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Toward the Goal of a Performance Fire Code

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The paper presents a strategy for the development and implementation of performance-based fire codes on an international scale. The process begins with agreement on a common set of goals which underlie the code. Existing code bodies then decide on an appropriate set of quantitative prediction tools with which they are comfortable, and use them to quantify the degree to which their current code addresses these goals by establishing a standard *design fire* for each occupancy. By applying standard safety criteria and safety factors appropriate to the choice of predictive methods, the performance of any building can be quantified against the stated goals. To allow for an orderly transition from current codes, an interim code structure under which currently acceptable methods are 'deemed to satisfy' the code is presented.

BACKGROUND

The Performance-based Fire Code (or fire regulation) has long been the holy grail of the international fire community. Many papers have proclaimed the need and argued the benefits of such a replacement for the prescriptive codes found in most nations. In this paper, the authors present a strategy which might be pursued on an international scale to work toward such a goal.

In 1982 the Japanese government initiated a five-year project to develop an innovative 'Design System for Building Fire Safety'.[1] The resulting method, which has recently been published, supplements the Building Standard Law of Japan by (1) explicitly defining the fundamental requirements, (2) expressing technical standards in performance terms to the extent possible, and (3) providing calculation methods and computer models for predicting fire-related behaviors.

A recent effort in Australia centered on the development of a risk-assessment model to evaluate the cost-effectiveness of various combinations of fire safety measures for specific building occupancies.[2] The project, conducted through the Warren Center at the University of Sydney, demonstrated the feasibility of characterizing building performance through a combination of expected risk to life and expected fire cost. An extension of this work is being conducted in collaboration with the National Research Council of Canada (NRCC).

The so-called prescriptive codes derive their name from the fact that they *prescribe* precisely how something is to be done in a given circumstance. For example, most US building codes limit the height of buildings constructed with combustible structural members to three stories, and require smoke-activated fire-alarm systems in the common areas (and single-station smoke detectors in guest rooms) of hotels.

The advantage of such codes is that verification of compliance is only a matter of visual inspection; in a hotel if there is no smoke detector in the hallway, the building is not in compliance. The disadvantage is that the code presumes that there is only one way of providing the desired level of safety. This provides little flexibility for innovative solutions which provide equivalent safety at less cost, or without compromising desired operational or aesthetic features of the building. Also, while most prescriptive codes purport to allow alternative approaches through equivalency clauses, evaluating such equivalency is generally by the judgement of a code official or approval authority, who is often not motivated to venture too far from the safety of the commonly accepted method.

Performance codes establish safety goals and leave the means of achieving those goals to the designer. Crucial to the practicability of performance codes is an objective method of evaluating the ability of the proposed design to meet the established goals, without the need to resort to expert judgement. The lack of such an evaluation tool has been the primary impediment to the implementation of performance codes to date. However, in recent years significant progress has been made in the development of numerical simulation models with the ability to produce accurate predictions of the outcome of building fires. Since these models can account for the mitigating effects of most fire-protection strategies they can fulfil the need for an objective evaluation of overall system performance against the established goals. However, certain steps must be taken to standardize the procedures before this can be realized.

ESTABLISHING THE FIRE SAFETY GOALS

The underlying goals for the public safety from fires are universal; only the means chosen to achieve them vary. These can be rather simply stated in the following short list:[3]

(1) Prevent the fire or retard its growth and spread.
- Control fire properties of combustible items.
- Provide adequate compartmentation.
- Provide for suppression of the fire.

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(2) Protect building occupants from the fire effects.
- Provide timely notification of the emergency.
- Protect escape routes.
- Provide areas of refuge where necessary.

(3) Minimize the impact of fire.
- Provide separation by tenant, occupancy, or maximum area.
- Maintain the structural integrity of building.
- Provide for continued operation of shared properties.

(4) Support fire-service operations.
- Provide for identification of fire location.
- Provide reliable communication with areas of refuge.
- Provide for fire department access, control, communication, and water supply.

