PM in baseline and actual scenarios can initially be used to determine the Fire Hazard Index (FHI) and subsequently the Fire Strategy.

PH (in both cases) = 18.0/100 = $18{\cdot}10^{-02}$

For the actual strategy, $FHI = PH/PM \times 100 = (18.0{\cdot}10^{-02}/19.2) \times 100 = 0.94$. (Note that for the baseline strategy, $FHI = 1$).

Using the Fi of $1.8{\cdot}10^{-2}$, we can calculate the Fire Strategy Risk Index for both strategies: for the baseline strategy, $FSRI = FHI{\cdot}F$i $=1 \times 1.8{\cdot}10^{-2} = 1.80{\cdot}10^{-02}$; and for the actual strategy, $FSRI = FHI{\cdot}Fi = 0.94 \times 1.8{\cdot}10^{-2} = 1.69{\cdot}10^{-02}$.

The calculations show that the actual FSRI is lower than the baseline figure. This infers that the protective measures implemented in the metro station fire strategy will keep the general safety level to at least at the same level as required by UK regulations.

3.2. School Building

In the case of a typical school building, a national code would be applicable. As an example, the baseline conditions will be based upon British Standard BS 9999 [13] with a risk profile of A2 (a building where occupants know the escape routes and with the potential for a medium growth fire). Note that the UK Government [47] has set a sustainability goal for schools to reduce waste, and this is particularly good news for fire strategy prevention techniques if the level of combustible materials (CC) is reduced. This is not covered specifically in the British Standards, but when adopted it would raise the value of the node for the baseline condition. Using the scoring system of the questionnaire (Table 1), the baseline conditions are shown in Table 3.

Table 3. Fire strategy value grid—actual conditions for the school building.

Node	W	Baseline	Actual
1 Control of ignition sources (CI)	0.125	15	12
2 Control of combustibles (CC)	0.05	10	7
3 Fire Compartmentation (FC)	0.125	15	8
4 Smoke Control Systems (SC)	0.125	10	10
5 Fire Detection (FD)	0.125	5	5
6 Fire Suppression (FS)	0.2	0	25
7 Fire service intervention (FI)	0.125	20	20
8 First aid firefighting (FA)	0.125	5	5

In the case of the school, the following was found:

a. Some irregular requirements for testing of electrical equipment (CI).
b. Some of the linings specified were found to be not fire resistant (CC).
c. Non-resistant glazing was specified for incorporation into some of the fire resisting partitions (FC).
d. A sprinkler system had been fitted throughout on the advice of the local authority (FS).

In this case, it is also believed that each node should not be equally weighted, based on threat analysis and the increased risk of arson affecting schools within the local community. It is suggested that there is increased importance for a sprinkler system (FS) with the weighting factor of W = 0.2 and less for the control of combustibles (CC) node with the weighting factor of W = 0.05, which becomes less influential in the case of sprinkler installation. All other weighting factors stay at the level of 0.125. Based on the assumptions above, PM factors for the baseline and actual strategies are calculated. Table 3 provides the results of the fire strategies scoring as well as the weighting factors values.

Using the scoring from Table 3, the fire strategy value grid can be completed as shown in Figure 4.

The school building would typically rely on a reasonable level of fire safety management, the maintenance of some level of fire containment, the intervention of the fire and rescue services, and less reliance on systems. The inclusion of sprinklers has distorted the shape due to an increased reliance on the system, whereas the slight reduction in the actual case may not be so relevant. In the next step of the evaluation, the PM factors for the baseline and actual strategies are calculated with the waiting factors application.

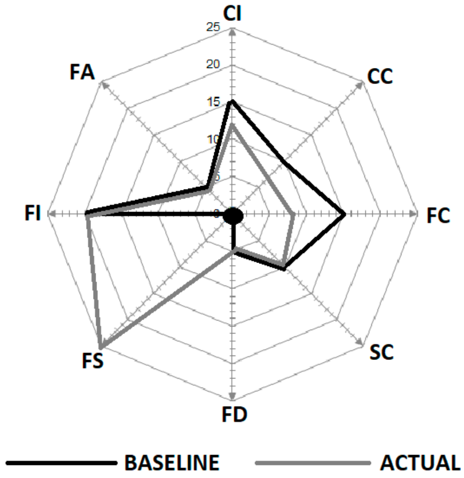

Figure 4. Strategy value grid for the school building.

