Code Official's Guide to Performance-Based Design Review

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INTERNATIONAL CODE COUNCIL®

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1.0 INTRODUCTION

1.1 EXECUTIVE SUMMARY

Performance-based design is an engineering approach to fire protection design based on established fire safety objectives and functional statements, analysis of fire scenarios, and assessment of designs based on those objectives and functional statements. Performance-based design differs from traditional prescriptive design in that specific methods for achieving compliance with the design intent are established by the design team, subject to the code official's concurrence, and a fire/life safety solution is developed that is tailored to the specific building, fire, and occupant characteristics contained within the building being assessed.

Performance-based design offers many benefits that are not available when using prescriptive design. A performance-based design gives code officials the discretion to allow the safety features of a building based on the specific hazards and risks and community expectations for building performance.

The review of performance-based designs typically requires greater knowledge and time than the review of prescriptive designs. This guide provides information to assist code officials review performance-based designs.

Figure 1.1 provides an overview of the performance-based design review process.

1.2 FREQUENTLY ASKED QUESTIONS

Q. *What is performance-based design?*

A. Performance-based design is an engineering approach based on establishing objectives, functional statements and performance requirements; design fire scenarios, trial design, and analysis methods with the stakeholders; and evaluation of the performance of these trial designs against design fire scenarios to assess whether objectives, functional statements, and performance requirements are met (see Sections 1.6 through 1.8 and Chapter 3).

Q. *How is performance-based design different from prescriptive-based design?*

A. A performance-based design is based on an engineering evaluation of a design based on objectives, functional statements, performance requirements, and design fire scenarios, and not prescriptive fire protection features. The prescriptive and the performance codes in essence have similar objectives. However, a performance-based design evaluates a specific building or structure for a specific occupancy and assigns distinct performance requirements rather than applying generic requirements to a broad classification of buildings and occupancies. For example, a performance-based design may evaluate a health food store differently than a furniture store in an identical space because of the fire loads. However, the same mercantile occupancy requirements would suffice for either store under the prescriptive code (see Sections 1.6 and 1.7).

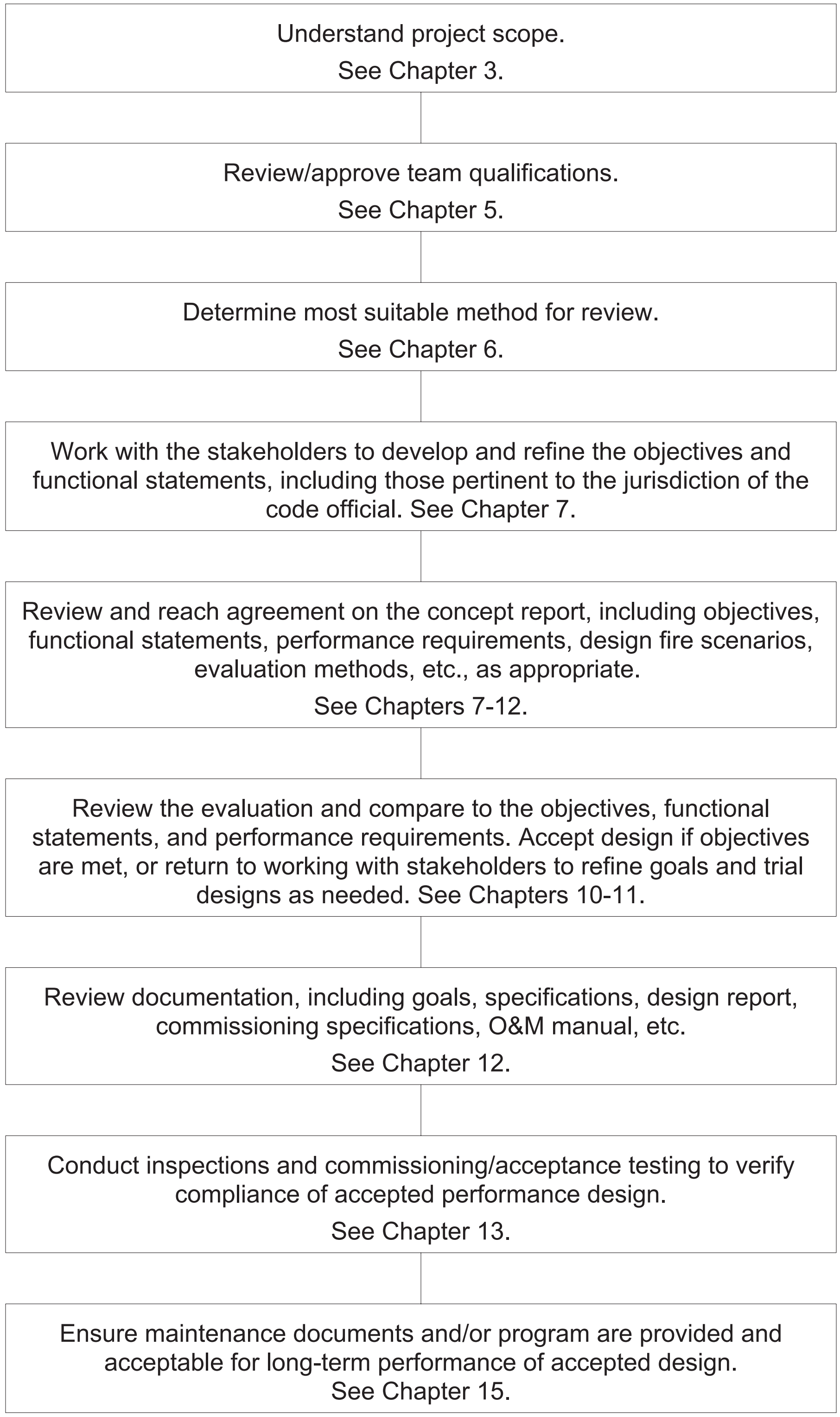

FIGURE 1.1. Performance-Based Design Review Process

Q. Why consider the use of performance-based design?

A.: In performance-based design, the fire protection provided in a building or facility is based on the specific objectives, functional statements, and unique building, fire, and occupant characteristics of the building or facility, and not on requirements that are based on broad classifications of occupancies or types of buildings or facilities. Numerous benefits of undertaking a performance-based design are further addressed in this chapter (see Section 1.7).

Q. How much detail should a performance-based design contain?

A. The amount of detail varies depending on the issues that need to be addressed and the methods proposed to address them (see Section 1.10).

1.3 PURPOSE

The purpose of this guide is to provide guidance to code officials and others who may be in the position of judging the adequacy of a performance-based fire protection design. While written for performance-based fire protection designs, the concepts in this guide may be applicable to performance-based designs that are prepared to protect against hazards other than fire.

This guide is applicable to performance-based fire protection designs that are prepared to meet performance-based codes, designs that are prepared as equivalencies to prescriptive-based code requirements, and designs that are intended to meet objectives that exceed those contained in a code or standard (business interruption, protection of contents, etc.).

The intent of this guide is to identify the types of items that a code official should consider when reviewing a performance-based design. This guide provides an overview of many of the factors that might be considered when reviewing a performance-based design; however, the scope of individual performance-based design projects can vary, and, therefore, every topic addressed in this guide may not be applicable to a specific project (see Section 1.9).

If additional detailed information on the performance-based design process is desired, reference to additional resources such as the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*,[1] *Introduction to Performance-Based Fire Safety*,[2] the *User's Guide of the ICC Performance Code for Buildings and Facilities*,[3] and the *Building Construction and Safety Code Handbook*[4] is recommended. Similarly, information on the scientific concepts that underpin specific performance-based designs is provided in numerous documents, including references identified in this guide and in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, as well as the *SFPE Handbook of Fire Protection Engineering*.[5] In addition, one also has the option of using a third-party reviewer (see Chapter 6).

1.4 SCOPE

The following topics are among those that are applicable to performance-based design and are presented in this guide:

- Roles and responsibilities of design team members.
- The necessary skills and qualifications of design team members and the code official team.
- Review process.
- Review options available to code officials.
- Defining objectives, functional statements, and performance requirements.

- Identification of design fire scenarios.
- Developing fire protection strategies (trial designs).
- Evaluation of the use of engineering methods and models.
- Identification of limitations of design methods used in the development of performance-based designs.
- Reviewing design documents.
- Commissioning and acceptance testing of fire protection systems that are used within a performance-based design.
- Determining the acceptability of changes that may be made within the field.
- Inspection, periodic testing, and maintenance of performance-based designs.
- Change of use/bounding conditions.
- Managing changes to the design.

1.5 AUDIENCE

This guide is intended for use by people with experience in building and fire codes/standards, or other construction codes, as well as those who are in an enforcement position but who may not possess a detailed knowledge of fire protection engineering or performance-based design.

1.6 COMPARISON OF PERFORMANCE-BASED DESIGN WITH PRESCRIPTIVE- BASED DESIGN

Historically, most fire protection designs have been developed to meet prescriptive code requirements. Examples of prescriptive requirements would include maximum allowable travel distances, minimum fire-resistance requirements, or maximum detector spacing. These requirements are typically applied based on broad occupancy classifications, which are based on "typical" hazards and risks found within those occupancies.

Performance-based design allows one to consider the specific hazards and risks that are expected to be present in a building or structure, the occupant characteristics, and the fire protection expectations of the building owner, occupants, insurers, members of society, and other stakeholders. Performance-based codes specify what level of performance is expected should a fire occur, without specifying how it should be accomplished.

Performance-based design may involve numerical values representative of tolerable limits of exposure to fire hazards. These numerical values are referred to as "performance requirements." Performance requirements may come from a performance-based code or may be developed by an engineer in consultation with a code official, building owner, insurer, tenant, or other stakeholders based on the stakeholders' fire safety objectives and functional statements.

Performance-based design also requires definition of the types of hazards and risks that a design is intended to manage, which take the form of design fire scenarios. As with performance requirements, fire scenarios may be specified by a performance-based code, or may be developed by an engineer based on the hazards present or foreseen in a building or facility. In the case of the *ICC Performance Code™ for Buildings and Facilities*,[3] design fire scenarios would be developed by the engineer based on the appropriate magnitude of the fire event identified in the code. In other building regulations incorporating performance-based design, parameters concerning the types of fire scenarios to be addressed by the performance-based design are provided.

In performance-based design, an engineer would typically develop trial design strategies to achieve the performance requirements when exposed to the design fire scenarios. These trial design strategies would subsequently be evaluated to determine whether they would achieve the performance requirements if a design fire scenario were to occur.

For a prescriptive-based design to be acceptable, it must meet the requirements of the prescriptive code. For a performance-based design to be acceptable, it must achieve the performance requirements in the selected design fire scenarios. Determining whether a design achieves the performance requirements would be accomplished by the engineer using engineering methods and models.

Table 1.1 provides a comparison of the code official's responsibilities when evaluating performance-based designs and when reviewing prescriptive designs.

TABLE 1.1. Comparison of Code Officials' Roles and Responsibilities

Prescriptive	Performance
	Review designer qualifications
	Participate in stakeholders' meetings and develop consensus
Preliminary meetings	Review, comment on concept report (Design Brief)
Plan review	Plan review (qualified plan reviewers)
Permit	Permit
Inspections	Inspections
Testing	Testing
Certificate of Occupancy	Certificate of occupancy and establishing the terms and conditions of occupancy (e.g., adherence to O&M manual)
Periodic inspection	Periodic inspection (boundary conditions and critical systems)

1.7 BENEFITS AND LIMITATIONS OF PERFORMANCE-BASED DESIGN

1.7.1 Benefits of Performance-Based Design

Performance-based design offers a number of benefits over prescriptive-based design:

- Performance-based design specifically addresses the unique building, occupant, and fire-related characteristics and uses of a building, as well as specific stakeholder needs and considers those of the broader community where appropriate. Although compliance with prescriptive codes is also intended to ensure that the needs of the community are met, prescriptive codes are written for broad classifications of building types and occupancies, and building, occupant, and fire characteristics may vary significantly within those classifications. Due to the range of actual building uses within the broad occupancy classifications used by prescriptive codes and standards, the actual level of protection afforded by these codes is not specifically or quantitatively known, and performance-based design helps quantify the performance.
- Performance-based design provides a basis for development and selection of alternative fire protection options based on the project's needs (e.g., in the case that the code-prescribed solution does not meet the stakeholders' needs, such as life safety or functional or design objectives).

- Performance-based design allows the level of safety afforded by alternative design options to be measured and compared. This provides a mechanism for determining which options provide an acceptable level of safety and allows comparison of the options based on the flexibility provided, the level of safety provided, and the cost, efficiency, maintainability, etc.
- Performance-based design requires increased engineering rigor, which results in a better understanding of the fire performance of a building and allows one to make engineering-informed decisions with respect to fire and life safety.
- Performance-based design can provide cost-effective solutions to achieve the level of safety desired by the prescriptive code and allow the design team to more effectively and appropriately allocate fire/life safety resources.
- Performance-based design results in a fire protection strategy in which fire protection systems are integrated to function together rather than being designed in isolation.
- Performance-based design can be used to provide a better understanding of the amount of loss or damage that could occur within a building in the event of a fire.

1.7.2 Limitations and Challenges of Performance-Based Design

There are also limitations and challenges associated with performance-based design. Further details addressing some of these may be found below, as well as in other chapters of this guide:

- Performance-based design requires a higher level of engineering skill on the part of the designer and enforcement team than prescriptive-based design.
- Performance-based design typically requires greater engineering effort to prepare or review than prescriptive-based design, but, when incorporated into the design and review process early, this does not need to affect the project schedule.
- As with prescriptive-based designs, a change in occupancy or use may change fire protection needs, which requires reanalysis and possibly modifications or additions to the fire protection in a building or facility; however, the impact of changes in occupancy or use can be better understood through performance-based design.
- Performance-based design is bounded by the limits of engineering science to develop and verify solutions beyond available methodologies. Although appropriate conservativeness may be factored into the design in the form of safety factors and failure and sensitivity analysis, it should be recognized that practical application limits may exist at any given time to the use of a performance-based design.
- There is often a concern for liability on the part of design professional and code officials using performance-based design. Using the process of a stakeholder team to develop agreed-upon project objectives and functional statements will provide due diligence to upholding the intent of the code, thereby minimizing liability situations. The designer is responsible for documenting the basis of the design. The code official is responsible for requiring and understanding the documentation.[6] Additionally, code officials have the choice of utilizing a qualified peer reviewer to provide additional expertise to evaluate whether engineering, technical, and process issues are adequately addressed.

1.8 PERFORMANCE-BASED DESIGN AND EQUIVALENCIES

Most prescriptive-based codes contain an "alternative methods and materials" or "equivalency" clause that permits the use of alternative means to meet the intent of the prescribed code provisions. This provides an opportunity for a performance-based design approach. Through performance-based design, it can be demonstrated whether or not a building design is satisfactory and complies with the implicit or explicit intent of the applicable code.

Performance-based designs using the "alternative materials and methods" or "equivalency" clauses should follow the approach contained in this guide, including identifying the prescriptive-based code provision being addressed (scope of the design); providing an interpretation of the intent of the provision (functional statement); establishing performance requirements, design fire scenarios, and analysis methods, and providing an alternative approach (trial design); and providing engineering support for how the suggested alternative meets the intent of the provision (evaluation).

1.9 IMPORTANCE OF OBJECTIVES AND FUNCTIONAL STATEMENTS

In performance-based design, objectives are statements in broad terms of what a fire protection design is intended to achieve. Functional statements provide more definition of the objectives, and performance requirements are further refinement of objectives and functional statements into measurable quantities that can be predicted by fire protection engineers to determine whether or not a trial design achieves the objectives.

Because objectives and functional statements explicitly define the level of safety that a performance-based design will achieve, it is important for code officials to understand and reach agreement on objectives and functional statements that are developed for a project. Because of the importance of objectives and functional statements, the design team and the code official should work together early in the design process to develop a set of objectives and functional statements that are acceptable to all parties.

1.10 LEVEL OF DESIGN

Performance-based design has traditionally occurred through the equivalency clause in the current prescriptive building and fire codes. A performance code takes this concept one step further and provides an infrastructure of information such as objectives, functional statements, and performance requirements to assist in the evaluation of whether a method, material, or specific product meets the needs of the regulations. Whether prepared as an equivalency or to meet a performance-based code, the level of design will vary in complexity and scope. The term "performance-based design" does not automatically mean an extremely broad and complex design that will necessarily require peer review and other costly mechanisms. In fact, many "performance-based designs" may be very basic. Performance-based design may be approached from a subsystem, system, or whole-building level of design. See Chapter 10 for further information.

1.11 EXAMPLES OF THE TYPES OF PROJECTS WHERE PERFORMANCE BASED DESIGN MIGHT BE USED

The following are examples of where performance-based design may be applied:

Application to a new building. The design team may wish to provide an innovative design that does not fit within the confines of a prescriptive code. For example, it might be desired to have an occupied level of an atrium where the smoke level would not meet a code-specified distance above floor level. Performance-based design may allow a design team to provide the innovative or unique features or uses that are desired, while providing a level of safety that meets or exceeds the adopted code.

Application to existing buildings. Performance-based design can be used when it is desired to upgrade the level of safety in an existing building where compliance with prescriptive codes would require significant modifications. For example, it might be desired to use an existing open stairway as a required exit. Alternative protection strategies could be used to provide a level of safety that would be equal or better than enclosing the stairway.

Application to historic buildings. Performance-based design can be used when it is desired to upgrade the level of safety in an existing building where compliance with prescriptive codes would cause adverse impact to the historic features.

Performance-based design can be used to provide a more cost-effective approach for the design aspects that are used to achieve the level of safety desired by the adopted code.

Performance-based design can be used to provide a better understanding of potential losses, damage, or interruptions to business operations that could occur in the event of a fire.

1.12 PERFORMANCE-BASED DESIGN SUBMITTALS

In prescriptive-based design, a code official typically does not become involved until a final design is submitted. In performance-based design, it is very important that the designer and the code official become involved at the earliest possible stage. Early involvement allows for the code official to develop an understanding of the proposed approach and the design as they evolve. This helps the designer to better understand the code official's expectations and concerns and allows input from the code official at an early stage.

The documentation that is provided will vary with the scope of the design. For designs of limited scope, the documentation might only be a few pages long. Larger projects that are more significant in scope will typically have more substantial documentation.

A number of documents should be prepared as part of the performance-based design (see Chapter 12). In general, code officials should expect to receive the following:

- **Concept report (fire protection engineering design brief).** The concept report documents the scope of the project, the members and qualifications of the design team, and key decisions and agreements that have been reached as a result of negotiations during the preliminary design phase, in addition to objectives and functional statements, performance requirements, design fire scenarios, trial designs, and proposed analysis methods.
- **Performance-based design report.** The performance-based design report should show the evaluation that demonstrates that the performance-based design meets the performance requirements in the design fire scenarios.
- **Specifications and drawings.** The specifications and drawings should identify how the performance-based design should be implemented.
- **Commissioning/acceptance testing procedures.** These procedures are used to verify that the engineering and design principles used to design a system coincide with the installation and construction practices for the system.
- **Operations and maintenance manual.** The operations and maintenance manual describes the limitations that are placed on the operation of the building and critical inspection and maintenance requirements necessary to verify continued acceptable performance of the design. The operations and maintenance manual provides a list of specific requirements to maintain the performance-based design. An operations and maintenance manual serves as a regulatory enforcement tool that is written for a specific building.

1.13 KEYS TO SUCCESS

During the performance-based design process, there are several considerations important to facilitating the performance-based process. These considerations may arise from the required interaction of the stakeholders, unfamiliarity with the performance-based design process, limited manpower for review, limited communication, or other items.

The performance-based design process consists of a progression of steps or phases. At each step of the process, the key stakeholders should evaluate the progress to determine whether or not the project is proceeding on the right track. If the design process is not proceeding on the right track, the code official might require that the design team step back in the process, restart the process, or, as a worst case, reject the performance-based design approach and revert to enforcement of the prescriptive-based codes. The following suggestions, if followed, may help to minimize the possibility of the design process not proceeding on the right track. These suggestions are grouped into the project phases where they are critical.

1.13.1 Project Initiation

- Submit qualifications of the design team to the code official.
- Verify that needed expertise is present on the design team.
- Reach consensus on the review mechanism.
- Determine review and permit fees.

1.13.2 Project Development

- Reach consensus on:
  - Objectives.
  - Functional statements.
  - Performance requirements.
  - Design fire scenarios.
  - Trial designs.
  - Methods.
  - Assumptions and limitations.
- Avoid significant changes in project scope.

1.13.3 Project Review/Evaluation

- Demonstrate that objectives and functional statements are satisfied.
- Reach consensus on material testing and field inspection methods.
- Avoid significant changes in project scope.

The success of a performance-based design project depends on early, open, timely, and consistent communication among the stakeholders. The further a performance-based design project gets into the process, the more time and resources the stakeholders expend. Therefore, the design team and the code official should assess the potential for success of the project early on and, once committed to the process, strive to resolve issues that develop further into the process.

Other considerations to facilitate the performance-based design process include the following:

1. Start early.

- The process should start early with familiarization meetings involving all parties.

2. ***Get the right people.***

- All parties, including the owner, designer, and code official, should identify the individual(s) who are empowered to make decisions on their behalf.
- Ensure that stakeholder representatives who have the authority to make decisions and commitments on behalf of the stakeholder are involved from the beginning.

3. ***Understand individual responsibilities.***

- It is essential that the stakeholders be prepared. For example, everyone should know the subjects for which they are responsible. The design team and code official should know the codes and understand their intent.
- There should be a clear commitment of the stakeholders to the project. In the end, the owner must be committed to fulfilling all the obligations required for the performance-based design to continue to function as designed.

4. ***Work toward a solution.***

- As in all design processes, all stakeholders are expected to work together toward a common solution.
- Communication of the desired information to allow decisions is essential. The communication must be timely to allow the process to continue as planned. Incomplete, inaccurate, or late communication could result in all the stakeholders being unhappy with the results. In addition, documents produced must be clear and complete so that code officials, owners, and others all understand the results and intent.
- The design team and code official should engage in a discussion of the objectives and functional statements that relate to the safety concerns of the code official to make sure that the design team addresses the appropriate issues.
- The design team is expected to propose solutions to address concerns for the code official to review. If the code official has definitive issues that need to be addressed, they should be identified early so the process can proceed toward a solution. An organizational or individual bias toward a solution should be identified early on.
- The design engineer should focus on how the design addresses the intent of the pertinent code issues, allowing the code official to easily determine if the code intent is met and if an acceptable level of life safety is achieved.
- The code official should establish a submittal review process, review times, and funding required, if any. This process can include required technical training and a commitment of personnel to the project. Continuity of personnel on the project is essential to its successful completion.

2.0 Definitions

- A -

Assumptions – An estimation relative to the characteristics of a fire protection system or a building characteristic, occupant characteristic, or fire characteristic.

Audit – To examine with intent to verify.

- B -

Bounding conditions – "Conditions, which if exceeded invalidate the performance-based design. These could be maximum or minimum allowable conditions such as fuel load or type and arrangement of fuel load that must be maintained throughout the life of a building to ensure that design parameters are not exceeded."[3]

Building characteristics – "A set of data that provides a detailed description of a building such as building layout (geometry), access and egress, construction, building materials, contents, building services and fire safety (hardware) systems."[1]

- C -

Change of use – Any change in activity, occupant characteristics, or contents that results in an increase in hazard or risk that exceeds the bounding conditions of a performance-based design.

Code official – The code enforcement officer or other designated authority charged by the applicable governing body with the duties of administration and enforcement of a code, including duly authorized representatives.

Commissioning – "The process of verifying that a system meets design, technical standards and code expectations via inspection, testing and operational functionality."[3]

Concept Report (Fire protection engineering brief) – A document summarizing agreed-upon performance requirements and methods that will be used to evaluate trial designs.[1]

Contract Review – "Plan review, as defined below, performed by a consultant who is retained by the code official for that purpose."[3]

- D -

Deed restriction – A restriction on the use of a building or facility that is recorded with the deed.

Design fire curve – A quantitative description of a fire's size and how that size varies with time. Design fire curves might be described in terms of heat release rate versus time, or in other terms.

Design fire scenario – "A set of conditions that defines or describes the factors critical to determining outcomes of trial designs."[1] Design fire scenarios are the fire scenarios that are selected for use in evaluating whether trial designs achieve the performance requirements.

Design professional – "An individual who is registered or licensed to practice their respective design profession as defined by the statutory requirements of the professional registration laws of the state or jurisdiction in which the project is to be constructed."[3]

Design team – A group of members, including the principal design professional and possibly other design professionals and special experts, who develop a design.

Deterministic approach – "A methodology based on physical relationships derived from scientific theories and empirical results that for a given set of initial conditions will always produce the same result or prediction. In a deterministic analysis, a single set of input data will determine a specific set of output predictions."[1]

- E -

Egress model – A physical or mathematical procedure that incorporates engineering and scientific principles for the analysis of people movement through building exiting arrangements and the prediction of time for evacuation.

Equivalency – In the design context, equivalency means that an alternative material or method performs, for the purpose intended, in a manner that is at least as effective as a material or method prescribed in terms of life safety, fire resistance, strength, and durability.

- F -

Failure analysis – A study of a failure to determine the mechanism by which the failure occurred and to develop strategies to prevent similar failures from occurring in the future.

Fire characteristics – "A set of data which provides a description of a fire."[1]

Fire dynamics – The scientific study of fire behavior and effects.

Fire model – "A physical or mathematical procedure that incorporates engineering and scientific principles for the analysis of fire and fire effects to simulate or predict fire characteristics and conditions of the fire environment."[1]

Fire scenario – "A set of conditions that defines the development of fire and the spread of combustion products throughout a building or part of a building."[1]

Functional statement – A requirement of the fire, building, system, or occupants that needs to be obtained in order to achieve an objective. Functional statements are stated in more specific terms than objectives. In general, functional statements define a series of actions necessary to make the achievement of an objective more likely. "Functional statements" are called "objectives" in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*.[1]

- H -

Hazard analysis – An assessment of a possible source of danger that could initiate or cause undesirable consequences.

Heat release rate – A measure of the intensity of a fire, which is the rate at which energy is released.

- M -

Management of change – A process for controlling the changes that occur in a building to ensure that they do not unacceptably affect the performance of a design.

- O -

Objective – Desired overall safety outcome expressed in qualitative terms. "Objectives" are called "goals" in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*.[1]

Occupant characteristics – "A set of data that describes conditions, abilities or behaviors of people before and during a fire."[1]

Operations and maintenance manual – Documentation that describes the requirements and procedures necessary to keep a performance-based design within the bounding conditions.

- P -

Pass/fail criteria – Criteria that are used to judge whether something is acceptable or not. Performance requirements are typically pass/fail criteria for the evaluation of performance-based designs.

