Fire Technology, 37, 167–180, 2001

Fire Risk Index for Historic Buildings[1]

John M. Watts, Jr., Fire Safety Institute, Middlebury, VT
Marilyn E. Kaplan, Preservation Architecture, Valatie, NY

Abstract. Fire protection engineers and preservation architects have long recognized the difficulty in applying building and fire codes to historic buildings. Small, older buildings of significant historic value need an efficient approach to performance-based evaluation. One technique that has gained acceptance is fire risk indexing. The Historic Fire Risk Index described in this paper uses a linear additive model of multiple attribute evaluation to produce a measure of relative fire risk. Weights are established to indicate the importance or significance of fire risk parameters. Then, for each specific historic structure, parameter grades, i.e., the amount or degree that a parameter is present, are determined from information collected in a detailed site survey. Fire risk is evaluated by the scalar product of the parameter weights and grades, producing a single numerical value representing the level of fire safety provided in the building. This is a more rational and more transparent method than the risk indexing systems currently published in model codes and standards.

Key words: historic buildings, historic house museums, code compliance alternatives, fire risk indexing, fire safety evaluation system

Introduction

Traditionally, US building codes have exempted historic buildings and rely on the code official to determine what is safe, or what is an acceptable equivalency to a specific code requirement [1]. Historic buildings suffer under codes that virtually ignore historic significance or that rigidly impose safety requirements with minimal regard for culturally significant spaces and materials. In the US, building codes are written to prescribe minimum safety requirements for occupants of new buildings. They do not provide guidance to design professionals or code officials working with historic properties. As a result, the historic character of a building can be desecrated by rigid application of fire safety regulations. At the same time, the current international perspective on fire safety objectives specifically includes the protection and preservation of life, property, mission, environment, and cultural heritage [2].

The historic building poses unique problems for fire protection. Unlike most public and commercial buildings, an historic structure exists as an artifact or visual record of architectural or historical significance. If the building is destroyed, this function ceases to exist. Creative solutions must be developed that meet fire and life safety objectives without compromising the historic or architectural significance of the historic building. Yet, no statistics are available to determine the vulnerability of historic buildings to fire [3]. How much of our cultural heritage is lost to fire is unknown. Fire loss data is collected only on factors that relate to fire cause and origin. There is no fire loss data by historic significance or building age. We learn about fire losses of historic buildings by observing those that occur around us or through media attention to those that are most significant and newsworthy.

The vulnerability of historic buildings to loss or damage from fire is reinforced with each major fire that destroys an historic structure and its contents. Historic structures are not buildings that can be replaced, but rather irreplaceable artifacts whose value cannot be recovered by insurance payments. Very few organizations can match the financial resources used to reconstruct Britain's Windsor Castle. Instead, buildings of less significance, albeit with historic designations, often fall prey to the wrecking ball following a major fire [4].

As rehabilitation and adaptive reuse of existing buildings has increased, some attempts have been made to devise separate code provisions for certain classes of these structures. While some of the resultant approaches are more progressive than others, most are riddled with immeasurable terms such as "minimum," "acceptable," "adequate," and "reasonable." This situation places a tremendous burden on the code official, the design professional, and the property owner who lack the technical and financial means to adequately determine alternatives and equivalencies.

Furthermore, building codes prescribe only minimum criteria for various fire safety features and do not associate benefit to buildings in which these criteria are surpassed. For example, reducing travel distances or increasing the number of exits beyond code requirements is not recognized as improving fire safety. New approaches to fire risk assessment and performance-based design are addressing this issue.

For world heritage class buildings, the evolution of performance-based fire safety evaluation and design is a boon. Computer fire modeling and simulation can identify solutions that meet multiple objectives of life safety and historic preservation. Performance-based codes and fire safety design methods involve comparing predicted outcomes with stated objectives. The performance-based approach is one that establishes fire safety objectives and leaves the means for achieving those objectives to the design professional. Implementation requires the capability to evaluate whether the stated fire safety objectives are met, which in turn mandates the establishment of an acceptable level of performance. An acceptable design is one that satisfies the specified performance evaluation.