The universal nature of these goals should make agreement to them on an international scale the easiest part of this process. Following such agreement, we can proceed to the establishment of the evaluation procedures and the infrastructure necessary to support their use. It is these steps which will be the focus of the remainder of this paper.

CHOOSING THE SIMULATION MODEL(S)

Because the criterion is the actual performance of the design against the established goals, any *valid* model or predictive procedure which provides the required level of detail can be used. This would allow the individual regulatory authority to employ the model in which they had the most confidence. Fire hazard assessment systems such as HAZARD I[4] can serve as a prototype for others, or individual modules of HAZARD I can be replaced with similar models if preferred.

Thus, the development work required in this area is to expand the scope of HAZARD I from residential occupancies into the broader range of regulated occupancies for which the performance code will be used. This involves the addition of physical phenomena such as the impact of mechanical ventilation in larger buildings and alternate evacuation models which place more emphasis on route selection and congestion at stairwells and less on the behavior of family groups. But again, the modular structure of these procedures allows portions developed by various groups to be utilized by those without expertise in those specific areas.

The real issue then becomes the development of three key elements which establish the details of the calculation. These elements encompass the specific problems of the building and its occupants with respect to their safety from the effects of fire and, as such, control the ability of the design to meet those needs. They also embody most of the areas in which cultural or regional factors will influence the fire safety needs for the building. Thus, there should be a standard procedure by which these are etablished but an allowance for them to vary when the need arises. The three key elements are:

(1) Standard fire conditions (design fire);
(2) Standard safety criteria; and
(3) Standard safety factors.

THE STANDARD FIRE CONDITIONS

This element refers to the range of fire conditions (or scenarios) which could occur in the building under evaluation. In structural engineering this corresponds to the design load, and in fire resistance it is equivalent to the standard time–temperature curve. However, this it is not a single value or curve but rather includes a range of possible fires, variations in building configuration (position of doors or operation of building systems), and an assumed number, location, and condition of occupants.

The traditional means of deriving such information has been from historical incidents in the form of the personal experience of code officials or participants in code committees. For our purposes we can do the same, although the mechanism needs to be more formalized.

In 1987, a project to develop a fire risk assessment method was initiated with funding from the National Fire Protection Research Foundation. This effort faced a similar need to derive fire scenarios for specified occupancies from (US) national fire incident databases, and developed a detailed procedure for doing so. This procedure described in the project reports[5–9] can be employed in conjunction with any national or regional fire incident database containing the same or equivalent data elements.

Establishing a peak rate of heat release

The risk assessment method referred to above incorporates a detailed method for quantifying the full range of fire sizes expected to originate in a given space of a specified occupancy. Such detailed scenario descriptions are necessary to evaluate the contribution to risk of individual products. For the purpose of building regulation, however, codes generally envision the maximum threat and design the protection systems to that threat.

Thus, for establishing the peak energy release rate for the design fire for a given occupancy the performance code should use the threat level considered in the current (specification) codes for that occupancy. This would be obtained by describing a building which just complies with the current code and modeling successively increasing fire sizes until the required building systems no longer provide the desired occupant protection. This value of peak energy release rate represents the current code requirement for which the performance code should provide equivalence.

While this method can be used to establish the peak value it does not address the growth phase or burn-out behavior of the design fire. The former is crucial in properly estimating the fire's effects on occupants near to the fire origin and the response of fire-initiated devices, and the latter will affect structural integrity and occupant safety in areas of refuge. This risk method uses a fire and smoke transport model, FAST,[10] to compute heat build-up from ignition through flashover based on an assumed exponentially growing fire, and fuel burn-out in the room of fire origin using estimates of total fire load.