Peer review – "An independent and objective technical review of the design of a building or structure to examine the proposed conceptual and analytical concepts, objectives and criteria of the design and/or construction."[3]

Performance-based code – A code or standard that specifically states its fire safety objectives and references acceptable methods that can be used to demonstrate compliance with its requirements. The document might be phrased as a method for quantifying equivalencies to an existing prescriptive-based document, and/or it might identify one or more prescriptive documents as approved solutions, or it might specify performance requirements without referencing prescriptive requirements. The document allows the use of any solution that demonstrates compliance.[1]

Performance-based design – "An engineering approach to design elements of a building based on agreed-upon performance goals and objectives, engineering analysis and quantitative assessment of alternatives against the design goals and objectives using accepted engineering tools, methodologies and performance criteria."[3]

Performance-based design report – Documentation that describes the development, evaluation, implementation, and critical features of a performance-based design.

Performance requirement – "Criteria that are stated in engineering terms against which the adequacy of any developed trial designs will be judged."[1] "Performance requirements" are called "performance criteria" in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*.[1]

Plan review – "A review of the construction documents by the code official to verify conformance to applicable performance and prescriptive code requirements."[3]

Principal design professional – "An architect or engineer who is responsible to the owner and has contractual responsibility and authority over all design disciplines to prepare and coordinate a complete and comprehensive set of design documents for a project."[3]

Probabilistic analysis – "An assessment to evaluate the fire losses and fire consequences which includes consideration of the likelihood of different fire scenarios and the inputs which define those fire scenarios."[1]

Project scope – "An identification of the range or extent of the design matter being addressed, including any specific limits of a performance-based design. This might be a subset of a larger development, evaluation, or design effort (e.g., one part of the building design process), or a stand-alone fire safety analysis and design project."[1]

- R -

Reliability – A measure of whether a design or system will function as intended.

Risk – "Risk is the product of the potential consequences and the expected frequency of occurrence. Consequences might include occupant death, monetary loss, business interruption, environmental damage, etc. The frequency of occurrence could be an estimate of how often the projected loss might occur."[1]

Risk analysis – An analysis that explicitly considers the magnitude or severity of possible events and the likelihood of those events occurring.

Robustness – In the context of a design or system, robustness is a measure of the system or design continuing to function as intended if there are changes that could affect performance. In the context of a model or calculation method, robustness is a measure of the ability to return an accurate calculation despite uncertainty in input.

- S -

Safety factor – "Adjustment made to compensate for uncertainty in the methods, calculations and assumptions employed in developing engineering designs."[1]

Sensitivity analysis – An analysis of how changes in one or more parameters in an analysis change the results and conclusions.

Special expert – "An individual who has demonstrated qualifications in a specific area, outside the practice of architecture or engineering, by education, training and experience."[3]

Special inspector – A qualified individual or entity performing intermittent or continuous observation of work or testing of materials, fabrication, erection or placement of materials or components, acceptance testing of systems, and related functions on behalf of the code official.

Stakeholder – "One who has a share or an interest, as in an enterprise. Specifically, an individual (or representative of same) having an interest in the successful completion of a project. The reason for having an interest in the successful completion of a project might be financial, safety related, etc."[1]

- T -

Tenability – A measure of the whether a fire environment poses a hazard to occupants.

Trial designs – A fire protection system design intended to achieve the stated fire safety objectives and expressed in terms that make it possible to assess whether the fire safety objectives have been achieved.[1]

- U -

Uncertainty – "The amount by which an observed or calculated value might differ from the true value."[1]

3.0 CODE OFFICIAL'S ROLE IN PERFORMANCE-BASED DESIGN

3.1 EXECUTIVE SUMMARY

This chapter addresses the design/review process and the code official's role during the development of a performance-based design or other alternatives to the prescriptive code. This chapter also addresses those tasks important to successful implementation of a performance-based design, which may include construction verification, system commissioning, site inspections, and post-occupancy maintenance and testing.

Regardless of the size of the project, it is imperative to maintain open communication throughout the performance-based design process to clarify technical information and other issues. The code official should ask questions during this process or provide input when deemed necessary. The result of the process is for the code official to have adequate information and a sufficient understanding of the performance-based design being proposed. This should allow the code official to make informed, appropriate, and fair decisions during the process.

3.2 FREQUENTLY ASKED QUESTIONS

Q. What are key aspects of the code official's role in a performance-based design?

A. Cooperation and communication. Regardless of the size of the project, it is important to maintain open communication throughout the process to clarify technical information and other issues, such as the jurisdiction's requirements and laws relative to the project. The code official should be open to asking questions during this process or to provide input when deemed necessary. The result of the process is for the code official to have adequate information and a sufficient understanding of the performance-based design to enable the code official to make a decision on behalf of the jurisdiction.

Q. What phases of a performance-based project require the code official's involvement?

A. The code official should be involved in the early to final design phases, the construction phase, and the post-occupancy phase of a project (see Sections 3.3 and 3.4).

Q. Should commissioning and testing requirements be addressed before the final design is approved?

A. Generally, yes. Although the actual testing and commissioning of systems does not occur during the design phase, it is critical that such activities be factored in during the design and analysis. This is important since the testing and commissioning procedures required may impact or influence features of the design and can have an effect on the practicality and economic feasibility of the project (see Section 3.4).

Q. What are the legal liabilities of a code official for approving a performance-based design?

A. A code official's culpability stems from acts of negligence. Allegations of negligence can be brought against a code official regardless of whether the prescriptive- or performance-based code is used (see Section 3.6).

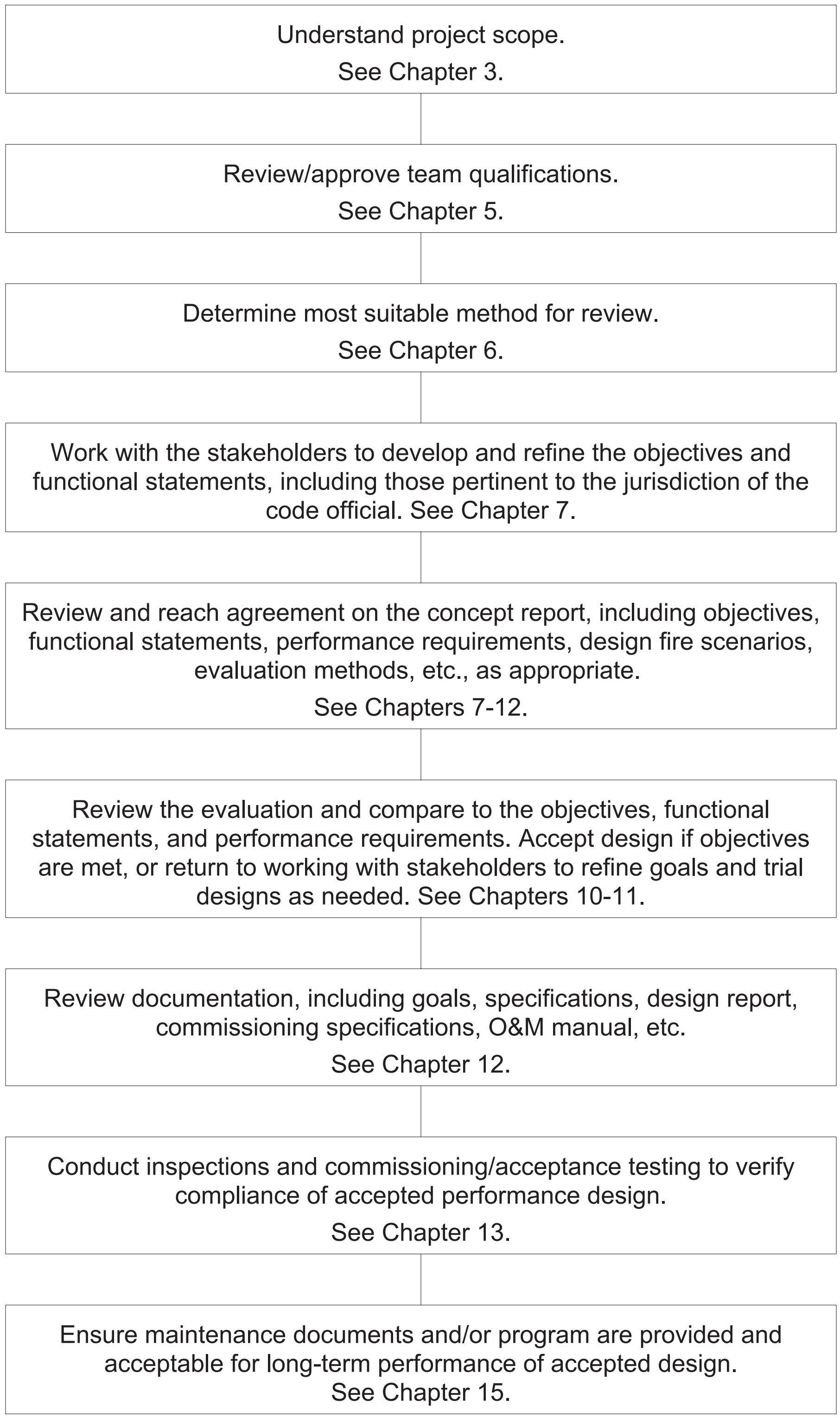

FIGURE 3.1. Performance-Based Design Review Process

3.3 THE PERFORMANCE-BASED DESIGN PROCESS (SEE FIGURE 3.1)

3.3.1 Typical applications

Many types of design issues can be addressed using a performance-based approach. Some of the common types of issues are as follows:

- **Evacuation/tenability.** This analysis evaluates fire scenarios and the effect on building occupants. This analysis will likely involve an assessment of time to untenable conditions versus time for evacuation or relocation of occupants.
- **Structural failure analysis.** This analysis assesses the response of structural members when exposed to design fires that may have different heat release rates and durations, and the ability of the structure to continue to bear its load. When such an analysis is undertaken, the functional statements need to be clearly understood, whether they are simply for building occupant evacuation or go further into protection of emergency responders and property. This will vary the performance requirements of the project.
- **Fire protection systems activation.** In some cases, typically on a subsystem level, the activation time of fire protection systems is analyzed. This analysis typically looks at activation times of the sprinklers or other detection devices versus fire growth and peak heat release rates and how that would relate to an alternative approach that provides an equivalent level of safety.
- **Product/material assessment.** Sometimes there is a need to assess the fire performance of certain building materials or products in a building design. These might be new products or existing products that are used in a unique application beyond the minimum standards of the code (i.e., a Class C flame spread material where Class B is normally required, or a new type of composite material). Other times a listed product may meet the minimum code requirement but still contribute significantly to the fire scenario. Evaluation of product performance often requires the collection of additional fire test data in a form that can be used in the analysis. Numerous fire test methods can be used to obtain the necessary data, such as heat release, propensity to ignition, or species generation rates.

3.3.2 Defining the project scope

This is the first step in the performance-based design process. The owner and design team will identify ideas such as the intended use of the building, the extent of performance-based design, desired type of construction, and special features and processes. The stakeholders who will be involved in the project are identified. The code official should identify the applicable codes and standards for the jurisdiction and any special requirements that may apply. The method of reviewing the design—peer review, contract review, in-house review—should be considered, and costs associated with review should be identified and discussed. These issues should typically be discussed with all the relevant stakeholders and may involve one or more preliminary meetings, depending on the size and complexity of the project.

3.3.3 Reviewing team qualifications

The code official should review team member qualifications and verify that appropriate expertise is represented.

3.3.4 Identifying objectives

At this stage, the stakeholders identify their objectives for the project, including those that address fire safety. Stakeholders may have differing objectives that should be reviewed and discussed to achieve consensus. The code official can consult resources such as appropriate performance codes for guidance in identifying objectives. It should be noted that some objectives may not be regulatory in nature and, therefore, do not require significant review by the code official, such as an owner's objective for minimizing construction cost.

3.3.5 Defining functional statements

Once the objectives are established, functional statements are developed to define how the objectives will be met. Functional statements are normally expressed in terms that can be quantified by the design team. Functional statements may include the tolerable consequences of a fire expressed in terms of dollar values, loss of life, impacts on business operations, or maximum allowable conditions, such as the extent of fire spread. Functional statements may be developed by the design team for review by the code official, as a collaborative effort involving meetings of the relevant stakeholders, or a combination of the two. The code official can consult the appropriate performance codes for guidance in developing and evaluating functional statements.

3.3.6 Developing performance requirements

Based on the established functional statements, performance requirements are developed for use in evaluating the performance-based design. Performance requirements are typically expressed as measurable values and define what is expected of trial designs. They may include clear layer heights, threshold values for the temperatures of materials, gas temperatures, carboxyhemoglobin (COHb) levels, smoke obscuration, or thermal exposure levels. Performance requirements will typically be developed by the design team and are then presented to the code official and other stakeholders for review and discussion. The code official should evaluate the performance requirements to assess whether they adequately define the expected level of performance. If a peer reviewer will be used, he or she should be involved at this stage.

3.3.7 Developing design fire scenarios

At this stage, possible fire scenarios are identified and defined. These fire scenarios will be used to challenge trial designs to determine if they satisfy the previously established performance requirements. The set of all possible fire scenarios may be large. Therefore, it may be desirable to select a set of design fire scenarios that are considered credible, based on size as well as probability, for actual evaluation. Design fire scenarios should address operational status of fire safety systems.

Possible fire events may be identified by the design team and presented to the code official and other stakeholders for review, or they may be identified through a collaborative effort of the relevant stakeholders. The code official should evaluate the possible fire scenarios to determine if they are reasonable, based on the expected building use, and assess whether other fire scenarios are possible. The code official should participate in the process of screening the set of all possible fires to determine a subset of those that are considered credible and that will be evaluated as design fire scenarios. Once the design fire scenarios are defined and selected, the design team will further develop the design fire scenarios for use with fire models and other tools. If a peer reviewer will be used, he or she should be involved at this stage.

3.3.8 Developing trial designs

Once the project scope, performance requirements, and design fire scenarios are established, the engineer develops preliminary designs, referred to as trial designs, intended to meet the project requirements. Trial designs include proposed fire protection systems, construction features, and operations that are provided in order for a design to meet the performance requirements when evaluated using the design fire scenarios. The evaluation method should also be determined at this point. The evaluation methods used must be appropriate for the situation and agreeable to the stakeholders. The code official should review the set of trial designs developed by the design team to verify that, in principle, the strategies proposed to be evaluated would be acceptable. Although the actual testing and commissioning of systems does not occur during the design phase, it is critical that such activities be factored in during the design and analysis.

3.3.9 Developing a fire protection engineering design brief

It is here that the code official looks at the brief to ensure it includes the project scope, objectives, functional statements, trial designs, performance requirements, design fire scenarios, and analysis methods and that they meet what was agreed upon throughout the process.

3.3.10 Evaluating trial designs

Each trial design is then evaluated using each design fire scenario. The evaluation results indicate whether the trial design will meet the performance requirements. Only trial design(s) that meet the performance requirements can be considered as final design proposals. Those not meeting performance requirements can be revised in conjunction with other stakeholders and reevaluated.

3.3.11 Final design

One of the trial designs meeting the identified performance requirements may be selected as the final design. Once the final design is identified, design documents need to be prepared. Proper documentation will help stakeholders understand what is necessary for the design implementation, maintenance, and continuity of the fire protection design. The documentation should include the fire protection engineering design brief, a performance design report, detailed specifications and drawings, and a building operations and maintenance manual that clearly establishes the bounding conditions for the building. The code official will review the documentation and provide input as needed (see Chapter 12).

Acceptance testing criteria are an important part of the design documentation. For instance, which tests will demonstrate compliance with the design parameters? Are additional testing and verification procedures needed for this particular project? Who will undertake the testing? Will the required testing and verification fit within the schedule and budget for the project? Discussing and making these decisions in this phase of the project will eliminate confusion and frustration when the construction is occurring. This is particularly important since in many cases the design engineer is not necessarily hired for the construction phase of the project.

3.3.12 Plans approval and permit issuance

After receiving the documentation, the official should proceed in a timely manner to complete a review of the plans and issue permits if the final design documentation fulfills the approval criteria.

3.4 CONSTRUCTION PHASE PROCESS

3.4.1 Construction

During the construction phase, the code official and owner should verify that the performance-based design is being implemented as intended. The traditional construction verification and inspection procedures used by the jurisdiction may or may not be sufficient for a performance-based project, and the code official may consider implementing alternative or special procedures to address inspection tasks.

It is important that design issues be factored into the project before construction since an initial effort to achieve cost savings through the use of a performance-based design may in fact cost money or time later in the project as a result of the complexity of the testing needs. Also, it is important for everyone involved to be prepared in advance for any unique procedures such as a third-party inspector or similar needs.

3.4.2 Testing

During the acceptance testing of fire protection systems and/or components, the code official should observe to verify that the systems are performing as intended and to become more familiar with the system.

3.4.3 Test Methods to Be Used

As noted, acceptance testing is important to factor into the initial analysis since it may have an effect on the choices made for the overall design. Therefore, this phase of the project should be thoroughly discussed. In many cases the traditional testing methods, such as those found in the sprinkler and alarm standards, may be used for a majority of the testing needs, but there will be specific elements of some performance designs where such methods are not applicable. The lack of applicability may be related to a unique layout or use not anticipated by the traditional prescriptive testing procedures. In some cases, the traditional prescriptive standards may be applicable but need to be augmented by some unique testing procedures to verify that the system or components will function as intended by the specific design. An example might include sprinkler protection of a unique fuel package or hazard for which test data is not available.

3.4.4 Inspections

Checks should be made to ensure proper inspections are being made during the construction of the building.

3.5 POST-OCCUPANCY PROCESS

3.5.1 Inspections

Periodic inspections should be performed after the construction of the building to verify compliance with the operations and maintenance manual and that the building's occupancy, use, and configuration still meet the bounding conditions for the facility.

3.5.2 Maintenance

The code official should verify that the proper documents are in place to provide proper guidance in the maintenance and upkeep of the fire protection system(s) and performance-based features.

3.6 LIABILITY CONCERNS

It is recognized that code officials may have concerns regarding increased liability exposure by reviewing a performance-based design. Potential liability may vary depending on the specific tort laws of the state and ordinances adopted by a particular jurisdiction, and discussion of this issue is beyond the scope of this guide. It is recommended that the code official consult with his or her jurisdiction's legal counsel for further guidance regarding liability. Additional information may be obtained from other resources.[6,7,8,9]

A sufficient demonstration of the level of safety provided by a design prior to approval by the code official can be obtained by following the performance-based design process. This includes:

- Open and regular stakeholder communications.
- Established objectives that meet or exceed the safety requirements of the prescriptive code.
- Increased levels of engineering rigor and documentation.
- Enhanced levels of review or peer review.

4.0 RESPONSIBILITIES OF OWNER, DESIGNER AND CODE OFFICIAL

4.1 EXECUTIVE SUMMARY

The performance-based design will be successful only if the stakeholders understand their respective roles and act accordingly. The owner, designer, and code official must form a team and coordinate their effort to achieve the common goal.

4.2 FREQUENTLY ASKED QUESTIONS

Q. What is the objective of the relationship among the owner, designer, and code official?

A. The owner, designer, and code official should work together as a team with a common goal of a successful project (see Section 4.3).

Q. When does the code official get involved?

A: The earlier in the process that the code official gets involved, the better. Early involvement can provide opportunities for the code official's concerns to be addressed before significant effort is put into the project. If the code official waits until the final submittal, the amount of effort required to address concerns raised can be substantial (see Section 4.6).

Q. Who pays for what?

A: The owner typically pays for design and construction services. If peer review is required, the owner will typically pay the peer reviewer's fees. If a contract review is used, the code official will typically pay for the contract reviewer's fees; however, these fees might be recouped through permit fees (see Sections 4.4 through 4.6).

Q. What is the owner's role?

A. The owner is responsible for selection of qualified design and construction personnel. The owner must also commit to working with the design team toward a mutually acceptable set of project assumptions, limitations, and risks. Also, the owner is responsible for maintaining the completed building within the bounding conditions of the design (see Section 4.4).

Q. What is the designer's role?

A. The designer is responsible for coordination of design professionals and preparing a coordinated set of design documents. Completion of a technically correct design is the responsibility of the designer (see Section 4.5).

Q. What is the code official's role?

A. The code official is responsible for making sure that the jurisdiction's objectives and functional statements are addressed in the design. The code official is also responsible for making sure that sufficient expertise is present on the review staff to adequately judge the acceptability of the design (see Section 4.6 and Chapter 3).

Q. What qualifications should the designer possess?

A. The designer must also make sure that the necessary expertise is present on the design team to prepare a thorough and correct design. This includes understanding the proper use and limitation of any tools or methods used to support the design development (see Section 4.5 and Chapter 5).

4.3 TEAM APPROACH

4.3.1 The team approach is essential to the success of a performance-based design. This provides an opportunity for the code official to rethink the traditional role and become a more active participant in project development early in the project.

4.3.2 The team often consists of the owner, designer, and the code official and possibly others. Together they should set a framework that will foster good communications and a clear understanding of the objectives and functional statements of the performance-based design.

4.3.3 It is essential that protocols for effective communication be established early. These protocols should be designed to minimize miscommunication and redundancy. Each team member should designate a contact person to minimize confusion.

4.3.4 A basic agreement should be reached in the initial stages on the fundamental aspects of any specific performance-based design. This encompasses the setting of objectives and functional statements. A schedule for meetings, reviews, deliverables, and the permitting and inspection process and associated fees is also necessary.

4.3.5 There should be a comprehensive review by applicable regulatory agencies that will be involved in the approval, construction, inspection, and commissioning of the project. A system to coordinate the involvement of such agencies helps in avoiding delays.

4.4 RESPONSIBILITY OF THE OWNER

4.4.1 The owner is responsible for the selection and compensation of qualified design professionals and special experts to meet the objectives of the project. In most cases, a principal design professional will be required to coordinate the efforts of multiple designers.

4.4.2 The selection and compensation of qualified and competent construction and quality control personnel is also the owner's responsibility. In addition, the owner must provide competent personnel and the compensation for construction oversight.

4.4.3 If the owner cannot attend meetings and carry out his or her responsibilities, then a designated representative who is empowered to act on behalf of the owner at meetings and all stages of the process is necessary for the success of the project. The owner must agree to project assumptions, limitations, and risks.

4.4.4 If peer review becomes part of the process, the owner should participate in the selection of the peer reviewer. It is usually the owner's responsibility to compensate the peer reviewer.

4.4.5 The owner will be responsible for retention of all project documents.

4.4.6 Management of change, both during the construction and operation of the facility, is critical. There must be a process and procedure with the proper staffing to manage change within the bounding conditions identified.

4.5 RESPONSIBILITY OF THE DESIGNER

4.5.1 The principal design professional is responsible for the coordination of designers and special experts. This should include, but is not limited to, the preparation of reports, investigations, and a comprehensive set of construction documents.

4.5.2 A natural outgrowth of this coordination process would be scheduling of reviews and submittals. These include the reviews and submittals between the designers and special experts and the owner, as well as the submittals and the reviews by the code official and/or peer reviewer.

4.5.3 All designers must possess the required professional expertise to establish, analyze, and report on the elements of a performance-based design that is within their scope of services.

4.5.4 The design team should assist the owner and code official in understanding the process and agreeing to objectives and functional statements by which the design will be judged.

4.5.5 The designer should be involved in the construction phase, including inspections, testing, and commissioning, to verify that the design intent is properly executed. The designer should be involved with any adjustments, analyses, or redesigns of the project. See Chapter 14 for additional information.

4.5.6 The designer should assist in identifying the need for special experts and the selection thereof.

4.6 RESPONSIBILITY OF THE CODE OFFICIAL

4.6.1 In the performance-based design process the code official should become involved at the beginning. This is not typically the traditional role of a regulator. The code official should provide input during the period where the project criteria are determined.

4.6.2 The code official should have the responsibility of ensuring that the objectives and functional statements of the adopted codes and ordinances of the jurisdiction are identified and addressed.

4.6.3 The code official must be committed to following through with agreed-upon decisions and assumptions for the project. This will include the scheduling, approval, permitting process, and the commitment of staffing.

4.6.4 There must be an evaluation of the review and inspection staffing and its expertise. If the required expertise is not contained within the current staff, its acquisition must be addressed, i.e., via contract review or peer review. If peer review will be part of the process to ensure the proper expertise, this should be identified early in the design process.

4.6.5 Internal coordination with other regulatory agencies may be required. The audit methodology and schedule should be developed, accepted, and closely monitored to ensure timely approval and permitting.

4.6.6 The code official should provide acceptance or rejection of the approach upon its completion. If the design complies with the performance requirements, approval should be granted. If not, the design should be rejected, with a written explanation of the reasons for rejection.

4.6.7 It is critical to retain records so that future inspections can be conducted properly and the basis of the design can be understood if a change of use occurs. The code official should ensure that a mechanism is in place to retain the documentation relevant to design bounding conditions, construction, and inspections.

4.6.8 In performance-based design, the operation and maintenance of the facility is critical. Therefore, the code official has some oversight responsibilities for the operation and maintenance of the facility after the completion of construction and should verify that the owner has developed and implemented a plan.

5.0 QUALIFICATIONS OF TEAM MEMBERS

5.1 EXECUTIVE SUMMARY

To complete a fully functional performance-based design, a team approach is critical. The team is composed of representatives of both the owner and code official. Members of the team need to have specialized knowledge and expertise in the areas of fire protection related to the specific challenge.

A formal declaration of education, training, and experience demonstrating competency in the related areas of fire protection needed for the specific challenge must be documented for the owner's records and submitted to the code official for review and acceptance. These qualifying levels of education, training, and experience are necessary for the design professionals and reviewers, as well as the individuals involved in the installation, commissioning, and maintenance of performance-based designs.

This chapter provides guidance as to what may constitute appropriate qualifications for many of the individuals who may be involved in the design, construction, and maintenance of performance-based approaches. This chapter provides guidance to determine the levels of the expertise that may be necessary for members of a team, but this chapter does not address all necessary qualifications for every member of the team. The specific needs will vary with the project scope.

5.2 FREQUENTLY ASKED QUESTIONS

Q. *How do I know a specific company is qualified?*

A. The owner's team can be expected to submit a list of similar projects for which they have been responsible. Copies of these lists should be retained as part of the approved documents (see Section 5.4).

Q. *How do I know a specific individual is qualified?*

A. The owner's team can be expected to submit resumes of pertinent members of the design team. Copies of resumes should be retained as part of the approved documents (see Section 5.4).

Q. *How do I know if my staff is qualified?*

A. Most managers will be able to determine if their own staff is qualified to fulfill the necessary responsibilities. If the code official is utilizing a peer/contract reviewer, the procedure will be similar to criteria for designers (see Section 5.5).