Difficulties with performance-based fire modeling that have yet to be overcome include identification of appropriate safety factors and how to address subjective attributes such as human behavior and emergency response. Additional problems for historic buildings are the limitation of design options for existing buildings and the high cost of performance-based fire-safety engineering.

Fire Risk Indexing

For many situations where a quantitative fire safety evaluation is desirable, an engineering assessment may not be cost-effective or appropriate. This could be the case where a large number of properties suggests a simple, standardized procedure or where the size and condition of a building does not warrant a detailed engineering analysis. Risk indexing can provide a cost-effective means of fire safety evaluation that is sufficient in both utility and validity. Other advantages of indexing systems include overcoming evaluation problems of inadequate data, eliminating need for safety factors, and integration of qualitative attributes.

Fire risk indexing systems, also referred to as risk ranking, rating schedules, point schemes, and numerical grading, are simplified models of fire safety. They constitute various processes of analyzing and scoring hazard and other risk parameters to produce a rapid and simple estimate of relative fire risk. Such quantitative approaches to fire risk assessment has been in use at least since the beginning of the twentieth century [5]. Fire risk indexing has been applied to a variety of hazard and risk assessment projects to reduce costs, to set priorities, and to facilitate the use of technical information. They have typically evolved in an *ad hoc* manner and the most widely used approaches are reviewed in the literature [6].

Indexing systems are based on relative or comparative risk rather than absolute risk. The lack of statistical data of fire loss in historic buildings makes determination of absolute risk impossible; thus, relative risk is the only alternative. In a study of comparative risk, there is no need to introduce explicit safety factors, as any uncertainties in the calculation procedures will apply to both benchmarks and alternative designs. While typical engineering models of fire risk are awkward in their consideration of subjective fire safety attributes such as human behavior and attitudes, the structure of a risk index facilitates quantification and inclusion of such factors.

Several risk-indexing systems have been applied to historic buildings. The Fire Safety Evaluation System (FSES) [7] is an indexing approach to determining equivalencies to the NFPA *Life Safety Code* [8]. It does not distinguish between new and existing buildings except in the total score. A similar system appears in Chapter 34, "Existing Buildings" of the BOCA *National Building Code* [9]. However, Section 3406 in that chapter specifically exempts historic structures.

Chapter ILHR 70 of the Wisconsin Administrative Code is a building code for historic structures [10]. Subchapter IV is an indexing system called the Building Evaluation Method. This system assesses life safety for a qualified historic building by comparing seventeen building safety parameters with the requirements of the prevailing building code of the State of Wisconsin. Most of these parameters are the same as in the BOCA system and quantitatively the difference in parameter values is negligible.

Like the other indexing systems, the Historic Fire Risk Index (HFRI) described in this paper provides a single numerical value used in fire safety decision making that is produced by analyzing and scoring safety features, hazards, and other risk parameters. Using professional judgment and past experience, fire risk indexing assigns values to selected variables representing both positive and negative fire safety features. The selected variables and assigned values are then operated on by some combination of arithmetic functions to arrive at a single value that is then compared with other similar assessments or to a standard. The HFRI is unique in its focus on historic house museums and its inclusion of attributes for fire prevention, building significance, fire growth rate, and emergency response.

Multiattribute Evaluation

Multiattribute evaluation is an aggregation of system attributes into a single index. It is used to develop simplified but robust models of complex systems. Meteorologists, for example, realized that temperature alone does not represent the coldness of a winter day. They created the wind-chill factor from a combination of temperature and wind speed to measure overall cooling effect. Such multiattribute evaluations have been widely used in fire safety.

Multiattribute evaluation is a common and powerful heuristic decision-making technique that is supported by a large body of knowledge described in the literature of decision analysis and management science. It is a formal procedure for structuring and quantifying complex problems with multiple concerns to provide a logical, rigorous, and defensible basis for resulting decisions. Multiattribute evaluation has been used to produce meaningful risk index models of fire safety that rely heavily but not exclusively on demonstrated principles of physical or management science [11].

