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R108

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Sincerely,

Dr. Denis Onieal, Superintendent
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Code Officials and Performance Based Fire Safety

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ABSTRACT

This paper will discuss some of the concerns that the Boston Fire Department has concerning Performance Based Codes and Performance Based Fire Safety Designs. There will be four areas of concern discussed: 1. Need for prescriptive rules on methodology; 2. Acceptable level of safety problem; 3. Maintenance/Enforcement problem; 4, Training and Education problem. For each area of concern, the problem will be introduced, examples will be provided, and possible solutions will be proposed.

THE LACK OF PRESCRIPTIVE RULES PROBLEM

The Problem

Performance based designs appear to rely on three sources of information: 1. A set of objectives (possibly from a performance based code); 2. A design guide (general rules on documentation and methodology); 3. Reference material (an engineering handbook). The problem with the use of this material is that it allows too much flexibility in the selection and use of critical items used in designs. A code official trying to use these documents to insure the safe design of buildings is analogous to a police officer trying to enforce a safe society by using books on philosophy and theology. These books may contain valuable information as to how one should conduct affairs but are also useless as a set of enforceable rules. These books might also be adequate in a society where everyone is well intentioned and are less useful in a society where human nature is less than perfect.

For example, performance criteria. Like many of the issues before us, are a troubling one for a code official. This is due to the fact that there is no consensus; the designer has the freedom to choose almost any tenability limits for which they can find a reference source. In fact, almost every design that we have seen has utilized different tenability criteria. The obvious reason why this becomes important is because by changing the tenability criteria, the time until untenable conditions may be changed to suit the engineer's needs with respect to the design. In doing so, one can artificially increase or decrease the available safe egress time.

Example

The two different criteria that were used in the "draft" and "final" version are listed below:

Table 1: Comparison of Tenability Criteria

Draft Boston High-Rise Tenability Limits	**Final Boston High-Rise Tenability Limits**
Upper layer at breathing height, 1.67 m	Temperature of 150ºC - less than 2 min.
	Radiant Flux of 25 kW/m^2
	CO of 2,000 ppm - less than 5 min. Visibility - 0.5 OD m"'

The reason for this change was never made clear by the designer but a consequence of the change was a drastic increase in the time available to exit the apartment. The need to increase the time available to egress the apartment was probably due to the fact that, in the final version, "reaction time" was taken into account. In the original "draft" report the Total Evacuation Time (Time to Detection + Egress Time) was less than the ASET (Available Safe Egress Time). Once a reaction time of 25 seconds was incorporated, at our insistence, into the Total Evacuation Time (Time to Detection + Reaction Time + Egress Time) the Total Evacuation Time often exceeded ASET. To get around this dilemma, the designers changed the assumptions. This type of flexibility is convenient for designers but as code officials, we find it troubling.

The engineer used his judgment and- considered all the correct factors as recommended by various design guides. So, what basis would I have to reject this criteria selection? No rules were broken. This is important due to the fact that traditionally, when we review plans, we are trying to find out if any rules were broken. What power do we have to insure safe building if there are no rules?

The proper use of safety factors is another area where there seem to be only general guidelines, as opposed to rules. It does not appear that any designs or models that we have reviewed are 100% accurate. As a consequence, it would seem prudent to utilize safety factors to offset the uncertainty. In actuality, many designs I have seen have not utilized any safety factor. Others have used safety factors of 1.5. All of these selections were based on "Engineering Judgment." In the SFPE Handbook, Pauls recommends that "...in relation to the Life Safety evaluation, there should be a factor of safety, especially in view of the incomplete technical grasp of both egress and fire issues at the present." For example, in a conservative approach, the "time available" should be at least twice as long as the "time required." [3] Despite this documented recommendation, one of the designs we reviewed stated: Jake Pauls method of doubling the occupant egress time is not commonly accepted or used for fire engineering analysis. For almost any engineering analysis you could find someone with an opposite analysis or result. [4] Do we have the right as a code official to reject this design based on this document?

Solution

We are willing to give designers freedom to choose different designs to achieve the same goal. However, we see no reason to allow freedom to pick any criteria and make any assumption that they can find a reference for in a technical handbook or peer reviewed journal. We understand that the occupant characteristics such as egress speed and reaction time as well as hazard criteria selected for an elderly housing complex will differ from the occupancy characteristics and hazard criteria for a high-rise office building. What we do not understand is why designers have the freedom to choose different occupant characteristics and hazard criteria for the same occupancy. It would seem to limit designers' freedom to create a prescriptive set of occupant characteristics and hazard criteria for different occupancy classifications. A guideline such as this would let us know when the assumptions made "break the rules."

We believe that a set of rules can also be developed for the selection of safety factors to deal with the uncertainty inherent in fire models. Several sources have estimated the accuracy of current methods at 10 to 30 per cent, when used with conservative inputs and within the limitations of the model. [5,6,7] The problem for code officials is to know when the designer has used the models correctly and even then, the code official does not know if the uncertainty is as low as 10 or as high as 30 per cent. Fortunately, the ASTM Standard Guide for Evaluating the Predictive Capability of Fire Models - 1994, has a standard to measure this predictability. This predictability is express as a percentage. In this guide it has been suggested that the predictive capabilities of a fire model may be expressed as percent accuracy. Other methods for presenting results of a sensitivity analysis are equally acceptable. [8]

Utilizing ASTM 1355-92, 1994, the predictive capability of models is suggested to be represented as % accuracy. This suggestion can be combined with an assumption that a typical safety factor should be approximately 2. The results are shown in Tables 2 and 3. Using these charts along with the documentation required by ASTM 1355 provides the code official with a much higher level of comfort than a safety factor whose sole justification is "Engineering Judgment" that is not typically peer reviewed.

Table 2:
Boston Fire Department Safety Factor Chart
Due to Uncertainty for Deterministic Timed Egress Analysis for
Moderate Hazard Occupancies, i.e. Business, Industrial

		Potential Error in ASET Calculations		
		10%	**20%**	**30%**
Potential Error in Egress Time Calculations	10%	1.5	1.75	2.0
	20%	1.75	2.0	2.25
	30%	2.0	2.25	2.5

***Uncertainty Safety Factor = (1+(potential error in ET)/(1-potential error in ASET).**

Table 3: Boston Fire Department Safety Factor Chart Due to Uncertainty for Deterministic Timed Egress Analysis For High Risk Occupancies. i.e. Nursing Homes Day Care

		Potential Error in ASET Calculations		
		10%	20%	**30%**
Potential Error in Egress Time Calculations	10%	2.0	2.25	2.5
	20%	2.25	2.5	2.75
	30%	2.50	2.75	3.0

***Uncertainty Safety Factor = (1+(potential error in ET)/(1-potential error in ASET).**

The actual rules that are eventually developed could differ from the examples provided here. The point is that a set of prescriptive rules, that a plans examiner can use in checking the validity of a design will make it much easier for a code official to review designs.