Q. *What do I do if it is determined that the qualifications are unsatisfactory?*

A. It is difficult to be in the position of being required to challenge the competency and abilities of another. Nevertheless, it is the code official's job to review and approve the qualifications of these individuals. To represent the interests of the jurisdiction fairly and justly, the code official must clearly communicate the specific areas where he or she feels that the qualifications fall short in order to give the individuals involved an opportunity to respond. Of course, tact in addressing these concerns will always be the most effective way to resolve any issues such as these. One option is to make pointed statements or ask pointed questions. One such approach frequently used is to express concern that if the owner's team is not fully experienced in the area(s) necessary to reach consensus for the respective subject, substantial delays can be expected with no assurance of approval.

5.3 GENERAL

As identified in Chapter 4, a team approach is essential to the success of a performance-based design project. It is also essential that both the owner's team and the code official's team contain individuals having sufficient knowledge in the area(s) of fire protection engineering related to the needs of the performance-based design project. Determination of whether an individual is qualified can be accomplished by reviewing their education, licenses, certifications, and a record of their experience.

5.4 OWNER'S TEAM QUALIFICATIONS

The owner is responsible for retaining design professionals with sufficient knowledge in the areas relevant to the performance-based design. The design team must have knowledge of the approaches that could be used to solve a design problem and the applicability and limitations of the method that is selected for the performance-based design under consideration.

5.4.1 Owner's Representative

If the owner cannot personally meet the needs and demands placed upon him or her, then he or she should designate an authorized representative. The representative must be authorized to make decisions for the owner.

5.4.2 Principal Design Professional

The principal design professional has overall responsibility for a complete and comprehensive design. The principal design professional might perform all or some of the design tasks associated with a project, or might delegate these tasks to other design professionals or special experts.

Federal, state, or local law might require that the principal design professional be registered or licensed in the state or jurisdiction in which the construction will be undertaken. Additionally, the coordination requirements of the project will require that the principal design professional have knowledge of all facets of the project and the performance-based approach being used. Also, the principal design professional should have knowledge of the level of protection intended by applicable codes and standards.

The principal design professional must also have an ability to perform as the primary point of contact for the project and coordinate activities among the design team members, owner, and code official.

A typical means to identify whether someone is qualified to serve as a principal design professional is to review prior design experience.

5.4.3 Fire Protection Design Professionals

Fire protection design professionals might be used by the principal design professional to perform specific tasks. Federal, state, or local law might require that fire protection design professionals be registered or licensed in the state or jurisdiction in which the construction will be undertaken; however, licensing may not be required depending upon their scope or roles in the project.

Fire protection design professionals should have sufficient relevant knowledge to know which approaches could be used to perform the tasks and the applicability and limitations of the method(s) that they select. Examples of areas in which fire protection design professionals might need an understanding include:

- Fire dynamics.
- Fire modeling.
- Active and passive fire protection systems.
- Fire testing.
- Fire department operations.
- Human behavior.

Also, fire protection design professionals should have an understanding of or an ability to interpret the level of safety intended by the codes or standards relevant to the project.

Fire protection design professionals should also have the ability to demonstrate and document the achievement of acceptable levels of protection. Whether or not fire protection design professionals are sufficiently qualified can be determined through a review of their education and experience.

5.4.4 Special Experts

Special experts might be used by design professionals to perform specific tasks. Special experts should have expertise in the area(s) in which they are performing. It may not be necessary for special experts to be licensed. Whether or not special experts are sufficiently qualified can be determined through a review of their education and experience.

5.4.5 Construction Personnel

Construction personnel may have to perform coordination and commissioning for complex design aspects that might not be present in a design that is prepared to meet prescriptive requirements. It is imperative that construction personnel understand that they must comply with the documentation of the performance-based design and not necessarily the prescriptive requirements to which they might be accustomed. Construction personnel should be licensed or certified as required by the regulations of the state or jurisdiction.

Determination of whether construction personnel are capable of constructing a performance-based design can be accomplished by reviewing their past experience or by communicating with them to make sure that they understand the requirements of the project.

5.4.6 Facility Staff

Aspects of a building or facility that have been designed on a performance basis may require increased or unique inspections, testing, maintenance, and record keeping beyond what would be required for a building or facility designed to meet prescriptive requirements. The owner should retain qualified staff at all times or contract with qualified companies or individuals to ensure all necessary periodic inspection, testing, and maintenance are provided.

Facility staff should have knowledge of the unique inspection, testing, and maintenance requirements of the performance-based designed systems and components to ensure that they remain within their bounding conditions. Facility staff should have the ability to prepare and retain appropriate records for internal information and for review by the code official. Facility staff should also have sufficient knowledge of the specific performance-based design and bounding conditions, or know to check the operations and maintenance manual, to be aware when proposed renovations might impact the original design. Additionally, facility staff should have the authority to perform actions needed to ensure continued compliance.

Determination of whether facility staff are capable of performing these tasks can be accomplished by reviewing their past education or experience or by communicating with them to make sure that they understand any unique requirements.

5.5 REVIEWER'S TEAM QUALIFICATIONS

The code official is responsible for acquiring competent reviewers/inspectors and to utilize registered, licensed, or certified individuals when required by a state or jurisdiction.

5.5.1 Reviewers

The reviewer(s) should have sufficient expertise to evaluate whether or not the design and analysis was performed properly and whether or not it meets the requirements of the adopted code. This will require knowledge of, or an ability to interpret, the underlying principles and concepts of the code and levels of protection intended by the code.

Reviewers should understand the applicability and limitations of the method(s) that are used to develop and evaluate the performance-based design. Examples of areas in which reviewers might need an understanding include fire dynamics, fire modeling, active and passive fire protection systems, fire testing, fire department operations, and human behavior.

A code official can determine whether a staff reviewer or contract reviewer is sufficiently qualified by reviewing his or her education and experience.

5.5.2 Inspectors

Personnel who inspect performance-based designs should have knowledge of the unique inspection, testing, and maintenance requirements of the performance-based designed systems and components to verify that the systems or components are within their bounding conditions. Inspectors should understand that they need to inspect based on the documentation of the performance-based design and not necessarily the prescriptive requirements to which they might be accustomed.

Inspectors should have an ability to apply the design documentation to the specific construction and coordination aspects needed to confirm compliance with the agreed-to performance-based design criteria. Inspectors should also have the ability to witness commissioning of complex systems and document the results. Additionally, inspectors should have the ability to review facility records to confirm compliance with approved operations and maintenance manuals.

Determination of whether inspectors are capable of performing these tasks can be accomplished by reviewing their education and/or past experience or by communicating with them to make sure that they understand the requirements of the project. Inspectors should indicate that they are capable of undertaking these tasks.

6.0 CONTRACT REVIEW/PEER REVIEW

6.1 EXECUTIVE SUMMARY

This chapter presents review options available to the code official for projects that utilize a performance-based design. The two specific options outlined in this chapter are contract review and peer review. The code official may choose to use either of these options or both of them. However, neither of these options is mandatory for a performance-based design.

A performance-based design may utilize new materials, testing, and installation standards that have not been adopted by any nationally recognized code organization, or designs that rely on fire tests, modeling, or research papers. In these cases, the plan reviewer (either contract or staff) and the peer reviewer (if any) should have an appropriate level of expertise, as specified in chapter 5, so as to adequately assess the project.

6.2 FREQUENTLY ASKED QUESTIONS

Q. What resources are available to the code official when presented with a performance-based design that exceeds staff's expertise?

A. The code official may decide to use a contract reviewer who has expertise in the area of the design and may require a peer reviewer to have a better understanding of the quality, completeness, or the scientific bases of the design (see Sections 6.3 and 6.4).

Q. How should a contract reviewer be selected?

A. The code official should look for a contract reviewer who meets the requirements specified in Section 6.3 of this guide. Because the contract reviewer is typically employed by the jurisdiction, there are legal issues relative to how the contract reviewer is selected and requirements for liability insurance (see Section 6.3.2).

Q. How should a peer reviewer be selected?

A. The peer reviewer is typically approved by the code official but hired by the owner or the owner's agent. A peer reviewer should have the necessary knowledge and fire protection engineering or fire science expertise to understand and evaluate the design that is being reviewed. The code official should check for conflicts of interest or technical bias on the part of any peer reviewer (see Section 6.4.2).

6.3 CONTRACT REVIEWER

6.3.1 When to Use (See Figure 6.1)

The code official may want to use a contract reviewer for projects that require technical expertise that exceeds staff capabilities, or for projects that will have an unacceptable effect on the backlog. In making this determination, the code official should first analyze the project, including the type of construction, the occupancy, and any special features.

The code official should then analyze staff's ability to perform the review as outlined in Chapter 5 of this guide. In addition to the staff's ability, the code official should look at the current workload and how the review will affect the current backlog level.

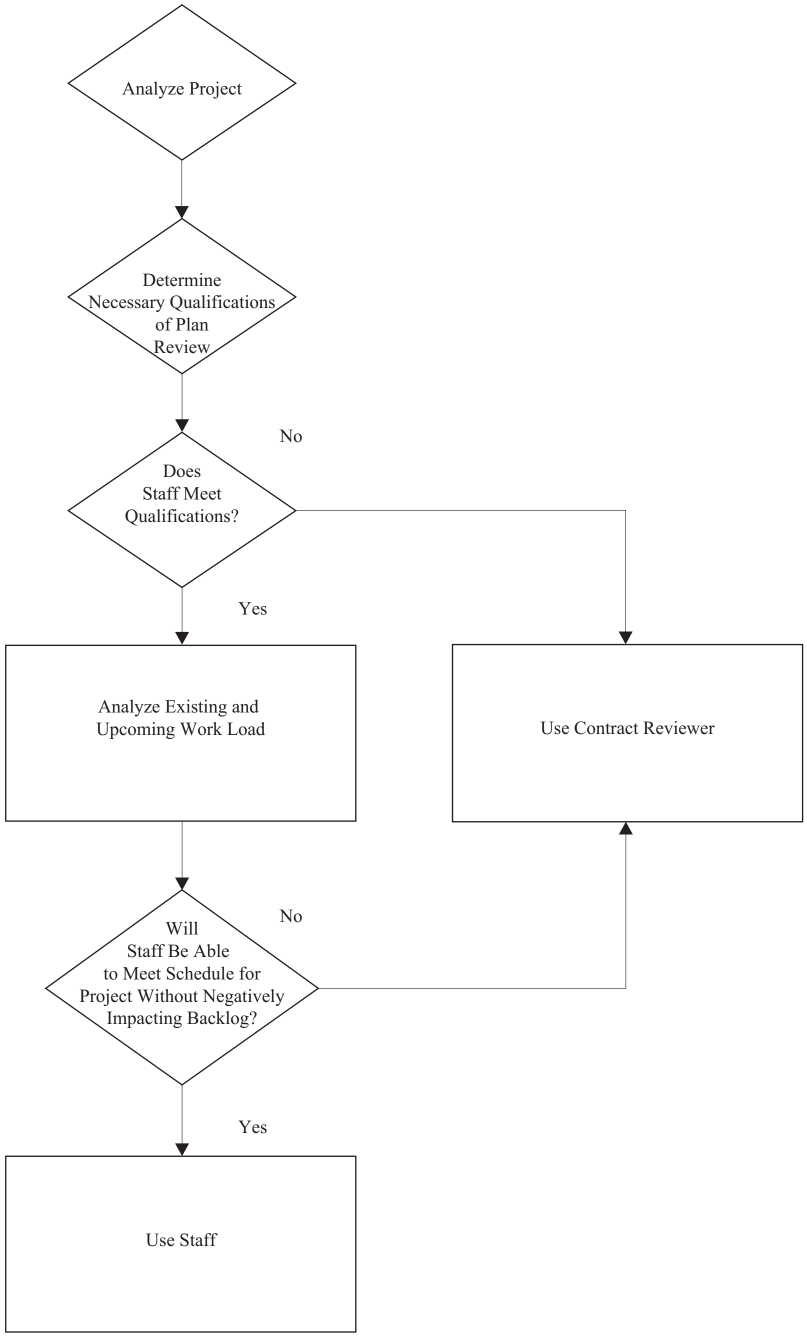

FIGURE 6.1. Selection Process for a Contract Reviewer

6.3.2 Selection of Contract Reviewer

Once the code official determines that there is a need for a contract reviewer, the selection of one begins. The code official may have one or more contract review firms already approved to perform reviews. If so, selection of a contract reviewer is just a matter of selecting the best-suited firm for the specific design. In other cases, the code official will need to go through the necessary steps to hire a contract reviewer, including sending out a request for proposals and screening the applicants in accordance with the procurement procedures in effect in the jurisdiction.

In making the selection, the code official should review the qualifications of the specific person who will be reviewing the project, as outlined in chapter 5 of this guide.

The code official should also ask for references from other code officials who have used the reviewer for similar projects. Not only are issues like competency and accuracy important, but responsiveness and timeliness also need to be considered.

The code official needs to review the errors and omissions insurance of the firm employing the contract reviewer to verify that it is adequate to protect the code official and the jurisdiction.

Typically, the cost for the contract reviewer is paid by the jurisdiction out of the plan review fee that is paid by the applicant. Based on the scope of the project, this fee may need to be revised to cover the actual cost of the review.

6.3.3 What the Code Official Should Expect from the Contract Reviewer

The contract reviewer should perform a complete review of the entire project, including all building code requirements. In addition, all other trades that have been agreed upon, such as mechanical, electrical, and plumbing review, should be included. This review will include the performance portion of the project as well as the prescriptive code requirements.

6.4 PEER REVIEW

6.4.1 When to Use Peer Review

The code official may want to require a peer review to have a better understanding of the quality, completeness, or the scientific bases of the design. In addition, the code official may require a peer review when there are resource limitations and the code official wishes to bring in outside assistance to evaluate the fire safety features of the design. Another possible reason to require a peer review might be to provide additional quality assurance for the design.

6.4.2 Selection of Peer Reviewer (See Figure 6.2)

When the code official requires a peer review of the design, the owner or owner's agent should submit information on two or more peer reviewers to the code official for consideration.

The importance of a peer reviewer's independence and technical expertise cannot be overemphasized. The peer reviewer should be objective and have no conflict of interest with the project. Any candidate being considered as a peer reviewer should be asked by the code official to disclose any conflict of interest or technical bias.

A peer reviewer should have the necessary knowledge and fire protection engineering or fire science expertise to understand and evaluate the design that is being evaluated. For example, a peer reviewer should at least have the necessary knowledge and fire protection engineering experience to prepare an acceptable design that is similar in scope to the design being reviewed (see Chapter 5). Peer reviewers should be able to demonstrate, through documented education and experience, that they are competent to perform the requested peer review.

The code official should approve all peer reviewers who are acceptable to perform the review, and the owner should determine which peer reviewer will be used.

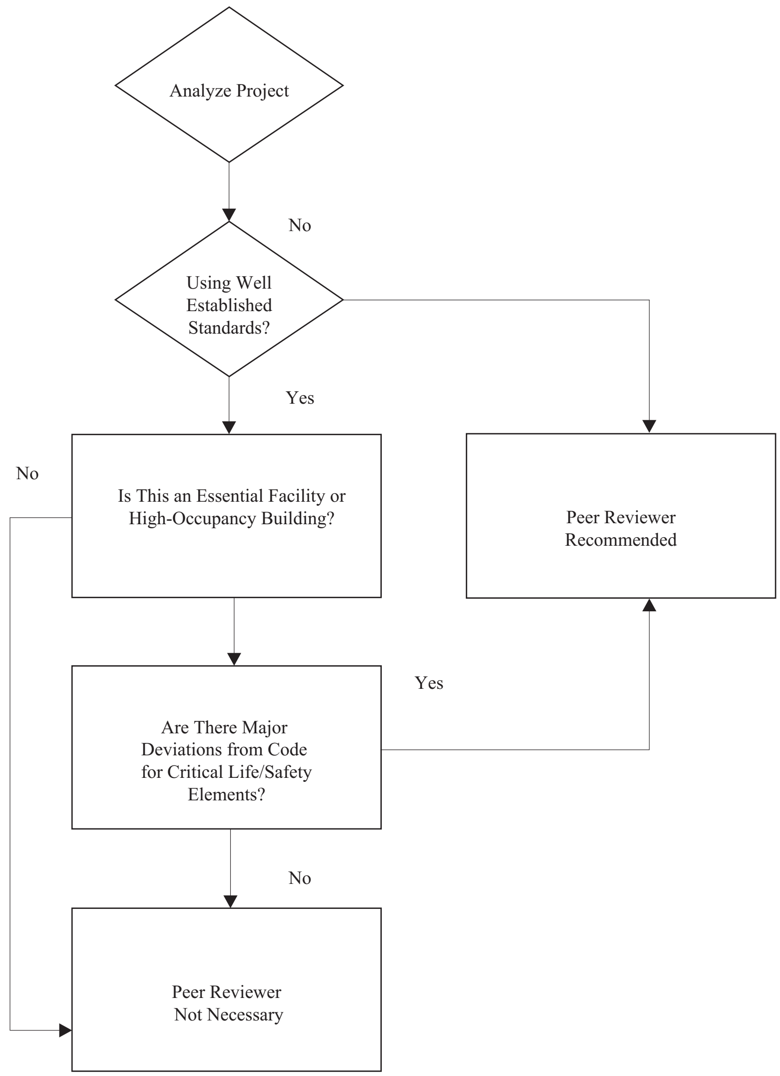

FIGURE 6.2. When to Use a Peer Reviewer

6.4.3 What the Code Official Should Expect from the Peer Reviewer

For guidance on peer reviews of performance-based designs, see the *SFPE Guidelines for Peer Review in the Fire Protection Design Process*.[10] At the conclusion of a review, the peer reviewer should prepare a written record that identifies the scope of the review and the findings. The following items should be addressed in the report:

- Applicable codes, standards, and guides.
- Design objectives.
- Assumptions made by the designer (e.g., performance requirements, design fire scenarios, material properties used in correlations or models).
- Technical approach used by the designer.
- Models and methods used to solve the design problem.
- Input data to the design problem and to the models and methods used.
- Appropriateness of recommendations or conclusions with respect to the results of design calculations.

- Correctness of the execution of the design approach (e.g., no mathematical errors or errors in interpretation of input or output data).
- Peer reviewer's opinion of whether the design meets the design objectives.

Peer reviewers should substantiate any comments on appropriateness by references to published technical documentation.

7.0 DEFINING OBJECTIVES, FUNCTIONAL STATEMENTS AND PERFORMANCE REQUIREMENTS

7.1 EXECUTIVE SUMMARY

The objectives, functional statements, and performance requirements are key elements of a performance-based design. The performance-based design process cannot move forward effectively without clear definition and consensus on these items. Once established with the understanding and agreement of the stakeholder team (owner, designer, code official, etc.), the objectives, functional statements, and performance requirements provide the basis by which the successful performance or nonperformance of a trial design can be assessed.

7.2 FREQUENTLY ASKED QUESTIONS

Q. *As a code official, what are my responsibilities to the stakeholder team regarding the objectives used in the design?*

A. The code official has the responsibility of ensuring that the objectives of the adopted codes or ordinances for his or her jurisdiction are identified and addressed by the stakeholder team (see Section 7.3).

Q. *What are the relationships and differences among objectives, functional statements, and performance requirements?*

A. Objectives are general broad statements that should express the broad nature of fire safety concerns to be addressed. They are typically stated in qualitative terms. Objectives are subsequently refined into more specific concerns and actions known as functional statements. Functional statements should represent requirements that need to be fulfilled to achieve a fire safety objective. The performance requirements are the functional statements stated in measurable or quantified engineering terms that are used to evaluate and judge the successful performance or nonperformance of a trial design (see Section 7.3).

Q. *What are some of the possible fire safety objectives or fire-related objectives of codes that the code official should be concerned about?*

A. Possible fire safety objectives include providing life safety, protecting property, protecting business operations, or limiting the environmental impact of fires (see Section 7.4).

Q. *How are objectives developed?*

A. Objectives for fire safety can be developed in many ways, which may include the stakeholders meeting and collaborating as a group to establish objectives, or the process may involve developing a proposal of objectives statements that can then be reviewed, discussed, and modified if necessary by the stakeholders as a group. Appropriate performance codes may also be used to either develop objectives or verify that the pertinent aspects of the project are covered within the objectives developed by the stakeholders. Regardless of the method of development of the objectives, it is important that agreement is reached among the stakeholders (see Section 7.4).

Q. *Can the stakeholders establish objectives that eliminate fire risks?*

A. It is impossible to eliminate all risk with respect to fire. There is always some likelihood that a fire could occur. Similarly, there is always some likelihood that a fire in an occupied building could result in injury or death, and a fire in any building will result in property damage or business interruption (see Section 7.3).

Q. *What constitutes performance requirements, and what are some examples?*

A. Performance requirements are threshold values, ranges of threshold values, or distributions that are used to develop and evaluate proposed or trial designs. The performance requirements must reflect the intent of the functional statements and be quantitative measures of the consequences of fire that need to be avoided to fulfill the objectives and functional statements agreed to by the stakeholder team. A possible example would be that structural steel should not exceed a specified maximum temperature (see Section 7.6).

7.3 GENERAL

Objectives are general broad statements that should express the broad nature of fire safety concerns to be addressed. (NOTE: the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* uses the term "goal" to describe general broad-based statements that are referred to herein as objectives.)

- Objectives are subsequently refined into more specific concerns and actions known as functional statements.
- Functional statements should represent requirements that need to be fulfilled to achieve the fire safety objective.
- Performance requirements are criteria stated in measurable engineering terms that are used to evaluate and judge the successful performance or nonperformance of a proposed design.

Objectives for fire safety can be developed in many ways, which may include the stakeholders meeting and collaborating as a group to establish objectives, or the process may involve one of the stakeholders developing proposed objectives statements that can then be reviewed, discussed, and modified if necessary by the stakeholders as a group. Generally, objectives and their related functional statements and performance requirements should be developed with some degree of conservatism that is agreeable to the stakeholders. Regardless of the method of development of the objectives, it is important that agreement be reached among the stakeholders. The design process cannot move forward effectively without clear definition and consensus on the objectives and their related functional statements and performance requirements.

The code official has the responsibility of ensuring that the objectives and functional statements of the adopted codes or ordinances for his his or her jurisdiction are identified and addressed among the stakeholder team. The code official does not have a responsibility or authority to address objectives and functional statements that are unrelated to the adopted codes or ordinances. Such unrelated objectives and functional statements can and should be within the purview of other stakeholders who have additional interests in a proposed design (e.g., insurance loss expectations).

There is no such concept as zero risk with respect to fire. There is always some possibility that a fire could occur. Similarly, there is always some likelihood that a fire in an occupied building could result in injury or death, and a fire in any building will result in property damage or business interruption. It is, therefore, important for the stakeholder team to establish design functional statements that are realistic and achievable since it is not possible to create an entirely hazard- or risk-free environment.

Table 7.1 provides examples of objectives, functional statements, and performance requirements.

TABLE 7.1. Examples of Objectives, Functional Statements and Performance Requirements

Fire Protection Objectives	Functional Statements	Performance Requirements
Minimize fire-related injuries and prevent undue loss of life.	No loss of life outside the room or compartment of fire origin.	COHb level not to exceed XX percent. Visibility greater than XX meters.
Minimize fire-related damage to the building, its contents, and its historical features and attributes.	No significant thermal damage outside the room or compartment of fire origin.	Upper layer temperature not greater than XX ºC.
Minimize undue loss of operations and business-related revenue due to fire-related damage.	No process downtime exceeding 8 hours.	HCl not greater than XX ppm. Particulate not greater than XX g/m^3.
Limit environmental impacts of fire and fire protection measures.	No groundwater contamination by fire suppression water runoff.	Impoundment capacity at least XX times the design discharge.

7.4 OBJECTIVES

7.4.1 Fundamental Objectives for Fire Safety

The following are fundamental objectives for fire safety as developed by the Society of Fire Protection Engineers.[1]

- Provide life safety for the public, building occupants, and emergency responders. Minimize fire-related injuries, and prevent undue loss of life.
- Protect property. Minimize damage to property and cultural resources from fire. Protect building, contents, and historical features from fire and exposure to and from adjacent buildings.
- Provide for continuity of operations. Protect the organization's ongoing mission, production, or operating capability. Minimize undue loss of operations and business related revenue due to fire-related damage.
- Limit the environmental impact of the fire.

The code official should identify which of these objectives are addressed by the codes or ordinances applicable to his or her jurisdiction.

7.4.2 Identifying Applicable Objectives

Several means can be used to help identify applicable objectives. Some of these are as follows:

- **Codes and standards.** Codes or standards may specify general or specific objectives. Authoritative documents, such as appropriate performance-based codes and the *SFPE Engineering Guide to Performance-Based Fire Protection*, can be useful resources that can aid in the development of objectives.

- **Alternatives and equivalencies.** When design alternatives or equivalencies to specific code requirements are proposed, the objectives or intent of the respective code section should be established and agreed upon among the stakeholders.
- **Local conditions.** As the result of local conditions, there may be policies or reasons that warrant establishment of objectives outside the purview of a building code or ordinance. An example may be objectives that need to be established for a building that adjoins a wildlands interface.
- **Insurance.** Property and business continuity functional statements of the insurer may provide a basis for objectives.
- **Owner's objectives.** The building owner may have objectives related to the design or operation of a building. Building owners may also have established safety policies that exceed those of codes or standards, which may need to be restated in the form of objectives.
- **Nonfire safety objectives.** There may also be other nonfire safety-related objectives that should also be understood at the beginning of a project. These may include the designer's objectives for appearance, aesthetics, or functionality. In addition, objectives for existing or historic structures may be pertinent for the preservation industry and related authorities.

7.4.3 Objectives from Codes

When undertaking a design based on a prescriptive-based code or performance-based code, the objective(s) might be embodied in an intent statement or objective statement. For example, the *ICC Performance Based Code™ for Buildings and Facilities*[3] provides the following objective statements for fire safety that are closely related to the SFPE fundamental objectives above.

- **Sources of fire ignition.** To limit or control the likelihood a fire will start as a result of the design, operation, or maintenance of a facility or its systems so as to minimize impacts on people, property, processes, and the environment.
- **Limiting fire impact.** To provide an acceptable level of fire safety performance when facilities are subjected to fires that could occur in the fire loads that may be present in the facility during construction or alteration and throughout the intended life.
- **Hazardous materials.** To protect people and property from the consequences of unauthorized discharge, fires, or explosions involving hazardous materials.
- **Means of egress.** To protect people during egress and rescue operations.
- **Fire prevention.** To limit or control the likelihood a fire will start due to the design, operation, or maintenance of a facility or its systems so as to minimize impacts on people, property, processes, and the environment.
- **Management of people.** To promote safe practices and actions of people, and to ensure that the actions and practices of people that are components of a design are maintained.
- **Emergency responder safety.** To protect emergency responders from unreasonable risks during emergencies.
- **Notification, access, and facilities for emergency responders.** To provide and maintain means of notification, access, and facilities for emergency operations and responders.
- **Notification for life safety and property protection.** To provide notification of the need to take some manual action to preserve the safety of occupants or to limit property damage.