Fire safety decisions require more than one attribute to capture all relevant aspects of the consequences. If there are n attributes for a decision problem, $x_1, x_2, x_3, \ldots, x_n$, then an evaluation function $E(x_1, x_2, x_3, \ldots, x_n)$ needs to be determined over these measures in order to conduct a performance assessment. A linear measure of the overall outcome of a system is given by

$$E(x_1, \ldots, x_i, \ldots, x_n) = \sum_{i=1}^{n} w_i R_i(x_i)$$

where the w_i are weighting constants greater than zero and the $R_i(x_i)$ are normalizing functions of the attributes' grades.

This is referred to as a linear additive model, in which each attribute of fire safety is decomposed into a weight and a grade and their products are summed to give a score. Since not all fire safety attributes are equally important, the role of weight serves to express the importance of each attribute compared with the others. Also, individual buildings will vary in the degree to which each attribute exists or occurs. Attribute grades, also called ratings or values, are measures of the intensity, level, or degree of danger or security afforded by the attributes in a particular application.

In a typical compensatory evaluation procedure, good performance of one attribute can at least partially compensate for low performance of another attribute. This is also called tradeoff or equivalency. Accommodating tradeoffs of low versus high performance among attributes generally requires normalization of incommensurate data, i.e., each quantitative attribute typically has a different unit of measurement. Quantitative attribute grades must be normalized to a scale that is common for all attributes. This is accomplished by constructing a normalizing function $R_i(x_i)$ for each attribute i. Normalization aims at obtaining comparable scales that allow interattribute comparison; consequently, the normalized grades are dimensionless.

The summation of the each attribute's weight times its grade is referred to as the scalar product and assumes that the attributes are independent; i.e. there is no accounting for interactions among attributes. Linear additive models are widely used in many areas of decision-making and have been found to be quite robust even when the attribute independence assumption is not fully valid [12].

Multiattribute evaluation requires selection of appropriate parameters, the assignment of levels of importance or significance to each parameter, and the identification a metric and corresponding normalizing function for each parameter. There are many different ways to accomplish these tasks and the procedures used for the HFRI represent just one approach.

Attributes

Fire safety is a complex system affected by a large number of factors ranging from ignitability of personal clothing to availability of a heliport for evacuation. However, it is appropriate to use only a relatively small number of these variables given our computational and cognitive limitations and since general fire loss figures indicate that a small number of factors are associated with a large proportion of fire loss. It is thus necessary to identify as attributes some defensible combination of factors that account for an acceptable portion of the fire risk.

Multiattribute evaluation begins with the generation of a list of attributes that provides a means of evaluating goal achievements. Fire safety attributes are components of fire risk that are quantitatively determinable by direct or indirect measurement or estimate. They are intended to represent factors that account for an acceptably large portion of the total fire risk. Usually they are not directly measurable. This is especially true for existing buildings where only limited information is readily available. Attributes may be either quantitative or qualitative and both types of attributes are important.

In the HFRI, the set of system attributes having the greatest impact on fire risk are referred to as the fire safety parameters. These parameters were chosen through examination of other well-established fire risk indexing systems. The initial list of HFRI parameters was derived from the two most widely used risk-indexing systems, FSES [13] and BOCA [14], which have a long history of accepted use for life safety evaluation. Each of these systems was analyzed with regard to the parameters used and the implied importance of weight placed on the parameters [15].

FSES

Table 1 shows the parameters of the FSES and values of their general fire safety scores. The twelve fire safety parameters are listed in the left-hand column. The second and third columns specify the minimum and maximum values for each parameter, extracted from Table 7-1 of NFPA 101A. The fourth column is the spread or difference between the minimum and maximum values and the last column is that spread as a percent of the total spread (94) in the evaluation system.

The table shows that the lowest possible General Fire Safety score for any business occupancy is −51 points. Similarly, the highest possible score is +43 points. The spread of possible General Fire Safety scores is the difference between the score for a building of worst-case conditions and the highest possible scoring building or 94 points. More details and other ramifications of this analysis of the NFPA Fire Safety Evaluation System for business occupancies are presented elsewhere [16].