LEVEL OF SAFETY PROBLEM

Many code officials are concerned that without having a given "prescribed level of safety" designers will feel free to submit their own assumptions as to what constitutes an acceptable level as part of their design. The designer will not only produce a design, the designer would be able to set the criteria against which it will be measured, as well as the level to which those criteria are met. When a code official disagrees with the designer's choice as to what constitutes an acceptable level of safety, the official will be forced to argue the legal and political concepts as opposed to design issues. More than once we have found ourselves before state appeals boards facing arguments that had more to do with whether or not the code requirement(s) in question were appropriate, rather than facing arguments on whether the design met the intent of the code. In fact, after a presentation of a case study at a local chapter of the SFPE, by the designer on several designs reviewed by the Fire Prevention Division, a couple of audience members commented that one area that was never discussed was whether or not the code requirement should have been there in the first place. The reply was the issue was not raised because it was not a valid issue to raise during a plans review or an appeal of a given plans review.

Examples

The performance codes that I am aware of contain language similar to the following.

Objective. To protect occupants from injury or illness when evacuating a building during a fire…

Functional Statement. Buildings shall be designed with safeguards against the spread of fire so that: 1. Occupants have sufficient time to escape without being overcome by fire and smoke...

Performance Requirements. Automatic fire suppression systems, when provided as a means to controlling fire growth shall deliver sufficient suppression to suppress a fire (Many other performance requirements are typically listed).

The problem that a code official has in trying to enforce language of this type is that not only are there many different designs that can achieve these objectives, there are many different levels at which the objectives can be met. Battery powered smoke detectors protect occupants to one level of safety. Quick response sprinklers and interconnected alarm systems also protect occupants. On what basis do we reject one level of safety over another? All levels meet the objectives; they do not meet the objectives to the same extent. This is not a hypothetical concern. We recently had to argue a case in court in which one of the main arguments being used against us was that a design which relied primarily on detectors was claimed to be equivalent to a prescriptive requirements of the installation of an automatic sprinkler system. This was due to the interpretation that the design met the same objectives that the prescriptive code was meant to address.

Solution

To provide the flexibility in design with the minimum and prescribed level of safety we would like to propose the following language:

DEFINITION OF REASONABLE LEVEL OF SAFETY

A facility taking a performance approach to meeting the code requirements has reached a "reasonable level of safety" when, at a minimum, the design meets the objectives of the code for all of the people, including fire fighters and property to the same overall level[b] that the prescriptive approach intends to protect them.

Exception: In the case where the facility is utilizing a design or approach that is not anticipated by the prescriptive code, the performance approach must meet the objectives of the code providing the level of safety that is intended by the most applicable nationally recognized standard for similar occupant, process or hazard.

a. In cases where the design analysis identifies areas where the prescriptive code do not meet the objectives of the code by providing a reasonable level of safety, the performance approach must exceed the minimum level prescribed by the code. This is anticipated to achieve the reasonable level of safety.

b. For portions of a design that are deterministic, an alternative design will be determined to meet the same overall level of safety when the results or prediction of the analysis produces at least as safe a result as the prescriptive code. For portions of a design that probabilistic or deterministic design will be determined to meet the same overall level of safety when the result of prediction of the analysis produces an estimate of risk that is lower than the prescriptive code. Redundancy and reliability of the design options must be analyzed.

Designers seem to be concerned that any text that implies equivalency is merely the "alternative but equivalent" option allowed by the prescriptive codes. They argue that this text does not encourage alternative designs. I would argue that it is not the "equivalency" requirement that discourages designs but it is how equivalency is demonstrated and interpreted. In the past there has been a lack of tools that would demonstrate "equivalency" in a convincing manner. This is rapidly changing. In cases where they are designing a building or a process that is anticipated by the prescriptive code, we believe the "alternative but equivalent" approach is adequate. The new "performance based design" techniques provide plenty of freedom of design within a given approach. This freedom of design is particularly apparent if one views equivalency as an *overall intended level of safety equivalency. This* overall equivalency is different from an item-by-item equivalency that might be required by some code officials.

By defining the acceptable level of safety as the level of safety provided by the prescriptive code, the freedom of the designer to design facilities where this equivalency doesn't exist or where it cannot be demonstrated. We do not view this as negative since this type of freedom should not be available to the designer. On the other hard, if by limiting the designers choice of options to ones where equivalency can be demonstrated, the code official has some documented assurance that the intent of the prescriptive code is being met. This requirement, instead of discouraging innovation could actually encourage it by facilitating the approval of these designs.

The exception is needed to provide the flexibility that new and unanticipated designs or processes need while requiring the final proposed level to have some rational basis to justify it. The burden to justify why a different level of safety, from the level implied by the prescriptive code should be placed on the, designer. The designer must also make it clear what the basis is for the level that is proposed.

MAINTENANCE/ENFORCEMENT PROBLEM

Problem

The question that arises as a fire official is: How are the assumptions that are made in an objective based design enforced? Our experience in Boston has shown that these types of designs are connected to a set of assumptions with no redundancies or room for error. Some of these assumptions are made with respect to people movement and fuel loading with little or no scientific background or statistical analysis. Furthermore, many times assumptions are made and used outside of the boundaries with which they were derived. This becomes an issue when managing the use of buildings on a day-to-day basis. In fact the day-to-day uses, repairs to fire protection equipment and owners' interests may act retrograde to the engineer's initial design assumptions. In recognition of these constraints, the Fire Prevention Division of the Boston Fire Department has outlined some issues that we believe must be discussed to illustrate some past failures and propose a path that the engineering, construction and code enforcement community can take.

Examples

In order to outline the concerns clearly, two actual cases will be used. The first will be a description of the assumptions that were made about an 18,000 seat arena and a high rise residential building and how future use negatively impacted the engineer's original design assumptions. Although the issues brought forth by these cases are indeed complex, a small cross section of the assumptions will be used to illustrate our case. It should be noted that none of the assumptions in this paper were taken out of context of the boundaries of the argument proposed by the engineer. In fact, they were critical in their relevance and nature of the overall project.

A submittal for the arena detailed the use of a "fast-fire" (see NFPA 72, Appendix B for explanation) in the ASST-BX model for a design fire. In part, the modeling was performed to show that an increase in seating and the deletion of an automatic sprinkler system could be allowed. This was based on the information from the model with respect to untenable conditions. Setting aside the issue of the use of the model, there were issues raised with the use of a fast-fire. The result was that the ownership capitulated and proposed the limitation of combustibles in the arena. Furthermore, the area was to be used for sporting type events and those with a low fuel load only. During the first weeks of operation of the arena, a concert event was held. The stage consisted of decorations consisting of 4 stories of flexible polyurethane material. In addition, there have been other events that use pyrotechnic displays. This type of use would seem to fall outside the boundaries of the solution that the engineer and owner proposed in order to obtain an increase in occupants and the deletion of an automatic sprinkler system. In the cases of the polyurethane decorations, no one from the arena notified the fire department nor the building department to determine if this particular use violated the appeals agreement

In the high rise residential building case. A proposal was made to omit the installation of an automatic sprinkler system at the time of construction. Instead of an automatic sprinkler system, the ownership proposed that an open balcony be constructed to connect adjacent units so that passage from one to another could be easily accomplished, fire extinguishers be installed in every kitchen and an automatic door closure be installed on the kitchen door. Over 30 years of use, the fire extinguishers are gone, the kitchens have been remodeled to look modern and the balconies have been enclosed so that passage from either one is impossible. No one consulted the fire department or the building department to determine if this type of construction and removal of fire protection features were legal modifications.

There are 5 questions and solutions we would like to propose that stem from our experiences and relate directly to the enforcement of assumptions used in an objectively based design. The questions are:

1. Where should documentation of assumptions used in an objective based design be kept? We believe that the owner and his agents are ultimately responsible for the maintenance of the documentation used in a performance based design. This information must remain on site and accessible for use. In addition, any conditions on the Certificate of Occupancy should be kept at the municipal building department as part of the legal documentation.