7.5 DEFINING FUNCTIONAL STATEMENTS

After the broad fire safety objectives are established, the code official should continue to be involved in the refinement of the objectives into specific functional statements.

- A functional statement provides more detail and is often stated in terms of acceptable or sustainable loss or in terms of a desired level of risk.
- Functional statements might be stated in terms of meeting the requirements of a specific code provision of a prescriptive- or performance-based code.
- Functional statements might reflect the maximum acceptable (tolerable) extent of injury to persons, damage to a building or contents, or risk or probability level criteria.

The performance-based regulations noted in Appendix A provide functional statements and performance requirements. These functional statements and performance requirements may be useful to the code official in working to develop functional statements with the stakeholder team.

Regardless of the form in which they are stated, functional statements should be clear and agreed to by those involved because the engineer will later translate these functional statements into quantifiable or numerical terms that can be evaluated.

7.6 DEVELOPMENT OF PERFORMANCE REQUIREMENTS

Following the development of functional statements is the selection or development of performance requirements. This will be done by the engineer and should be presented for review to the code official. Performance requirements are threshold values, ranges of threshold values, or distributions that are used to develop and evaluate proposed or trial designs. The performance requirements must reflect the intent of the functional statements and be quantitative measures of the consequences of fire that need to be avoided to fulfill the objectives and functional statements agreed to by the stakeholders. Performance requirements established will depend on the method of performance assessment (see Section 10.3).

Life safety criteria address tenable conditions for survivability of persons exposed to fire and its products. The performance requirements may need to vary depending on the physical and mental conditions of the occupants and the length of time of expected exposure. Three sample categories for which performance requirements may need to be developed are as follows:

1. Thermal effects.
2. Toxicity.
3. Visibility.

Nonlife safety criteria address issues relating to damage thresholds for property, business interruption, protection of the environment, etc. Damage thresholds may relate to thermal energy exposure, resulting in ignition or unacceptable damage. Thresholds may also consider exposure to smoke aerosols and particulate or corrosive combustion products. Categories for which criteria may need to be developed include the following:

- Thermal effects.
- Fire spread.
- Smoke damage.
- Fire barrier damage and structural integrity.
- Damage to exposed properties.
- Damage to the environment.

More than one performance requirement may be required to adequately address a functional statement and evaluate a trial design. For example, emergency responders (e.g., fire department) might be required to delay their evacuation in order to secure an industrial process and, therefore, might experience tenable conditions, or performance requirements for life safety, that are less tenable than for personnel not involved as emergency responders who evacuate sooner. The fire department personnel might be provided with special equipment, training, or defend-in-place capability to be able to survive under these conditions.

In addition, more than one type of performance requirement may be required to address a functional statement. For example, for performance requirements related to life safety, one may quantify tenable conditions not only in terms of visibility, but also in terms of clear layer height, temperature, gas concentrations, etc., that the design would need to achieve to maintain safe conditions.

8.0 DESIGN FIRE SCENARIOS

8.1 EXECUTIVE SUMMARY

Design fire scenarios represent the types and severities of fires that a proposed trial design will need to manage in order to meet the performance requirements. As such, selection of appropriate hazards to assess the effectiveness of the proposed trial designs is important.

In reviewing performance-based designs, it is important to assess the appropriateness of the design fire scenarios that have been selected for analysis by the fire protection engineer.

8.2 FREQUENTLY ASKED QUESTIONS

Q. What is the difference between possible fire scenarios and design fire scenarios?

A. Fire scenarios describe a set of conditions that define the development of fire and the spread of combustion products throughout a space or a building. These are often the factors that are critical to the outcome of fires. "Possible fire scenarios" describe the entire spectrum of all scenarios that may occur. "Design fire scenarios" are a subset of those "possible fire scenarios" that the stakeholders considered credible for evaluation (e.g., a meteor impacting a building and starting a fire is possible, but is not generally considered a credible event for design purposes) (see Sections 8.4 and 8.5).

Q. How can one narrow down possible fire scenarios to design fire scenarios?

A. One can narrow down possible fire scenarios to design fire scenarios through engineering judgment, risk assessment, or through statistical analysis techniques, such as failure models and effects analysis, failure analysis, historical data, and statistical data (see Section 8.5).

Q. What information should the engineer provide in defining possible and design fire scenarios?

A. The engineer should provide information and assumptions regarding occupant characteristics, building characteristics, and fire characteristics that are critical to the outcome of the analysis (see Sections 8.3 and 8.4.

Q. How can someone determine which factors have the most significant impact on a design?

A. A thorough engineering analysis should address the issue of uncertainty. This can be achieved through many methods.[1] Performance-based designs commonly address uncertainty through sensitivity analysis (holding one input variable constant while changing another over a range) or bounding of variables (inputting the ends of a possible spectrum of values for a variable). For example, if the activation of a sprinkler is dependent on fire growth rate, and a single fire growth rate is used, sensitivity analysis would involve varying the heat release rate by some amount to see what the impact is on the outcomes. If the outcome varies significantly more than this amount (i.e., not a one-for-one type of relationship), one can identify the fire growth rate as being critical to the outcome of the analysis, and information and assumptions about the fire growth rate should be provided.

Q. What is the importance of providing occupant and building characteristic information?

A. Occupant and building characteristics have considerable impacts on the success of trial designs. For example, occupant characteristics have an impact on the egress analysis and evacuation design, from ability to see, hear, or otherwise be notified of an emergency situation, to the ability of occupants to egress without the assistance of others. Building characteristics include such factors as type, construction, and ventilation, among others, all of which impact fire growth and spread, as well as egress system design (see Section 8.3).

Q. What are the different phases of a design fire curve?

A. The different phases include ignition, growth, fully developed, and decay. These stages are important because most fire prevention and protection measures are targeted at being effective during various phases. For example, sprinklers do not do anything to impact ignition, yet can control fire growth and prevent a fire from becoming fully developed (a term typically applied to fire that utilizes all available fuel, oxygen permitting, in the fire area). Thus, if the objective is to prevent ignition and sprinklers are proposed as the solution, the solution would not be acceptable (see Section 8.7).

Q: Should information always be provided for each aspect of the design fire curve?

A. Information for each phase does not always need to be provided. This will depend on the objectives/functional statements, performance requirements and trial designs, needs of the stakeholders, and the intent of the analysis. For instance, an analysis of smoke detector response may not be needed to consider the decay phase (see Section 8.7).

Q: Where can one find additional information on occupant characteristics or fire characteristics?

A. There are several resources for information on occupant characteristics. Among them are the *SFPE Handbook of Fire Protection Engineering*,[5] National Fire Protection Association *Fire Protection Handbook*,[11] and *Introduction to Performance-Based Fire Safety*.[2] There are also references listed within the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*.[1] One should also talk with experts in the field or perform a literature review (see Sections 8.3 and 8.4).

8.3 OVERVIEW

A fire scenario represents a set of conditions defining the development of a fire and the spread of combustion products throughout a building or part thereof.[1] The broad ranges of fire scenarios initially selected are considered possible fire scenarios and form the basis for design fire scenarios. Design fire scenarios are quantified and in turn used to evaluate trial designs.

The process of identifying possible fire scenarios and developing them into design fire scenarios consists of the following steps[1]:

1. Identify possible fire scenarios.
2. Identify design fire scenarios (a subset of the possible fire scenarios).
3. Characterize design fire scenarios.
4. Quantify design fire curves.

The design fire scenario development process may be a combination of hazard analysis and risk analysis. The hazard analysis identifies potential ignition sources, fuels, and fire development. The risk analysis might include the hazard analysis, but also looks at the likelihood of the occurrence, either quantitatively or qualitatively, and the severity of the outcomes.

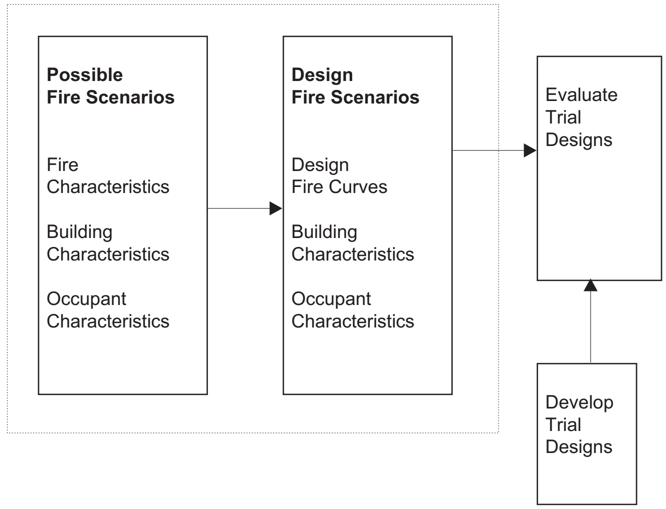

FIGURE 8.1. Fire Scenarios and Design Fire Scenarios

Design fire scenarios are the basis for developing and testing trial designs and hence should present a conservative approach for analysis and determination of required fire safety measures. One of the assumptions often made in the development of the design fire is that a fire will be of a particular type or result from a specific type of fuel under a given set of conditions. It should be noted that design fire scenarios are not necessarily an exact description of how the majority of real fires in the building might be expected to behave. While the engineer cannot anticipate every conceivable fire, the stakeholders should check that reasonable and appropriate fires are considered.

It is also important that the owner and other applicable stakeholders provide the engineers with appropriate information as to how the building or space is to be used and as much information as to combustible contents as possible. Information regarding multiple uses of spaces, and desired flexibility in a space, is also very important in developing ranges of credible design fire scenarios. Various layouts/configurations of the space and fuel loads, variations in occupant characteristics and numbers, introduction of additional loads either on a permanent or temporary basis, etc., should be contemplated when design fire scenarios are developed.

At the completion of this phase, the engineer should present the code official with a description of design fire scenarios. Sufficient detail should be provided as to why the selected scenarios are considered credible and why others were not. Typically, there is more than one scenario that would be selected for a compartment. Code officials should be cautious if only one scenario is being presented and should be provided with sufficient information regarding why the selected scenario is appropriate.

The code official, owner, and other applicable stakeholders should review these design fire scenarios and agree on them prior to detailed analysis being conducted, since this data is typically used for direct input to the fire models. Agreeing on design fire scenarios prior to the detailed analysis helps reduce the potential for undertaking unnecessary work.

8.4 IDENTIFYING POSSIBLE FIRE SCENARIOS

8.4.1 General

A fire scenario represents a description of a set of fire conditions that are potentially threatening to a building, its occupants, and/or contents. Fire scenarios describe factors critical to the outcome of fires. Therefore, when identifying a possible fire scenario, various prefire characteristics of the specific building and the building's occupants should be gathered. Such information will affect any estimations or predictions relative to the likelihood of fire occurring, how it might develop and spread, and its potential to cause damage to the occupants, structure, and contents. This information will also be used as input variables in evaluating trial designs. Therefore, when describing each possible fire scenario, information should be provided to define three components: building characteristics, occupant characteristics, and fire characteristics.

8.4.2 Building Characteristics

In developing possible fire scenarios, building characteristics describe the physical features, contents, and ambient internal and external environments of the building. Building characteristics can affect the evacuation of occupants and the growth and spread of a fire, as well as the movement of products of combustion. Therefore, the pertinent items that may impact building characteristics should be provided.

The extent to which building characteristics need to be quantified is a function of the level of analysis. For a subsystem level design, the factors pertinent to the design are often all that are needed. However, for a building performance level design, more of the building characteristics will likely require quantification.

The following are among the building characteristic features that may need to be defined:

- Site location.
- Use/operational characteristics.
- Architectural features.
- Area/geometry of structure.
- Construction materials.
- Structural components.
- Fuel load and locations of hazards.
- Egress components.
- Fire protection systems.
- Building services/processes.
- Emergency procedures.
- Fire department response characteristics.

8.4.3 Occupant Characteristics

Occupant characteristics need to be defined in order to determine the ability of occupants to respond and evacuate during an emergency. This includes both the physical and mental capacities of the occupants. For instance, occupants in a hospital or home for the elderly may be considered less mobile than for a school, or occupants in a nightclub may be under the influence of alcohol, which may affect their ability/capacity to respond.

Occupant characteristics that may need to be defined include:

- Number.
- Distribution.
- Human behavior.
- Response characteristics.
- Physical limitation.
- Mental capabilities.
- Evacuation times.

8.4.4 Fire Characteristics

Fire characteristics describe the history of a design fire, including the ignition, growth, flashover, fully developed, and extinction phases, as well as location, extension potential, and potential ignition sources. Fire characteristics impact the fire and life safety features that are provided as trial designs. Fire characteristics are used in the evaluation of trial designs to determine if the performance requirements are achieved. Potential ignition sources, fuel sources, and pertinent fire characteristics should be identified and quantified as indicated later in this section.

Additional discussions and information regarding the above characteristics that may need to be defined when developing possible fire scenarios are contained in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings* [1] and *Introduction to Performance-Based Fire Safety*.[2]

Fire characteristics and their assumptions should be clearly defined and agreed to as early as possible since some of these assumptions may have an adverse impact on the overall results if changed. Discussions should also be undertaken with the stakeholders as to how much variability there may be in these assumptions to provide a sufficient amount of flexibility in the use of the space.

8.4.5 Tools to Identify Possible Fire Scenarios

Various tools are available to assist in identifying possible fire scenarios, including Failure Modes and Effects Analysis (FMEA), failure analysis, historical data, and statistical data. Further details on the use of these tools specific to identifying possible design fires are contained in other references, including the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*[1] and the *SFPE Handbook of Fire Protection Engineering.*[5]

In addition to the above, some codes and standards provide discussions of scenarios that should be assessed if they are credible and applicable to the specific building or spaces being assessed.

It may also be desirable to assess scenarios that are more indicative of extreme events (arson, etc.). These scenarios should be developed in conjunction with input from the stakeholders as to what other scenarios may be considered credible based on information specific to the proposed use and location and to what extent they are to be addressed to either mitigate or reduce their potential impact.

8.5 IDENTIFYING DESIGN FIRE SCENARIOS

8.5.1 Approaches

Because of the large number of possible fire scenarios that may exist for a performance-based design, it is often necessary to reduce the number of possible fire scenarios to a manageable number of design fire scenarios for evaluating trial designs. Generally, possible fire scenarios can be filtered into design fire scenarios using engineering judgment on what fires may bound the potential hazards. In addition, the development of fire scenarios may include both probabilistic and deterministic approaches.[2] Further information regarding these approaches is available in Chapter 10 and other references.[1,5]

8.5.2 Challenges

One of the main challenges in selecting design fire scenarios from possible fire scenarios is determining a manageable number of scenarios that are sufficiently diverse and representative. The selected fire scenarios should ensure that, if the design results in acceptable outcomes for those scenarios, it may be considered safe for the applicable scenarios, except for those specifically excluded as too unrealistically severe, too unlikely to be fair tests of the design, or considered to be outside the bounds of how the building or space is intended to be used. Detailed discussions need to be undertaken with the stakeholders in defining the above so stakeholders are in agreement as to which design fires are and are not credible.

In reviewing the selection of design fire scenarios, care should be taken so that if a scenario is selected that is not likely to occur, or one that is too severe or too conservative, the result may be a design that is too expensive to build or a solution that is not cost-effective. However, a design fire scenario developed using a nonconservative approach, such as a lower heat release rate than what may be considered credible, could lead to a design where there is an unacceptably high risk to occupants, or one with little or no safety factor.

Design fire scenarios should therefore include a sufficient range of scenarios to take into consideration reasonableness, frequency, and severity and should cover low frequency/high consequence fires, high frequency/low consequence fires, and special challenge fires, where applicable.

Some codes dictate the size of the fire that is to be addressed when designing various fire protection systems.[12] For instance, some of the model codes define a specific heat release rate for designing smoke extraction systems. Care should be taken when using these to determine whether these design fires are credible for the area being assessed, other combustible loads are or are not present, and management plans are in place to monitor this over the future. For instance, stakeholders should be provided with information as to what represents a 5 MW fire in terms of anticipated contents/furnishings, as well as the fact that adjacent fuel packages can be ignited from the first item ignited, which may result in fires larger than the intended design fire. This may also impose limitations on the configuration of fuel packages or the use of the space.

8.6 CHARACTERIZING DESIGN FIRE SCENARIOS

Once design fire scenarios have been identified from the list of possible design fire scenarios, then the significant aspects of the occupant, building, and fire characteristics for the selected design fire scenarios that will affect the outcome should be further quantified. These parameters will function as inputs during the evaluation stage.

Often there are neither the resources nor data available to quantify every aspect of a design fire scenario. The detailed analysis and quantification should be limited to the more significant aspects. Significant aspects might include a range of different fire types (including smoldering fires), fire growth rates, compartment ventilation rates, etc. In addition, depending on what the particular design or analysis is intended to determine, various aspects may or may not be required to be defined. For instance, assessment of a smoke management system using the clear layer method may not need details regarding soot yields or visibility criteria to be defined, nor definition of the details of the decay phase. Various analysis methods including sensitivity and uncertainty analyses may need to be performed to show which aspects are pertinent and need to be appropriately addressed.

8.7 DESIGN FIRE CURVES

8.7.1 Characterizing Design Fire Curves

Part of the characterization of the design fire scenario is characterizing design fire curves. A design fire curve describes the heat release rate (HRR) history of a fuel package. A fuel package may be one or more combustible items. Figure 8.2 depicts the phases of a design fire curve that typically may need to be defined.

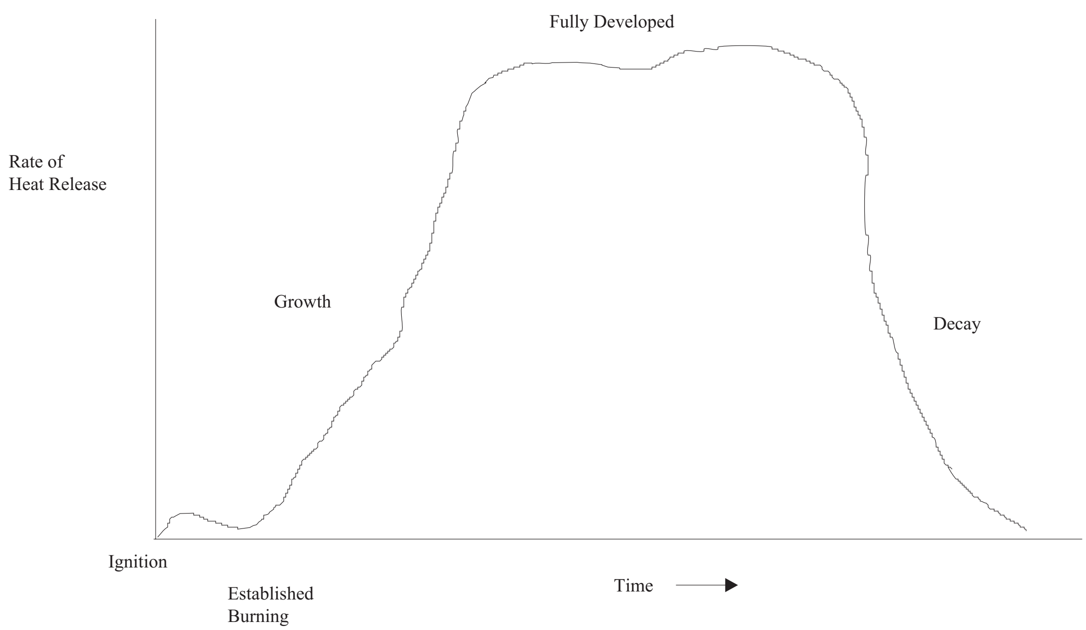

FIGURE 8.2. Phases of a Design Fire Curve

Although HRR is the basic input to most fire effect prediction methods and fire models and would form the basis for the design fire curve, other characteristics, such as mass loss rate, can be used.

Information is available on rates of heat release, heat of combustion, mass loss rate, etc.[1,13,14,15,16,17] However, the information is typically limited to an individual commodity and/or simply arranged fuel packages, and care should be taken in understanding the source of this data (full-scale tests, small-scale tests, theoretical derivation, etc.) and how it applies to the specific analysis and to what degree information can be extrapolated.

Fuel loads often involve composite fuel packages with various types of combustible materials that may be contained in a complex geometry. Since these factors affect how a fire burns, careful application of the available data is needed. Frequently, however, the data will not be complete or directly applicable to the fuel package selected. Input data must therefore be applied in a way consistent with the manner in which it was generated. If the information comes from actual tests, the user should consider the applicability of those tests to the expected scenario under the proposed design. If the information comes from theoretical analysis, again the user should consider the applicability, usually by looking at the underlying assumptions and/or test data for the theoretical analysis, and determine the proper manner of use for that analytical method.

Various aspects of the fire curve can be calculated to obtain approximations for predicted behavior. Other aspects can be roughly estimated or may require subjective testing. At the present time, there is no overall framework that provides exact solutions for the entire design fire. Therefore, the fire protection engineer should determine which portions of the design fire curve are important since it may not always be necessary to quantify each aspect of the design fire curve.

In developing the design fire curve, the engineer needs to focus on the intent of the analysis, the damage mechanisms (smoke, toxicity, thermal, corrosion), the performance requirements that will be evaluated in the given design fire scenario, and the fire characteristics of the burning fuel package(s) to determine which aspects are critical. For example, if in a performance-based design the response of an alternative automatic fire suppression system to standard sprinklers is being examined for equivalence, the design fire scenario might stop at the point of activation of the suppression system or at complete extinguishment. Or, the growth phase may be of interest in detection actuation analysis, while completion of the fully developed phase may be required to determine whether or not structural failure will occur.

A thorough review of potential and typical fuel packages and ignition sources for the building should therefore be performed and presented to the authorities. It is often difficult to obtain specific information about building contents (furniture, stored materials, etc.) during the design stages of a project; however, an attempt should be made to understand what combustibles will be in the building as well as what may be there in the future. If assumptions are made regarding specific burning characteristics of materials, they should be documented and incorporated into final project specifications (such as architectural furniture specifications, if necessary).

8.7.2 Data Resources

There is a large amount of information and data available for developing design fire curves. As indicated by Hall,[18] it can be broken into various categories:

- Laboratory test data.
- Incident data.
- Field observation data.
- Usage and exposure data.

Laboratory test data is typically used in quantifying design fire curves. Additional details regarding HRRs, fire growth rates, species production rates, and other information relevant to design fire curves are available in numerous references. [1,13,14,15,16] In addition, there are additional resources mentioned by Hall,[18] as well as available on the Internet (e.g., www.nist.gov) that should be considered during the development of design fire curves.

At times, it may be necessary to perform a fire test to develop a more explicit HRR history for a particular fuel package. If unique fire testing is required, a number of additional considerations become involved. Issues such as compartment effects, instrumentation, and data collection, as well as maximum fire size, effluent control, and suppression may govern the limits of the test. Working with the testing laboratory personnel to develop an appropriate testing protocol is essential. Any of a number of texts and guides can be consulted to analyze the appropriateness of a protocol.[19,20,21] The protocol should be reviewed with the stakeholders to determine whether the data, if obtained, will be acceptable for use in the problem analysis. Agreement by the stakeholders may allow the use of limited testing to validate design curve modeling through analytical techniques, thereby reducing overall costs.

9.0 FIRE PROTECTION DESIGN STRATEGIES

9.1 EXECUTIVE SUMMARY

Once objectives and functional statements, performance requirements, and design fire scenarios have been identified, trial designs should be developed. Trial designs represent fire protection system design alternatives developed to address design fire scenarios to achieve the previously established performance requirements.

Trial designs can be developed on a subsystem or system level, depending on the depth of the analysis required. Trial designs may involve comparison with a prescriptive system design requirement or system performance. Results can be assessed on a comparative basis (i.e., performance of prescriptive requirement relative to the proposed trial design) or compared to the performance requirements.

Trial designs that are developed for assessment on the basis of performance requirements should be developed using design features that address the performance requirements. Trial design subsystems can include fire detection and alarm; fire suppression, occupant behavior and egress; passive fire protection; fire initiation and development; and smoke management. Some or all of these may comprise the various trial designs. These systems interact with each other to provide an overall level of safety for the building. It is possible to assess the performance of individual subsystems. However, the interaction among various subsystems should also be assessed to help reduce the chance that certain subsystems may negatively impact the performance of other subsystems.

9.2 FREQUENTLY ASKED QUESTIONS

Q. What is a trial design?

A. Trial designs are the fire protection strategies developed by the design team that are intended to meet the objectives, functional statements, and performance requirements in the event that fires no more severe than the design fires occur (see Section 9.1).

Q. Is there only one alternative solution to address fire and life safety needs in a building?

A. One of the biggest advantages to a performance-based design is the ability to consider multiple strategies and various alternatives to test for compliance with the design objectives and functional statements. This approach can allow for greater flexibility to the various stakeholders in terms of operations, aesthetics, functionality, and ability to meet objectives, and even a greater level of safety than would otherwise be provided under a traditional prescriptive code design and review (see Section 9.3).

Q. Why is it important to understand and define functional statements and performance requirements when developing trial designs?

A. Functional statements and performance requirements, once agreed upon by all stakeholders, become the design focus and benchmarks for evaluating the proposed solutions. It is therefore difficult to effectively evaluate trial designs for conformance without a clearly defined set of functional statements and measurable performance requirements (see Section 9.3).

Q. What are subsystems?

A. A subsystem is a grouping of similar fire protection strategies (detection, alarm, suppression, compartmentation, etc.) A proposed performance-based design could include none, one, or many subsystems as fire protection strategies to deal with the prevention, control, or impact of a fire as part of a solution. These subsystems can act independently of one another or in concert to achieve the desired effects. Grouping fire protection strategies into subsystems is intended to facilitate the analysis of trial designs (see Section 9.4).

Q. What is the purpose of the various subsystems?

A. The functional statements range from controlling the size or effects of a fire to managing the impact of a fire on a facility and its occupants. Among the typical functional statements might be to provide early warning of a developing fire to all facility occupants prior to a prescribed level of smoke in an area, or to control growth of a fire to prevent flashover through automatic suppression (see Section 9.4).

Q. How does one develop trial designs?

A: Trial designs are developed by understanding the objectives and functional statements, as well as the performance requirements, and looking at the various individual or combinations of subsystems that will allow one to achieve the performance requirements. More than one trial design can be developed to meet a given set of performance requirements (see Section 9.4).

9.3 FUNCTIONAL STATEMENTS, PERFORMANCE REQUIREMENTS AND TRIAL DESIGNS

When selecting performance requirements and trial designs for a given functional statement, there may be more than one set of requirements to achieve each functional statement. For instance, for an objective of no loss of life outside the room of origin, performance requirements and trial designs could be developed around preventing flashover in the room of origin, containing fire and smoke within the room of origin, or maintaining tenable conditions outside the room of origin.

In developing trial designs, it is therefore necessary to first understand what functional statements and performance requirements must be achieved and then to develop trial designs comprising various subsystems to meet them.