TABLE 1
Parameter Values for FSES for Business Occupancies

Parameter	Min	Max	Spread	Percent (%)
1. Construction	−12	2	14	16
2. Segregation of Hazards	−7	0	7	7
3. Vertical Openings	−10	1	11	12
4. Automatic Sprinklers	0	12	12	13
5. Fire Alarm	−2	4	6	6
6. Smoke Detection	0	4	4	4
7. Interior Finish	−3	2	5	5
8. Smoke Control	0	4	4	4
9. Exit Access	−2	3	5	5
10. Exit System	−6	5	11	12
11. Corridor/Room Separation	−6	4	10	11
12. Occupant Emergency Program	−3	2	5	5
Total	−51	43	94	100

BOCA

The eighteen safety parameters in BOCA Section 3408 are listed in column one of Table 2. The second and third columns specify the minimum and maximum values of each parameter for the business use group, as extracted from the formulas and tables in Sections 3408.6.1 through 3408.6.18. Column four in Table 2 is the spread or difference between the minimum and maximum values, and the last column is the percentage of the total spread attributable to each parameter. Assumptions used to derive these values are described in reference [15].

Table 2 indicates that the lowest possible General Safety score for any business use group is −196 points. Similarly, the highest possible score is +130 points. The spread of possible General Safety scores is the difference between the score for a building of worst-case conditions and the highest possible scoring building or 326 points. The last column in Table 2 is the percentage of each parameter's spread out of the total spread of points (326) in the General Safety scoring.

Comparison

To make meaningful comparisons between these systems, the individual parameter spreads were normalized. This was accomplished by adjusting for variations between systems in terms of overall spread in total scoring and the difference in the number of parameters used in each system. Table 3 shows the parameters of both systems, aligned according to the approximately equivalent parameters [15].

The third and last columns of Table 3 are normalized spreads (NS) for the parameters of each system. Individual parameter spreads (S) shown in columns two and five of the table were adjusted to account for the magnitude of overall spread (FSES 94 points and BOCA, 326 points) and the different total number of parameters in each system

TABLE 2
Parameter Values for BOCA Section 3408 (Business Use Group)

Parameter	Min	Max	Spread	Percent (%)
1. Building Height	−20*	10	30	9
2. Building Area	−20*	20	40	12
3. Compartmentation	0	20	20	6
4. Unit Separations	−4	4	8	2
5. Corridor Walls	−5	5	10	3
6. Vertical Openings	−70	2	72	22
7. HVAC Systems	−15	5	20	6
8. Automatic Fire Detection	−4	8	12	4
9. Fire Alarm System	−10	5	15	5
10. Smoke Control	0	4	4	1
11. Means of Egress	−1	0	1	0
12. Dead Ends	−2	2	4	1
13. Max. Travel Distance	−20	20	40	12
14. Elevator Control	−4	4	8	2
15. Egress Emergency Light.	0	4	4	1
16. Mixed Use Groups	−5	5	10	3
17. Sprinklers	−12	12	24	7
18. Spec. Occ. Area Protect.	−4	0	4	1
Total	−196	130	326	100

TABLE 3
Comparative Parameter Spreads for BOCA and FSES

BOCA parameter	S	NS	NFPA parameter	S	NS
1. Building Height	30	1.66	1. Construction	14	1.85
2. Building Area	40	2.21			
3. Compartmentation	20	1.10			
4. Unit Separations	8	0.44			
5. Corridor Walls	10	0.55	11. Corridor/Room Sep.	10	1.32
6. Vertical Openings	72	3.98	3. Vertical Openings	11	1.45
7. HVAC Systems	20	1.10			0.00
8. Automatic Fire Detection	12	0.66	6. Smoke Detection	4	0.53
9. Fire Alarm System	15	0.83	5. Fire Alarm	6	0.79
10. Smoke Control	4	0.22	8. Smoke Control	4	0.53
11. Means of Egress	1	0.06	10. Exit System	11	1.45
12. Dead Ends	4	0.22	9. Exit Access	5	0.66
13. Max. Travel Distance	40	2.21	9. Exit Access	—	0.00
14. Elevator Control	8	0.44			
15. Egress Emergency Light.	4	0.22			
16. Mixed Use Groups	10	0.55			
17. Sprinklers	24	1.33	4. Automatic Sprinklers	12	1.58
18. Spec. Occ. Area Protect.	4	0.22	2. Segregation of Hazards	7	0.92
			7. Interior Finish	5	0.66
			12. Occ. Emergency Prog.	5	0.66
Totals	326	18		94	12