2. Who should review and approve modifications prior to building permit application? Due to the fact that these types of designs are so assumption driven, any deviations or proposed modifications should be approved by the original engineer of record. The ramifications of this statement are wide ranging. However, if an engineer cannot determine if a modification will not adversely impact his assumptions why should the authority having jurisdiction be responsible for the decision.

3. Who is responsible for maintaining the records and that all the assumptions used in a design are followed? A concept like a Fire Safety Director would seem like a logical choice. This person would be on site to determine if events or modifications impact the design assumptions used by the engineer. If the documentation on the design is on site and the individual is qualified to make judgments of this magnitude, we believe that incidents like the arena and the high-rise can be avoided. These type of events must be avoided if we are to use objective based designs. We have had experiences with other major property owners in the city that are similar to the fire safety director concept. These people are onsite to determine if the day to day operation complies with the requirements of the building code and legally sanctioned variances. However, questions remain if this concept is used. What level of training is required for this type of person? There is a definite void of information on this topic. The final issue on this subject is: how does an AHJ site someone for not being qualified?

4. What happens if the assumptions must be violated due to repair of a fire protection system? We presently manage this type of situation by requiring the owner to make provisions such that an adequate level of protection is provided if a required or non-required fire protection system is impaired. Many times this requires removal of all combustible material and fire watches that an owner supplies while other cases require temporary water supplied be made with fire department personnel and apparatus. In any case of severity, the impairment issue is great and must be dealt with as much care as is taken in the initial design phases of construction.

5. Who submits a status report to the AHJ on the state of the assumptions used in the design? We believe that a status report should be submitted on a frequent basis. The content of the report would indicate that all assumptions are being followed and include all test data of all the fire protection systems used. This would range from automatic sprinkler systems to the status of doors with automatic door closures.

It is important that a systems approach be used in objective based designs. What is ever more important is that a systems approach be take to maintain and determine if compliance exists on a system wide basis. It is important to explain to individuals that will be using the built environment the importance of the assumptions and how they will impact on occupant safety if they are not followed. By empowering the user of the built environment with this information, the intentions of the original design and overall level of safety will be realized. Due to the size and scope of objective based designs, the maintenance of the assumptions by the code official cannot be done alone. The concept and importance of the fire safety director should be embraced by the fire protection community as a whole.

TRAINING AND EDUCATION PROBLEM

Problem

A problem, which will impede the use of performance-based fire protection design methodologies, is that many code officials, engineers, and architects lack proper training and education about the use of these methodologies. There are both short and long term implications concerning the training and education problem. Short-term problems will arise when one tries to obtain the code official's acceptance to use performance-based fire protection design methodologies within the official's jurisdiction and is met with stiff resistance. As a minimum, if the use of performance-based fire protection design methodologies is permitted, the review process could be very slow as many designs will be subjected to a lengthy appeal and review process due to the code official not being qualified to properly review submitted performance-based designs. It is worth mentioning that long review periods, in many instances, are attributable to insufficient, inadequate, or misleading information being submitted for review. Long-term problems will arise due to changes that will occur over time to a building's use, function, and built in fire protection characteristics. These changes to the building will necessitate a re-review of the original performance-based fire protection design's, objectives, assumptions, and performance criteria.

An improperly trained code official, engineer, or architect will not recognize that the originally approved performance based fire protection design requires additional evaluation because of the changed conditions. However the long-term problem is also an enforcement problem which is covered in another part of this paper. Additionally, inadequately trained code officials may also approve unsafe performance-based fire protection designs quickly without rigorous and adequate analysis because the code official would not know the appropriate questions to ask of the designer or even where to go to seek additional information regarding performance-based fire protection designs. This situation opens up the question as to why a designer is submitting an unsafe design in the first place for a code official's approval.

Another problem area related to training and education is the necessity of a code official, engineer, or architect to exercise judgment when deciding upon the acceptability of a proposed performance based design--in other words what makes a design safe or even more simply stated what is safe design. Performance based designs utilize many assumptions, performance criteria, and design methodologies, which are many times subjectively chosen by the designer. For example, a designer may select that a design be deemed safe if the time for occupants to egress a building is less than the time for a hazardous condition to develop such as the height of the bottom of a descending smoke layer to reach a pre-determined level. Upon thorough analysis the designer may then discover that given the pre-selected design fire scenario and original performance criteria the available safe egress time is not achievable and proceeds to abandon the objective of obtaining a safe egress time using the concept of a descending smoke layer.

The designer then proceeds to use the same design fire scenario in the same building, yet changes the performance criteria to new threshold levels using radiant heat flux, maximum layer temperature, carbon monoxide concentration, and visibility. Upon re-calculation, the designer now determines that the building occupants will egress prior to the onset of unsafe levels using the new performance criteria. How can the same building design be deemed unsafe for occupants in one design scenario but safe in another when the only change was different performance criteria? When designers make final selection of their assumptions, performance criteria, and design method and submit them for review to the code official, the code official is obligated to judge their acceptability. The design and review process is fraught with subjectivity for both the designer and the code official.

Proper training and education of both code officials and designers will address only part of the judgment and subjectivity dilemma. A prescriptive review methodology for use by code officials could also solve part of the problem concerning a code official and designer's proper use of judgment and design subjectivity.

Examples

Recently, the owner of a high-rise building submitted a performance-based design as an alternative to installing a complete NFPA 13 sprinkler system within the building. The owner's design team, during the course of review with the code official, made approximately six major changes to their design fire assumptions, two major changes as to the selection of their performance criteria, three major changes concerning their assumptions about human behavior and egress from hazardous conditions, and numerous other changes to the overall design including fire department response times. Reviewing all of the changes and the final proposal required over 250 hours of review time by the code official. In this instance, the code official was left with the question of how to accept a proposed performance-based design, which involved such subjective establishment of assumptions, design fires, and performance criteria, by the design team. A considerable amount of review time was spent by the code official getting educated on the engineering material that was requested of the design team in order to substantiate the analysis and conclusions of their design proposal.

A performance based fire protection design was submitted for an 18,000-seat arena. The original design was not properly documented or justified by the designer concerning the manual activation of the arena smoke control system and the timed egress analysis of the arena occupants. In addition, the designer submitted documentation that the arena's stage and floor fuel load would never exceed a certain quantify and hence a certain size fire would never develop based on this fuel loading. This limitation and its implications were not known by the building owner and were not directly made a condition of the building's certificate of occupancy. Upon discovery of this matter by the code official at a later date, the arena owner must either eliminate a large portion of his trade show business or take expensive measures in order to ensure occupant safety.

Solution

It is obvious that code officials must obtain some formal type of certification in order to ensure proper evaluation of performance-based fire protection designs. Many code officials are presently career employees who are qualified by a combination of experience and education. It is imperative that the instructive portion of a code official's qualifications incorporate training in the review of performance-based designs. Unfortunately, until this training is more universally, uniformly, and inexpensively provided by inspector associations, universities, model building code groups, SFPE, and the like there is little that can be done on a large scale to help solve the training and education dilemma faced by code officials

Architects and engineers are more uniformly schooled in traditional university settings and the availability of engineering and architectural programs perhaps puts these occupations in a better position to respond to the lack of available training in performance-based fire protection design. Not everyone in the building design professions can be a truly qualified fire protection engineer but neither should the traditional engineering and architectural schools offer so little on performance based fire protection design. Again until more faculty are provided with training in fire protection engineering within mainstream engineering/architectural programs the option of the traditional engineer/architect to seek advanced training in fire protection engineering will be limited to a small cadre of universities offering fire protection engineering program. Technology today does offer the opportunity for distance learning on a much larger scale than ever before. It is worth mentioning that the Society of Fire Protection Engineers has offered numerous short programs about performance based fire protection design.