To assist in developing trial designs and achieving the desired functional statements, one could use NFPA 550, the *Fire Safety Concepts Tree*[22] (see Figures 9.1 through 9.6). This tree assists in showing various elements that should be considered in developing trial designs and their interrelationships.

For example, one of the more common uses of performance-based design is to extend travel distances. Assuming it may be difficult to "Prevent Fire Ignition" for this space, the "Manage Fire Impact" branch is used. Under this branch, one can "Manage Fire" or "Manage Exposed." Hence, one may develop a trial design using the "Control Combustion Process" subbranch and control the fuel by limiting fuel quantity. In addition, one would also want to manage the exposed (the occupants) to evacuate them safely. Therefore, the "Safeguard Exposed" and "Move Exposed" subbranches could be used, which would recommend use of detection and alarm systems to notify occupants and providing adequate egress facilities to allow the occupants to evacuate to a safe location. As another alternative, should the stakeholders want to maintain flexibility in the space and allow some combustibles, under the "Manage Fire" branch, the "Control Fire by Construction" subbranch could be used to control the movement of smoke by either confining/containing the smoke, if appropriate, to the space or venting the smoke to maintain tenable conditions.

A trial design should express expected fire growth and spread in the context of the fire hazard, available ventilation, and compartment geometry. One of a number of trial designs might include strategies to confine a fire to a room or compartment of origin from which occupants might reasonably be expected to find a safe egress prior to untenable conditions being reached. (see the "Confine/Contain Fire" subbranch under the "Control Fire by Construction" branch of the Fire Safety Concepts Tree.) This may or may not include the integration with other subsystems, including additional active fire protection to achieve the performance requirements.

As seen, the Fire Safety Concepts Tree can be used to develop various alternatives. In addition, some of these alternatives incorporate multiple subsystems that are further described below.

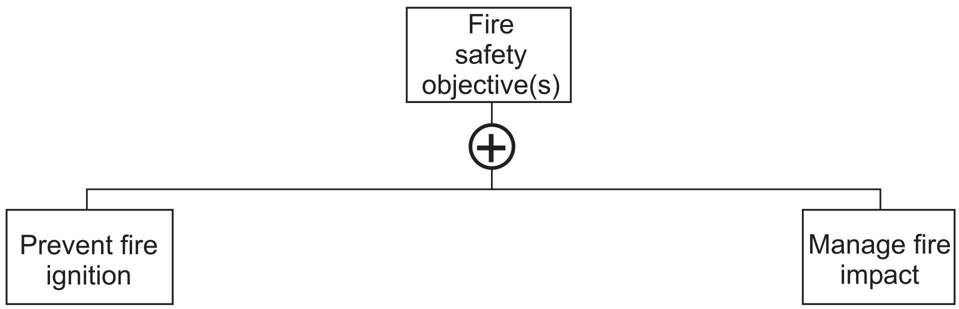

FIGURE 9.1. Top Gate of Fire Safety Concepts Tree. Reprinted with permission from NFPA 550, Guide to the Fire Safety Concepts Tree, Figure 4.3. Copyright © 2002 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject, which is represented only by the standard in its entirety.

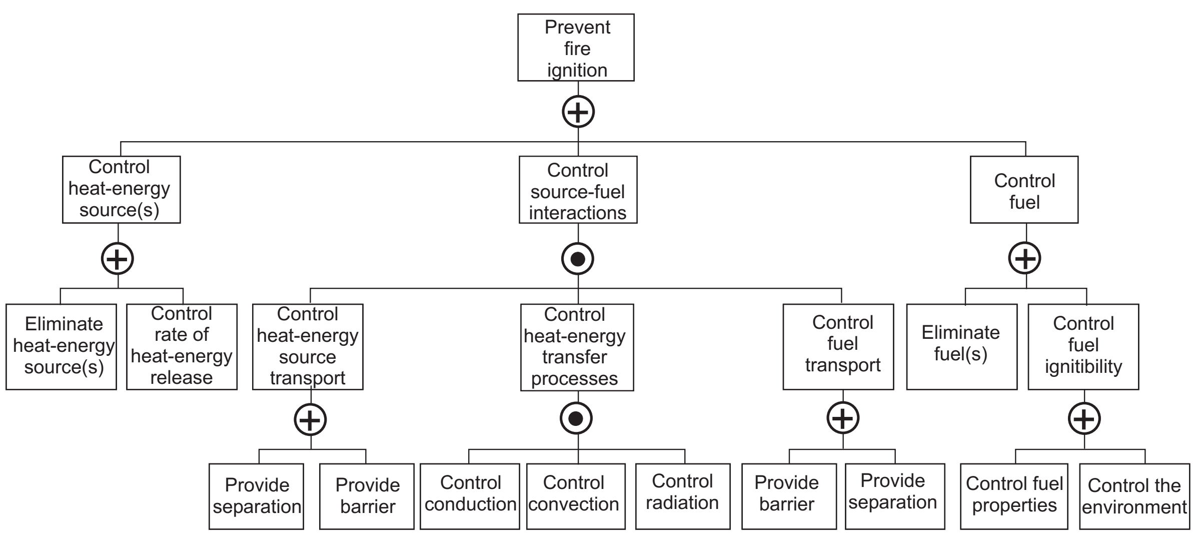

FIGURE 9.2. Prevent Fire Ignition Branch of Fire Safety Concepts Tree. Reprinted with permission from NFPA 550, Guide to the Fire Safety Concepts Tree, Figure 4.4.1. Copyright © 2002 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject, which is represented only by the standard in its entirety.

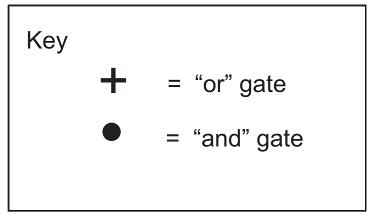

FIGURE 9.3. Logic Symbols Used in Fire Safety Concepts Tree. Reprinted with permission from NFPA 550, Guide to the Fire Safety Concepts Tree, Figure 4.4.3. Copyright © 2002 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject, which is represented only by the standard in its entirety.

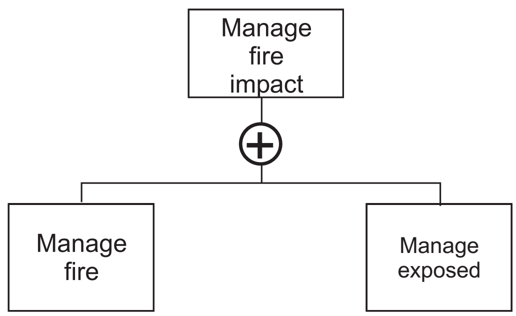

FIGURE 9.4. Major Branches of Manage Fire Impact. Reprinted with permission from NFPA 550, Guide to the Fire Safety Concepts Tree, Figure 4.5. Copyright © 2002 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject, which is represented only by the standard in its entirety.

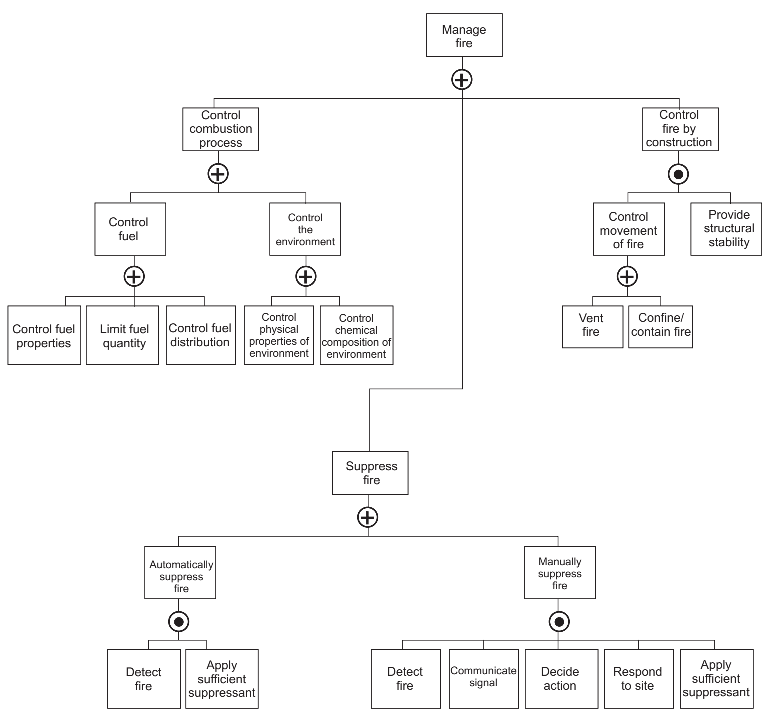

FIGURE 9.5. Manage Fire Branch of Fire Safety Concepts Tree. Reprinted with permission from NFPA 550, Guide to the Fire Safety Concepts Tree, Figure 4.5.1. Copyright © 2002 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject, which is represented only by the standard in its entirety.

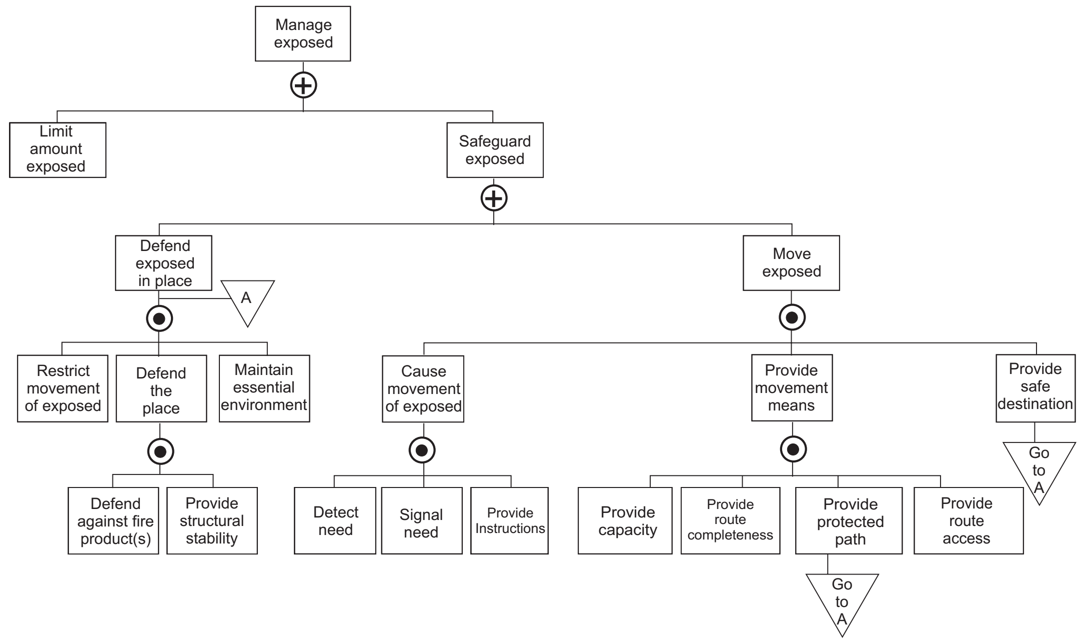

FIGURE 9.6. Manage Exposed Branch of Fire Safety Concepts Tree. Reprinted with permission from NFPA 550, Guide to the Fire Safety Concepts Tree, Figure 4.5.2.1. Copyright © 2002 National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association on the referenced subject, which is represented only by the standard in its entirety.

9.4 SUBSYSTEMS

When developing trial designs, various subsystems can be used alone or in combination with other systems. The following provides an overview of some of these subsystems.

9.4.1 Fire Initiation and Development

The fire initiation and development subsystem can be used to either assist in fire prevention or to control the development of the fire once it is started. Fire prevention is intended to reduce the likelihood that ignition will occur. Various concepts that can be employed may include controlling ignition sources, controlling materials, selecting materials that are inherently resistant to ignition, or implementing fire safety management procedures to assist in controlling ignition sources or accumulations of combustible materials. These concepts are also covered in the "Prevent Ignition" branch of the Fire Safety Concepts Tree.

Controlling fire development can be used to assist in reducing the development rate of a fire and its associated smoke and heat production. Concepts often employed to assist include selection and placement of contents, selection of interior finishes and construction materials, limiting the quantity of materials, and controlling the size and geometry of a compartment and its ventilation.

Fire prevention codes often provide detailed information to assist in reducing fire initiation and controlling development of fires.

9.4.2 Spread, Control, and Management of Smoke

This subsystem assists in addressing the hazards resulting from smoke by limiting its production, controlling its movement, and/or reducing the amount of it. This subsystem concept can be used to either control materials to exclude those that produce large quantities of smoke and toxic gases, and to manage the smoke through various methods including containment, extraction, or pressurization, as well as to use suppression systems to reduce the amount of smoke that is being produced.

Various guides are available providing additional information on smoke management, including *Design of Smoke Management Systems*,[23] *SFPE Handbook of Fire Protection Engineering*,[24] NFPA 92A, *Recommended Practice for Smoke Control Systems*,[25] and NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*.[26]

Use of this option often entails management procedures to control the quantities and types of combustible materials allowed in various spaces. Interfaces with other subsystems that often need to be evaluated in parallel include suppression systems with regard to their potential effect on the design fire size and duration, as well as detection systems to help determine the activation time of a smoke management system.

Information should be provided to the code official when using the smoke management subsystem that includes detector activation times, fan startup times, controls, interfaces with building management systems, supply air, extract rates, ducting, and fan design criteria.

9.4.3 Fire Detection and Alarm

Fire detection can assist in providing detection of a fire to notify occupants or emergency responders. Detection can also be used as a means of activating ancillary fire protection systems (smoke management systems, special suppression systems, etc.). Detection can be provided manually by people or by automatic initiating devices.

Detectors usually sense fires through various means, including heat, smoke, or radiant emissions. In specifying the types of detectors to be used, information should be provided as to the type of fire signature being produced by a fire during the phase where detection is intended to occur. For instance, different fire signatures are produced/ available during the smoldering phase (e.g., smoke) versus the fully developed phase (heat, radiant emissions, etc.) and will impact the ability of the detector to perform as intended.

Detector location should also be addressed since the configuration and geometry of the space (volume, ceiling height) as well as configuration of the ceiling (sloped, beams, etc.) can have an impact on the time and ability of the fire signature to reach the detector. Further guidance regarding performance-based designs of detection and alarm systems can be found in NFPA 72, *National Fire Alarm Code*,[15] Appendix A, and the *SFPE Handbook of Fire Protection Engineering*.[27]

Notification systems may be initiated either manually or automatically. They may provide audible and/or visual notification.

Notification may also include provision of information to emergency responders once on site to assist them in determining the location and possible extent of the fire.

Overall, when assessing the fire detection and alarm subsystem, information should be provided to the code official indicating the fire signatures that the detection system can detect as well as the location of the initiating devices in relation to the location of the fires. In addition, delays of detection systems in sensing fire signatures, alarm verification, and system processing times, and delays in sending signals to emergency responders, including via intermediate monitoring facilities, should be understood and included in the descriptions of the trial designs.

9.4.4 Automatic Fire Suppression Systems

Fire suppression systems are provided to either extinguish or control the development of a fire. Suppression can be either by manual or automatic means.

Automatic suppression systems require no human interaction and typically entail sprinkler, foam, or gaseous suppression systems. Different types of fires may require different types of suppression agents. For instance, some flammable liquid fires are better addressed by foam than water. In addition, the maximum tolerable size of the fire is important in selecting a suppression system. For instance, in computer/telecommunication rooms where early detection and suppression are desired, an early detection system activating a special suppression system would typically provide earlier suppression (i.e., smaller fire) than an automatic sprinkler system.

Some of these systems depend on activation of a fire detection system, and hence, assessment of detection time and time to discharge of the suppression agent is important. Therefore, details on the interface and pertinent features of these integrated systems that impact the suppression system's effectiveness to activate in a sufficient amount of time and discharge an appropriate quantity and type of suppressant should be provided to the code official so they can be appropriately assessed.

The characteristics of the room/space should be included in the assessment to determine the effectiveness of the suppression system in activating and performing as desired. They should include the size and geometry of the space. Sprinklers provided on a high ceiling, for instance, in an atrium, may not only be delayed in activating, but also have difficulty in providing sufficient quantities of water on the fire below once the fire has grown to a size sufficient to cause activation.

If it is desired to use manual suppression, whether by occupants, internal fire brigades, or the fire department, various aspects should be assessed including notification, response time to site, access to site/facility/fire area, number of emergency responders, equipment, and fire-fighting features provided at the facility, including water supply.

It is important to understand that some types of suppression systems are used to control fires (e.g., sprinklers), while others are intended to extinguish fires (gaseous systems, early suppression fast response sprinklers). In choosing one for a trial design, it should be clear what the suppression system is intended to do. If it is only controlling the fire, then the resultant ongoing fire-induced conditions should continue to be assessed to ensure functional statements and performance requirements are still achieved.

9.4.5 Occupant Behavior and Egress

When developing performance requirements and trial designs to meet the objectives and functional statements, it is critical to define the characteristics of the occupants and their anticipated behavior during a fire as well as the egress features and building characteristics.

The design team needs to consider several general principles regarding the occupant and egress features as they relate to their surroundings in developing a trial design[3]:

- What are the minimum and maximum number of persons expected/permitted to be in the structure, facility, or specific portions thereof?
- What is the maximum length of time the structure is occupied?
- How mobile are the occupants? Do people normally sleep or might they be expected to sleep in the building or facility?
- Can occupants reasonably be expected to be familiar with the building layout and means of egress?
- What percentage of occupants, including employees and visitors, can be considered members of a vulnerable population (children, elderly, disabled, incapacitated persons, etc.)?
- Are the egress facilities adequate?
- What is the nature of the hazard in the building or facility, and what are the expected responses of the occupants?

Once the relevant occupant characteristics, egress features, and resulting risk factors are assessed, appropriate trial designs can be developed based on managing fire impact strategies: whether to provide suitable protected egress routes, defend in place, provide early notification or assisted egress, etc. While a certain level of knowledge regarding egress and human behavior currently exists to evaluate egress in certain trial designs, the design team should undertake various "what-if" assessments to help provide appropriate alternatives (What if the occupant loads are higher? What if an exit is blocked by fire, etc.?).

9.4.6 Passive Fire Protection

Passive fire protection is intended to address two components:

1. Structural stability.
2. Issues related to limiting fire and smoke spread in a facility.

The structural stability subsystem addresses preventing premature collapse of part or all of a facility. Various approaches and methods are available to assess the necessary protection for structural members to limit the possibility of structural failure due to the anticipated thermal loading imposed by the design fire scenarios. In performing these assessments, the inherent stability of an unprotected element may be sufficient, whereas, in others, protection in addition to what is required by code is needed.

In undertaking these assessments, issues including fire performance of structural systems, fire performance of fire protective materials, connection ductility, protection of connections, effect of load transfers, composite actions of floor slabs and frames, and susceptibility to progressive collapse may need to be considered.

The subsystem of limiting fire and smoke spread through passive means includes concepts that can be used independent of each other, or integrated to limit the spread of fire and smoke in a space. These features include compartmentation, fire barriers, protection of openings, prevention of external fire spread, and controlling the fire by means such as automatic or manual suppression.

Nonfire-rated glazing, glass partitions, and unrated construction may all provide some limited fire endurance, but the trial design should thoroughly evaluate the consequences when these are exposed to credible design fire scenarios. It is important to note that there are multiple strategies available that may be considered in developing trial designs that include combinations of active and passive fire protection, one or the other, or none at all.

While building codes have historically measured fire endurance in the context of components tested to a standard time-temperature exposure in a standardized test facility with fixed, laboratory conditions, the performance of these components or systems in the field will vary. This is due to changes in fire- and temperature-induced conditions from what are used in the test furnaces and can either be more or less severe depending on the credible fires for a specific facility. In addition, changes in compartment characteristics will affect the transfer of heat from the fire to the structural or compartment components, and thus also affect their ability to perform for their anticipated time. In addition, when structural elements/components are interconnected to other structural components or building systems, their performance will be affected by heat transfer between these components, as well as the ability for various components to redistribute their loads. Therefore, these should be included when undertaking a performance-based design that involves passive fire protection.

10.0 METHODS FOR EVALUATING TRIAL DESIGNS

10.1 EXECUTIVE SUMMARY

The intent of this chapter is to familiarize code officials with the different types of methods or design approaches typically used in performance-based design and the various levels of detail and complexity they may entail. The term "method" involves the overall analytical process used to develop and analyze a trial design.

Methods will, in many cases, involve the use of models, whether they are computer based or a simple hand calculation. Chapter 11 discusses models in more detail.

In fire protection engineering, assumptions and limitations are often identified when developing or assessing trial designs. Methods for addressing these limitations will be discussed along with methods for addressing uncertainty and the application of safety factors.

10.2 FREQUENTLY ASKED QUESTIONS

Q. What are the limitations of performance-based designs, and how can these limitations be addressed?

A. Performance-based designs have limitations based on the assumptions that are used in the analysis. Various methods are outlined in the following sections (see Section 10.6).

10.3 METHODS OF PERFORMANCE ASSESSMENT

10.3.1 Specific Performance Requirements

Performance requirements can be developed, such as temperature, visibility, clear layer heights, CO_2 levels, etc., that the design should be able to meet to demonstrate that the functional statements have been met in a pass/fail analysis.

10.3.2 Comparative Analysis

A second alternative is to use a comparative analysis, for example, to a prescriptive design, where the performance of a proposed design is compared to the performance of a prescribed design solution. This approach is limited by the lack of documented intent of the prescriptive code requirements and by not knowing the absolute level of safety provided by the prescriptive solution; therefore, modeling the solution prescribed by the code and comparing it to the proposed alternative may be required.

10.4 LEVELS OF DESIGN

The design method(s) used to assess trial designs may, at times, be driven by the complexity or scope of the design, referred to herein as the level of design. The level of design is typically classified as one of the following:

- **Subsystem.** A subsystem performance evaluation typically consists of a simple comparative analysis in which it is required to demonstrate that a selected subsystem (egress, detection, suppression, passive fire protection, etc.) provides equivalent performance to that specified by the prescriptive code. At this level, one subsystem is evaluated in isolation. An example of a subsystem evaluation would be the use of a different type of extinguishing agent.

- **System.** A system performance evaluation might consist of a comparison to prescriptive requirements or an analysis based on specific performance requirements. A system performance evaluation is used when more than one fire protection system or feature is involved. It is more complex than a subsystem evaluation because the analysis may need to account for the interaction among subsystems. A typical systems analysis would be an alternative means of egress approach, such as one where the travel distance mandated by the prescriptive building code is exceeded. Such an analysis may involve elements such as human behavior, fire detection, passive fire protection, sprinkler systems, and smoke management. This level of design has become more frequent as tools in the fire protection engineering industry have developed.
- **Whole building.** In a building performance analysis, all the subsystems used in the protection strategy and their interactions are considered. A performance-based design that analyzes total building fire safety can provide more comprehensive solutions than subsystem or system performance analysis because the entire building-fire-target (where "targets" are the items being protected, such as people, property, etc.) interaction is evaluated.

Generally, at the subsystem and system levels, the engineer typically uses either a comparative analysis or a performance requirements analysis. As a design gets closer to whole building performance, the more it may be compared to specific performance requirements as the approach is typically different than that presented in the traditional prescriptive methods.

10.5 DETERMINISTIC AND PROBABILISTIC METHODS

10.5.1 Deterministic Methods

A deterministic approach typically addresses a single set of input data independent of the likelihood of occurrence. This approach is often termed a "hazard analysis," where specific fire scenarios are used to determine if the performance requirements are achieved. For example, trial designs may be assessed to evaluate whether occupants can evacuate with enough time before smoke and heat make it too difficult.

The challenge with this method is that the actual probability of a given scenario occurring and associated reliabilities of fire protection systems and elements are not addressed. Though probabilities of occurrence are not directly included in the analysis, some implicit probabilities are built into the analysis and assumptions. These may be based on the justification for the fire scenario(s) that may be developed from historical losses and other information. One may also be able to assess the criticality of whether these probabilities should be further determined or refined by conducting analyses, such as uncertainty analysis, to assess reliability of certain fire protection features.

The deterministic method is typically more common and less complex than a risk or probabilistic-based approach. Such analysis is typically used for subsystem and system analyses.

10.5.2 Risk or Probabilistic Method

A risk or probabilistic method takes both the hazard (i.e., fire scenario) and the likelihood of such a scenario occurring into account. This will likely result in a range of different scenarios with different probabilities of occurrence. Such an analysis can also review reliabilities of associated fire protection systems. A classical risk approach will look at possible outcomes. Another approach, which is somewhat simplified, is the risk binning approach. This approach instead sets bounding levels of damage/consequences and analyzes these levels with several different frequencies of events. Therefore, instead of looking at every possible outcome that could occur, the various outcomes are bounded at different probabilities of occurrence and levels of damage. This is the approach used in Chapter 3 of the *ICC Performance Code™ for Buildings and Facilities*.[3] This approach is used in other fields beyond fire, such as seismic design. NFPA 551, *Guide for Evaluation of Fire Risk Assessment Methods*,[28] provides additional information.A risk or probabilistic method is more thorough, but stakeholders should be aware of impacts on time, cost, and availability of data.

This type of analysis is more likely to be seen at the top end of a system analysis and for whole-building-oriented analysis.

10.6 METHODS FOR ADDRESSING LIMITATIONS/UNCERTAINTIES

When undertaking a performance-based design, limitations are often placed on the design. These limitations may result from design assumptions (building characteristics, fire characteristics, occupant characteristics, etc.), constraints of the model, reliability of systems, configurations of the building, space, etc. These different limitations include bounding conditions and uncertainty.

10.6.1 Bounding Conditions

Bounding conditions are used particularly in deterministic engineering designs, where the analysis is based on particular conditions such as a particular fuel load being present. Other conditions may include occupant load or floor plan layout. Such conditions have the potential to be exceeded when a change of use or occupancy occurs, if major renovations or additions are made to the existing use, or in some cases minor adjustments to the conditions within the existing building or facility. The effect of exceeding such limitations will vary based on how sensitive the design is to that particular condition. Some design features may have a very minor effect, while others may invalidate the entire design. A design may not be considered very robust if a minor change makes a significant difference in outcome.

The bounding conditions need to be identified in the documentation. This information is especially critical in the operations and maintenance manual to help determine if a new analysis is needed.

10.6.2 Uncertainty and Safety Factors

Uncertainty is the amount by which an observed or calculated value might differ from the true value. These differences stem from uncertainties found in the following areas[1]:

- **Knowledge in the science and engineering being used.** In all scientific areas there is a limitation on the amount of knowledge available with regard to the theories, models, and amount of data that can be used in the models.
- **Human behavior.** There are many unknowns with regard to the exact behavior of people during an emergency; for example, whether they take an active role in fire prevention or in creating hazards. Many qualitative studies of actual incidents available, in addition to correlations made related to movement speeds during evacuation, should be consulted when making assumptions about human behavior.[29]
- **Risk perceptions, attitudes, and values.** Though as many stakeholders as possible should be involved in the project, there may be a concern that all issues may or may not be addressed completely. It is difficult to capture all societal views when undertaking a project.

