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Risk Index Method—A Tool for Building Fire Safety Assessments

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Featured Application: The presented concept of fire strategies evaluation can be applied to a range of industrial fire safety assessments and can be adapted for specific needs relative to different industries.

Abstract: The use of fire safety engineering and performance-based techniques continues to grow in prominence as building design becomes more ambitious, increasing complexity. National fire safety enforcement agencies are tasked with evaluating and approving the resulting fire strategies, which have similarly continued to become more advanced and specialist. To assist with the evaluation of fire strategies, this paper introduces a methodology dedicated to sustainable building fire safety level simulations. The methodology derives from ideas originally introduced in British Standard Specification PAS 911 in 2007 and combines a visual representation of fire strategies with a semi-quantitative approach to allow for their evaluation. The concept can be applied to a range of industrial fire safety assessments and can be modified for specific needs relative to different industries.

Keywords: fire strategy; fire protection; performance-based design; fire resistance

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1. Introduction

1.1. Fire Safety Engineering and the Use of A Performance-Based Approach

Fire safety engineering is generally recognized as a unique branch of engineering [1]. Whereas other engineering disciplines make use of known laws, fire safety engineering is rarely absolute in its science and application. Therefore, traditionally, a strongly prescriptive approach has been applied for the fire safety and protection requirements of buildings by the use of national codes, such as British Standards [2].

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 typically provide specific details that should be followed. However, such an approach has often restricted advances in building design British Standard DD 240–1 [3].

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

An early alternative approach (1997) developed within the UK is a standard, referred to as a "Draft for Development", introduced by British Standards Institution (BSI) in 1997 (British Standard DD 240–1) [3]. The scope of the standard highlighted that it provided a framework for an engineering approach to the achievement of fire safety in buildings by giving guidance on the application of scientific and engineering principles to the protection of people and property from fire. A second supporting standard, British Standard DD 240–2 [4] was also published to provide commentary on the equations given in Part 1 [3]. This Draft for Development was seen as a breakthrough in allowing building designers the option of applying fire safety to a building based upon performance objectives determined for that building. The idea was that one or more meetings would be held involving relevant stakeholders who would set these performance objectives. These meetings were described as "qualitative design reviews", in that the qualitative decisions made would guide the subsequent quantitative analysis described in British Standard DD 240–1 [3].

The key concepts of DD 240 were developed further by BSI when, in 2001, British Standard BS 7974 [5] was published to supersede DD 240. The Standard used the same framework for an engineering approach as described for British Standard DD 240–1 [3]. It also provided a "rational methodology for the design of buildings". The main standard was supported by eight "Public Documents", PD 7974 parts 0–8, which allowed fire safety engineers to create effective and relevant performance-based fire strategies [6–14]. At the time of the publication of BS 7974 (5), a series of prescriptive British Standards were still in force and referred to as the BS 5588 series [2]. These standards supported the UK Building Regulations and specifically Approved Document B (volumes 1 and 2), which covered fire safety (2010) [15,16].

BSI determined that the restrictive nature of these 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 the performance-based standards. The British Standard BS 9999:2017 [17] 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 and the potential for not being awake during a fire). Another relevant standard introduced by BSI is the British Standard Specification PAS 911:2007 [18]. This document was designed to provide a methodology for the preparation of fire strategies, whether they used prescriptive standards or a performance-based approach. In itself, this document does not give recommendations or requirements for the fire safety design of buildings. It aims to provide a consistent platform for fire strategies, such that they will follow a consistent format, whatever the building type is and where it is.

The USA's National Fire Protection Association has also standardized the performance-based approach, albeit it more recently than in the UK. This is covered in NFPA 101A: A guide on alternative approaches to life safety [19], on the basis of Nelson's system for healthcare facilities [20]. The NFPA 101A document itself was originally found as an appendix to the main life safety standard NFPA 101 [21] (2018). The standard follows on from NFPA 101 by allocating a number of self-contained sections to various types of building use, from healthcare to correctional facilities and so on.

1.2. Issues Surrounding Reality in the Application of a Performance-Based Approach

With so much in the way of standardization and guidance in place, it could be considered that the fire safety community, as well as all relevant stakeholders, are well served, but the authors do not believe that this is the case. Listed below are some areas where issues persist. This is not just in the UK or in countries that use standards such as those listed above but is recognized as a global issue. Let us not also forget that a performance-based building regulatory system puts added responsibility on fire protection engineers, as they are generally expected to demonstrate that the proposed fire safety design solution satisfies the performance objectives [19,21–23]. There is another aspect and that is the cost-benefit assessment of the impact and quantitative comparison of fire safety and protection system designs [24–28]. This is a factor that should be considered relevant for all fire strategies. Some countries are increasingly adopting their own performance-based codes: New Zealand [22] and the United Arab Emirates [23] are two examples.

1.3. Fire Strategy Evaluation and Fire Risk Assessment

There is an established understanding that integral to the subject of fire safety, especially fire safety engineering, is the assessment of the risk of fire. Fire risk analysis can range from a simplistic assessment to a much more detailed analysis of how the building, the occupants and the fire itself, interact. Park et al. [28] introduce a hierarchical holistic model, known as the Integrated Characteristic Interaction Model (ICIM), which considers fire protection viz a viz the relationship with both the building and the persons within the building. They aimed to derive a quantitative method to support a holistic approach to developing a fire strategy and reducing subjectivity in its development.

