Performance-based design achieves fire, life safety

Specifying a single product or system within a facility using a performance-based specification, when the design is subject to performance-based design (PBD), can fundamentally reduce the level of safety achieved.

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05/23/2018

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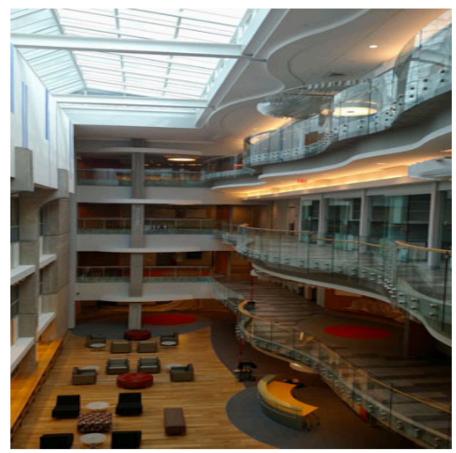
Learning objectives:

- Understand the factors that can play a part in performance-based design (PBD).
- Explore where critical changes to specifications can result in unintended changes to levels of safety.
- Know the impact early design decisions can have on achieving safety standards and minimizing waste.
- Learn from case studies where poor design approaches resulted in waste.

When creating fire specifications for a building project that includes performance-based design (PBD), an uninformed engineer of record can fundamentally change the level of safety achieved. While the engineer for the PBD will attempt to include all stakeholders, it is the responsibility of all parties to communicate the design requirements of the PBD, and the specification language associated with the design requirements to ensure safety is maintained.

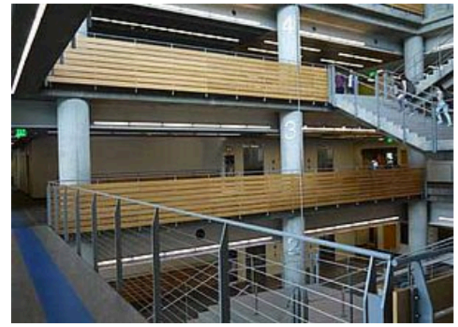


The process of PBD is a lesser-known path for building design; the following discusses the concepts of PBD, the parties involved, implications of decisions, and the importance and implications of specification development and changes.

If the engineer of record for the PBD follows industry-acknowledged processes, such as the Society of Fire Protection Engineer's (SFPE) Engineering Guide to Performance-Based Fire Protection, then all stakeholders (including the engineer of record for specification development) will come to the project informed about the various aspects of the PBD. It is therefore the engineer of record's responsibility to make all parties aware of product changes or updates to performance-based specifications that are broad in nature.

With a holistic approach to PBD, all members of the design team need to be aware of how PBD can impact their approach to design and specifications. It is more likely that the engineers who are not aware of PBD may "over specify." Over specifying may result in both wasted cost and materials, and also may in some instances actively work against the PBD, thereby reducing levels of safety.

Performance-based design



PBD in the context of fire safety is absent from many codes including the International Building Code (IBC), International Fire Code (IFC), and International Mechanical Code (IMC). NFPA 101: Life Safety Code, however, introduces the "performance-based option," referring to the consideration of fire safety performance as a method of generating design/egress parameters for a building. That stated, PBD also is a term used in many disciplines related to using a performance target as the basis for the design (structural, mechanical, etc.), and so the fundamental approach on a macro level can be viewed as universally similar.

Most definitions would speak to using science and engineering techniques applied to a problem with the goal of achieving a performance that is agreed to by the stakeholders involved. When looking at how alternative means and methods are applied, that performance may be benchmarked to a predetermined level of safety/standard with the intent for the design solution to be commensurate or superior to that benchmark.

So, where is that performance metric derived? For fire safety following the performance-based option in NFPA 101, as an example, the performance required is to provide an "environment that is reasonably safe from fire." When using true PBD, the goals and objectives must be defined by the group of stakeholders as one of the first steps. The stakeholders should include not just owners, designers, and approving authorities, but also users, insurers, and property management, to name a few.

Through the stakeholder communication process, the design parameters can be aligned to meet many needs, rather than purely meeting what is intended to be achieved by the prescribed method in the applicable code.

The IBC, IMC, and IFC introduce the alternative means and methods section in Chapter 1. Depending on the applicable edition in the jurisdiction of the engineer, the specific subsection of the code will vary. In each instance, Section 104.11 of the code states that the level of performance or standard of safety should not be reduced:

" … the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method, or work offered is, for the purpose intended, not less than the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability, and safety … "

PBD approaches, when including the stakeholders in determining the performance requirements, may result in owners and developers citing construction cost and time as a factor. Insurers may cite property loss. Users may cite aesthetics. The approving authorities may end up citing the above statement as their goal from a safety perspective. So PBD in the United States may result in the following question: When applying alternative means and methods as the standard to achieve, what is the safety performance of the code?