These uncertainties can be dealt with in various ways. The most common and simplest method is to apply safety factors. Safety factors can be defined as "adjustments made to compensate for uncertainty in the methods, calculations, and assumptions employed in the development of engineering designs."[1] In some cases, actual safety factors may not be necessary since the actual calculations and values used are conservative.

Various other methods may be used to address uncertainty such as a "sensitivity analysis." A sensitivity analysis will evaluate how changing a single parameter will affect the outcome of the trial design. Sensitivity analysis will demonstrate which particular elements are more critical. Understanding the more critical elements of the design helps make better decisions in terms of robustness of the design. Other methods include the following:[1]

- Classic uncertainty analysis.
- Analysis margin.
- Importance analysis.
- Switchover analysis.
- Parametric analysis.
- Comparative analysis.
- Expert elicitation (peer review).

The level of qualifications required will affect the availability of those able to undertake such analysis. Generally, the more complex and time consuming the analysis, the higher the qualification needs become.

11.0 MODELS

11.1 EXECUTIVE SUMMARY

Models are mathematical tools used to represent a real-life situation. Models can also be placed into a computer to simplify the calculation process. This is especially necessary when the equations get very complex and where multiple variables need to be solved simultaneously.

Models range from simple equations that can be solved with a calculator to complex programs that require powerful computers. For instance, the equation that provides the area of a circle, $A = \pi r^2$, is a simple model. All models have limitations, and the model must be used within its limitations, or appropriate conservatism must be used. Results should be checked for reasonableness.

11.2 FREQUENTLY ASKED QUESTIONS

Q. What is a model?

A. Fire safety engineering models are mathematical tools used to assess trial designs. Models can range from single equations that can be solved by hand or with a calculator to complex programs that require powerful computers (see Appendix A).

Q. Are public domain models better than proprietary models?

A. Public domain models are widely available and free of cost. Whether one model (public or proprietary) is better than another should be judged on the basis of how well it fits the needs of the analysis, how well it has been validated and peer reviewed, and how well it documents its limitations, and not whether it is public or private. It should also be noted that, as a result of the wide availability and freedom of use of public domain models, there is potentially more peer review of the model and its abilities (see Sections 11.3 and 11.4).

Q. When are models used?

A. Models are typically used during the evaluation of trial designs. The models yield results that can be compared to the performance requirements. Sometimes models are also used to develop design fire scenarios, which are then used in the evaluation of trial designs (see Sections 11.3 and 11.4).

Q. Are there instances when a model should not be used?

A. The complexity of a design or engineering study will often dictate the type of model used. Sometimes the limitation of the model will determine its usefulness. Generally, the complexity of a model, ranging from simple hand calculations to field models, will dictate the level of effort required to produce the results. A more rigorous analysis generally is more costly to conduct but does not necessarily provide better results. Finally, the selection of a model is also determined by its appropriateness for the study. For example, a model that addresses heat transfer from a fire to a structural element is not appropriate to analyze smoke movement throughout a building (see Section 11.3).

Q. Why is a model used?

A. One of the benefits of using models in fire safety engineering is repeatability. What this means is that the results of the fire model, given the exact same input, will be the same wherever and by whomever it is used. This is not to say that the models always give the right answer, but rather they give consistent answers. Also, the use of models can represent a significant cost saving as compared to undertaking full-scale fire testing or experimentation (see Appendix A).

Q. How do you choose a model?

A. Generally, a model is chosen based on the relationship of the output it provides and the information required by the performance requirements. For example, does the model provide estimates of the temperature of the smoke layer in a room adjacent to the room of fire origin? For this, one would need to select a fire effects model that tracks smoke temperature in multiple rooms (see Section 11.4).

Q. Who is qualified to use what types of models?

A. The model user should be able to demonstrate, based on education and experience, that he or she has the appropriate level of knowledge to use the model. For example, does the user have education and experience in fire dynamics that may help demonstrate, in part, the qualifications to use a fire effects model? Likewise, a model user should show equivalent levels of education and experience in areas such as human behavior when using egress models (see Section 11.3).

Q. How can I be sure that a model chosen is appropriate for the design or engineering study?

A. As a minimum, the model selected has to provide output of results that are useful to the analysis (i.e., upper layer temperature, smoke obscuration, egress time). Second, the model needs to be used within its stated limitations, or else using the model outside of its limitations should be justified in some manner. Often, these limitations are documented in the user's manual or other materials associated with the model. Availability, applicability, validation, and knowledge of the user in using the models are other factors that also should be considered (See sections 11.3 and 11.4).

Q. How important is the input data and where does it come from?

A. Input data is very important. Some models require more input data than others. The ability of an engineer to use a specific model may be limited by the availability of data. Sometimes assumptions are made due to the lack of specific data. These assumptions need to be clearly stated as part of the modeling analysis. Other times, fire tests or other research may be necessary to produce the needed model input (see Section 11.5).

Q. What assumptions are made and what is the basis?

A. It is often necessary to make assumptions in the use of models. Some of these assumptions might be inherent in the model itself, such as in a zone model where there is a base assumption that there is a distinct two-layer environment in a room with a fire—the hot upper layer and the cool ambient layer. The code offical might ask the model user to indicate what assumptions are inherent in the model being used. Another type of assumption is used when there is a lack of specific data as required input into a model. Examples include the heat capacity of a certain wall lining material within a room or the average speed of the population within a specific building. Often, when assumptions are made by the model user, the user may, lacking better data, choose a conservative number as an assumption. These types of assumptions should also be documented in the modeling submittal (see Sections 11.5 and 10.6).

Q. How do I know how accurate the result is?

A. The code official should be aware that it is difficult for a model to be 100 percent accurate. The accuracy of a model's results is based on the model's inherent limitations, the precision of the input data, and the sensitivity of the model to that data. What this means is that, for a given model, if it is used within its limits (i.e., to a single room of a certain maximum size), and the input data is based on specific materials' properties and heat release from an actual fire, then the model should provide accurate results (see Sections 11.3 and 11.6).

Q. How do I know how close the result will be to a real-life incident?

A. The comparison of a model's results to a real-life incident is called verification. Verification is often difficult, and costly, since this may mean testing multiple fire scenarios in a building with the exact configuration of the building that is being designed. In some cases, there may have been some research conducted in a prototypical building where data may have been collected for temperature profiles or time for sprinkler or smoke detector activation. These types of prototypical studies can yield useful data for comparison to a modeling analysis. One legitimate way of evaluating the model output is to apply a reasonableness check: if the data does not look right or appropriate, it probably is not (see Sections 11.3 and 11.6).

Q. Can I challenge the model chosen and/or the results? What questions should I ask?

A. The code official can ask for documentation of the model being used. The model documentation should provide information about how it was validated and provide stated limitations. If the model is being used outside the stated limitations or valid range, then the code official can require additional justification. Second, models may be sensitive to certain types of input. This can lead to some uncertainty about the results if a range of input has not been considered or documented. The code official can ask the model user how input sensitivity has been addressed. Finally, the code official can ask if the results have been verified with any research data or real-world fire experience. As noted above, verification can be very difficult to achieve. However, it is reasonable to question any results that are not consistent with your experience (see Sections 11.3 and 10.6 and Appendix A).

Q. Where can I go to learn more about models?

A. ASTM International (ASTM),[30,31,32,33] the Society of Fire Protection Engineers (SFPE),[16,34,35] and the National Institute of Standards and Technology web page (www.fire.nist.gov)

11.3 LIMITATIONS

11.3.1 Typical Limitations

Models typically have limitations. These limitations may be inherent in the governing assumptions of the model (i.e., a two-layer environment in a room), validations (i.e., the use of a furniture model for materials or configurations beyond the range of the furnishings that were originally tested), or alternatively the quality of the input data (i.e., garbage in, garbage out). The design team should be able to identify the limitations of the model used and whether the model was used within its limitations. If the model was not used within its limitations, the design team should be able to identify how the limitations were overcome.

11.3.2 User's Ability

Models may also be limited by one's ability to use them. These limitations might be in the form of inadequate computer processing, speed, or individual experience. Some of these limitations may be found in the user's guide for the model or in the original peer-reviewed papers supporting the model development. At other times, limitations may not be documented. Some specific limitations are discussed below.

11.3.3 Relevance of Design Fire

Most models that are used to study fire effects and dynamics typically require a heat release rate as input. The heat release rate is a numerical description of the fire size, typically in kilowatts or

BTUs per hour, as a function of time that describes the fire of interest or "design fire scenario" (see Chapter 8). The relevance of a fire effects and dynamics analysis is therefore dictated by the relevance of the design fire(s) selected for the study. Therefore, the selection of the design fire is critical. It should also be noted that some models do not account for the impact of such things as the cooling and downward entrainment effects of fire sprinklers, or the constraint on burning when the percentage of oxygen has been limited within a room fire.

11.3.4 Level of Complexity

The level of complexity of a fire model in ascending order from hand calculations to field models can place limitations on the user. Generally, the more complex the model, the more demanding it is on computing power and the experience of the model user. Therefore, these limitations may result in the selection of a less complex method or model. However, it is important to note that the complexity of a model and the level of detail studied do not necessarily result in a better answer (see Section 11.4).

11.3.5 Configuration of the Study's Space

Some models have limitations placed on the configuration of the space in which the fire study is conducted. These limitations may be based upon the governing assumptions of the model or the configurations of the rooms in which the fire research was conducted that led to the development of the model.

11.3.5.1 Room Scale

The scale of the room in which the study is conducted might be limited. The fire effects in a small bedroom can be quite different than the fire effects found in a high-bay warehouse. It is important to understand whether the model can be scaled up or down to address these differences.

11.3.5.2 Aspect Ratio

The aspect ratio of the room in which the modeling study is to be conducted may be bound by the limitations of the model. The conditions where there is a very high ceiling, or a very long but narrow space, may be beyond the bounds of certain models' capabilities.

11.3.5.3 Ceiling

Most fire models are developed or evaluated based upon experiments in a room with a horizontal ceiling. The study of a room with a sloped ceiling could exceed the limitations of the model.

11.3.5.4 Unusual Geometries

Some models may be based on assumptions of smooth ceilings or generally cubic spaces. The desire to model a room with deep beams, which create ceiling pockets, or spaces with unusual geometries must take into consideration the limitations of the model being used.

11.3.6 Demonstration of Model Acceptability

Any models used to evaluate a design should either be accepted by the relevant professional community, or the design team should be able to demonstrate that the model is acceptable.

The evaluation of a model is an assessment of the model's ability to give results that are consistent with the research upon which the model was developed. If the model was developed on first principles, it should be shown that it has been validated against a range of results from either fire tests or other validated models. The validation of a particular model is often found in the user's guide or in references to peer-reviewed papers.

However, it is not always possible to verify the results of a particular model. The verification of a model's results would occur at the end of an assessment. Ideally, the model's results would be verified against actual documented experience or tests that were conducted that are similar to the assessment undertaken. For instance, one could look at the observed time to reach flashover in a room identical to that modeled or the time to evacuate a building similar to that evaluated.

When a model has multiple input variables, another means of assessing the results of a model is to identify the sensitivity of model output to each of the input variables. For example, if a fire model evaluates the upper layer temperature based on the heat release of the fire and the loss of energy to the ceiling and walls, it is appropriate to vary the heat release rate and vary the thermal properties of the walls and ceiling materials. If the results vary substantially with a change in either of these input variables, then the model is sensitive to that particular type of input. The more sensitive a variable is to variations in data, the more important it becomes to use a good approximation of the true value of the input or select a worst-case value. This sensitivity and uncertainty should be considered as part of the use of a model in an engineering study or design.

11.4 FACTORS AFFECTING MODELS USED

The complexity of a design or engineering study will often dictate the type of model used. Sometimes the limitation of the model will determine its usefulness. For example, a single-room model might predict the actuation of a heat detector in the room of origin. However, a more complex multiroom model would be required to predict the activation of a heat detector in rooms outside the room of origin. Likewise, the level of detail required will often dictate the selection of a model. For example, the average upper layer temperature assumption of zone models may be appropriate for one study whereas in another study it is necessary to understand a much more detailed temperature profile within the room.

Using a model to evaluate a design will result in one of three outcomes: [36]

1. The calculation definitively shows that the attribute being evaluated is acceptable.
2. The calculation does not definitively show that the attribute being evaluated is either acceptable or unacceptable.
3. The calculation definitively shows that the attribute being evaluated is not acceptable.

In the case where a model clearly demonstrates that the attribute being evaluated is clearly acceptable or unacceptable, a simple model is typically sufficient. However, when the model does not clearly demonstrate either acceptability or unacceptability, a more powerful tool is needed to reduce uncertainty. How well the model represents the scenario under consideration determines the difference between clearly or not clearly demonstrating acceptability or unacceptability. Mowrer developed the following figure to illustrate this concept:[36]

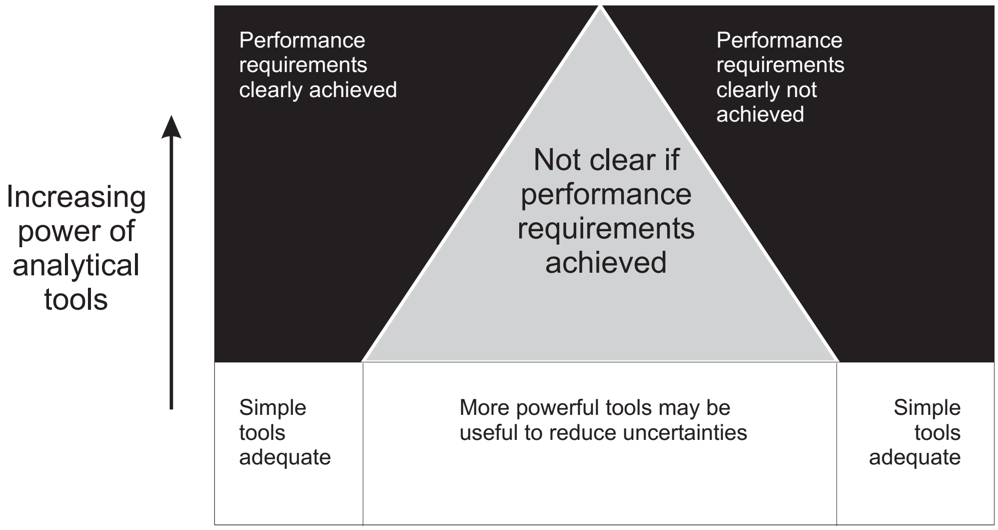

FIGURE 11.1. Required Model Complexity

The selection of a model is also determined by its appropriateness for the study (i.e., a model that addresses heat transfer is not appropriate to analyze smoke movement). One reference available to the model user is ASTM E 1895.[30] Included in this standard guide is a list of questions that a user may ask of a model to determine its appropriateness for a specific application.

11.5 INPUT DATA

Some models require more input data than others. The ability of an engineer to use a specific model may be limited by the availability of data. Types of data include heat release rates for specific materials or fuel packages, material properties for the bounding surfaces (walls, floors, ceilings), toxic gas production rates, and occupant movement rates.

Assumptions are often made due to the lack of specific data. These assumptions may be the result of interpretation or extrapolation of known data or may be a conservative estimate. It is important when documenting the use of the particular model to include a listing of all assumptions.

When reviewing modeling submissions, the input data should be reviewed in addition to the model. The design team should be able to demonstrate why the input data is representative of the scenario being modeled and how much confidence to place in the input data. If the input data is only loosely applicable to the scenario being modeled, or has low confidence, the design team should be able to demonstrate how this was overcome.

11.6 MODEL OUTPUT

The output for models can take many forms, ranging from a single numerical answer to a three-dimensional color video. The visual quality of output from a model does not necessarily translate to the technical quality of the output.

One way that model output should be checked is to apply a reasonableness check: if the data does not look right, it probably isn't.

12.0 DOCUMENTATION

12.1 EXECUTIVE SUMMARY

Each performance-based design is unique. The use, occupancy, protection features, and limitations will vary from project to project. Therefore, the documentation needs for performance-based design are greater than for prescriptive designs. This chapter discusses the types of documentation that should be provided for a performance-based design, including documentation of the design analysis, the final selected design, and requirements for maintaining the performance-based design for the life of the building/occupancy.

12.2 FREQUENTLY ASKED QUESTIONS

Q. Who is responsible for preparing the documentation associated with a performance-based design?

A. The owner is ultimately responsible for ensuring that all required documentation is prepared and submitted. However, these responsibilities are often delegated to members of the design team, such as the design professional (see Section 12.5).

Q. What forms of documentation are essential to the success of a performance-based design?

A. A performance-based design will use various forms of documentation, including the statement of design team qualifications and capabilities, concept report, design report, specifications and drawings, deed restrictions, and operations and maintenance manuals. The extent of documentation, and the relative importance of each type of documentation, will vary depending on the scope and complexity of the particular project (see Section 12.6).

Q. What information should each type of documentation include?

A. Section 12.6 lists the generic contents of the various types of performance-based design documentation. Not all of this information will be necessary for every project. The information and level of detail required will vary depending on the specific document and the scope of the project (see Section 12.6).

Q. Why is documentation critical to the success of a performance-based design?

A. Documentation provides the road map for the project, memorializes decisions and agreements that have been made, and provides a historical record of the actual design basis of the project, including the actual construction and how to address future changes. Since performance-based design projects may vary from the requirements of the available prescriptive codes, the performance-based design documentation essentially constitutes the building and fire code for the specific project (see Section 12.3).

Q. What forms of documentation should be submitted at each stage of a performance-based design project?

A. The performance-based design documentation process is a progression that continues through the entire design process. Certain documents should be submitted at key milestones during the process in order to allow for review, concurrence, acceptance, etc. Section 12.6 provides general guidance for when each piece of documentation would typically be submitted. However, the actual timing will vary depending on the scope and complexity of the project (see Section 12.6).

12.3 IMPORTANCE OF DOCUMENTATION

One of the benefits of performance-based design is that it considers the specific use and characteristics of each building rather than determining the required level of protection based on a broad, generic occupancy classification. This feature complicates the process of evaluating a performance-based design and ensuring compliance with the performance-based design over the life of the building. Since a performance-based design considers specific features and characteristics of the building, it may provide less margin for changes in the use of the building. Therefore, it is critical to adequately document what the conditions of use are, what changes are acceptable, and what must be done to compensate for changes in the future.

12.4 DOCUMENTATION OVERVIEW

12.4.1 Types of Documentation

Several key pieces of documentation have been identified to assist in the performance-based design, maintenance, and enforcement process:

- Concept report (fire protection engineering design brief).
- Design report (performance-based design report).
- Specifications and drawings.
- Deed restrictions.
- Special inspection requirements and reports.
- Verifications/certifications of compliance.
- Operations and maintenance manuals.

12.4.2 Documentation for Different Project Phases

It should be noted that not all forms of documentation will be used on all performance-based design projects. The specific forms of documentation submitted and the contents of the various forms of documentation will vary depending on the scope and complexity of the project and any specific requirements of the applicable building regulations. The matrix in Table 12.1 provides a generic guide for when each type of documentation should be submitted, if required for a particular project.

12.5 RESPONSIBILITY FOR PROVIDING DOCUMENTATION

The responsibility for preparing complete documentation for a performance-based design rests solely with the owner of the proposed project. The documentation will likely be prepared by members of the design team, such as the fire protection engineer, on behalf of the owner. The owner should fully understand the importance of complete, accurate documentation and the potential impact on the overall project if proper documentation is not completed at appropriate milestones during the project.

TABLE 12.1. Documentation for Different Project Phases

	PROJECT PHASE				
DOCUMENT	Preliminary/ Initiation	Post-Agreement/ Preanalysis	Plan Review/ Permitting	Acceptance Testing	Certificate of Occupancy
Statement of Qualifications	X				
Scope Statement	X				
Concept Report		X			
Design Report			X		
Specifications & Drawings			X		
Operations & Maintenance Manual				X	
Verification of Compliance					X
As-Built Drawings					X

12.6 FORMS OF DOCUMENTATION

12.6.1 Statement of Design Team Qualifications and Capabilities

A qualified design team is critical to the success of a performance-based design project. As such, it is critical to ensure that the design team possesses appropriate education, training, and experience, as well as appropriate professional certifications and licenses, to design the project. Some form of screening of the design team normally occurs during the owner's selection process. However, it is possible that the owner does not understand the unique requirements necessary to complete a performance-based design project or the design team may embellish its credentials to the owner in order to win a contract. Therefore, it is critical that the code official carefully review the qualifications and capabilities of the design team.

To facilitate this review, the design team should submit a statement of design team qualifications and capabilities to the code official at the outset of the project. The code official should have the opportunity to review and, if necessary, challenge the qualifications of the design team before significant resources are expended on the project (see Chapter 5).

The Statement of design team qualifications and capabilities should include the following key information:

- Resumes of key design team members that clearly document:
  - Education.
  - Experience.
  - Professional certifications and/or licenses.
- Description of the design team's experience working on performance-based design projects.
- References from past projects:
  - Owners.
  - Code officials.

12.6.2 Concept Report (Fire Protection Engineering Design Brief)

The purpose of the concept report is to document the scope of the performance-based design project, the members of the design team, and key decisions and agreements that have been reached as a result of negotiations during the preliminary design phase. These key decisions include the intended use of the building, the types of scenarios to be analyzed, and the performance objectives and functional statements that must be achieved in order for the performance-based design to be considered acceptable.

The concept report may be revised several times during the design of a project to account for changes in project scope, the intended use of the building, etc. As previously noted, the primary purpose of the report is to document the key decisions regarding the project.

The concept report should be completed, submitted, and approved before the design team begins detailed analysis and design of the project. This is essential since the concept report establishes and documents the parameters of the detailed analysis and design. The concept report is the instrument by which the design team obtains the code official's concurrence on the project parameters and design approach.

The concept report may be considered as a collection of interrelated, yet independent, modules. Depending on the scope, complexity, and duration of the project, the entire report may be submitted at one time, or individual components may be submitted for review as the project progresses. For example, the statement of qualifications may be formally submitted at the outset of the project, before any discussions are held regarding objectives and functional statements. When components of the report are submitted individually during project development, a final concept report that compiles all the individual modules into a single, comprehensive document should be produced for record purposes.

Figure 12.1 identifies the key information that should be included in the concept report.

12.6.3 Design Report (Performance-Based Design Report)

Completion and approval of the concept report provides the design team with the target for advancing the performance-based design. At this stage, the design team can perform the appropriate analysis to determine the combination of features and systems that will provide the agreed-upon level of performance. The design report serves to document the results of these analysis efforts.

The design report proves the acceptability of, or validates, the selected design. The design report describes the final design, documents the engineering analysis used to determine the final design, and identifies the bounding conditions for the analysis.

Contents

1. Definition of Project Scope
    a. Identification of which portions of the project are performance-based and which portions are based on prescriptive codes
2. Identification of the Project Participants
    a. Owner
    b. Tenant(s)
    c. Architect
    d. Engineer(s)
    e. Code official
    f. Insurance carriers
    g. Contractors
    h. Peer/contract reviewers, if used
    i. Others
3. Documentation of Design Team Qualifications and Capabilities
    a. Professional licenses
    b. Resumes
    c. References
4. Description of the Building and Occupant Characteristics
5. Identification of Applicable Codes and Standards
6. Objectives
7. Functional Statements
8. Performance Requirements
9. Selected Event Scenarios
10. Trial Designs
11. Level and Method of Evaluation
12. Record of Agreement for Key Project Issues
13. Proposed and Existing Deed Restrictions, If Applicable

FIGURE 12.1. Contents of Concept Report

Since the design report details the engineering analysis and any discrepancies could impact the final design, it should be completed, submitted, and approved by the code official before the design team proceeds with the development of detailed design drawings and specifications. The outline in Figure 12.2 identifies the contents of the design report.

12.6.4 Specifications and Drawings

Specifications and drawings are the tools used by the design team to convey the details of the final design to the trade professionals who will actually construct the building. Specifications and drawings for a performance-based design project will generally need to contain more detail than those for a project being designed and constructed to comply with prescriptive-based codes. Under a prescriptive code, the trade professionals can often refer to the actual code to obtain clarifications of the design intent and specific methods of construction. Since the configuration and construction methods for a performance-based design project may be unique to the particular project, the specifications and drawings must convey sufficient detail to the trade professionals to enable them to properly construct the building. In addition, the specifications and drawings must convey sufficient information for the code official and other parties to determine compliance with the design parameters.

Contents

1. All Material Contained in the Design Brief
2. Description of Final Design
3. Engineering Evaluation
   a. Evaluation method(s)
   b. Design tool(s) used
   c. Analysis results
      i. Calculations
      ii. Computer model input and output
      iii. Test reports
   d. Safety factors/uncertainty/sensitivity analysis
   e. Identification of any design assumptions that are not explicitly addressed by the analysis
4. Bounding Conditions
   a. Critical design assumptions
   b. Critical design features
5. Proposed and Existing Deed Restrictions
6. References, Including Data Sources

FIGURE 12.2. Contents of Design Report

The specifications and drawings must include specific requirements for building components and systems and any special installation methods that must be followed in order to comply with the performance-based design. For example, rather than issuing drawings and specifications that require smoke detectors to be spaced so that the maximum coverage per detector does not exceed 900 square feet, the specifications and drawings for a performance-based design may show specific critical installation locations for detectors, such as at the intersection of airstreams.

A performance-based design analysis may be based on specific material properties of building components, such as the flame spread rating of interior finish materials. The specifications must detail what these critical material properties are so that the installed materials are within the bounds of the performance-based design. In some cases, it may be necessary to specify acceptable manufacturers and models to ensure that the performance requirements are achieved.

The specifications for a performance-based design must also define specific procedures, measurement techniques, and required results for acceptance testing and commissioning of building systems. This information includes the minimum qualifications for individuals who will perform the commissioning activities, required measurements and documentation, type of measuring equipment to use, calibration requirements for measuring equipment, etc. For example, a smoke management system may have to produce a specified pressure differential between a fire compartment and those adjacent to it, as well as a specified minimum airflow velocity within the fire compartment. The specifications must detail where pressure and airflow measurements will be taken, what instrumentation will be used, and other criteria necessary to demonstrate how compliance with the requirements will be demonstrated. The specifications should also indicate acceptable tolerances, if any, for each performance metric.

12.6.5 Special Inspection Requirements and Reports

Special inspections may be required on a performance-based design project for a variety of reasons, including the amount of time required to achieve the desired level of oversight, the complexity of the system, etc. The specifications and drawings should identify the building components and systems that require special inspections and should detail the minimum qualifications for the special inspectors; the scope, frequency, and extent of inspections; inspection and measurement methods; and reporting requirements. These requirements should also be contained in the contract documents used to retain the services of the special inspectors.