Presently, the best option for overcoming the lack of training and education in performance-based fire protection design is to require peer review of proposed designs upon submittal to the code official. A suggested format for peer review selection could go as follows:

1. The code official provides a list of qualified fire protection engineers to the owner.

2. The owner is given a set of ground rules by the code official as to the expected extent of the code officials review--this could be the prescriptive review methodology used by the code official described elsewhere in this paper.

3. The owner could then select a fire protection engineer from the list after the prospective engineers have reviewed the proposed design documents and the prescriptive review methodology developed by the code official. The owner should now have a variety of bids and price ranges to select from.

4. Once the owner has selected the peer reviewer it shall be a requirement that the peer reviewer be ethically bound to work for the code official in determining the adequacy of the performance-based fire protection design.

5. A peer review report is generated and is used by the owner and the code official as the basis of discussion during the approval process. This sets the ground rules so to speak.

While not perfect solution it does address the immediate needs of the performance-based fire protection designer and their code official counterparts.

SUMMARY

Although this paper is entitled Code Officials and Performance Based Fire Safety, we believe that the items that have been discussed are also valuable to many others in the process. The prescriptive rules of design will make it easier for the designers to select assumptions and set criteria. They could also have less liability in the event an assumption or criteria leads to an unsafe design, since the assumption or criteria was agreed to by some consensus process. These benefits are also derived by defining the acceptable level of safety as the level implied by the prescriptive code.

Another benefit of tying the acceptable level to the prescriptive code is that it automatically allows a single national model to be adopted by different jurisdictions that have different levels of "acceptability". If indeed a jurisdiction does have a different level of acceptability than a national model prescriptive code, it should be reflected in the prescriptive code for that jurisdiction. This allows one model code to take into account the different level of safety that different areas of the country accept.

The requirements for training code officials will enhance a jurisdiction's ability to adequately review performance-based designs. However, if our experience is typical, an added benefit is an enhanced ability to provide consultative services to the applicant as well as an increased ability to review prescriptive based designs. We have found that the questions that are raised during performance based reviews apply to all designs. In particular, the importance of maintenance, safety during phases of construction, and qualifications of on-site personnel. In discussing these concerns with property management people they recognize these shortfalls. They are asking us to help train their in-house personnel to deal with these issues.

We believe that the solution to these problems will accelerate the acceptance of performance-based codes. Although these requirements will make it harder for poor designs to get approved, they will simultaneously make it easier for good designs to get approved. In society, people give up a small percentage of their freedoms to protect the rest. We are asking the designers to give up a small amount of freedom, such as the freedom to use unjustified safety factors, so that code officials feel comfortable dealing with the freedom to utilize different design options. We believe these recommendations will have a practical affect to provide designers more freedom by making it easier for code officials to accept these designs for review.

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Heat release rate: a brief primer

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Background

When the aftermath of a serious fire is being investigated, one of the most common questions is: *Why did the fire get so large?* Until relatively recently, the 'large' questions could only be answered qualitatively, since means of quantifying a fire size in engineering units did not exist. Eventually, it was recognized that since heat is the energy output of the fire, and scientific means exist for measuring energy, the problem may be soluble. The principles are clear. Heat is measured in units of Joules. What is usually more of interest is the rate at which heat is released, not the total amount. The heat release rate (HRR) can thus be measured in Joules per second, which is termed Watts. Since a fire puts out much more than 1 Watt, it is usually convenient to quantify the HRR in kilowatts (1000 W) or megawatts (a million watts).

Bench-scale measurement of HRR

Prior to the 1970s, such ideas, while theoretically accessible, were not usable, since actual means of measuring HRR from fires were not available. The first instruments for HRR measurement started being available in the 1970s and they were bench-scale devices. (One specialized unit had been already built in the 1950s in one lab.) Bench-scale means such instruments can measure samples on the order of a few inches or a few centimeters in size, but not real objects that could be man-sized (or even warehouse-sized). The early HRR instruments (OSU apparatus, developed by Prof. Ed. Smith; NBS-I calorimeter, developed by Alex Robertson and Bill Parker; etc.) suffered from normal first-generation issues of usability and cost. The NBS-II calorimeter, for instance, cost NIST $250,000 to build in 1977-78 (actual 1977 dollars). Shortly after joining NIST in 1977, I was tasked to find a better way. Several years of exploration elapsed, and by 1982 I had invented the Cone Calorimeter, in its first iteration. This has since become the world standard, available at test laboratories around the globe.

Furniture calorimeters (large-scale products calorimeters)

Having a bench-scale HRR apparatus is not enough for comprehensive studies of fires. In many cases, it is necessary to study the HRR of objects in their full scale, or at least nearly full-scale. This development was also started around 1979, and by 1982 two different apparatuses were independently invented. The NIST furniture calorimeter was developed by myself, along with Doug Walton, Randy Lawson, and Bill Twilley. The FMRC products collector was developed by Gunnar Heskestad. These have also now become used around the world and are the basis of numerous standards of ASTM, NFPA, and other organizations.

Room calorimeters

The final HRR measuring apparatus which was needed was a room calorimeter. Furniture calorimeters can measure the HRR of discrete objects, able to support themselves on the floor. This does not include such products as ceiling tiles nor wallboard. Also, special measuring issues arise when one wants to measure a whole burning room, fully furnished. For such studies, room calorimeters were needed. Room calorimeters were developed in a parallel effort between Fred Fisher and Prof. Brady Williamson at UC Berkeley and by Billy Lee and Jin Fang at NIST. This effort was also largely completed in 1982, meaning that instruments of all three needed scales became available nearly simultaneously in 1982.

Which scale to use?

It is costlier and more difficult to test in larger-scale instruments, thus it would seem that preference would always go towards running a bench-scale test. This is not necessarily true, since to make intelligent use of the bench-scale data one needs a **predictive model**. In other words, it is not of much interest to know what a 10 cm size sample would do; what is of interest is the full-scale behavior of a piece of furniture, appliance, wall covering, or even a whole room. For some categories of objects, such models have been developed. These include upholstered furniture, wall linings, carpets, and some others. But the available categories are few, while the types of objects which can potentially be of interest in fire reconstructions are numerous. Thus, one of the things which must first be determined is whether it is reasonable to run bench-scale tests or whether full-scale testing is needed. We may note that for polymer manufacturers and others developing new materials, it is often sufficient to only use bench-scale testing. This is because they mainly wish to find the relative differences in fire behavior, while actual product performance may not be relevant to them since they do not even make the end product.

The overwhelmingly important role of HRR in fires

HRR is not just 'one of many' variables used to describe a fire. It is, in fact, the single most important variable in describing fire hazard. (The only notable exception is for explosions). There are three main reasons for this.

1. HRR is the driving force for fire.

The HRR can be viewed as the engine driving the fire. This tends to occur in a positive-feedback way: heat makes more heat. This does not occur, for instance, with carbon monoxide. Carbon monoxide does not make more carbon monoxide.