To answer the question of "what is the safety performance of the code?", a preliminary question may be: What information is needed to achieve the PBD solution? Some of the key factors and questions we must consider to achieve a PBD solution include:

- Establishing stakeholder buy-in. Is everyone able to agree to the approach proposed? The last thing a designer should want is to complete a design only for it to be rejected by the lead designer, owner, or authority having jurisdiction (AHJ).

- Determining the performance of the prescribed method. Use quantified methods to establish the performance of the prescribed method. This allows the designer to establish the level of safety that can be achieved by the prescribed method.
- Specifically outlining for the AHJ and lead designer what the PBD may include and identifying the goals of the exercise. This is important as it is the second point at which major issues can be ironed out ahead of extensive effort. This phase may include a design brief or statement of work.
- Reviewing the system or process. Are the systems or processes connected to surrounding systems or adjacent processes? Understanding this consideration starts to define the scope of the proposed alternative method. For example, smoke damper operation (opening or closing) may impact a smoke control system performance.
- Completing the analysis and quantifying the performance of the proposed design. In almost every instance of a PBD, this should be an iterative process. Even if the first analysis passes, consideration of variables should reveal at what point the analysis may fail.

Requirements for accepting PBDs

The requirements for acceptance of a proposed PBD cannot be stated categorically in a broad sense. Each building design, location, occupancy, and goal will be different. For fire safety PBD, many items are already identified for consideration—this may include design choices, such as means of egress or smoke-layer height, or it may need to allow for external temperature fluctuations and humidity.

It is also important for designers to provide backup to the performance benchmark on a quantitative basis. Once a value of a performance criteria has been identified and agreed to, the value of performance is fixed. It becomes a standard for the design team and AHJ. As a result of that standard being defined, the PBD has a benchmark of performance to exceed.

When considering fire resistance as an example, the code states that in a fire, the performance goal is 60 minutes. As ASTM E 119 is a referenced test standard, 60 minutes fire resistance is based on the ASTM E 119 time-temperature curve. As the ASTM E 119 time-temperature curve does not represent "real" fire conditions for most buildings an alternative time-temperature curve may be an appropriate heating regime for structural elements thereby demonstrating 60 minutes of fire resistance based on "real" PBD fire conditions, and thereby demonstrating the standard of safety defined by the code is achieved.

PBD applications

When considering the applications of PBD, the possibilities are constrained only by the ability to quantify levels of safety or performance of the prescriptive requirements. Consider an enclosed parking deck's mechanical exhaust system. The IMC requires ventilation to limit the concentrations of carbon monoxide (CO) and nitrogen dioxide (NO2) gases in parking decks. Within enclosed parking decks, such control is prescribed to occur through mechanical exhaust systems at 0.75 cfm/sq ft and activated either continuously or upon automatic detection of the exhaust effluent as outlined in IMC Section 404.1.

Stakeholders—Proposing an approach to analyze the vehicle exhaust (CO and NO2) requires stakeholder buy-in. In this type of project, the stakeholders would include the owner/developer, the mechanical designer, the architect, the electrical engineer, the structural engineer, and the AHJ.

Why so many stakeholders?

Considering just a few stakeholders, the following groups would be impacted: The developer would benefit from realized savings and therefore needs to make a return-on-investment decision. The mechanical engineer would have to design smaller fans and smaller exhaust ducts due to changes in flow rates. The architect would need to coordinate the change across the design team. The electrical engineer would have to account for lower fan loads that may impact emergency power and generator circuits. The structural engineer would have to consider the smaller shaft sizes. And the AHJ would be the approving authority.

Determine the performance of the prescribed method—To make the determination, the standard of care must first be established. With research, one may find that the levels of CO and NO2 may be acceptable for the simple reason the levels are not prescribed. Alternatively, using a large-eddy simulation (LES) computational fluid dynamics (CFD) model, the PBD engineer can establish what an IMC-prescribed system performance may achieve. This approach may be more appropriate as it is less arbitrary and more specific to the building. Further, the source of the emissions needs to be considered.

To determine the emissions source, the U.S. Environmental Protection Agency's (EPA) document "Idling Vehicle Emissions for Passenger Cars, Light-Duty Trucks, and Heavy-Duty Trucks" (EPA420-F-08-025) may be particularly useful. Based on the region of the country, the type of vehicle most prevalent may change—in Southern states, large vehicles, such as pickup trucks, are the most popular type of vehicle. In more congested cities like Washington, D.C., small cars may be the most popular. What is common, however, is that whenever parking decks are used for events or business operations, large numbers of people leave at the same time, so consideration that all vehicles will be running at the same time may be a fair assumption.

Regardless of the number and type of source, the source must be used for both prescribed analysis and performance analysis, as only one variable should change: the exhaust method. Once the prescribed method has been analyzed, the impact of the performance design can be reviewed.

Specific impacts to designers—Once the performance of the proposed system is shown to exceed the prescribed system, the design parameters assumed in the performance design analysis must be conveyed to the stakeholders. As outlined above, the owner, engineers, and the AHJ will be impacted by the design outcome. So, while obvious to many, clear communication of the results and design assumptions is critical and must be combined with a back-check verification of constructability by the stakeholders.