Xin [29] considers how fire risk analysis can be adapted and improved using "scenario clusters" to assess building fire hazards. Meacham [30] proposes the use of holistic methods to better evaluate fire risk, particularly for a performance-based approach to fire safety engineering. More specifically, Van Hees et al. [31] proposes that the holistic approach is suitable for determining the fire safety attributes in the design of building facade systems.

The common objectives behind such research are to provide more inclusive and consistent methods to apply fire safety to buildings. A holistic methodology to the development of fire strategies, using both qualitative and quantitative approaches, but most of all "strategic" techniques, is, therefore, an appropriate direction of travel for the fire industry.

British Standard PAS 911 [18] identifies several inputs required for the formulation of a fire strategy. The inputs cover everything from the mandatory framework (national legislation and codes) to the characteristics of the building and its occupancy and even the consideration of practical issues such as logistics and economics. One of these inputs is "Risk and Hazard Assessment". The document states that "a fire risk and hazard assessment will focus the strategy on those aspects of the building that could lead to an actual fire incident". Furthermore, within the UK, the Regulatory Reform (Fire Safety) Order 2005 uses fire risk assessment as the cornerstone of the legislation. Prior to this, UK legislation was largely prescriptive and did not explicitly consider risk.

The use of fire risk assessment to help determine appropriate levels of fire safety design has become increasingly embedded in current fire safety engineering methodologies, especially with the increasing move towards performance-based solutions. To support this, a range of international guides and standards have been produced. These include:

American standards NFPA 550 [32] and NFPA 551 [33] are guides for the evaluation of fire risk assessments. The scope of these documents states that they are intended to provide assistance in evaluating the appropriateness and execution of a fire risk assessment for a given fire safety problem. The documents are focused on assisting enforcing authorities with jurisdiction over a building in question. They acknowledge that various quantitative, qualitative and semi-quantitative methods may be used to provide a framework and methodology to ensure that various aspects have been properly considered.

British Standard PD 7974–7 [13] is a standard that provides guidance for the use of a performance-based approach to the development of fire strategies. The standard explains that probabilistic risk assessment can be used to rank the performance of (fire safety) design alternatives. The standard includes a series of flow charts explaining how the risk approach can be applied. It also introduces a term that has also become increasingly used to define an acceptable level of residual risk: ALARP (as low as reasonably practicable) [34]. This term's idea is that there will always be a level of risk that may be deemed acceptable after reasonable precautions have been taken.

Standard ISO 31000: Risk management–Guidelines [35] explains the risk management process, including risk assessment. It can be used to provide an overview of the key factors behind the development of a risk management plan.

As well as the above documents, there are also practical guides covering fire risk assessments. One such guide is British Standard PAS 79: Fire risk assessment–Guidance and recommended methodology [36]. Furthermore, there are also numerous software-based products that can assist with the risk assessment process. FRAME (Fire Risk Assessment

Method for Engineering) was developed in Belgium in 2008 to allow calculation of the key risk assessment parameters and thus support the eventual fire strategy [37].

Given that there are numerous methodologies available to assess fire risk, it could be said that the subject of fire risk assessment is well covered. However, conversely, it could also be said that the range of methodologies could lead to a high degree of variability in approach, both nationally and internationally. Would not a single methodology, that can be transposed across the globe provide a more consistent solution?

The general rule of the fire risk assessment process, following Watts [38], is to provide answers to key questions:

- What fire scenarios could be possible?
- What could be the consequences of the fire event?
- What is the likelihood of such an event (or events)?

One of the practical limitations of the fire risk assessment process is the sparseness of reliable failure data required for the risk calculation. Then, there is a lack of unified risk acceptability levels, which often preclude a credible risk assessment. Nevertheless, fire safety evaluations and decisions must be made under conditions with no detailed data. This is one reason for using fire risk indexing methods (FRI). The FRI process could be described using a heuristic model and can provide a much more cost-effective technique whilst still providing a useful and valid process. In different scenarios, the risk analysis method's accuracy may vary, so the method should be chosen accordingly. Consequently, a complex fire risk assessment process can be replaced with any much simpler fire risk index method. There are several representative FRI methods that can be used. Examples include various insurance rating schemes, including commercial property evaluation schedules. There are also recognized generic approaches such as the Gretener Method or Dow's Fire and Explosion Index [39].

However, the Gretener Method, developed by Swiss engineer Max Gretener [38,39], could be used 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 measure values, which are used for the final fire hazard index calculation. The method uses empirical figures, estimated individually for the building, based on the level of its fire protection and in comparison, with solutions either generic or required by national legislation.

The next section describes how the Gretener method can be used for the creation of a new methodology of fire strategies evaluation (FSE), which is the subject of this paper. The new methodology is not based upon statistics, but uses values achieved from a fire safety and protection measures evaluation. The final fire risk index value is assessed by comparison with a baseline fire strategy evaluation [39]. This will eventually form one aspect of the Holistic Fire Engineering approach's metric template, as described above.

2. Materials and Methods

The presented method for fire strategy evaluation is originally based upon a British fire strategies methodology [1,18] combined with the Gretener [39] method described above. In 2018, the method was published in Poland [40]. The new semi-quantitative method of evaluation assumes the:

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

2.1. Fire Strategy Evaluation Methodology

The method assumes, for each evaluated building (or part thereof, such as a fire zone), a comparison of two fire strategies: the baseline strategy (default, based on the building risk profile or determined individually) and the actual strategy (real, realized for a new build project or for existing building). Figure 1 illustrates the flow chart of required fire strategy evaluation steps.