Reports documenting the results of special inspections should be submitted to the code official for review and acceptance. The special inspection reports should identify the individual and company performing the special inspection; the date(s) and time(s) that the inspections were conducted; detailed observations, measurements, and test results; and a statement indicating the acceptability of the inspection results.

12.6.6 Deed Restrictions

Deed restrictions may be used to establish legally binding documentation of the conditions of a performance-based design. This method of documentation also ensures that potential future owners are aware of the conditions of use imposed on the property by the performance-based design. Deed restrictions should identify those features of the performance-based design that have bounding conditions that must be maintained over the life of the building. Deed restrictions may be accomplished using a generic statement, such as "building was designed using performance-based design; see Operations & Maintenance Manual for restrictions on operations, use, and alterations," or by identifying specific conditions, such as a 50-foot-wide no-build zone along the property line that must be maintained. The actual language and extent of deed restrictions will vary depending on the scope and complexity of the project and the specific requirements of the individual jurisdiction. Legal counsel should be consulted when developing deed restrictions.

12.6.7 Verification of Compliance

At the completion of construction, the code official may require the submission of a verification of compliance statement by the design professional. The decision to require a verification of compliance statement will be based on the scope and complexity of the project, the extent of field changes, etc. The owner should be made aware of the requirement for a verification of compliance statement as early in the process as possible to ensure the involvement of the design professional throughout the construction process.

The verification of compliance statement certifies that all performance and prescriptive code provisions have been met. This certification should be based on review of special inspection reports, commissioning reports, and first-hand observations made during the construction process.

In completing the verification of compliance, the design professional should consider all field changes that have occurred during the construction process. As a minimum, the design professional should ensure that all field changes have been properly identified, evaluated by the design team, approved by the code official, and completely incorporated into the project documentation.

Requiring that the verification of compliance be completed by the original design professional serves two purposes:

1. It ensures the continued involvement of the design professional during the construction process.

2. It eliminates the learning curve that will have to be overcome if an individual who is unfamiliar with the project is brought on board for the sole purpose of verifying compliance with the design intent.

It should be noted that the verification of compliance is not intended to take the place of special inspections, third-party reviews and inspections, or inspections by the code official or the code official's designees.

12.6.8 Operations and Maintenance Manuals

Operations and maintenance manuals (O & M manuals) provide the documentation necessary for the day-to-day and long-term operation of a performance-based-designed building. O&M manuals provide details of inspection and testing requirements for specific components and systems. They also provide guidance for implementing compensatory measures when critical protection systems are impaired, managing the combustible loading within the building, and managing alterations and other changes within the building. Detailed information regarding O&M manuals is provided in Chapter 15.

12.6.9 Certificate of Occupancy

The certificate of occupancy is a familiar document in the prescriptive code arena. Issuing a certificate of occupancy signifies that construction is complete, that all of the applicable code and regulatory requirements have been satisfied, and the owner can begin to use the facility. The concept and function of a certificate of occupancy are no different in the performance-based design arena. However, it may be helpful to identify additional information on the certification of occupancy for a performance-based design project.

As a minimum, a certificate of occupancy for a performance-based design project should note that performance-based design was used and refer to the operations and maintenance manuals for additional information.

For projects where performance-based design was applied to a small portion of the project or the performance approach was relatively simple, it may be desirable to specify the actual performance requirements and the area of application on the certificate of occupancy.

12.7 SUBMITTAL REQUIREMENTS

The following types of documentation should be submitted to the code official at the building permit and certificate of occupancy stages of the performance-based design process. It should be noted that not all forms of documentation will be necessary for every performance-based design project. Some performance-based design projects may warrant forms of documentation that have not been specifically identified in this guide.

12.7.1 Building Permit

The following forms of documentation should be submitted and approved/accepted by the code official prior to issuing a building permit:

- Concept report (fire protection engineering design brief).
- Design report (performance-based design report).
- Specifications and drawings.
- Proposed and existing deed restrictions.
- Identification of areas requiring special inspections and testing.
- Product data and test reports.

12.7.2 Certification of Occupancy

The following forms of documentation should be submitted and approved/accepted by the code official prior to issuing a certificate of occupancy:

- Operations and maintenance manuals.
- Special inspections and testing reports.
- Verification of compliance.

13.0 COMMISSIONING AND ACCEPTANCE TESTING

13.1 EXECUTIVE SUMMARY

This chapter describes the process for commissioning and acceptance testing of fire protection systems used in performance-based design and the evaluation of the acceptance testing for compliance with the design. Also addressed is the evaluation of materials used in a performance-based design.

The objectives of performance-based design system commissioning and acceptance testing are similar to those for prescriptive-based codes. These objectives include providing the code official and other stakeholders with a tool to verify that the engineering and design principles used to design a system coincide with the installation and construction practices for that system. The code official must have a method of accepting a system after installation without necessarily having the luxury of using acceptance criteria in a prescriptive code as the reference.

The overall purpose of commissioning and acceptance testing is the audit and verification of the systems installation in accordance with the pass/fail criteria established in the design. This chapter explains in more detail the methodology for reconciling the testing data and reporting with the performance-based design and for system commissioning. Commissioning and acceptance testing are different from long-term maintenance in that commissioning and acceptance testing only examine initial acceptance of the system.

Acceptance testing is important to factor into the initial analysis as it may have an effect on the choices made for the overall design. This is important since the testing and commissioning procedures required may have an effect on the practicality and costs of the selected designs. The acceptance process will require a consensus from the design team, property owners/managers, and the code official as to how the system can be accepted so that the system will provide the level of protection and life safety anticipated in the design. The documentation identified in Chapter 12 provides the details on the desired capabilities and intended function.

13.2 FREQUENTLY ASKED QUESTIONS

Q. Who is responsible for performing the acceptance testing?

A. The responsibilities for testing are the same as they would otherwise be in any project. Performance of acceptance testing would be done by the contractor who installed the equipment (see Section 13.3).

Q. Who is responsible for overseeing the acceptance testing?

A. Testing oversight would be performed by the responsible registered design professional (see Section 13.3).

Q. Who is responsible for final approval of the installation?

A. As with current practice in the prescriptive codes and recognized standards, the code official retains responsibility for final approval (see Section 13.4).

Q. Who is responsible for paying for the acceptance testing?

A. The building owner would be responsible for paying for the acceptance testing.

Q. *Who is responsible for developing the acceptance testing?*

A. In most cases, the acceptance testing would be the same as described in the applicable design and installation standard, such as NFPA 13, *Standard for the Installation of Sprinkler Systems*.[37] In the case of hybrid test protocols, the registered design professional responsible for the particular aspect of the design, along with the registered design professional who has responsibility for the project, would work together to develop the testing. In some cases, this test development could also require a peer review. Finally, the test protocol would need to be reviewed and approved by the code official (see Section 13.3).

Q. *What happens if the acceptance testing results do not meet minimum requirements?*

A. Whether the acceptance testing is being witnessed directly by the code official or the code official's designee, by a third-party quality assurance agency or a contractor, a protocol should be established during the design stage to report system acceptance results promptly and in sufficient detail to all parties. A failure to address either a deficiency or aspect of a system outside accepted tolerances can result in significant future stress and hardship if not managed at the time of discovery. Potential fixes can include system repair or alteration, design change, or even a reevaluation of the system or subsystem to determine what effect the failure to meet the minimum requirements has on the overall design (see Section 13.3).

Q. *Are acceptance tests in current standards and prescriptive-based codes acceptable?*

A. Current recognized standards and prescriptive codes often contain acceptance criteria based on a given set of expected performance. The application of fire protection and other systems in a performance-based design may anticipate the systems to perform in the same manner and may well be subject to the same acceptance testing found in current codes and standards. For reasons of reliability, enhanced performance expectations, or to reduce reliance on other redundancies, designers and code officials may specify more rigorous standards for acceptance. The most critical point is that these issues must be established during the design development phase and included in the design documents, and not determined in the field (see Section 13.3).

Q. *Why would a design team specify more rigorous pass/fail or tolerance criteria than nationally recognized codes or standards require?*

A. In some cases, more restrictive criteria would not be applicable. However, in cases where a feature of performance-based design is compensating for another feature, more stringent criteria may be applied. For example, sprinkler activation requirements may limit sprinkler spacing to less than allowed by nationally recognized criteria (see Section 13.3).

Q. *Should acceptance testing always be witnessed by the code official?*

A. Depending on the scope and complexity of the system's acceptance involved in a design, the code official needs to exercise judgment concerning which critical tests, portions of the acceptance, and how many tests must be conducted with a designated representative present. The code official, design team, and owner should agree and designate early on the respective roles of public versus third-party or contractor validation (see Section 13.4).

Q. *Should the code official keep detailed records of the testing and test results?*

A. As mentioned earlier, some systems may be required to meet different or more restrictive pass/fail criteria than outlined in national standards. Likewise, there may be reduced tolerances for acceptance at critical points within the overall acceptance process. Even though the code official can expect to receive a final report from the design professional validating the systems are in accordance with the design intent, thorough and detailed record keeping are essential to a public entity acceptance. Similarly, future maintenance and periodic testing may require reference to original pass/fail criteria (see Section 13.3).

Q. Do systems other than fire protection need to be tested to qualify a performance-based design?

A. Conceivably, other systems might need to be tested. For instance, a performance-based design might rely upon evacuation in part using elevators that would be required to move to certain floors of the building. Proper operation of the elevator equipment in response to a signaling system linked to the fire detection equipment would need to be tested (see Section 13.3).

Q: Do all performance-based designs require acceptance testing?

A. In the same manner that most prescriptive-based fire safety systems in buildings require acceptance, so would performance-based design approaches. The acceptance test may be the same as for a typical fire safety system (e.g., test in accordance with NFPA 72, *National Fire Alarm Code*[15]) or unique to a performance-based design. A unique approach may be limiting sprinkler spacing to less than 10 feet or requiring a greater water supply from a sprinkler system (see Section 13.3).

Q. How are specific products and materials selected in a performance-based design?

A. In many cases, products and materials that would be acceptable in a prescriptive-based design would be acceptable in a performance-based design. However, in some cases where innovative products or materials are used, or where products or materials are used in an innovative manner, special consideration is needed to ensure that the objectives and functional statements of the design are met (see Section 13.5).

13.3 PROCESS OF COMMISSIONING AND ACCEPTANCE TESTING

13.3.1 General

An important part of a design analysis is establishing the acceptance criteria for testing and acceptance of the project's systems and features. A wide range of issues should undergo careful consideration in balancing project needs and costs with adequate verification. Some questions to consider include the following:

- Which tests will demonstrate compliance with the design parameters?
- Are additional or enhanced testing and verification procedures needed for this particular project?
- Who will undertake the testing?
- Who will provide verification?
- Will the required testing and verification fit within the schedule and budget for the project?

Discussing and reaching consensus in an early phase of the project will minimize confusion and frustration during the construction and acceptance phases.

The approach for commissioning and acceptance testing potentially has several elements:

- Establish the desired capability and intended function of the particular system.
- Determine the methodology that best tests these capabilities.
- Establish pass/fail criteria.
- Perform commissioning and acceptance tests.
- Adjust the system or revisit the methodology, or pass/fail criteria, if necessary.
- Reperform commissioning and acceptance tests, if necessary.
- Document test results.

Many systems used in performance-based design will be conventional systems and not require unique or specialized commissioning and acceptance testing. For many types or components of a life safety and fire protection system, acceptance will be similar or the same as the acceptance of a system installed using prescriptive codes. For example, fire alarm, detection, and releasing systems can be physically inspected utilizing NFPA 72[15] as a reference. Likewise, fire sprinkler systems and the associated components may be tested/accepted in accordance with NFPA 13.[37] System acceptance should include verifying that the placement and spacing of detectors/sprinklers and other required system components are provided in accordance with the design documents and applicable codes.

While the fire codes and standards can be used as a baseline, some systems will require specific unique or specialized commissioning and acceptance testing issues to be examined. For example, if specific automatic sprinklers (e.g., temperature rating or RTI) are required, the commissioning and acceptance testing should examine these specific features. In these cases, it is the responsibility of the design engineer to provide rationale to the code official regarding specific variations from the applicable codes. The purpose is not to discourage specialized criteria that differ from the prescriptive codes, but to ensure a comprehensive testing and commissioning program that incorporates the appropriate prescriptive and performance-based requirements.

Communication among stakeholders should be established from the beginning regarding the commissioning and acceptance testing. If the code official has specific issues he or she would like to see addressed or sample testing criteria used in the past, the code official should identify these prior to the initial development of the testing methodology and pass/fail criteria by the engineer.

The design engineer should present information to the code official proposing how desired functions, testing methodology, and pass/fail criteria will be addressed. The code official should review this information and provide input into the determination of the final testing process. Both the code official and engineer should be present to witness the final commissioning and acceptance testing of the systems, or alternative arrangements agreed to in advance by all stakeholders.

13.3.2 Establish the Desired Capability and Intended Function of the Particular System

The desired capability and intended function of the system should be established through the performance-based design process. Performance-based systems can include any type of system—fire suppression, fire detection and alarm, smoke control, egress, or construction features. The documentation discussed in Chapter 12, including the performance-based design report and drawings and specifications, should specifically identify the pertinent features and intended function. The design engineer should detail what specific features are important to the system. This includes features related to installation and quality control. As a result, these features can be evaluated to ensure the construction of a fire-safe structure.

The performance-based design report must correlate the intended function of specialized performance-based systems into engineering terms that can be incorporated into the design and evaluated during the commissioning and acceptance testing. For example, a detection system may be designed to activate a fire suppression system prior to a fire exceeding 50 kW in size. However, this function is difficult to test once installed. The engineer must correlate the system characteristics, such as detector RTI or suppression agent discharge time, needed to achieve the intended function.

Examples of capabilities of systems or features required could include the following:

- **Automatic sprinkler:** spacing, RTI, temperature rating, and design flow rates.
- **Detection:** spacing, sensitivity, and type.
- **Construction:** fire-resistance rating and specific construction details.
- **Fuel load:** peak heat release rates, spacing of fuel packages, total heat release rate, and type of fuel.
- **Smoke control:** flow rates, zones, and responses to alarms.

Issues related to reliability, maintenance, or capabilities must also be clearly identifiable. Therefore, it is important for the designer to provide a clear reference for those capabilities or functions back to the design assumptions, limitations, or results. Even though all these features may not be verified through commissioning and acceptance testing, they may well be a factor throughout the life of the facility, so their impact should be examined and recorded.

13.3.3 Determine the Methodology That Best Tests These Capabilities

Each performance-based design will require the development of a test protocol that effectively demonstrates the system's capability. The engineer responsible for the design should develop test procedures that meet or exceed the objectives of the stakeholders. The applicable prescriptive codes should serve as the baseline for the test protocol with rationale submitted for variations from the codes. If the system is unique to the point where the prescriptive codes provide little useful guidance on commissioning and acceptance testing, the engineer must develop a comprehensive test protocol for review and approval by the code official.

The methodology used for commissioning and acceptance testing can vary. All commissioning methods would potentially include comparing the design documents to the actual installation. However, the testing of the systems will vary. Each testing approach may be appropriate or inappropriate, depending on the desired system features. Many construction, detection, or suppression features may be examined with simply a site inspection, whereas a functional test may be more appropriate for a smoke control system. The engineer must provide the appropriate rationale to support the proposed program.

Several resources may assist in specifying the appropriate approach, depending on the system type. For example, the *International Building Code*[12] provides guidance on smoke control system and hood system suppression testing. Technical references such as *Design of Smoke Management Systems*[23] provide additional guidance. National Fire Protection Association standards specify criteria for testing water-based and gaseous suppression systems, fire detection and alarm, fire pumps, and smoke control systems. Manufacturers' data sheets, Underwriters Laboratories directories, and Factory Mutual approval guides provide insight for the review of system features or construction assemblies.

The engineer of the system should develop the appropriate method and references, if any, on which the proposal for commissioning and acceptance testing is based. The test method should indicate the critical path sequence for testing and installation to ensure all who participate are aware of the required actions and approximate timeframes. For example, testing of ducts in a smoke control system will most likely occur prior to testing of system operation.

The role of each party should be identified. The engineer, code official, owner, contractor, and others will all have a role in commissioning and acceptance testing. Each person should be aware of his or her and others' roles for the project to be successful.

The use of a special inspector should be established at the beginning. This third-party inspector can provide quality assurance for the code official if there is insufficient manpower or capabilities to address specific issues. However, the presence of a special inspector could affect the methodology and timeframe of the commissioning and acceptance testing process.

13.3.4 Establish Pass/Fail Criteria

The pass/fail criteria related to acceptance testing depend on the system and its desired features. Pass/fail criteria will be affected by the methodology used to test the system and performance-based design limitations, assumptions, and desired results.

Pass/fail criteria should be in easily understandable units and can include a pressure differential or fan flow rate (smoke control), or temperature rating or RTI (automatic sprinklers). It is preferential to establish definitive criteria (e.g., flow rates or RTI) as opposed to subjective criteria (e.g., visibility or smoke locations). However, developing definitive criteria may not be possible. In addition, tolerances should be established for the limits of the criteria.

The engineer should propose the pass/fail criteria to the code official along with any rationale for criteria varying from the prescriptive codes. The adequacy of the overall commissioning and testing program must also be demonstrated.

13.3.5 Perform Commissioning and Acceptance Tests

The commissioning and acceptance testing should be performed based on the methodology established. If complicated, a matrix or test checklist can be developed to allow the stakeholders to review and track the system testing. The smoke control section of the *International Building Code*[12] and NFPA 92B, *Guide for Smoke Management Systems in Malls, Atria, and Large Areas*,[26] provide examples of testing methodologies.

The results of the test should be documented in detail. Prior to the code official attending the final commissioning and acceptance test, the contractor or owner should provide details of testing to be performed that demonstrate the site is prepared for the code official's participation.

13.3.6 Adjust System or Revisit Methodology, or Pass/Fail Criteria, If Necessary

The systems may or may not pass the initial commissioning and acceptance testing. In cases where they do not, a system may need to be adjusted, rebuilt, or have parts reinstalled correctly.

It is possible that in some circumstances when the system fails, the methodology or pass/fail criteria can be revised. During the initial development of pass/fail criteria, the designer or code official may propose a testing approach or criteria that in retrospect are overly restrictive or inappropriate (e.g., cold smoke in atriums). Therefore, it may be proposed to the code official that different criteria be applied to the commissioning and acceptance testing. Alternative pass/fail criteria can be accepted by the code official only if accompanied by an acceptable rationale for choosing the revised criteria. It should be remembered that changing the pass/fail criteria is tantamount to changing the construction documents and requires the full review of the design professional in responsible charge, as well as the code official and the engineer responsible for the testing.

13.3.7 Reperform Commissioning and Acceptance Tests

Once the system or criterion has been adjusted, commissioning and acceptance testing should be reperformed as necessary. Once again, documentation of pretesting should be provided to the code official.

13.3.8 Document Test Results

The records of the test should be maintained. Final documentation should include acknowledgment of all acceptance testing by the design engineer, contract or peer reviewer, special inspector, or other stakeholders in the design to confirm the system's installation is in accordance with the design documents. The specific pass/fail criteria and rationale must also be documented.

13.4 EVALUATION OF ACCEPTANCE TESTING/SYSTEM COMMISSIONING RESULTS

13.4.1 General

This section explains in detail the methodology for reconciling the acceptance testing and system commissioning of fire protection elements of the project with the performance-based design. The project documentation (see Chapter 12) provides details regarding the desired capabilities and intended functions of building systems and components.

Once consensus has been reached concerning the specific acceptance testing and commissioning required for various facets of a performance-based design, a protocol must be developed to verify each component or system test, including any design requirements incorporating unique acceptance thresholds or pass/fail criteria. These tests may be performed by any combination of installation contractors, manufacturers' representatives, or private, special inspectors (third-party test agencies), with or without the code official or design professional present. The evaluation process, therefore, becomes critical in terms of verification of the design objectives. An installation contractor conducting standard acceptance testing under NFPA 13 for a dry-pipe sprinkler system may not be aware of and fail to document any special pass/fail criteria from the design, such as reduced water delivery times, or fail to document proper use of faster response, low-RTI sprinklers.

The design professional must also be presented with sufficiently clear and complete acceptance test and commissioning data to confirm to the code official that all such systems and components have been installed and are operational within the tolerances the design professional established.

13.4.2 Process for Evaluation of Acceptance Testing

The approved performance-based design must be clear in its documentation concerning not only the nature and types of fire protection systems and components to be provided, but also the nature and extent of acceptance testing. The acceptance criteria should clearly indicate those systems and components that will achieve the design objective via conventional (standard) acceptance testing, those with modifications or enhancements to conventional (standard) acceptance testing, and those with unique in-situ test criteria.

The code official can expect to receive such test reports at various points during the course of construction. While there is no irreparable harm in this approach, the official should be aware that, unlike prescriptive code acceptance, the design professional in a performance-based design must first evaluate the test data for compliance with the design prior to presenting such acceptance documentation to the code official in terms of final acceptance.

Code officials can be helpful in reviewing such acceptance test data on an interim basis to ensure the public entity's understanding of ongoing test data is met. The final submission from the design professional can occur weeks or months later, long after the test agency has completed its work, complicating any retesting or supplemental test work. The code official may also establish distinct levels of test and verification data required based on whether or not the public entity is being represented during the test, either by a code official or an approved third-party agency.

13.4.3 Audit/Verification Process for All Special Inspectors/Third-Party Agencies

During the design phase, local enforcing agencies will establish the specific protocols for acceptance testing, including identifying at which tests and inspections agency staff are required to be present, which can be witnessed by the design professional, those not requiring supervision, and those involving a private, special inspector or third-party testing agency. Such private agencies have existed for many years for inspections of structural building systems and components, as well as fire protection systems.

While certain jurisdictions have lists of preapproved third-party agencies in various fields, the complexity of a performance-based design might require an additional layer of audit/verification that an agency is qualified to witness and/or perform required acceptance tests and inspections. The code official should exercise care in reviewing the qualifications of a special inspector or a third-party agency and in determining that its staff for a project or part of a project is acceptable.

Since the special inspector or third-party agency is performing as a surrogate for the local enforcing agency, suitable controls must be in place to establish credibility of the acceptance testing, reporting of deficiencies, and acceptable test/inspection documentation to facilitate final system commissioning. Where test agencies are used, internal project rules must be established governing when such tests and inspections will be performed, who will authorize them, time frames for frequency and timeliness of agency submissions, reporting of deficiencies, and form of reports, including medium and distribution.

Code officials are encouraged to perform one or more unannounced audit visits during the test/inspection phase involving a third-party agency. The purpose of the unannounced visit is to ensure that the third party's work is being adequately performed.

13.5 EVALUATION OF MATERIALS AND METHODS

An important, fundamental difference between the performance code and the prescriptive codes is that, with regard to materials, the prescriptive codes prescribe minimums for the materials that provide a level of assurance that a material will not cause significant contribution to a fire hazard. Materials manufacturers design their products with these minimums in mind and may or may not be able to supply information on the characteristics of the product that would be necessary in fire modeling.

An example of this is foam plastic used as interior trim. The prescriptive codes call for this material to be a minimum density and maximum thickness and be restricted to a maximum percentage of the wall. In addition, the flame spread index is limited to a maximum when tested in accordance with ASTM E 84. [38]

A manufacturer of foam plastic interior trim materials such as a baseboard would then know exactly what is needed in order to market its product:

- Minimum density.
- Maximum thickness.
- A maximum flame spread index.

The designer of the building interior would be limited to a maximum percentage of the wall area.

The performance code may not impose these limitations. One could use any thickness, any density, and any level of combustibility and flame spread as long as the evaluation technique indicated that fire safety objectives were met. However, the data necessary for incorporating this product in the analysis may be different than what the manufacturer typically presents or knows from current test data. For the analysis, the manufacturer might need to provide the engineer with the ignition temperature, the rate of heat release, smoke-development parameters, or whatever was necessary for modeling. Standardized tests such as ASTM E 84[38] may not provide sufficient data to characterize these parameters.

Some other examples of products or systems that are tested by standardized tests where yet other data may be required for a performance-based design include:

- Roof materials, presently tested for classification in accordance with ASTM E 108.
- Insulation materials tested to ASTM E 84.
- Foam plastics in roof assemblies applied directly to a steel deck tested in accordance with UL 1256 or FM 4450.

14.0 FIELD CHANGES AND ADHERENCE TO DESIGN DOCUMENTS

14.1 EXECUTIVE SUMMARY

Because of the interdependence of building systems in a performance-based design, what appear to be relatively minor changes may significantly alter the anticipated performance of a performance-based design. Therefore, it is critical that construction occurs in strict conformance with the design documents and that all field modifications are thoroughly evaluated to determine their impact on overall performance.

14.2 FREQUENTLY ASKED QUESTIONS

Q. Who is responsible for quality control during construction?

A. As with other aspects of the performance-based design process, quality control is ultimately the owner's responsibility. However, the actual responsibility for the quality control process is often delegated to a member of the design team, such as the design professional, or to the general contractor (see Section 14.3).

Q. Who must be notified when field modifications occur?

A. When field modifications are necessary or occur inadvertently, the impact of the change on the overall performance-based design must be assessed. The design team must be notified initially in order to begin the assessment process. The code official also needs to be notified, either for review and approval of the modification or simply to ensure that the code official has the most up-to-date information, depending on the magnitude and impact of the change (see Section 14.5).

Q. What are the potential impacts of field modifications?

A. The impact of field modifications can range from no or negligible impact to a significant impact that invalidates the entire performance-based design. The actual impact will depend on the scope and nature of the field modification, what systems the modification affects, and the scope of the performance-based design. Modifications such as changing type of interior finish materials, changing the exhaust rate for engineered smoke management systems, or altering the spacing of automatic smoke detectors can all have an impact on the basis of the performance-based design. Field modifications can have both positive and negative impacts (see Section 14.3).

Q. Do field modifications require reanalysis of the entire performance-based design?

A: Some field modifications will require reanalysis of the entire performance-based design. The extent of reanalysis will depend on the extent of the modification (see Section 14.5).

14.3 QUALITY CONTROL DURING CONSTRUCTION

14.3.1 Responsibility for Quality Control

Because of the interdependence of building components and systems in a performance-based design, field modifications that are perceived as minor can significantly impact the overall fire safety performance of the completed building. Therefore, strict quality control during construction is imperative to achieve successful performance-based design. Quality control is ultimately the owner's responsibility. In practice, however, the responsibility for quality control typically falls on the general contractor.

14.3.2 Quality Control Practices

Quality control involves a number of practices, including, but not limited to:

- Conformance with design specifications and drawings.
- Adherence to design tolerances.
- Use of specified materials.
- Adherence to manufacturer's and designer's installation instructions.
- Utilization of qualified trade professionals.
- Adherence to generally accepted engineering and construction practices.