Fuel load per square meter

Because a flashover fire will involve all components of the room's fuel load this quantity will need to be estimated, possibly from field surveys or, if necessary, from expert judgement. It will normally be expressed as two terms—the fuel load per square meter (normally expressed as an equivalent weight of wood) and the effective heat of combustion (the value assumed in deriving the equivalency). When multiplied by the room area the fuel load per square meter converts to the entire fuel load of the room.

Quantifying the rate of fire growth

The fire growth (heat release) rate for any item can be represented by an exponential curve. Many such experimental curves can be shown to be approximately proportional to time squared, where the curve is defined by the time required for the heat release rate to reach a particular value.

Three growth rate curves would be employed—slow, which grows to 1055 kW in 600 s; medium, which grows to 1055 kW in 300 s; and fast, which grows to 1055 kW in 150 s (see Fig. 1). Typical contents items expected to be found in the building occupancy of interest can be assigned to one of these curves based on typical form and type of *material first ignited* data found in the national database. The NFPA Technical Committees on Detection Devices and on Automatic Sprinklers are using these same curves in detector and sprinkler design systems that require similar assignments of general burning items to classes. Some of these assignments are tabulated in Appendix C of the Standard on Automatic Fire Detectors (NFPA 72E).[11]

In the absence of manual or automatic intervention (suppression), it can be arbitrarily assumed that the rate of heat release declines from its peak value according to a linear curve that requires the same time to decline to zero as was needed to reach the peak rate from zero.

Establishing the standard fire conditions

The procedures described above can be utilized to develop a standard (design) fire for each principal occupancy class or building (construction) type considered in the current code. This will result in an associated design fire for each building (and major space within that building) which, for the first time, establishes a quantitative benchmark for the threat against which the building is expected to perform.

The design fire for one building becomes the quantified exposure threat to its neighboring buildings. By expressing required performance in such terms, the code becomes unambiguous, and directly comparable to required performance levels for similar buildings in other code jurisdictions using the same performance code system.

STANDARD SAFETY CRITERIA

The establishment of standard safety criteria is the second element in the performance code development. Extensive work conducted over the past decade has resulted in a body of knowledge about the susceptibility of people to the fire environment. These data and a resulting model for human tolerance are presented in the *Technical Reference Guide for HAZARD I*.[12] Since there is no evidence that there are significant differences in human tolerance among persons in different countries, these values should represent a universal set of criteria.

Another crucial addition to our capability to produce realistic predictions of the outcome of building fires involves the addition of human behavior to the modeling of evacuation. The egress model included in the HAZARD I package contains such behavioral rules which allow the occupants to respond to the individual situation (i.e. investigation, rescue, way finding, impedance by smoke, etc.). Thus, the *psychological* impacts of alarm/notification systems, path markings, and other features which affect the efficiency with which that process proceeds can now be explicitly included. Such models also provide the means to deal directly with specific

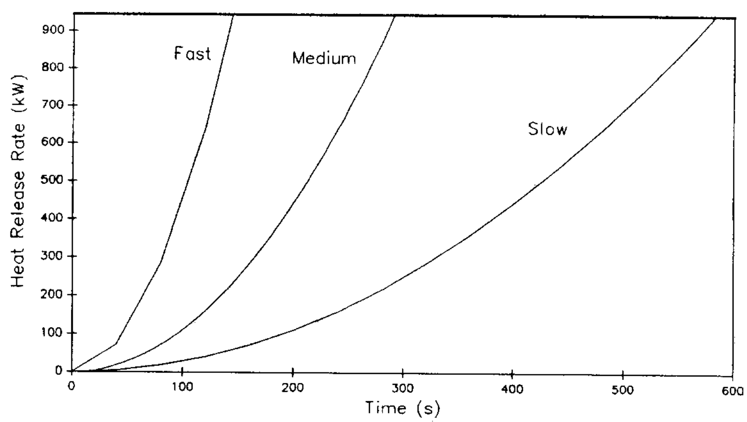

Figure 1. T-square fire-growth curves.

handicaps to senses or locomotion rather than applying all handicaps to a single class.