For the PBD engineer, an important step at this stage is to communicate parameters that will be needed in the development of performance-based specification language. It is therefore incumbent on the stakeholders to be mindful of the direction their particular expertise may take the design approach. For example, the type of gas detection that may be specified may be generic and allow for a passive-type detector. If part of the mechanical system considerations is related to the 0.05 cfm/sq ft standby ventilation, the PBD engineer may question whether gas detection should be active and whether a passive-type detector would achieve the intended performance.

Completion and communication—The results of the PBD analysis require clear and precise communication to the stakeholders. The details associated with the outcome are important, as the analysis has shown a level of safety has been achieved. Should the systems that are required as an outcome of the analysis not meet the standards assumed, then the performance of the system or building may not be adequate.

An analysis of this type, therefore, also requires the PBD engineer to know what systems are available for use for the given application. What becomes more difficult for the specifying engineer is whether the language used, or the details specified, are accurate enough to ensure the correct equipment is selected, purchased, installed, and commissioned.

In high-rise buildings, and in buildings with smoke-control systems, Section 901.6.2 of the IBC requires NFPA 4: Standard for Integrated Fire Protection and Life Safety System Testing. Section 1.2 creates a back-check for integrated testing of the system's accuracy to record documents, which would include PBD documentation. For other buildings, NFPA 4 is not a required standard; through section 901.6.2 of the IBC, when more than one system is included integrated testing will be required.

When considering a PBD solution, it will be incumbent on the engineer of record to verify such checks take place. The challenge for many PBD designers is related to limitations in contracting, where the engineer may not be contracted to be present during, or at the end of, construction. This type of contracting limitation would, therefore, place the burden on the owner's representative overseeing the design team.

Interrelationships between disciplines

One PBD on a building can impact multiple design team members. Conveying the full story to the whole design team when dealing with an unusual situation is important. As an example, using fire-modeling CFD can reduce exhaust rates by 50% and inlet-air path demands by 75% or more when compared against algebraic equations typically used in NFPA 92: Standard for Smoke Control Systems or other similar guidance.

If the design parameters that result from fire modeling are not conveyed properly to the design team, several design areas may be in excess of what is needed:

- The roof structure supporting the fans may be overdesigned.
- Electrical supplies and generator loads may be based on larger motors than are needed for the exhaust fans.
- The fire alarm system may include lower-quality and more expensive smoke detectors.
- Fire and smoke dampers may be included in walls that are no longer needed as fire and smoke barriers.
- In some extreme cases, designers have included tunnels for make-up air, which would not be needed.

Responses to designs of excess are often positive—surely more is better? Unfortunately, that is not always the case. For example, in fire-modeling efforts, excessive exhaust can have a disruptive effect on smoke migration and create untenable conditions in areas remote from the fire.

The importance of a holistic view

Changes to buildings during construction can always have unintended consequences. Changing a façade material on a building based on ambiguous test-certification data can create challenges. Several relatively new sleeping-accommodation buildings have already been identified in the U.S. that have combustible cladding. Where a PBD approach that looks at all the fire safety systems may be used to allow façade changes, when a builder or specifier changes the façade during construction without informing the PBD engineer, there are immediate changes to the risk profile of the building that require immediate consideration. Based on some materials and systems used in buildings, small and subtle differences may be the only indicator of the product change and risk profile change. Those differences may be difficult to identify and could be as simple as a referenced test standard.

When considering the product stored in a leased warehouse building, the perception of the landlord and leaseholder is the change in materials are nominal—the landlord may not even be aware. The stored material may be disposable cups. The original cups were paper; the new cups are plastic. The racking, fire alarm, sprinkler, and architectural layout may all be the same, but that one product change may mean the sprinkler, fire pump, underground supply, and electrical supply all need reviewing.

Critical change with unintended consequences

During a recent project, the general contractor changed an element of an exhaust system related to a PBD smoke-control system. To reduce consulting fees, the engineer who had conducted the PBD analysis was not initially part of the construction-period services. The lead designer knew of the PBD and reached out to inquire about the change in the exhaust system. The change resulted in the following reversals of the PBD:

- An additional 5-story staircase was required.
- An additional fire-service access elevator was required.
- Larger exhaust fans and larger ducts were needed.

Fortunately, the change was caught early in the process and the decision was reversed, but this instance highlights the importance of a holistic view with PBD.

In prescribed building design, the design team and contractor team are aware of the impact of choices made. With PBD, the interrelation of systems, particularly life safety and fire safety systems, becomes more intertwined, often resulting in simpler systems (which enhances safety), but the impacts of choices are not always realized.

As consulting-specifying engineers, it is the duty of all of us to consider not just the performance basis we are intending for the system from our perspective, but also what the system interconnectivity may do when a PBD is in place, and how the decisions we make can impact the safety achieved.

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