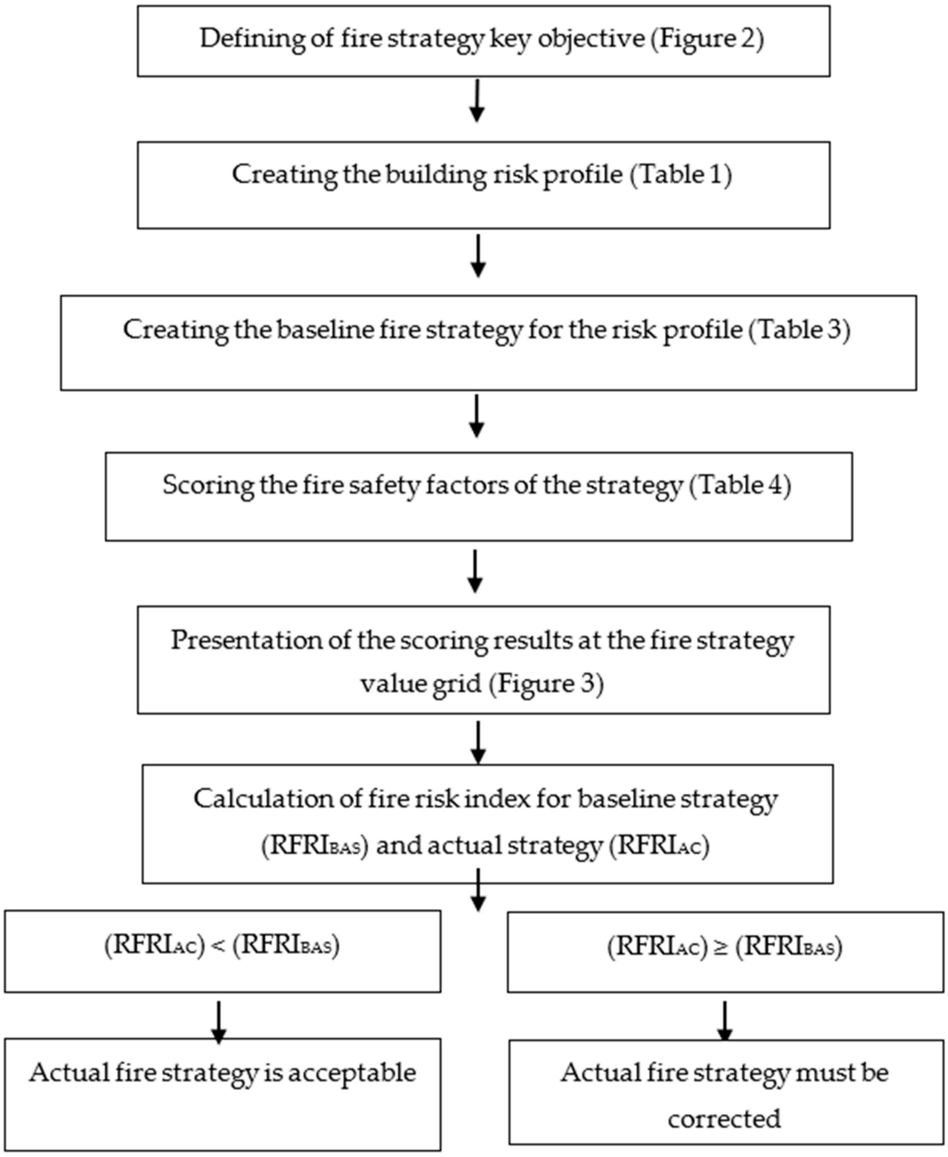

Figure 1. Fire strategy evaluation stages [40,41].

When reviewing the needs of the building, its owners, its occupants and its processes, there may be a number of objectives relevant to the fire strategy. These may be over and above the mandatory framework British Standard [18], which includes national legislation and fire safety codes. Figure 2 shows four key objectives that should be considered for the building fire strategy. Each of these objectives is broken down into four sub-objectives to assist in decision-making.

2.2. Risk Profile

The application of risk profiles allows the grading of buildings and other infrastructure in terms of fire risk. The profile makes use of a combination of occupancy characteristics and fire growth rate. It is possible that a building, especially a complex one, may comprise multiple risk profiles throughout the whole of the premises. Ancillary accommodation can contain different fire growth rates or occupant profiles to that of the main building and mixed-use buildings are also likely to have a variety of occupancy types. The methodology's risk profiles should be determined according to British Standard BS 9999 [17], based on the expected occupancy characteristics and fire growth rate (Table 1).