(FSES 12 parameters and BOCA 18 parameters). Normalized spread values were calculated by dividing each parameter spread by the average spread in its evaluation system. For example, the normalized spread for BOCA parameter 1. Building Height is 30/(326/18) = 1.66. This normalization produces comparable indicators of the relevant importance of each parameter.

Overall, the variation between low and high normalized spread values is much greater in BOCA (0.06 to 3.98) than in the FSES (0.53 to 1.75). This is partially due to the larger number of parameters in the BOCA system. Though normalized for the number of parameters, as the number of parameters increases, new parameters will alter the value distribution. Further discussion is found in reference [15].

Combined BOCA and FSES Parameters

Table 4 is a list of the parameters from both systems ordered according to the combined normalized spread expressed as a percentage of the overall sum. For example, the normalized spread for vertical openings in Table 4 is the sum of the normalized spreads for BOCA parameter 6 (3.98) and FSES parameter 3 (1.45) divided by the total for all parameters (30). These values were calculated as a general indicator of what a

TABLE 4
Ranked Normalized Spread for Combined BOCA and FSES Parameters

Parameter	Percent (%)
Vertical Openings/Vertical Openings	18
Building Height/Construction	12
Sprinklers/Automatic Sprinklers	10
Building Area	7
Maximum Travel Distance/Exit Access	7
Corridor Walls/Corridor/Room Separation	6
Fire Alarm System/Fire Alarm	5
Means of Egress/Exit System	5
Automatic Fire Detection/Smoke Detection	4
Spec Occ Area Prot/Segregation of Hazards	4
Compartmentation	4
HVAC Systems	4
Smoke Control/Smoke Control	2
Dead Ends/Exit Access	2
Interior Finish	2
Mixed Use Groups	2
Occupant Emergency Program	2
Unit Separations	1
Elevator Control	1
Egress Emergency Lighting	1
Total	100

combination of these two evaluation systems might be. The combined list of twenty fire-safety parameters consists of eleven parameters represented in both systems and nine parameters that are unique to one system or the other.

This list ignores what may be very significant effects of differences in scope and application of the two systems and differences in specific definitions of the parameters. It is not intended to be viewed as an archetype for a fire risk index. However, it does provide a ranked list of fire safety parameters for which there is explicit justification based on the extensive experience with the BOCA and FSES systems.

Some observations can be made from this list. First, there are fewer parameters than one might expect given the voluminous nature of building codes and standards. This is attributable to the Paretian nature of fire safety attributes in which there are a small number of major and a large number of minor contributors to fire safety [15]. Also, there are some obvious missing factors such as fuel, fire prevention, fire department response, and human factors. This suggests modifications to the list that better correspond to our present level of knowledge.

Historic House Museums

Historic house museums were selected as the occupancy for development of a prototype HFRI. An historic house museum is considered to be a structure with recognized historic designation or apparent historic significance that is open to the public in order to display the building and its contents. Most often, the historic house museum was originally designed as a single-family residence. Professional or qualified staff or volunteers with specific expertise in museum management or historic preservation usually manage the historic house museum.

For the HFRI, it was assumed that the primary function of the building is as a museum. There is no residential or lodging use of the building; accessory functions that support the museum are limited to offices and storage; and no conservation processes using laboratory-type facilities are undertaken within the building.

Historic house museums are distinct from other museums and galleries, as typically, the structure housing the collections has not been fully modernized for use as a museum. Items are exhibited in context as they were seen and used when the houses were occupied by their last owners, and not in cases or behind glass or segregated by type or material.

For historic house museums, the size of the structure and interior spaces are relatively small. It is assumed that there are no rooms in which more than fifty persons assemble. In U.S. model building codes and the NFPA *Life Safety Code* [8], these buildings are classified as business occupancies.