2. Most other variables are correlated to HRR

The generation of most other undesirable fire products tends to increase with increasing HRR. Smoke, toxic gases, room temperatures and other fire hazard variables generally march step-in-step with HRR as HRR increases.

3. High HRR indicates high threat to life.

Some fire hazard variables do not relate directly to threats to life. For instance, if a product shows very easy ignitability or high flame spread rates, this does not necessarily mean that fire conditions are expected to be dangerous. Such behavior may merely suggest a propensity to nuisance fires. High HRR fires, however, are intrinsically dangerous. This is because high HRR causes high temperatures and high heat flux conditions, which may prove lethal to occupants.

If HRR is so important, why are regulators not regulating it?

In the US, over the last decade, HRR has shown up in various regulations and specifications, but this has been in specialized areas. Where it has not yet shown up in is in the building codes. The US model building codes still regulate products according to the Steiner Tunnel Test. This test was developed during the late 1930s and early 1940s and, of course, predates all of modern fire protection engineering knowledge. The test controls flame spread which is not, as noted above, a primary factor in determining human untenability. Over the years, a number of research projects documented various shortcomings of this test. The basic reason why we have not yet progressed beyond 1940s technology in the building codes has to do with the inertia of the process and of the lack of funding resources necessary to propel a building code change. In the US, there is no public-interest organ with specific funding to conduct research leading to building code improvements. Changes, instead, are usually originated by commercial entities. As of now, no commercial group has decided that it would be advantageous for them to sponsor a change, intended to introduce improved engineering methods in this area. In fire litigation however, HRR testing is well established, and eventually it is also certain to become utilized in building codes.

Some common misconceptions

- *We have taken measures to control the ignitability, so we don't have to worry about HRR*

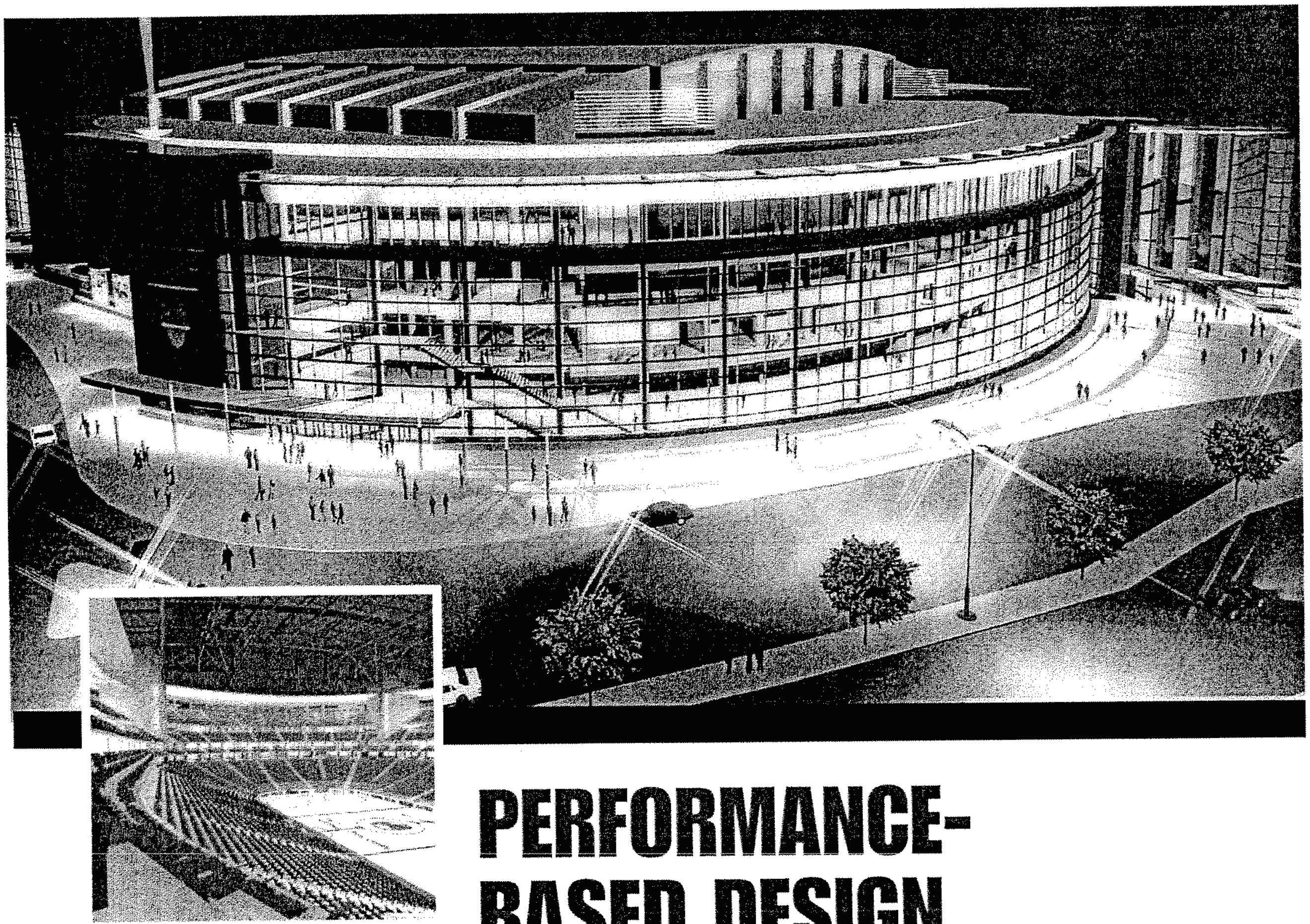
It is certainly wise to always control ignition sources and also to use less ignition-prone materials, when possible. Such a strategy, however, can never be **relied upon** to avoid an ignition. Neither HRR nor any other consequences of fire will come into play as long as there is no ignition. However, when an ignition does occur, limiting the HRR means that the fire has a chance to be controllable and not disastrous.

One must also realize that if the application is not in aircraft safety, military or NASA areas, the affordable, commercial materials that are available are not very ignition resistant. Studies have shown that even small ignition sources normally apply about 35 kW m^2 heat flux to their target. If one then seeks materials able to resist an ignition flux of 35 kW m^2, one finds that these are rare and costly.

- *Coroners tell us that inhalation of toxic fire gases is the main cause of fire deaths, so we should control toxicity, not HRR*

This fallacy rests on the imprecise definition of the term 'toxicity.' Regulatory officials sometimes presume that this means that 'toxic potency' is the root problem and that this is what must be controlled. Toxic potency is the toxicologist's term for defining **how toxic is the substance when you inhale 1 gram of it**. But of course the victim will inhale something other than 1 g of it. **How much** of the substance will be inhaled is governed by the fire's **mass loss rate**. The mass loss rate is closely proportional to the HRR of the fire. Now, what is important to realize is that studies at NIST and elsewhere have shown that for commercial products, burned under realistic fire conditions, toxic potencies vary only within a narrow band. By contrast, mass loss rates (same as HRR) vary over an enormous range among products of any given type. Since both toxic potency and mass loss rate affect the total impact of the fire on the victim, it is clear that effective control can be mounted by limiting mass loss rates, but there is little that can be achieved by attempting to control toxic potencies.

For further reading, see the textbook Heat Release in Fires.