What would remain to be determined is the susceptibility of the building and its components to the fire environment. For example, failure of partitions needs to be predicted for both its influence on the distribution of products throughout the building and its role in structural failure. This will require some translation of data from current fire resistance tests (e.g. ASTM E-119) and the response of these assemblies to different temperature histories. Since calculated fire resistance has been a topic of research in a number of countries and has been adopted to a limited extent in a few, this should not be an impossible task.

STANDARD SAFETY FACTORS

Safety factors are a universal, engineering approach to account for uncertainties in calculations, and would serve the same purpose here. Standard safety factors would be needed to account for our inability to incorporate details, assumptions made for practicality, and for conservatism until experience is gained with a new system. These safety factors would differ only if the models or calculational procedures employed to evaluate compliance with the performance code varied among jurisdictions. Otherwise they would be established by experts from the modeling and code-enforcement communities through traditional consensus procedures.

STRATEGY FOR DEVELOPING THE PERFORMANCE CODE

The process by which we work toward the performance code should be evolutionary rather than revolutionary. Thus a development strategy has been established by which we can move in that direction. This involves the initial reorganization of existing code requirements relative to a set of performance goals such as those listed earlier. For example, requirements which impact limiting the spread of fire or protecting escape routes would be identified with these goals. This will result in the cataloging of the current requirements for each goal. These may be prescriptive specifications or descriptions which rely on the judgement of the regulatory authority, or might currently represent a performance type rule.

This type of organization is not new, but would be quite similar to the Fire Safety Evaluation Systems developed by CFR and now incorporated into the Life Safety Code from the National Fire Protection Association (NFPA) in the USA.[13] These code-equivalency systems assign point values to various protection features and weight them according to their contribution to safety in each of several categories such as evacuation of occupants. This weighting is a quantification of the relative benefit provided by the feature to that safety category. Similarly, the performance code would need to relate the influence of the feature to its impact. In this way, a partial sprinkler system installed only in the corridors would assure safe exit access but would not receive full credit for maintaining the building's structural integrity.

A prototype tabulation for such a performance code supporting the list of goals presented earlier is shown in Table 1. In each case a judgement has been made as to whether each requirement could currently be assessed in terms of a Performance Standard (PS), Specification Standard (SS), Deemed to Satisfy (DS), or would require Expert Judgement (EJ). The Performance Standard would be one where only the safety goals (*what* is the desired outcome of condition) were specified. The Specification Standard would state *how* something was to be done, although it, too, should be clear on the goal and should be based on defensible, technical arguments. For example, modern stair design is based on extensive research with people walking stairs, which results in specifications for tread dimensions which allow safe and efficient movement, and the layout of sprinklers is determined by the design of their spray patterns.

The category 'Deemed to Satisfy' would be used for specifications in the current codes which are not based on hard data. For example, the 'heights and areas' tables in the codes limit building height and maximum area of a fire compartment based on construction and occupancy. These are arbitrary specifications which have been handed down from code committees and represent their best judgements for safety. Therefore a three-storey wood-frame building would be 'deemed to satisfy' the code. As research data become available some items in this category will transfer into the Specification Standard or Performance Standard categories. The Expert Judgement category refers to all those qualitative decisions which have traditionally been left up to the local authority. Such decisions usually involve a determination as to whether to accept one thing in combination with a number of other factors, or other special cases. The code must continue to allow for the approval authority's discretion.

Once this process is completed, we can begin to develop the design fires, safety criteria, and safety factors necessary to replace each specification-related goal to a performance base. In some cases the existing specifications may be judged to be sufficient (for example, the detailed specifications on stair design—height of rise and length of run—are well established and need not be made more subjective.)

NATIONAL AND CULTURAL VARIATIONS

Most modern codes focus on life safety, with property protection secondary. (A possible exception may be the Soviets, who seem to place primary emphasis on avoiding an interruption in use of the building.) Thus we feel that most nations could agree in principle to a list of goals such as those presented in this paper. Certain code sections, such as the provisions relating to urban fires from the Japanese code, could be made optional as a function of local need.