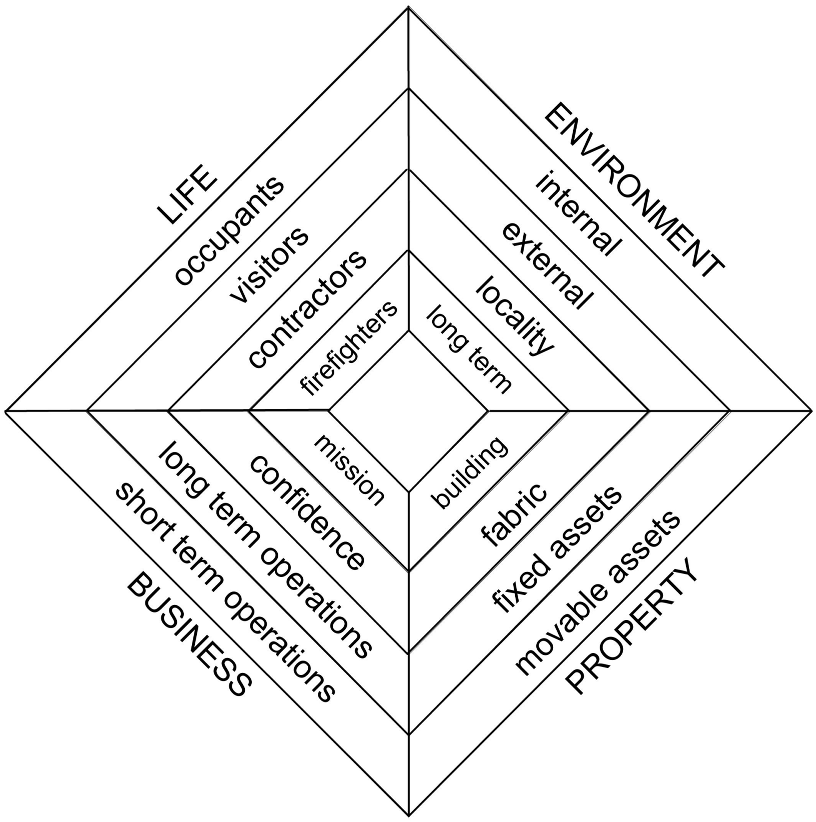

Figure 2. The fire strategy objectives matrix [1,18,40,41].

Table 1. Risk profiles.

Occupancy Characteristic	Fire Growth Rate	Risk Profile
A (Occupants who are awake and familiar with the building)	1 Slow	A1
	2 Medium	A2
	3 Fast	A3
	4 Ultrafast	A4 (A)
B (Occupants who are awake and unfamiliar with the building)	1 Slow	B1
	2 Medium	B2
	3 Fast	B3
	4 Ultrafast	B4 (A)
C (Occupants who are likely to be asleep)	1 Slow	C1 (B)
	2 Medium	C2 (B)
	3 Fast	C3 (B),(C)
	4 Ultrafast	C4 (A),(B)

(A) These categories are unacceptable within the scope of BS 9999. Addition of an effective localized suppression system or sprinklers will reduce the fire growth rate and consequently change the category. (B) Risk profile C has sub-categories. (C) Risk profile C3 is unacceptable under many circumstances unless special precautions are taken.

2.3. Scoring of Fire Safety Factors

The fire strategy is constructed of eight fire safety factors (FSF), which represent three fundamental layers: fire prevention (including the limitation of fire spread), the use of automatic fire protection measures and systems and professional fire fighter intervention. The level (relevance) of each fire safety factor is scored from 0 to 25 (Table 2) [40,41].

2.4. Baseline Fire Strategy

The baseline fire strategy is the strategy that represents fire prevention and protection solutions acceptable as a minimum for the risk profile of a specific building type or form of infrastructure. The suggested default scores for baseline fire strategies, including consideration of the crucial fire strategy key objectives of life safety are presented in Table 3 [40].

Table 2. Fire safety factors in fire strategy.

Layer of Fire Protection	Fire safety Factor (FSF)	Symbol	Score
Fire prevention and fire spread limitation	1. Organisation and Management [ORG]	ORG	0–25
	2. Control of ignition sources and combustible materials [LIM]	LIM	0–25
	3. Fire and smoke spread limitation-passive systems [PAS]	PAS	0–25
Fire protection measures	4. Detection and alarm communication [DET]	DET	0–25
	5. Fire suppression [SUP]	SUP	0–25
	6. Smoke control and evacuation [SC]	SC	0–25
	7. Maintenance of fire precautions and systems [MAI]	MAI	0–25
Fire fighting	8. Fire services intervention [FB]	FB	0–25

Table 3. The authors determined the default (determined by the authors based on their validation works and consultations with the Polish local authorities) scores proposed for baseline fire strategies values.

Objective	Life											
Risk Profile/ Fire Safety Factor	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
E_{ORG}	3	3	10	20	6	8	12	17	4	3	9	16
E_{LIM}	21	19	13	9	21	19	13	9	21	19	13	9
E_{PAS}	8	9	17	19	9	11	18	24	10	12	19	24
E_{DET}	1	5	13	23	1	7	16	25	5	10	18	25
E_{SUP}	1	1	14	21	1	3	18	23	3	3	19	25
E_{SC}	2	2	10	19	2	8	12	19	14	14	18	19
E_{MAI}	1	7	13	19	1	7	13	19	3	7	13	19
E_{FB}	1	3	14	23	1	6	14	23	4	7	14	23

2.5. Actual Fire Strategy

The actual fire strategy is the adopted or utilized strategy for a building project or as applied for an existing building. The methodology requires the individual assessment and scoring of each fire safety factor, making use of typically the most relevant fire safety elements (Table 4). Each scoring decision should be briefly justified to allow other stakeholders to understand the thought process [40].

Table 4. Actual fire strategy elements scoring.