PERFORMANCE-BASED DESIGN OF A PROFESSIONAL HOCKEY ARENA

By Michael A. O'Hara, P.E.,
with Ryan Bierwerth

The MountainStar Group, Inc., developed a performance-based design (PBD) to meet the Uniform Building Code intent for the smoke-protected seating concept in a 19,000-seat multipurpose indoor arena, the new home of the National Hockey League franchise Minnesota Wild. The arena is still under construction with a planned opening of September 2000.

The performance-based fire safety plan essentially followed the process delineated in the draft copy of *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*.[1] The overall PBD approach used on this project is a fire-hazard analysis as opposed to a probabilistic assessment. Specific fire scenarios were identified and trial designs applied to them and compared to performance criteria.

The fire/life safety systems being implemented in this complex are a result of a combination of performance-based fire protection technology and application of prescriptive building and fire code requirements. Design solutions reflect the collaborative efforts of the design team, jurisdictional authorities and the owner.

Table 1 - Goals, Objective and Criteria

Fire Protection Goal	Objectives	Performance Objectives	Performance Criteria
Minimize fire-related injuries and prevent undue loss of life	■ Adequate time for egress prior to smoke involvement and structural failure ■ Protect firefighters by employing active systems ■ Provide credible building systems to support firefighter tactics	■ Detect and control a fire early in its developmental stage ■ Maintain tenable egress ■ Manage smoke movement ■ Prevent flashover in the area of origin ■ Maintain fire attack locations	■ Egress within 23 minutes, assuming a 4-minute delay ■ Tenability values addressed CO, visibility and temperature ■ Preclude flashover in confined and open spaces 1100°F (600°C) at the ceiling and a radiant heat *flux of 20* kW/m^2 ■ Provide smoke detection in under 4 minutes ■ Provide sprinkler response precluding flashover in confined spaces ■ Evacuating occupants before the descending smoke layer reaches 10 ft (3 m) above the highest level of general public egress (upper deck), a UBC requirement ■ Permit each event
Minimize downtime	■ Meet the life and property objectives	■ Safeguard contents and procedures	■ Fire department prefire planning ■ Site access on at least three sides ■ Permit each event
Minimize property damage and structural collapse	■ Provide aggressive fire detection and control systems ■ *Reduce the chance* of structural collapse ■ Limit fire development to maintain structural integrity for 2 hours	■ Detect a fire early in its developmental stage ■ Prevent flashover in the *area of origin* ■ Prevent flame impingement on steel	■ Detect a fire at less than its design basis for smoke control ■ Keep upper layer fire temperature below 1000°F (540°C) per UBC Standard 7-1 within proximity of the critical structural framing components ■ Restrict flame impingement upon the steel trusses ■ 10-minute fire department response time ■ Permit each event

The St. Paul Arena is located in downtown St. Paul, Minnesota, and will be home to the National Hockey League's Minnesota Wild, an expansion team beginning play during the 2000-2001 season. The arena was designed by Hellmuth, Obata & Kassabaum, Inc., Sports Division (HOK Sport) under state-amended versions of the 1997 Editions of the Uniform Building and Fire Codes (UBC and UFC, respectively)[2,3].

The primary use of the St. Paul Arena is for National Hockey League games. However, other possible uses include basketball games, trade shows, boxing events, concerts, conventions and exhibitions. The building gross floor area is approximately 650,000 ft^2 (60,000 m^2). The building has a height of 142 ft (43.3 m) from the floor to the roof. The arena is attached on its east side to a skyway and convention center. Public streets border to the north, west and south. The predominant occupancy classification is A-2.1 (assembly), but other accessory occupancies are A-3, S-1 (storage) and B (business). Fire protection strategies address the multiuse and architectural focus, which is best described as an "open environment" between the spectator "bowl" area and the concourses.

DEFINE PROJECT SCOPE

The scope included compliance with the code provisions for smoke-protected seating and eliminating sprinklers over the bowl area. The St. Paul Arena project included 3 different authorizing agencies and 14 different firms, all of whom made up the design team.

Smoke-Protected Seating: UBC Section 1002 defines smoke-protected assembly seating as "seating served by a means of egress and is not subject to blockage by smoke accumulation within or under a structure." Smoke-protected seating allows for reductions in spacing of seats, aisleways and egress components provided the building is equipped with an engineered smoke control system and a life safety evaluation is undertaken.

NFPA 101, the Life Safety Code[4], provided guidance as to the composition of a life safety evaluation given the lack of clarity in the UBC. Specific stakeholders were identified to execute the evaluation. This organizational framework required stakeholders to understand their primary responsibilities. The life safety evaluation incorporated key aspects of the PBD.

UBC provides guidance for design calculations for smoke control; however, NFPA 92B[5], *Society of Fire Protection Engineers Handbook*[6] and *Design of Smoke Management Systems*[7] were also utilized. UBC calculations for smoke control using the "exhaust method" provided the primary guidance.

Sprinklers over the bowl: The necessity of sprinklers over the bowl was evaluated, considering fire scenarios and fire department operations.

PROJECT GOALS/OBJECTIVES AND CRITERIA

Table 1 summarizes the relationship between goals and objectives, and they were translated into performance criteria.

Performance criteria came from published literature primarily extracted from the *SFPE Handbook*,[6] NFPA 92B,[5] DD240[8] and *Design of Smoke Management Systems*[7]. From an enforcement perspective, permitting each event became a critical perfor-

Continued on p. 37

mance criterion as a quality-assurance tool to assure compliance with the design parameters and assumptions of the PBD.

DESIGN FIRE SCENARIOS AND DESIGN FIRES

Attaining stakeholder agreement regarding the credible fire scenarios was the most challenging part of the process because the scientific literature provides a broad and sometimes conflicting range of data.

Probable design fire scenarios considered inherent characteristics of the building: people, use, construction and fixed in-place fire protection. Critical information was researched regarding the space such as ignition sources, nature and configuration of the fuel, ventilation, as well as characteristics and locations of occupants.

To determine the design fire size, MountainStar and the City of St. Paul researched fire tests, like facilities and methods found in *The SFPE Handbook of Fire Protection Engineering*, published fire test reports and results of the large-scale fire tests conducted in the former St. Paul Civic Center[10].

Four primary building fire scenarios assumed steady-state conditions and specified locations within the facility:

1. Spectator Event: Any event where the fixed seating is used throughout the bowl to accommodate the general public. This scenario, for example, includes hockey games, sporting events and entertainment, but does not include occupancy of the arena floor. [10,000 BTU/s (10 MW) design fire in the bowl and 5,000 BTU/s (5 MW) to 7,000 BTU/s (7 MW) in the concourse areas]

1A. Spectator Event/Concert: All the criteria of Scenario 1, but also including the occupation of the bowl floor space using nonfixed seating and a stage. This event, for example, includes concerts and stockholder meetings. [10,000 BTU/s (10 MW) design fire]

2. Consumer/Trade Show Event: Any event where the fixed seating above the suite level is restricted from general public use. Occupants are concentrated in the lower bowl and arena floor. Displays, salable goods, boats, vehicles and similar temporary structures are concentrated on the arena floor. [50,000 BTU/s (50 MW) design fire in the bowl area]

3. Unoccupied: This scenario implies that any of the above scenarios may be occurring yet it is during non-event hours and the general public is not present (i.e., late night or early morning).