Cultural differences are more difficult to address. While occupant behavior is a major part of the evacuation model in HAZARD I (EXITT), these behaviors are displayed generally only with family groups. They are not

Table 1. Current status of performance code elements

Requirements	PS	SS	DS	EJ
1. Fundamental requirements for fire safety of individual buildings				
1.1 Prevention of fire			X	
1.2 Exclusion of hazardous areas			X	
1.3 Assurance of safe evacuation				
1.3.1 Restrictions on the use of certain materials			X	
1.3.2 Evacuation planning				
1.3.2.1 Plans prepared in advance				X
1.3.2.2 Plans include all potential occupants				X
1.3.2.3 Plans consider all important building uses				X
1.3.2.4 Plans are practicable				X
1.3.3 Assurance of safe refuge				
1.3.3.1 Adequate refuge(s) provided	X			
1.3.3.2 Safe refuge(s) provided	X			
1.3.3.3 Location of refuge(s)				X
1.3.3.4 Alternate refuge(s)				X
1.3.4 Assurance of safe paths of egress				
1.3.4.1 Assurance of at least one exit			X	
1.3.4.2 Exits are clear and continuous			X	
1.3.4.3 Exits are protected	X			
1.3.4.4 Exits are properly designed		X		
1.3.4.5 Special protection for unique circumstances			X	
1.4 Prevention of damage to third parties				
1.4.1 Prevention of fire spread to other tenant's space	X			
1.4.1.1 Prevention of spread to other buildings	X			
1.4.1.2 Prevention of collapse onto other buildings		X		
1.4.1.3 Reuse of buildings of multiple ownership		X		
1.5 Assurance of firefighting activities				
1.5.1 Design to facilitate fire service operations			X	
1.5.2 Bases of operation			X	
1.5.2.1 Sufficient bases provided			X	
1.5.2.2 Bases are safe	X			
1.5.3 Access to bases			X	
1.5.4 Arrangement of bases			X	
1.5.4.1 Cover search and rescue range			X	
1.5.4.2 Cover suppression range			X	
1.5.5 Limitation of fire size			X	
2. Prevention of urban fires				
2.1 Buildings in designated urban fire districts			X	
2.2 Buildings in designated quasi-urban fire districts			X	

important in the present context since most residences in the USA are not regulated occupancies. In other circumstances or for other cultural differences such as the inherent trust the Japanese place in people following instructions, some allowances can be incorporated into the code provisions.

CONCLUSIONS

In spite of the almost universal nature of statements in support of performance-based codes, there may be some apprehension when it appears that such a code is more than just a dream. In Japan, the National Building Code is extremely detailed—so much so that architects need know little about fire safety design. The presumption is that they have only to comply with the code to assure occupant safety. Here, the apprehension may come from the assumption of more responsibility for safety-related decisions. However, since Japan has a single national code, implementation should be straightforward.

Because US codes are promulgated at the local level, even though they are usually based on one of four model codes, there are many variations in codes among jurisdictions. Thus, it will be necessary to convince an estimated 35 000 code jurisdictions of the wisdom of this performance code in place of what they currently use. While this will make implementation more complex, US architects are more vocal about their desire for more flexibility in the regulations, so they should be support a change.

Further, the current system of product regulation through pass/fail test methods provides manufacturers with a certain degree of comfort. They know that if their product passes the test it will nearly always be accepted. With a performance requirement, the final decision on whether the product meets the goal will likely rest with the local authority.

However, in spite of the problems which will certainly arise, a performance code holds the promise of allowing improved safety and functionality to be designed into buildings at reduced cost. It could put the codes of many countries into a common framework which could reduce trade barriers and allow a truly international construction industry to flourish. Most of all, it should reduce the economic and human burden of fire on the world's societies in a way never imagined.

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