Fire Safety Factor (FSF)	Fire Strategy Evaluation Form		
	Fire Safety Element		Maximum Score
1. Organisation and Management (ORG)	1	Fire strategy: not developed (0)/has been developed for selected aspects (1)/has been developed and documented in all aspects necessary for the pre-defined strategy objectives (4)	4
	2	Documented fire safety procedures for the building (1) + implementation of the procedures (1) + regularly controlled updates (1) + documented evacuation plans for all floors (1)	4
	3	Central building security personnel for the building (1) + trained fire wardens on all floors/in zones (3) + regular evacuation drills with specific staff participation (2)/regular evacuation drills involving all building occupants (3)	7
	4	Fire safety training: only key staff (2)/all staff (4)	4

Table 4. *Cont.*

Fire Safety Factor (FSF)	Fire Strategy Evaluation Form		
		Fire Safety Element	Maximum Score
	5	Independent certification and audit system for fire safety management: only mandatory checks (1) + full regular fire safety audits, undertaken by specialist bodies (1)	2
	6	Management commitment to fire safety including fire safety management review meetings and training of personnel in the key aspects of the management, operation and maintenance of fire protection systems and the principles of fire strategy, evacuation strategy awareness, etc. (0 to 4)	4
		Total	25
2. Control of ignition sources and combustible materials (LIM)	1	Fire load density [MJ/m2] (>4000) (0)/(>2000, ≤4000) (1)/(>1000, ≤2000) (2)/(>500, ≤1000) (4)/(≤500) (5) + High hazard ignition sources Y (0)/N (2)	7
	2	Expected fire growth: ultrafast (0), fast (1), medium (4), slow (5)	5
	3	High-risk areas of the building are separated from other parts of the building by suitable fire-resisting construction Y (2)/N (0) + high levels of combustible materials stored in the building-Y (0)/N (2)	4
	4	Smoke production from construction products and fixed equipment (the worst case): s3 and products of reaction to fire class ≤E (0)/s2 (1)/s1 and products of reaction to fire class A1 (2)	2
	5	Reaction to fire class of construction products (claddings/coverings) (the worst case) ≤E (0)/D i C (1)/B (2) ≥A2 (3)	3
	6	Reaction to fire class of the building insulation products (external walls, roof) (the worst case): ≤E (0)/D i C (1)/B (2) ≥A2 (4)	4
		Total maximum	25
3. Fire and smoke spread limitation-passive systems (PAS)	1	Fire resistance of structural elements: <15 min (0), 15 min (1), 30 min (2), 60 min (3), 90 min (4), ≥120 min (6),	6
	2	Maximum fire resistance of internal subdivisions: 30 min (1), 60 min (2), 120 min (3), 240 min (4)	4
	3	Fire resistance of doors and shutters: No resistance rating (0)/30 min (1), 60 min (2), 120 min (3), 240 min (4)	4
	4	Distance from neighbouring buildings: Not in accordance with regulations (0)/in accordance with regulations (2)/fire wall used as separation (2)/the heat flux density on adjacent object walls <12,5 kW/m^2 (2)	2
	5	Compartmentation-fire zones [m^2] (>20000) (0)/(>10000, ≤20000) (1)/(>5000, ≤10000) (2)/(>2000, ≤5000) (3)/(>1000, ≤2000) (4)/(≤1000) (5)	5
	6	Activation of fire shutters, doors, dampers etc. with fusible links (1), manual activation via control panel (2)/automatic after verification (3)/automatic (4)	4
		Total maximum	25
4. Detection and alarm communication (DET)	1	Full monitoring, i.e. detection in all risk areas (5)/partial monitoring (1) + detection in evacuation routes (1)/manual system (1)/no detection (0)	5
	2	Expected detection response time (>420 s) (0)/(>300 s, ≤420 s) (2)/(>180 s, ≤300 s) (3)/(≤180 s) (5)?	5
	3	All detection devices are appropriate for the risk (0 to 4)	4
	4	Sufficient and suitable control and indicating equipment in the building, including power supplies and cables (2) + certified systems (1)	3

Table 4. *Cont.*

Fire Safety Factor (FSF)	Fire Strategy Evaluation Form		
		Fire Safety Element	Maximum Score
	5	False alarms controlling procedures: No (0)/Yes (4)	4
	6	Alarm warning systems: sounders (1)/voice alarm (2)/Voice alarm with public address (3) + active visual support signage (1)	4
		Total maximum	25
5. Fire suppression (SUP)	1	Fire suppression systems covering all risk areas (3)/partial coverage only (2)/no suppression systems (0) + fast response sprinklers (1)	4
	2	Fire suppression response time index (RTI): standard B (>200, ≤300) (1)/standard A (>80, ≤200) (2)/special (>50, ≤80) (3)/fast (≤50) (4)?	4
	3	Expected activation time: (s): >300 (0)/(>200, ≤300) (1)/(>150, ≤200) (2)/(>120, ≤150) (3)/(≤120) (4)?	4
	4	Fire suppression systems appropriate to the height of storage (2) + type of combustible material (2) + storage method (2)	6
	5	Reliability of suppression installation: system monitoring (1), independent power supply and water suppression systems (1) operation + dual water supply (1) + double source water supply (1)	4
	6	Hose reels covering all parts of the building Y (1)/N (0) + portable fire extinguishers (pfe) with rated extinguishing efficiency provided sited to standard accepted densities (1) or enhanced densities (2).	3
		Total maximum	25
6. Smoke control and evacuation (SC)	1	Stair core smoke control: Non-existent (0)/in place but effectiveness not specified (1)/assured protection of means of escape (2) + assured support for firefighting operations (1) + monitored for all system failures (1)	4
	2	Horizontal evacuation routes smoke control system: Non-existent (0)/in place but effectiveness not specified (1)/assured protection of means of escape (2) + assured support for firefighting operations (1) + monitored for all system failures (1)	4
	3	Smoke enclosure control system: Non-existent (0)/in place but effectiveness not specified (1)/assured protection of means of escape (2) + assured support for firefighting operations (1) + monitored for all system failures (1)	4
	4	Aspects of the construction of the means of escape could potentially lead to uncontrolled smoke production (0)/Suitable control of combustible materials on horizontal evacuation routes (1) + vertical evacuation routes (2)	3
	5	Dimensions of stair cores and horizontal evacuation routes relevant to the amount and profile of occupants (0 to 2) + at least two stair cores (2) + at least two directions of travel from each area (2).	6
	6	Evacuation signage: Passive signage correctly selected and arranged (1)/illuminated signage systems (2)/dynamic illuminated signage systems to control movement of occupants (4)	4
		Total maximum	25
7. Maintenance of fire precautions and systems (MAI)	1	Has the design, installation and commissioning of firefighting and fire protection systems been carried out in accordance with the manufacturer's instructions and standards? Y (2)/N (0) + by certified contractors Y (2)/partly (1)/N (0)	4
	2	Is there a suitable inventory of firefighting and fire protection systems (1) + operation and maintenance information (2)?	3