Additional research assisted in establishing the fire loads anticipated. BSI DD 240, "Fire Safety Engineering in Buildings",[8] suggests a rate of heat release per unit area of 500 kW/m^2 for retail spaces (Table 11 in DD 240). Supplemental guidance in DD 240 suggests a medium t^2 fire as a design basis. Australia's *Fire Engineering Guidelines*,[9] yields like results (See Table 2 above).

Table 2 - Summary of Fire Load Data

Summary Australia, DD240 & UBC			
Fire HRR	**UBC (kW/m^2)**	**DD 240 (kW/m^2)**	**Australian Code (kW/m^2)**
Office	284	250	250
Retail	567	500	500

RESULTS OF LARGE-SCALE FIRE TESTS BY THE STAKEHOLDERS[9]

Prior to demolition on June 6, 1999, a series of full-scale fire tests were conducted at the 15,000-seat St. Paul Civic Center Arena, St. Paul, Minnesota, to assist the stakeholders in conceptualizing the magnitude of different fire sizes and their effects on large spaces. This aspect is what made the St. Paul Arena project unique, because it allowed the design team to compare empirical and engineering calculations with actual experimental data that were obtained on a large scale.

Test results indicated:

- Calculations tracked with empirical results.
- Sprinklers at the heights in this structure did not activate at the fire sizes tested.
- Temperatures drop off significantly in large spaces as height and distance from a fire increase.
- Smoke stratifies as it cools yet remains relatively high in a large space with typical ambient conditions for an occupied space.
- Structural integrity was not threatened.
- Axis-symmetric fire smoke production volumes are readily inflated by the introduction of makeup air. The UBC calculations appear conservative.

DEVELOPING AND EVALUATING TRIAL DESIGNS: FINAL DESIGN SELECTION

The trial designs applied against the four specified fire scenarios encompassed fixed, in-place protection, management practices and fire department response times. An understanding of the sprinklers in confined spaces and areas with low ceilings achieved group agreement that those spaces were well protected. Smoke-protected seating required a close look at tenability and smoke production given the expected fire scenarios. Structural performance over the bowl was studied against the steady state fire sizes.

Fire Department: A letter written by the city fire department to the design team indicated a three-minute response time based upon historical data; MountainStar added time to this given the need to determine the fire location, setup and apply water. Fire department access includes site access from all sides, as well as strategic placement of standpipes within the arena and hydrant location outside. Arena management is implementing a traffic management plan fostering the historical response times.

The steady-state fire conditions of four scenarios were compared to the anticipated fire department response based on different t^2 fire growth rates to ascertain a better understanding of fire sizes and conditions upon fire department arrival. Figure 1 outlines expected fire sizes vs. time based on t^2 fires in anticipation of fire department response negating any effects of fixed, in-place fire suppression or the operational plan that affects content spacing and use. The shaded region indicates expected fire department response ranges.

Egress/Tenability: Two approaches estimating egress times were used based on the operational scenarios: one based upon calculations outlined in both the *SFPE Handbook,*[11, 12] the *NFPA Handbook,*[13] and other references[8, 9]; and the second using the egress subroutine of FPETool.[14] Calculations considered delay factors, recognition times and speeds typical of smoke-protected seating. Queuing at the stair towers doors of the upper deck posed what was the governing criterion given the smoke movement in the structure and tenability.

The stakeholders agreed to a study comparing tenability to egress times of the most vulnerable areas within the arena. Tenability of performance-based design can be formulated to meet the objectives of a smoke exhaust system designed for life safety. This can be accomplished by analyzing the impact of the smoke management system based on the hazard parameters. The hazard parameters used for this project were temperature, light obstruction and carbon monoxide concentration based upon polyurethane and red oak. Klote and Milke give examples of this method.[7] Temperature of the smoke layer became the governing factor as CO levels in the smoke layer remained low given the smoke dilution in a space of over 4,500,000 ft^3 (130,000 m^3) in the upper reaches of the bowl.

Smoke-fill rates were simplified and calculated at a defined smoke layer height in accordance with UBC provisions. Smoke layer heights varied with the scenario analyzed. The quality of the smoke can be approximated. Assuming the 10,000 BTU/s (10 MW) steady-state fire, a temperature rise of 34°F (18.9°C) is expected due to the large volume of space. Most of the heat is lost to the large volume surroundings. CO concentrations again remained low, considering 50 ppm is the allowable 8-hour exposure in a parking ramp per UBC requirements. With the smoke layer height 10 ft (3 m) above the highest point occupied by the general public, a 500,000 cfm (236 m^3/s) exhaust rate was calculated. Tenability data based upon data calculations from *Design of Smoke Management Systems*[7] are summarized in Table 3.

The viable trial design resulted in 500,000 cfm (236 m^3/s) of exhaust at the roof level of the bowl with selected exhaust via specified fans and openings in the concourse with makeup air introduced primarily at the floor and main concourse of the arena. Smoke detection at the roof level or in designated concourse areas triggered the smoke exhaust system, as well as addressed the city's concern of a fire when the building is unoccupied. Smoke detector response times were calculated using FPETool[14] at an RTI of 1 (ft/sec)$^{1/2}$ [0.5 (m/sec)$^{1/2}$] and at a spacing per the listing of the detector. Trial designs that resulted in smoke detection in greater than four minutes, as calculated by FPETool, were modified until that design criterion was achieved.

Confined spaces pose the greatest threat given flashover, yet are well protected with sprinklers to preclude this condition. Large open spaces pose the least threat because the shear volume dissipates the smoke and precludes the likelihood of flashover.

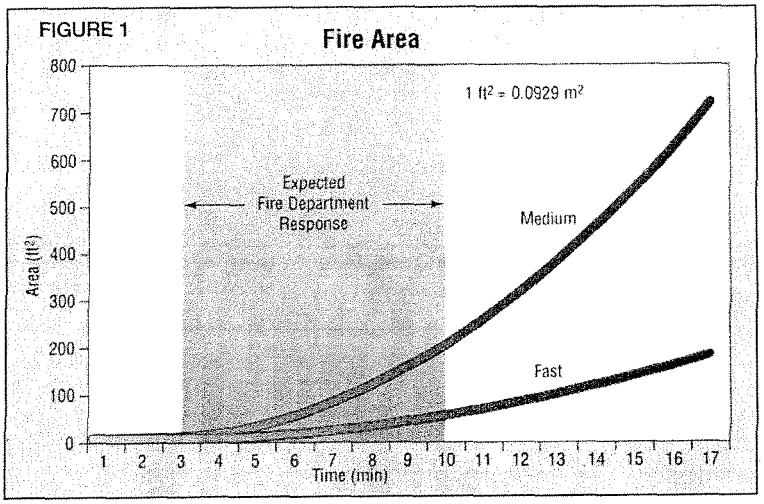
For example, given the 50,000 BTU/s (50 MW) design fire, the stakeholders agreed that this condition might exist in a consumer trade event, such as a car show. The general public is typically on the floor of the arena viewing the displays. Maintaining the smoke layer height to the level of public access, which is the lower portion of the bowl in this case, provided for realistic smoke exhaust capacity. The smoke layer, along with most all other fire physics parameters, was calculated using the equations and methodologies outlined in Section 905.5 of the UBC.

Sprinklers over the bowl: Test results[10] in addition to the calculations support the conclusion that sprinklers over the bowl would not activate due to elevated height.