Using this definition and set of characteristics, the combined FSES and BOCA parameter list (Table 4) was modified based on professional experience. Parameters not applicable to historic house museums were deleted, some parameters were combined to simplify application, several parameters were expanded to include important components, and new parameters deemed necessary to fire risk assessment were added. It was determined that five of the parameters in Table 4 were not applicable to historic house museums: Building Area, Corridor Walls/Corridor/Room Separation, Mixed Use Groups, Occupant Emergency Program, Unit Separations, and Elevator Control. The parameters Maximum Travel Distance/Exit Access, Means of Egress/Exit System, Dead Ends/Exit Access, and

TABLE 5
Parameters for Fire Safety Evaluation of Historic House Museums

Fire Prevention	Compartmentation
Egress	Fuel
Historic Significance	Detection & Alarm
Vertical Openings	Emergency Response
Automatic Suppression	Smoke Control
Building Height & Construction	

Egress Emergency Lighting were combined as a single parameter, Egress. Fire Alarm System/Fire Alarm and Automatic Fire Detection/Smoke Detection were combined as Detection and Alarm. The Compartmentation parameter was expanded to include Specific Occupancy Area Protection/Segregation of Hazards and HVAC Systems. Fuel is a new parameter that represents an expansion of Interior Finish to include other combustibles in the facility and entirely new parameters were introduced to cover areas of Fire Prevention, Historic Significance, and Emergency Response. The resulting list of eleven parameters of the HFRI is shown as Table 5.

Parameter Weights

Not all fire safety attributes have equal importance. Parameter weights serve to express the importance of each attribute compared with the others. Hence the assignment of weights is a key component of multiattribute evaluation. Implied weights from the FSES and BOCA fire risk indexing systems were used to develop a set of parameter weights for the HFRI.

In the FSES and BOCA systems each parameter is evaluated by only a single measure, thus weights and grades are not distinguished. Using a form of reverse engineering, implicit weights were extracted from these systems. The weight of a parameter is a measure indicating its influence or significance to fire risk. The spread or range of possible values of each parameter was assumed as a measure of this importance. As described earlier, to make meaningful comparisons between the two systems, the individual parameter spreads were normalized by adjusting for variations between systems in terms of overall spread in total scoring and the difference in the number of parameters used in each system. This process resulted in a combined list of twenty weighted parameters of Table 4.

For this analysis, importance is defined as the magnitude of the potential contribution of a parameter to the total fire safety score. This value is measured as the percent of variability in the score potentially attributable to a single parameter. If a_i is the value of parameter i, then the total fire safety score is defined as $S = \sum a_i$. The total variability of the score S is its range S^* given by $S^* = \sum a_{i,\max} - \sum a_{i,\min}$. The spread or range of a single parameter, is defined as $r_i = a_{i,\max} - a_{i,\min}$. Then by the associative law $S^* = \sum r_i$, and the importance of any parameter, is given by $100 r_i/S^*$, for example, the percent columns in Tables 1 and 2.

The validity of this approach relies on its similarity to multiple attribute utility theory of management science, e.g., Keeny and Raiffa [17]. Each of the parameter values is the product of a weight, w_i, and a physical value, r_i, as specified in the general linear

TABLE 6
Weighted Parameters for Historic House Museums

Parameters	(%)
Fire Prevention	15
Egress	13
Historic Significance	13
Vertical Openings	12
Automatic Suppression	8
Building Height & Construction	8
Compartmentation	8
Fuel	8
Detection & Alarm	5
Emergency Response	5
Smoke Control	5
Total	100

additive model $S = \sum w_i r_i$ where S is the total safety score. In such a model the range of physical values is normalized to a Likert scale so that all attributes are measured over the same range. Since the physical value range is constant for all attributes, the difference in variability of attribute values is directly attributable to their weight or importance.

The percentages from Table 5 were used to assign weights to the HFRI parameters, maintaining the ranking and scaling of Table 5. The new parameters were located in the ranking and assigned weights according to experienced judgment. The resulting HFRI parameters weights are shown in Table 6.