Table 4. *Cont.*

Fire Safety Factor (FSF)	Fire Strategy Evaluation Form		
		Fire Safety Element	Maximum Score
	3	Maintenance procedures and inspections in accordance with minimum national regulations (1) + manufacturer's instructions (2) + national standards (2)?	5
	4	Functional testing (over and above minimum requirements) of firefighting and fire protection systems to ensure maximum levels of availability and reliability: Y (6)/partly (3)/N (0)?	6
	5	Systems used to monitor in real-time the availability and reliability of firefighting and fire protection systems: Y (3)/partly (1)/N (0)?	3
	6	Modifications to firefighting and protection system recorded (1) + monitored (1) + audited (2)	4
		Total maximum	25
8. Fire services intervention (FB)	1	Method of communication with fire-fighters: Manual means by building user (e.g., no automatic fire detection) (0)/manual means by building user in the case of fire detection operation (1)/automatic, via alarm receiving center with alarm confirmed by external staff (2)/automatic, via alarm receiving center with alarm confirmed by staff on site (4).	4
	2	Availability of on-site fire safety personnel to assist (2)/nominal or part time availability (1)/no availability (0)	2
	3	Fire brigade arrival time [s] (>900) (0)/(>600, ≤900) (2)/(>300, ≤600) (4)/(≤300) (6)	6
	4	Access to the building: No direct access (0)/limited access to the building (1)/direct access to at least 50% or two sides of a building (2)/direct access to all parts of building perimeter (3)	3
	5	Internal communication for fire-fighting purposes within the building: difficult (0)/easy (1) + easy access to the fire control panel (1) + graphic display showing fire locations (1) + lighting of evacuation routes suitable for firefighting effort (1) + at least 2 staircases (1) + fire-fighters lifts with lobbies (1)	6
	6	Fire service facilities: No firefighting facilities (0)/suitable fire-fighting hose reels or dry/wet risers on each level (2) + smoke ventilation controls available (1) + fire pump provisions on site (1)	4
		Total maximum	25

2.6. Fire Strategy Value Grid

Values derived from the fire safety factors scoring each fire strategies (baseline strategy and actual strategy) are presented on a fire strategy value grid. The diagrams of actual and baseline strategies allow for a quick and straightforward comparison of the strategies' main differences. Figure 3 illustrates an example of the fire strategy value grid, prepared for an exemplar shopping mall, which made use of a B3 risk profile. The presented baseline strategy design uses the values presented in Table 3 for the chosen risk profile, whereas the actual strategy was based upon evaluating each of the fire safety elements, prepared in accordance with Table 4. Note that detailed scoring for the actual strategy is not shown [40,41].

Results of the actual and baseline fire strategies show that, for the actual case, the shopping mall makes greater use of active systems (detection, suppression and smoke control) and less reliance on management and fire service intervention. However, the purpose of the evaluation is to determine if that solution provides at least the same overall level of fire safety and protection as is expected for the baseline strategy for a shopping mall with a B3 risk profile. This can be assessed after launching a fire risk index calculation for both baseline and actual strategies, which is presented in Section 2.7.