Analysis indicates flame impingement on the trusses, based upon calculating the effective flame height per calculations found in UBC Section 905, did not occur as long as displays in the bowl were limited in height. This was done for each design fire scenario.

In design fire scenarios that were not protected by automatic sprinklers (i.e., under the bowl), the heat release rate of the steady-state design fires

FIGURE 1



Fire Area

were used in calculating flame heights. These flame heights were shown not to reach the 92 ft (28.0 m) required to impinge on the structural steel of the St. Paul Arena. Furthermore, these calculations were consistent with visual observation of the large-scale fire tests performed at the former Civic Center.

Using FPETool calculations, a 50,000 BTU/s (50 MW) fire produces a flame height of 36 ft (11.0 m), and the critical members are at a height of 92 feet (28.0 m). Conservatively assuming a flat ceiling at the truss, placing a fire directly below the truss at floor level produces ceiling plume temperatures of 280°F (138°C), if the fire is 92 feet (28.0 m) vertically below. Ceiling plume temperatures are calculated within the impingement zone. Further calculations fostered a use limit of displays or equipment no higher than 30 ft (9.1 m) in height above the bowl floor.

DESIGN DOCUMENTATION

Reports generated included the resulting fire protection design, performance-based analysis and building/fire code review. Close coordination with the design and construction team improves effectiveness of PBD implementation. Reviews of applicable shop drawings and schematics, along with consistent communications, are critical. Contractors with numerous requests for information are typical. This became a critical conjuncture because this is where the PBD analysis meets the reality of application.

The city and building management requested a summary operational plan that describes the fire protection features and operational plan in concise and comprehendible terms for use after the Certificate of Occupancy is obtained. This reference guide is useful for field enforcement, event permitting and event planning.

Operational plans address compliance with the PBD assumptions. The fuel packages in each scenario were nonpermanent structures and equipment such as vehicles, trade booths, displays and temporary stages. These fuel packages were converted into heat-release rates as outlined in Section 905.6 of the UBC[2]. A heat-release rate per area of 570 kW/m^2 was used, which is representative of mercantile and residential occupancies. This calculation determined operational limits and

Table 3 - Smoke, Egress And Tenablity

Event Scenario	Bowl Fire $\dot{Q}$	Bowl Smoke Layer	Smoke Temp. & CO	Smoke Volume Exhaust Provided	Egress Upper Deck	Tenability
Smoke Exhaust Design I & IA	10,000 BTU/s (10 MW)	95 ft (29.0 m)	104°F (40°C) <15 ppm	500,000 cfm (236 m^3/s)	15 minutes	60 minutes

Table 4 - Fire Scenarios and Associated Operational Limits

Use/ Area	Design Fire	Example Fuel Load Clusters	Operational Limits
Consumer Event	50,000 BTU/s (50 MW)	Multilevel Trade Show Booths, Boats, Recreational Vehicles, Cars and Trucks (e.g., consumer shows) in the Bowl	Maximum 1000 ft^2 (93 m^2) per cluster with a minimum horizontal separation between the clusters of 5 ft (1.5 m), per Figure 2, and maximum height of 30 ft (9.1 m). No general public allowed above the suite level. Submit event plan to city. Implement a one-person fire watch during setup of the event.
Sporting Event	10,000 BTU/s (10 MW)	Hockey and Sporting Events, Concerts in the Bowl	Maximum 200 ft^2 (19 m^2) per each cluster with a minimum horizontal separation distance between the clusters of 5 ft (1.5 m), per Figure 2, and a maximum height of 12 ft (3.7 m). Submit event plan to city. Implement a one-person fire watch during setup and during the event.
Displays	5,000 BTU/s (5 MW)	General Displays of Any Kind throughout Concourses	Displays are unlimited in area and spacing, but not to be located under stairs or in an area defined having draft stops or closed-space sprinklers (e.g., escalators). Submit event plan to the city. Figure 2 does not apply. Maintain exit widths.
III	7,000 BTU/s (7 MW)	Single-Level Booths, Cars, Boats under 18 ft (5.5 m) long, and Kiosks in the Atrium Concourses	Maximum 200 ft^2 (19 m^2) of area per cluster with a minimum horizontal separation between clusters of 5 ft (1.5 m), per the enforcement guide and a maximum height of 12 ft (3.7 m). Submit event plan to the city.

parameters such as separation distances to preclude nonpiloted ignition of nearby combustibles.

In line with these operational limits, each event must receive a permit and comply with the intent of the PBD. Configurations of contents representing the design basis fires are translated into field enforcement and building/event management guides. Areas of the building are identified with specific area, use and spacing requirements. (See Figure 2.)

A cluster is defined as a single item or group of items, structures or displays that take up a given area. There can be more than one item in a cluster as long as it does not exceed the area restrictions. The city emphasized that even if a use falls outside the boundaries of the limits, it does not necessarily mean the use is unacceptable. Rather, the city will require closer review and may request supplemental fire defenses for that specific event.

Figure 2 provides guidance to the fire inspector if the need arises to verify display or cluster spacing. It illustrates the relationship of area versus separation distance required to prevent nonpiloted ignition of combustibles using a 20 kW/m^2 threshold. This establishes spacing requirements given specific heat-release rate values. The 20 kW/m^2 appears to provide a nominal target for the diverse range of materials to be found. Enforcement of the fire prevention aspects of the Minnesota Uniform Fire Code for materials control will assist.

CONCLUSION

PBD requires intense involvement of all stakeholders. The time and energy expended by all stakeholders on the PBD exceeds the traditional prescriptive approach. The body of fire science knowledge to defend specific design-basis fire scenarios still requires improvement. PBD requires a combination of fixed, in-place fire safety and continual building fire safety management including fire prevention review, inspection and maintenance.

Educating the stakeholders as to the limits of a performance-based design is essential. The limits are based upon fire design assumptions. Translation of the limits into pragmatic owner use and field enforcement is a challenge, yet essential.

The City of St. Paul jurisdictional authorities spent countless hours with the design team to come to closure on design objectives and implementation. The project is still under construction with a September 2000 grand opening. Continuous communications coordination with field personnel remains essential. The Minnesota Wild management and all the stakeholders have an outstanding commitment to a fire-safe facility. When all stakeholders come to the table to resolve the performance-based design issues in earnest, the performance-based design approach works well.

Michael O'Hara and Ryan Bierwerth are with the MountainStar Group.

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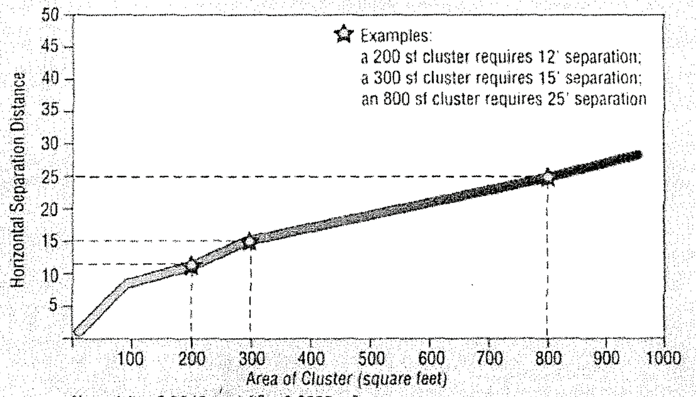
FIGURE 2 **Enforcement Guide**



Note: 1 ft = 0.3048 m; 1 ft^2 = 0.0929 m^2