Baseline strategy: $PM = 0.125 \times (15 + 15 + 10 + 5 + 20 + 5) + 0.05 \times 10 + 0.2 \times 0 = 9.25$
Actual strategy: $PM = 0.125 \times (12 + 8 + 10 + 5 + 20 + 5) + 0.05 \times 7 + 0.2 \times 25 = 11.60$
PH (in both cases) = 9.25/100 = $9.25 \cdot 10^{-02}$

Actual strategy: $FHI = PH/PM \times 100 = (9.25 \cdot 10^{-02}/11.60) \times 100 = 0.797$.

(Note that for the baseline strategy: $FHI = 1$)

Using the Fi of $1.4 \cdot 10^{-2}$ we can calculate the Fire Strategy Risk Index for both strategies:
Baseline strategy: $FSRI = FHI \cdot F\text{i} = 1 \times 1.4 \cdot 10^{-2} = 1.40 \cdot 10^{-02}$
Actual strategy: $FSRI = FHI \cdot Fi = 0.797 \times 1.4 \cdot 10^{-2} = 1.12 \cdot 10^{-02}$

In this case, the FSRI for the actual fire strategies is substantially lower than the baseline. This concludes that the risk in the actual case is substantially lower, and thus the strategy is satisfactory. By examination, it will be concluded that the inclusion of the sprinkler system was the main reason for the positive scoring.

In contrast to the examples presented, real projects allow multiple “actual” examples to be trialled for both new and existing buildings. Alternative strategies can be examined also with the use of computational fluid dynamics (CFD) modelling to assess the efficacy of adjusting parameters such as fire suppression and smoke control options. Perhaps even the baseline assessment could be varied by comparing a purely prescriptive baseline with one that uses a performance-based approach.

The inclusion of the frequency of ignition also focuses on the additional risk introduced from historical fire data. Although the frequency of ignition factor is not directly relevant when comparing the actual and baseline scores for a specific case, this could allow for a comparison between different risk profiles given that each risk profile will have a different value of Fi, the value increasing with risk. Quite possibly, a catalogue of fire strategy risk indices can be built up and used in the comparison of fire strategies.

4. Conclusions

It is suggested that only a more flexible, performance-based approach to fire safety engineering will enable “sustainable” solutions for the fire safety of buildings. This requires acceptance of the methodology by all stakeholders, as well as an acceptance that prescriptive fire safety rules will not provide more sustainable building designs. In order to meet this goal, it is deemed necessary to improve the auditability of performance-based fire strategies so they will be accepted by enforcement agencies and by the wider fire community. One factor that will need to be considered is the manner by which a fire strategy is evaluated. This paper presents a method for fire strategy evaluation by providing a new, comparative index methodology for the assessment of fire strategies.

The most significant element of the methodology is the possibility of determining if a prepared fire strategy is appropriate for a specific building, with its risk profile set against a baseline fire strategy. The idea allows for sustainability to be built into the baseline strategy so that the actual strategy could be assessed against such objectives.

It also allows for the comparison of different fire strategy concepts for a building or other form of infrastructure, as well as comparison of similar fire strategies used in different buildings. The simple rule of the methodology assumes that, where the fire risk index for the actual fire strategy is equal or lower than the baseline fire strategy, then this strategy is deemed suitable and fit for purpose. A higher score means that the fire strategy should be reviewed and the elements of the strategy revisited. Due to the presented methodology, enforcement agencies or other interested stakeholders will have a tool for making simulations of different fire protection concepts and finally finding an optimal solution for a building.

Once a more consistent and universal methodology is accepted, other factors can be gradually incorporated into the fire strategy process to improve the way fire safety is specified, particularly with regards to issues such as the environmental impact of a strategy. In this way, sustainability can feature as a fundamental part of the fire safety engineering approach to building design.

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