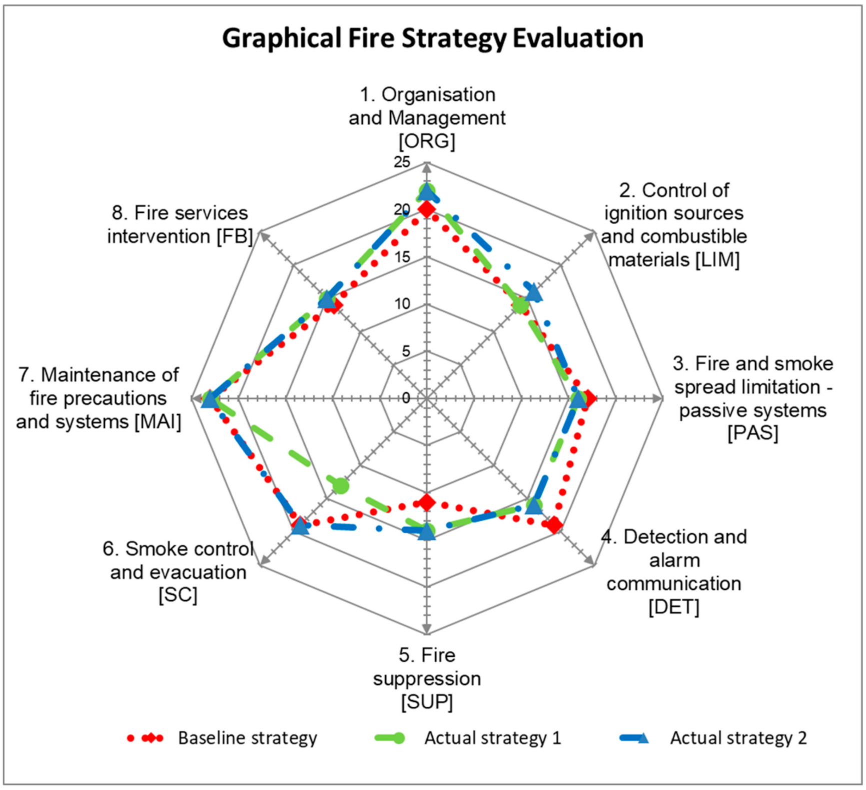

Figure 3. Fire strategy value grid for a shopping mall-example.

2.7. Fire Risk Index Calculation

The last step of fire strategy evaluation is a calculation of a fire risk index (FRI). In the original Gretener method, fire risk was assumed as a product of hazard severity (fire hazard) and loss expectation represented by the fire frequency of ignition. In the presented method, the fire risk and fire hazard terms are replaced respectively by fire (strategy) risk index (FRI) and fire hazard index (FHI), but the general assumptions stay the same Equation (1) [40,41].

$$\text{Fire risk index (FRI)} = \text{Fire hazard index (FHI)} \cdot \text{Frequency of ignition (Fi)} \quad (1)$$

The hazard severity referred to as the fire hazard index in Equation (1) is proportional to the potential hazard, reduced by protective measures Equation (2).

$$\text{Fire Hazard Index (FHI)} = (\text{Potential Hazard (PH)})/(\text{Protective Measures (PM)} \quad (2)$$

The original Gretener formula expressed empirically derived numerical factors for fire initiation and spread, with factors for fire protection. The idea used in the method presented here is based upon the values achieved from the scoring of each fire safety factor in accordance with Tables 3 and 4 for the baseline and actual strategies, respectively.

Additionally, appropriate weighting factors for FRI and FHI calculations are applied (Table 5). The weighting factors are proportional to the baseline fire strategies values from Table 3 and their role is to keep the same hierarchies between several safety factors in the actual fire strategy as in baseline one.

Table 5. Weighting factors appropriate for building risk profiles [40,41].

Objective	Life												Property			
Risk Profile/ Weighting Factor	**A1**	**A2**	**A3**	**A4**	**B1**	**B2**	**B3**	**B4**	**C1**	**C2**	**C3**	**C4**	**A1**	**A2**	**A3**	**A4**
W_{ORG}	0.6	0.6	2.0	4.0	1.2	1.6	2.4	3.4	0.8	0.6	1.8	3.2	0.8	0.8	2.8	3.6
W_{LIM}	4.2	3.8	2.6	1.8	4.2	3.8	2.6	1.8	4.2	3.8	2.6	1.8	2.4	2.0	1.2	0.4
W_{PAS}	1.6	1.8	3.4	3.8	1.8	2.2	3.6	4.8	2.0	2.4	3.8	4.8	1.8	2.2	3.8	4.8
W_{DET}	0.2	1.0	2.6	4.6	0.2	1.4	3.2	5.0	1.0	2.0	3.6	5.0	0.2	1.4	3.2	4.4
W_{SUP}	0.2	0.2	2.8	4.2	0.2	0.6	3.6	4.6	0.6	0.6	3.8	5.0	0.6	2.8	3.8	4.8
W_{SC}	0.4	0.4	2.0	3.8	0.4	1.6	2.4	3.8	2.8	2.8	3.6	3.8	0.6	0.6	1.4	1.4
W_{MAI}	0.2	1.4	2.6	3.8	0.2	1.4	2.6	3.8	0.6	1.4	2.6	3.8	0.8	2.4	3.8	4.6
W_{FB}	0.2	0.6	2.8	4.6	0.2	1.2	2.8	4.6	0.8	1.4	2.8	4.6	0.8	1.8	3.4	4.6

Total scoring 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 factor from Table 5.

$$PM = \Sigma W_i E_i \quad (3)$$

where

E_i: E_{ORG}, E_{LIM}, E_{PAS}, E_{DET}, E_{SUP}, E_{SC}, E_{MAI}, E_{FB}–score of each fire safety factor,
W_i: W_{ORG}, W_{LIM}, W_{PAS}, W_{DET}, W_{SUP}, W_{SC}, W_{MAI}, W_{FB}-weighting factors from Table 5.

By determining the result of the assessment of protective measures (PM), the value of the fire hazard index FHI, for both baseline and actual fire strategies can be calculated from the formula Equation (4).

$$FHI = PH/PM \cdot 100 \quad (4)$$

where

FHI—fire hazard index,
PH—potential hazard,
PM—protective measures.

The potential hazard is applied, respectively, to the building risk profile, in accordance with Table 6 [40].