Parameter Grades

Parameter grades are measures of the intensity, level, or degree of danger or security afforded by the attributes. Individual buildings will vary in the degree to which each parameter exists or occurs. In the HFRI the parameters are comprised of both quantitative and qualitative attributes, and methods to make them commensurable are necessary.

Scaling techniques are used to capture the essential meaning of qualitative parameters and to develop scales upon which surrogate measures or grades are based. Quantitative parameters are readily measured but still require scaling to convert to a compensatory measure. In most cases, parameters are not directly measurable. Parameter grades are built up from values of sub-parameters that are more readily determinable, recognized, components of a parameter. Sub-parameters are directly associated with measurable fire safety features or survey items of a building.

One technique for evaluating and combining sub-parameters to develop parameters grades is decision tables [18]. Measurable items make up the conditions and the conclusions in the table are the possible grades. Examples of such decision tables and other techniques are found in similar fire risk indexing approaches [19, 20].

In the HFRI, Likert scaling, as the simplest and most direct, was used to grade parameters as 0, 1, 2, 3, 4, or 5, reading from unfavorable to favorable. Most of the parameter

TABLE 7
HFRI Summary Score Sheet

Parameter	Parameter Grade (A)	Weight (%) (B)	Fire Safety Score (A x B)
Fire Prevention		15	
Exposure			
Security			
Staff			
Management/Fire Safety Plan			
Housekeeping			
Egress/Evacuation		13	
Adequacy (Automatic suppression, travel distance)			
Utilization (detection and alarm, emergency lighting)			
Protection (exits, ways out, direct exit)			
Availability (capacity, dead ends)			
Significance		13	
Building			
Contents			
Vertical Openings		12	
Floors Penetrated			
Protection			
Fire Stopping			
Automatic Suppression		8	
Coverage			
Response Time			
Building Height & Construction		8	
Height and Construction			
Compartmentation		8	
Hazard Segregation			
Interior Walls			
Attic Compartmentation			
Fuel		8	
Fire Growth Rate			
Detection And Alarm		5	
Detection			
Alarm			
Emergency Response		5	
Fire Service Capability			
Water Supply			
Response Time			
Accessibility			
Smoke Control		5	
Total Fire Safety Score			

ranges are similar to their counterparts in the NFPA and BOCA index systems. An example and list of sources for the parameter grading are discussed elsewhere [21]. The subparameters for each parameter are listed on the HFRI scoring sheet shown in Table 7.

The final fire safety score of a facility is given by the scalar product of the parameter weights and grades as shown in Table 7. This score enables one building to be compared to another or to a standard established by management or society.

Conclusions

Fire risk indexing is openly subjective and one of the major criticisms is its validity in view of such subjectivity. Such criticism is no more warranted than for any other evaluation system, as all rely on subjective components. In most cases, validity is established through longevity or by default. An approach to validity taken in this paper is to extract information from "accepted" fire safety practices. Applying a form of reverse engineering on two well-established fire risk indexing methods allowed the extraction of parameter weights that have associated empirical validity.

Although the evaluation systems of FSES and BOCA are not fully transparent, and in some aspects may be considered counterintuitive, much is to be said for the apparent consensus they achieve within the community of code officials, architects, and fire protection engineers. Using the parameters of these systems and their implicit measure of importance, attributes and their weights were derived to create a fire risk index applicable to historic house museums. This example is intended to encourage more formal structured approaches to the development of fire risk indexing.

Acknowledgment

This work was partially supported by a grant from the National Park Service and the National Center for Preservation Technology and Training. The contents of this paper are solely the responsibility of the authors and do not necessarily represent the official position or policies of any supporting agencies.

Note

1. This paper is adapted from J.M. Watts, Jr. and M.E. Kaplan, "Development of an Historic Fire Risk Index," in *Fire Risk and Hazard Assessment Research Application Symposium Proceedings*, Quincy, MA: National Fire Protection Research Foundation, 1997, pp. 315–327.

References

[1] M.E. Kaplan, "The Regulation of Existing and Historic Buildings," unpublished thesis, Troy, NY: Rensselaer Polytechnic Institute, 1996.