14.4 IDENTIFICATION OF FIELD CHANGES

14.4.1 Identification for Evaluation and Reporting

It is essential that deviations from the design documents are identified so that they can be evaluated to determine their impact on the overall performance-based design. At the outset of the construction process, all contractors should be advised of the importance of adhering to the design documents, and procedures should be established for required notifications in the event of deviations. When deviations from the design documents occur, the contractor(s) must notify the design professional so that evaluation and reporting of the deviations can be accomplished.

14.4.2 Inspectors' Discretion

In addition, all inspectors, including special inspectors engaged by the owner and employees of the code official, must be cognizant of deviations from the design documents. Because of the interdependence of building systems and components in a performance-based design, field inspectors should have limited discretion to evaluate and accept or reject deviations. All deviations that exceed the predetermined design tolerances must be identified and evaluated in the context of the overall performance-based design.

14.5 REPORTING AND DOCUMENTATION OF FIELD CHANGES

14.5.1 Procedure

As noted previously, a procedure for reporting and documenting field changes should be established prior to commencing construction on a performance-based design project. The contractor(s) should notify the design team who, in turn, should notify the code official.

14.5.2 Assessment of Impact

Once notified of the deviation, the design team should assess the impact of the deviation. This assessment may be qualitative, such as comparing the properties and performance of the specified product to those of the product actually provided. The assessment may also require that the design team revisit the original engineering analysis and revise key assumptions or calculations. The assessment should evaluate the effect of the deviations on other systems. For example, increasing the spacing of smoke detectors or automatic sprinklers within an atrium may require a corresponding increase in the capacity of the atrium smoke exhaust fans.

14.5.3 Documentation Modification

The design team should make appropriate modifications to the performance-based design documents based on the impact of the deviation. The deviation may require revisions to the specifications and drawings, the operations and maintenance manuals, and the design report. Documentation requirements are discussed in detail in Chapter 12 of this guide.

14.6 CODE OFFICIAL REVIEW AND ACCEPTANCE OF FIELD CHANGES

The design professional should notify the code official of any deviations from the approved performance-based design. The procedures and time frames for notification should be established prior to the start of construction. When notifying the code official, the design professional should identify the scope and reason for the deviation as well as the design team's assessment of the deviation's impact on the overall performance-based design.

The code official should review the deviation, including the revised analysis and documentation. This may require that additional peer review or contract reviews take place. Prior to issuing a certificate of occupancy, all deviations from the original performance-based design should be addressed to the satisfaction of the code official.

15.0 OPERATIONS AND MAINTENANCE

15.1 EXECUTIVE SUMMARY

As with prescriptive-based designs, performance-based designs require regular inspection, testing, and maintenance. However, the types of inspection, testing, and maintenance needed may differ. An essential component of a successful performance-based design project is a comprehensive operations and maintenance (O&M) program that includes the following:

- Building components and systems are inspected, tested, and maintained.
- Building operations are conducted within the bounds of the performance-based design.
- Renovations do not invalidate the original performance-based design.
- Building staff and tenants are appropriately trained in their responsibilities regarding the operations and maintenance program.
- Appropriate compensatory measures are implemented when protection features are impaired.

This chapter identifies key considerations that should be addressed in an O&M program. The responsibilities of the building owner, designer, and code official are addressed. Guidance is also provided on addressing when a design must be reanalyzed because of changes in use.

15.2 FREQUENTLY ASKED QUESTIONS

Q. What is an O&M program?

A. An O&M program defines the policies and procedures for operating and maintaining a performance-based-designed building (see Section 15.3).

Q. What are the key components of an O&M program?

A. An O&M program addresses many aspects of building operation and maintenance, including inspection, testing, and maintenance of systems; how to address changes in building use; what to do when a system is impaired, etc. The components of an O&M program will vary depending on the extent to which performance-based design was applied to the building design process (see Section 15.3).

Q. What is an O&M manual?

A. An O&M manual consists of the formal documentation of an O&M program. It identifies activities that must be performed in order to operate and maintain the building (see Section 15.4).

Q. What information should an O&M manual include?

A. Section 15.4 identifies the information that may be included in an O&M manual. The actual contents of an O&M manual will vary depending on the scope of the O&M program and the extent to which performance-based design was applied during the design process. An O&M manual will typically include drawings; product data; inspection, testing, and maintenance procedures and schedules; compensatory measures, etc (see Section 15.4).

Q. What limits should be imposed on the use of a building?

A. The limits imposed on the use of a building will vary depending on the extent that performance-based design was applied during the design process, the safety factors that were incorporated into the performance-based design, and the assumptions and bounding conditions of the performance-based design (see Section 15.5).

Q. What are the testing and maintenance requirements for a performance-based design?

A. Testing requirements will vary depending on the scope and complexity of the performance-based design. System testing requirements are typically similar to those for systems provided under prescriptive codes (see Section 15.8).

Q. What are compensatory measures?

A. Compensatory measures are actions to be implemented when a required protection feature or system is impaired in order to continue operation of the facility (see Section 15.9).

Q. What alterations are permissible within the scope of a performance-based design?

A. The extent of permissible alterations will vary with each performance-based design and is documented in the O&M manual (see Section 15.11).

Q. How does the code official inspect a performance-based-designed building?

A. The physical inspection of a performance-based-designed building is very similar to that for a building designed and constructed under a prescriptive code. However, rather than comparing the building to the prescriptive code to determine continued compliance, the building is compared to the conditions specified in the O&M manual and other performance-based design documents (see Section 15.12).

15.3 OPERATIONS AND MAINTENANCE PROGRAM

A comprehensive operations and maintenance program is critical to the success of a performance-based design project. Since a performance-based design is tailored to a specific building use and to achieve specified objectives and functional statements, the final design will be unique to the particular building. To maintain the desired/required level of performance, the building components and systems must be maintained in proper operating condition. In addition, activities occurring within the building must be managed to remain within the boundary conditions of the performance-based design analysis. Proposed renovations must also be assessed to determine their impact on the building's performance. Specific components of an O&M program are discussed in more detail later in this chapter.

15.4 OPERATIONS AND MAINTENANCE MANUALS

In simplistic terms, the O&M manual defines the O&M program. An O&M manual may include those items listed in Figure 15.1.

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      c. Allowable occupancies
      d. Maintenance of exits
H. Inspections by Code Official (or Designated Representative)
   1. Frequency
   2. Scope and procedures
   3. Inspection forms

FIGURE 15.1. Contents of an O&M Manual

15.5 LIMITATIONS ON USE OF BUILDING

15.5.1 Bounding Conditions on Anticipated Use

A performance-based design analysis is based on the anticipated use of the proposed building. To complete the analysis process described earlier in this guide, the design team must quantify the characteristics of the building and its use, including the type of construction, interior finish materials, fuel loading, occupant characteristics, etc. These characteristics define the bounding conditions for the performance-based design and, therefore, the use of the building. These criteria may be selected from prescriptive-based codes or they may be developed specifically for the project at hand. These bounding conditions or limitations must be clearly documented in the O&M manual. The O&M program must ensure that the use and occupancy characteristics of the building remain within these bounding conditions.

15.5.2 Example of Limiting Condition

For example, if the performance-based design analysis is based on all interior finish materials having a flame spread rating of 25 or less, the O&M manual would stipulate that this is a limiting condition on the use of the building. Building staff must ensure that all interior finishes installed within the building have a flame spread rating equal to, or better than, that stipulated in the O&M manual.

15.6 MANAGEMENT OF CHANGE PROTOCOL

The O&M program must include a procedure for evaluating and managing change within a performance-based-designed building. To accomplish this, the O&M manual must clearly identify the limiting conditions for operating the building. There should be a clearly defined procedure for review and evaluation of all changes within the building, including changes to be carried out by tenants.

15.7 FACILITIES STAFFING AND TRAINING ISSUES

To maintain a performance-based-designed facility within the bounds of the performance-based design analysis, it is important that facility staff and tenants be adequately trained regarding the conditions of the performance-based design. Building maintenance staff should be adequately trained to properly maintain all building components and systems and to recognize what materials are acceptable for use within the building. Building maintenance and/or management staff must be made cognizant of regarding the operation and maintenance of building systems and must understand the procedures for implementing compensatory measures if a building system is impaired. Finally, building tenants must be instructed regarding the conditions of use of their spaces within the building so that they do not undertake operations that would adversely affect the building's performance. The terms used to define the conditions of use may be broad terms, such as "office use," or may be more specific, such as "high-density files," depending on the safety margins incorporated in the original performance-based design and the capabilities of the personnel.

15.8 TESTING AND MAINTENANCE

15.8.1 Need

The proper operation of building components and systems is essential to maintaining the required level of performance within the building. To ensure proper operation, regular testing and maintenance of building systems must occur. System testing and maintenance is the primary function of the O&M program.

15.8.2 Responsible Personnel

System testing and maintenance may be conducted by in-house staff or by outside contractors, or a combination of the two. All personnel responsible for system testing and maintenance should be adequately trained to perform the necessary tasks and identify system impairments.

15.8.3 Frequency, Method, and Documentation

The O&M manual should specify the method of testing for each system, the frequency of testing, and the acceptable results. The O&M manual should include forms for documenting the performance and results of system testing and maintenance.

15.9 COMPENSATORY MEASURES

15.9.1 Need

Because of the interdependence of building systems in a performance-based design, the overall level of protection could be adversely affected if a critical protection system is impaired. To maintain the level of performance, the O&M program must implement temporary protection measures, or compensatory measures, when a critical protection system is impaired.

15.9.2 Identification of Critical Systems

As part of the performance-based design analysis, the design team should identify systems that are critical to achieving the required level of performance within the building. As part of the sensitivity analysis, they should evaluate the impact of potential impairments of those systems and identify measures to mitigate those impacts. The required compensatory measures for postulated system impairments should be clearly defined in the O&M manual. Having predefined compensatory measures provides building staff with clear direction in the event of a system impairment and prevents the need to develop appropriate compensatory measures after a system is impaired.

15.9.3 Duration of Impairment

The impact of system impairments and their associated compensatory measures should consider the duration of the impairment. For example, if a fire suppression system will be impaired for 1 hour to facilitate testing, specific compensatory measures may not be warranted. However, a 10-hour impairment to replace the water service may require provision of an interim water supply. The O&M manual should quantify threshold impairment durations and may specify additional compensatory measures based on the anticipated impairment duration.

15.9.4 Example

For example, consider a performance-based design that relies on automatic smoke detection to activate a smoke management system in order to maintain tenable conditions within a means of egress. If the smoke detection system is impaired, the smoke management system will not be automatically activated and untenable conditions may result in the means of egress in the event of a fire. To compensate for the system impairment exceeding a predetermined time duration, the O&M manual may stipulate that trained personnel implement a fire watch in the affected area and be provided with the ability to manually activate the smoke management system in the event that the watch observes a fire.

15.10 CONTROL OF FUEL LOADING

The type, quantity, and arrangement of fuel present within a building can significantly impact the magnitude of a fire event. The performance-based design analysis may contemplate a specified maximum fuel loading within the building for purposes of designing the building's protection systems. The O&M manual will stipulate the fuel-loading conditions that can exist within the building, including:

- The size and type of fuel packages.
- Maximum quantity of fuel packages within a specified area.
- Allowable locations for storage or display of specified fuel packages.

- Required spatial separation between fuel packages.

15.11 ALLOWABLE ALTERATIONS

15.11.1 Characteristics and Material Properties

Similar to the combustible loading of a building, the design analysis may be based on characteristics and material properties that are less restrictive than the conditions that will actually exist within the building. This provides a factor of safety within the design, but also provides for a degree of flexibility in the use of the building.

15.11.2 Flexibility Within Bounding Conditions

The conditions that the analysis is based upon are the bounding conditions for the use of the building. If the actual building construction characteristics are below the analyzed bounding conditions, there is flexibility for changes to the use and configuration of the building that will not invalidate the original performance-based design analysis. To account for this, the O&M manual may define a range of building renovations that are permissible within the bounding conditions of the analysis. Specifically, the O&M manual may stipulate the maximum size of spaces; allowable finish materials; allowable uses, occupancies, materials, or processes; maintenance of exits; etc.

15.11.3 Example

For example, the performance-based design analysis may be based on fire areas of 2,000 square feet maximum size. The building is constructed with fire areas having a maximum area of 1,500 square feet. The O&M manual may allow renovations that would result in increasing the size of individual fire areas to not more than 1,900 square feet in order to remain within the bounding conditions of the performance-based design analysis and still provide a safety margin.

15.12 INSPECTIONS BY CODE OFFICIAL

15.12.1 Scope

As with any facility, the code official has a duty to ensure regulatory compliance. The physical inspection of a performance-based-designed building is very similar to that for a building designed and constructed under a prescriptive code. However, rather than comparing the building to the prescriptive code to determine continued compliance, the building is compared to the conditions specified in the O&M manual and other performance-based design documents. An inspector must evaluate the building based on the specific conditions of the performance-based design.

15.12.2 Notation on Certificate of Occupancy

As noted in Chapter 12, the certificate of occupancy should identify that the building, or portions of it, were designed using performance-based design and refer to the O&M manual for specific information. This notation will serve as a flag for an inspector to "shift gears" when conducting the inspection. The inspector must review the O&M manual with specific attention to the inspection procedures identified within it.

15.12.3 Definition of Inspection in O&M Manual

To facilitate this inspection process, the O&M manual should define the key building features and operating limitations that must be maintained in order to provide the required level of protection. The manual should define the frequency of inspections, the procedures that will be followed during the inspections, and acceptable conditions. By defining the inspection procedures and conditions to be expected, any inspector should be able to conduct a verification inspection of the facility. The O&M manual may also contain inspection forms for use by the code official.

15.12.4 Independent Compliance Assessment

Because of the complexity of the performance-based design, the code official may require the owner to have independent compliance assessments conducted on a regular basis. This should be agreed upon and documented in the O&M manual during the design process. The O&M manual should stipulate the frequency of these independent assessments, the minimum qualifications of the independent assessor, the scope of the assessments, and the form of documentation to be submitted. To ensure that the conditions of the performance-based design are maintained, the code official may opt to tie compliance verification with other regulatory functions, such as business license renewal.

15.12.5 Inspectors

Inspections, or compliance assessments, may be conducted by the code official or the code official's designated representative, e.g., an inspector employed by the jurisdiction. Inspections may also be conducted by members of the original design team, independent design professionals, or third-party contractors that specialize in building compliance inspections.

15.12.6 Third-Party Inspectors

When a third party is used to conduct the ongoing inspections, the code official should consider requiring a formal audit process to ensure that the ongoing assessments are being properly conducted and achieving the desired results. The audit process may involve "shadowing" the inspector, i.e., walking the building while the inspector conducts the inspection in order to see the same things the inspector sees at the same time. Another means for auditing the process is to require submission of inspection reports and then spot check the accuracy and validity of the report in the field.

16.0 MANAGING BUILDING CHANGES

16.1 EXECUTIVE SUMMARY

Since performance-based designs are tailored to the specific use of a building, changes in use or operation may require reanalysis to ensure that acceptable performance will still be achieved. Similarly, phased construction, such as the progressive renovation of a high-rise building, could cause interruptions in service, which could temporarily cause a design to not perform as intended. Properly managing such changes is essential to maintaining the required level of protection within the building.

16.2 FREQUENTLY ASKED QUESTIONS

Q. What constitutes a change to the building?

A. Many events constitute a change to the building, including physical alterations to the building, changes in occupancy or processes conducted within the building, or replacement or modification of a building system. Not all changes will impact the performance-based design. However, all proposed changes should be evaluated to determine their impact (see Section 16.3).

Q. What steps need to be taken if a change of use is contemplated?

A. Proposed changes must be evaluated to determine the impact of the change on the performance-based design. A change with a negligible impact on the performance-based design may require revisions to the O&M manuals to document the change. More significant changes may require reanalysis of the performance-based design, review and approval by the code official, and updating the O&M manuals (see Sections 16.4 and 16.5).

Q. Do all alterations require reevaluation of the design?

A. All alterations must be evaluated to assess their impact on the performance-based design. However, not all alterations will require reevaluation or reanalysis of the original design. The need to perform a new analysis will depend on the scope and magnitude of the proposed alteration. The original performance-based design and the O&M manual may identify alterations that are within the bounding conditions of the original analysis and, therefore, do not require reanalysis. Any alteration beyond those permitted by the O&M manual will typically require reanalysis (see Sections 16.4 and 16.5).

Q. Does a small change necessarily not impact the design?

A. A small or minor change may not impact the performance-based design by itself. However, the cumulative effect of several small changes performed simultaneously or over time may be sufficient to invalidate the original design basis. For this reason, it is important to keep accurate records of all changes that occur and to consider each change as a part of a complete building system rather than a stand-alone entity (see Section 16.4).

16.3 BUILDING ALTERATIONS

16.3.1 Evaluation

In the prescriptive code arena, owners are typically required to file for building permits in order to perform renovations or alterations within the building. During that process, the code official has the opportunity to determine whether the proposed alterations comply with the requirements of the prescriptive code. Even if no alterations occur, many jurisdictions require a certificate of occupancy inspection when tenants change. These inspections provide the code official the opportunity to determine if the new use falls within the allowable uses for the type of building.

Alterations to performance-based-designed buildings must also be evaluated to determine the impact of the alteration on the performance-based design.

16.3.2 Changes in Use

Prescriptive codes classify buildings into broad occupancy and use categories. Generally, changes within the building do not require evaluation of or changes to the protection features unless the change constitutes a change of occupancy or use. Since performance-based designs are more closely tailored to the specific characteristics of a building, any changes of building use must be evaluated to determine their impact on the performance-based design. It is important to note that a change to one protection system may necessitate corresponding changes to other systems as a result of the interdependence of systems in a performance-based design.

16.3.3 Bounding Conditions

The O&M manual, which is described in detail in Chapter 15, defines the bounding conditions for the performance-based design and establishes the extent of renovations that can occur without exceeding the limits of the performance-based design. All changes to the building must be addressed, regardless of whether or not they exceed the bounding condition of the design. However, the manner in which the changes are addressed will vary depending on the extent of the change.

16.4 RENOVATION WITHIN SCOPE OF O&M MANUAL

16.4.1 Notification and Permits

Building renovations within the scope of the operations and maintenance manual will be relatively straightforward to deal with. As with any other construction work within any building, it is ultimately the responsibility of the owner to notify the code official of proposed renovation work and obtain necessary permits. This activity will most often be carried out by a qualified design professional. As part of the notification and permit application process, the owner/design professional identifies the scope of the renovation and determines whether it is within the scope of the O&M manual. If the code official is satisfied that the renovation is within the bounding conditions of the performance-based design and that the overall level of protection is not compromised, the appropriate permits should be issued.

16.4.2 O&M Manual Updating

The owner/design professional should update the O&M manual to account for the renovation. If additional copies of the O&M manual exist, such as in the code official's files, the insurance company's files, etc., these manuals must also be updated. Specifically, as-built drawings, system documentation, testing and maintenance information, and inspection data should be updated to reflect the changes in the building. The bounding conditions of the design, such as limitations on fuel loading, should also be updated to account for changes resulting from the renovation.

16.4.3 Example of Updating O&M Manual

It is important to note that, while any single renovation within the scope of the O&M manual may not invalidate the original performance-based design, the cumulative effects of multiple renovations may exceed the bounding conditions of the original performance-based design. For example, if the original performance-based design allows for a 30-percent increase in the occupant load within a building, a 3-percent increase in the overall loading would have a negligible effect. However, 10 such minor renovations would invalidate the original performance-based design. For this reason, it is important to update the O&M manual to reflect all changes in the building. In the case of the cited occupant load example, the O&M manual would be updated after the first minor renovation to indicate that the occupant load can only be increased by 27 percent of the original loading.

16.5 RENOVATION/CHANGE OF USE BEYOND SCOPE OF O&M MANUAL

16.5.1 Renovation Analysis

Renovations that are beyond the scope of the O&M manual will be more complex since they will essentially require a reassessment of the original performance-based design. When the owner/design professional determines that a proposed renovation is beyond the scope of the O&M manual, they should initiate an analysis of the proposed renovation.

16.5.2 Incorporation of Improvements

The design professional's analysis should assess the impact of the renovation on the overall performance of the building. Based on this assessment, appropriate improvements should be incorporated to restore/maintain the level of protection in accordance with the documented objectives and functional statements of the original performance-based design. Once the design professional has determined the improvements that should be implemented in order to maintain the documented level of performance, the analysis should be submitted to the code official for review. The design professional should identify the scope of the renovation and the impact of the renovation on the original performance-based design. The engineering analysis that substantiates that the proposed improvements maintain the level of performance of the original performance-based design must also be submitted for review and acceptance. It should be noted that the code official may require the revised analysis to be subjected to peer or contract review to determine its acceptability.

16.5.3 Reassessment of Entire Performance-Based Design

If the requisite level of performance cannot be achieved, it may be necessary to revert to the beginning of the performance-based design process and reassess the entire performance-based design. It may be necessary to adjust the objectives and functional statements and evaluate different event scenarios and trial designs. Of course, this process must be conducted in concert with the code official.

16.5.4 Revision/Creation of Documentation

These renovations may require the revision of existing or creation of new performance-based design documents. If the objectives, functional statements, design fire scenarios, or trial designs are changed, then the original concept report and design report must be revised or replaced with a new version. In all cases, the O&M manual must be updated to reflect the renovation work, including revisions to as-built drawings, system documentation, bounding conditions, testing and maintenance information, and inspection data.

Appendix A Computer Modeling Fundamentals

A.1 ORIGIN OF MODELS

A.1.1 EMPIRICAL MODELS

Models are either empirical or are developed from first principles. Empirical models use mathematical equations that were developed from actual fire experiments and fire tests. An example of this type of model is the furniture model developed by Babrauskas.[39] This mathematical model was based on the results of numerous fire tests on various types of full-scale furnishings. An equation was developed that described the heat release based on the different types of furnishings that were burned. This equation can be used to predict the burn behavior of other furniture types. Therefore, the heat release rate of a furniture item that has not been tested can be predicted (modeled) in a reasonable way. These types of models differ from those developed from first principles.

A.1.2 FIRST PRINCIPLE MODELS

First principle models are developed from fundamental concepts found in chemistry and physics. These models are built on a combination and interaction of numerous fundamental equations. An example is the detector response algorithm in DETACT,[40] which predicts the activation of a heat detector or fire sprinkler based on the heat from a fire being transported to a detector located on the ceiling.

A.1.3 HAND CALCULATIONS

Some models can be used to calculate an answer by hand. These are usually simple models with a limited number of inputs. When these models become more complex with multiple variables, or when there is the need to determine the outcome over a period of time, the mathematical calculations can be more easily handled by a computer than by an individual with a calculator.

A.2 BENEFITS

A.2.1 REPEATABILITY

One of the benefits of using models in fire safety engineering is repeatability. What this means is that the results of the fire model, given the exact same input, will be the same wherever and by whomever it is used. The model can be used over and over again without any degradation or error that might be otherwise found in a fire testing or research laboratory environment. This is not to say that models always give the right answer, but rather that they give consistent answers. This is further explained in chapter 11.

A.2.2 COST SAVINGS

The use of models can represent a significant cost savings as compared to undertaking full-scale fire testing or experimentation. It is certainly less costly to model the results of a fire burning within the middle of a living room as compared to the time, cost of materials, and instrumentation required to burn a couch in the middle of a living room to obtain answers. Furthermore, the use of models allows numerous evaluations with slight changes in the input (for example, a chair instead of a couch, or the evacuation of elderly occupants versus adolescent occupants for the same movie theater).

A.3 TYPES OF MODELS

A.3.1 OCCUPANT MOVEMENT/EGRESS MODELS

Occupant movement/egress models predict the time to egress from a room or a building through defined paths of travel (i.e., doors, stairs, corridors). The hand-calculation methods, as well as the computer models for egress, are based on the concepts of fluid flow, such as water through a pipe. For example, the analogy of people flowing through a door opening is the same as water flowing through an orifice. The users of this type of model often have to define the speed at which people move and their rate of flow through openings. Some of the more complex computer models account for additional behaviors, such as people making decisions to go in a different direction when they find that one exit is blocked by a large number of people queuing at the opening.

It is important to understand that many egress models are optimization models. What that means is that the time calculated to exit a defined space or building represents the least amount of time it takes for the defined area to be evacuated. These models do not take into account many of the human behaviors that can result in the delay of evacuation. These are important considerations in using the results of an occupant movement or egress model.

A.3.2 FIRE DYNAMICS/FIRE EFFECTS MODELS

A.3.2.1 Numerical Models

Numerous numerical models are used to study fire effects and fire dynamics. Fire effects and dynamics include the heat release from a fire, the spread of heat and smoke, the production of toxic gases, and fire spread, among other fire-related aspects. Fire models can be found that address fire phenomena that range from quite simple to very complex.

A.3.2.2 Hand Calculation Methods

There are numerous hand calculation methods based on empirical methods. Some of these methods include the minimum heat release rate necessary to cause flashover and plume correlations that allow the user to predict the temperature and velocity profiles directly above a fire at various heights. Other correlations are used to calculate the quantity of smoke produced, given the heat release rate and the height above the fire. The former can be used to predict the heat transfer to a ceiling element directly above the fire, and the latter used for design of smoke control systems.

A.3.2.3 Zone Fire Models

Another class of fire model, more complex than those used in the examples noted above, are zone fire models. These models are based on a unifying assumption that in any room where the effects of fire are present there are distinct layers, a hot upper layer and a cool lower layer. This simplifying assumption is consistent in rooms or spaces prior to flashover. These fluid-flow models are useful in predicting the average upper layer temperature and height of the heated upper layer relative to the floor. This type of model is often used in studying the time that occupants have to safely egress before the hot upper layer descends to a height where the occupants would be impacted. Post-flashover fire models approximate a compartment as a single zone with uniform temperature throughout.

A.3.2.4 Field Models

A third class of fire models are considered field models. These are far more complex than the zone models and the single correlation models noted above. These models are based on the volume of a space being divided into small interconnected cells or fields. These models are able to evaluate the fire effects and dynamics within each individual field. The model also looks at how each individual field relates to all the fields immediately adjacent to it. The fundamental equations of mass, momentum, and energy are solved across each of these interfaces.

If, for example, a room is subdivided into 10,000 such fields, simultaneous study of the effects in each field results in a much higher level of detail and resolution. However, the level of effort required to conduct simultaneous calculations in each field results in a very high demand on computing power. These types of models are solely computer models.

A.3.3 HEAT TRANSFER MODEL

Another type of model used in fire safety engineering is the heat transfer model. Heat transfer occurs in three ways: conduction, convection, and radiation. Models can be used to predict heat transfer in each of these individual modes or in all three simultaneously. Models for the single mode of heat transfer can be done by hand, whereas computer models are needed to conduct heat transfer studies of multimode heat transfer problems. One model might be used to predict the time for a heat detector or sprinkler to activate given a certain fire in a particular room, whereas another model may be used to predict the failure of a concrete-encased steel column, given a certain fire exposure.

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