Table 6. Potential hazard factors appropriate for building risk profiles.

Objective	Risk Profile	Potential Hazard Factor (PH) *
Life	A1	1.04
	A2	1.08
	A3	2.78
	A4	6.13
	B1	1.13
	B2	1.51
	B3	3.45
	B4	6.70
	C1	1.62
	C2	1.83
	C3	3.97
	C4	6.83
Property	A/B/C1	0.58
	A/B/C2	1.43
	A/B/C3	3.82
	A/B/C4	6.14

* Default potential hazard factor values were determined as they always give the FHI = 1 for each baseline strategy for appropriate risk profile. It also means that using the potential hazard values from Table 6, the fire hazard index for acceptable actual fire strategy should always be smaller than FHI = 1.

The final step of the fire strategy assessment is the determination of the fire risk index from the formula Equation (5) [40–45].

$$\text{FRI} = \text{FHI}\cdot\text{Fi} \tag{5}$$

where

FRI—fire risk index,
FHI—fire hazard index,
Fi—Frequency of ignition (Table 7).

Table 7. The overall probability of a fire starting in different occupancies per year.

Occupancy	Probability of Fire (y^{-1})
Industrial	$0.9\cdot10^{-2}$
Offices	$0.4\cdot10^{-2}$
Assembly entertainment	$0.7\cdot10^{-2}$
Hospitals	$2.6\cdot10^{-2}$
Schools	$1.4\cdot10^{-2}$
Dwellings	$0.13\cdot10^{-2}$
Food and drinks premises, hotels, hostels, communal living	$4.6\cdot10^{-2}$
Other public buildings and services	$1.8\cdot10^{-2}$

The frequency of ignition value in Equation (5) can be taken from different statistics or standards, for example, as in Table 7 of the British Standard PD-7974-7 [13].

Below is presented a summary of the calculated weighting and scoring of the Fire risk index for the exemplar Fire strategy evaluation, which is graphicly shown in Figure 3:

Baseline strategy: PM = 490.6
Actual strategy 1: PM = 470.4
Actual strategy 2: PM = 498.8
PH (in all cases) = 345.2/100 = 4.906
Actual strategy 1: FHI = PH/PM × 100 = (4.906/470.4) × 100 = 1.04
Actual strategy 2: FHI = PH/PM × 100 = (4.906/498.8) × 100 = 0.98
(Note that for the baseline strategy: FHI = 1).

The value of Fi for public buildings is given as Fi of $1.8\cdot10^{-2}$ (Table 7).

Therefore, the Fire Strategy Risk Index (FSRI) for each strategy is:

Baseline strategy: FSRI = FHI·Fi = $1 \times 1.8 \times 10^{-2} = 1.8 \times 10^{-2}$
Actual strategy 1: FSRI = FHI·Fi = $1.04\times 1.8 \times 10^{-2} = 1.97 \times 10^{-2}$
Actual strategy 2: FSRI = FHI·Fi = $0.98 \times 1.8 \times 10^{-2} = 1.86 \times10^{-2}$.

In this case, the FSRI for the actual fire strategy as currently provided (actual strategy 1) is slightly higher than that required for baseline conditions, which would require some re-assessment of one or more aspects of the strategy. However, the revised actual strategy (actual strategy 2) shows some improvement and scores marginally better. This is primarily due to suggested advances to the smoke control arrangements. The calculations follow the fire strategy value grid given in Figure 3.

2.8. Strengths and Limitations of the Presented Methodology and A Future Research

As with all other index methods, the above Fire Strategy Evaluation Methodology has many strengths and some limitations. These are listed below:

Strengths include:

- a structured process which motivates the fire strategist to take a closer look at the fire protection measures included in the building's fire strategy and their systematic presentation;
- a transparent and simultaneous form of presentation of all the fire measures,

- independent of failure statistics, which traditionally are deemed to not be entirely credible;
- a focus on the real objectives which the fire strategy should cover;
- a better understanding of the holistic approach to fire strategies;
- an ability to identify the fire risk index and verify the actual fire strategy against the baseline fire strategy.
- Limitations include:
- the requirement to identify a frequency of ignition factor, which is typically unreliable because of lack of data;
- the subjectivity of the baseline fire strategy default scores, as well as the potential hazard factors and weighting factors values;
- the evaluation factors are limited.

Future research expects an engagement of modeling methods and safety management into the presented methodology. This would be applied to methods used in industrial safety, such as, for example, those described in [46,47]. Furthermore, the topical issues of sustainability and the increasing use of building information modeling (BIM) are considered related to the assurance of building fire safety [48].

3. Conclusions

It is increasingly recognized within the fire safety engineering community that the current methods used to formulate and evaluate fire strategies for buildings require improvement. Research has identified that a more holistic approach is necessary to provide effective fire safety engineered solutions. The approach should properly consider all elements that impact fire safety and protection for the building and its occupants. It is also proposed that more sophisticated methods should be used to evaluate all parameters which may not be adequately covered in national fire codes.

This paper presents a method for fire strategy evaluation by providing a novel, comparative, index methodology for the assessment of fire strategies. The most practically helpful element of the method is allowing the comparison of alternative proposed fire strategies with a baseline fire strategy. This can help determine a minimum safety level for a fire strategy of a building. The concept could assist stakeholders by assessing different fire protection options and finding an optimal solution. This proposal should be seen very much as a first pass and further research and experience will help improve the validity of the concept.

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