[2] ISO/TC 92/SC 4, "Fire Safety Engineering—The Application of Fire Performance Concepts to Design Objectives," Committee Draft ISO CD 13387, International Organization for Standards, 1997, p. 5.

[3] J.M. Watts, Jr., "Fire Risk Assessment in Cultural Resource Facilities," in *Fire Risk and Hazard Assessment Symposium Proceedings*, Quincy, MA: National Fire Protection Research Foundation, 1996, pp. 508–522.

[4] J.M. Watts, Jr., and M.E. Kaplan, "Performance-Based Approaches to Protecting ou Heritage," in *Proceedings of the International Conference on Performance-Based Codes an Fire Safety Design Methods*, Ottawa, Canada, September 24–26, 1996, Boston: Society o Fire Protection Engineers, 1997.

[5] A.F. Dean, "Analytic System for the Measurement of Relative Fire Hazard," Chicago: Western Actuarial Bureau, 1902.

[6] J.M. Watts, Jr., "Fire Risk Indexing," in P.J. DiNenno *et al.* (eds.), *SFPE Handbook of Fir Protection Engineering*, 3rd ed., Quincy MA: National Fire Protection Association, 2002 sec. 5, chap. 10.

[7] NFPA 101A, *Guide on Alternative Approaches to Life Safety*, Quincy, MA: National Fir Protection Association, 1998.

[8] NFPA 101, *Life Safety Code*, Quincy MA: National Fire Protection Association, 1997.

[9] *The BOCA National Building Code/1996*, Country Club Hills, IL: Building Officials an Code Administrators International, 1996.

[10] Wisconsin Administrative Code, chapter ILHR 70, "Historic Buildings," Madison: Depart ment of Industry, Labor, and Human Relations, 1995.

[11] J.M. Watts, Jr., "Fire Risk Assessment Using Multiattribute Evaluation," in *Fire Safety Sci ence, Proceedings of the Fifth International Symposium*, International Association for Fir Safety Science, 1997, pp. 679–690.

[12] R.M. Dawes, "The Robust Beauty of Improper Linear Models in Decision Making," *America Psychologist*, vol. 34, no. 7, 1979, pp. 571–582.

[13] "Fire Safety Evaluation System for Business Occupancies," in NFPA 101A, *Guide o Alternative Approaches to Life Safety*, Quincy, MA: National Fire Protection Associatio 1998, Chap. 7.

[14] "Compliance Alternatives," in *The BOCA National Building Code/1996*, Country Club Hill IL: Building Officials and Code Administrators International, 1996, Section 3408.

[15] J.M. Watts, Jr., "Fire Risk Evaluation in the Codes: A Comparative Analysis," in *Proceedin of the 2nd International Conference on Fire Research and Engineering*, Gaithersburg, MI 1997, pp. 226–237.

[16] J.M. Watts, Jr., "Analysis of the NFPA Fire Safety Evaluation System for Busine Occupancies," *Fire Technology*, vol. 33, no. 3, 1997.

[17] R.L. Keeny, and H. Raiffa, *Decisions with Multiple Objectives*, New York: John Wiley, 197

[18] J.M. Watts, Jr., E.K. Budnick, and B.D. Kushler, "Using Decision Tables to Quantify Fi Risk Parameters," in *Proceedings of the International Conference on Fire Research an Engineering*, Boston: Society of Fire Protection Engineers, 1995, pp. 241–246.

[19] L.L. Parks, B.D. Kushler, M.J. Serapiglia, L.A. McKenna, Jr., E.K. Budnick, and J.M Watts, Jr., "Fire Risk Assessment for Telecommunications Central Offices," *Fire Techno ogy*, vol. 34, no. 2, 1998, pp. 156–176.

[20] E.W. Marchant, "Fire Safety Evaluation (Points) Scheme for Patient Areas Within Hospitals Department of Fire Safety Engineering, University of Edinburgh, 1982.

[21] M.E. Kaplan, and J.M. Watts, Jr., "Development of a Prototypical Historic Fire Risk Index Evaluate Fire Safety in Historic Buildings," *APT Bulletin*, vol. 30, nos. 2–3, 1999, pp. 49–5