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PERFORMANCE SYSTEM MODEL –A FRAMEWORK FOR DESCRIBING THE TOTALITY OF BUILDING PERFORMANCE

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INTRODUCTION

Performance-based building regulations have been in place or are being developed in various countries. Although these regulations have been relatively successful, they have not yet reached their full potential. In part, this can be attributed to the fact that the overall regulatory system has not yet been fully addressed, and gaps exist in several key areas. For example, the overall regulatory system includes public policy, education, technology, support (infrastructure) frameworks, and overall system management issues.

This totality of the building regulatory system and the associated issues are what groups such as the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) and International Council for Building Research and Innovation (CIB) TG37, Performance Based Building Regulatory Systems, have been focused upon in recent years. One issue in particular that has motivated a closer look at the overall framework of performance-based regulations is the role of standards, performance criteria and verification methods within the overall regulatory system. What has been found by the IRCC, CIB TG37, and regulators not involved in these groups, is that there appears to be a disconnect between the standards, performance criteria and verification methods referenced by regulations and the qualitative performance or functional objectives found within the regulations. More specifically, standards, performance criteria and verification methods often times have requirements that do not match the objectives of the performance (functional or objective-based) regulations. Also, there continues to be a heavy dependence upon prescriptive solutions as a comparative tool when undertaking performance design. This reliance occurs primarily because it has been difficult to quantify the existing prescriptive methods and there is a lack of technological advancement in many areas. Combined with these issues is a liability concern. It was felt that in order to move past this dependence more emphasis on a model which shows clear connections to the performance criteria and verification methods is necessary.

As a result of these concerns, it has become clear that a model that addresses all of these components needs to be developed. It was also realized that this model has the potential to address the full spectrum of building performance issues which go from pure regulatory issues to consumer driven or individual building owner expectations. For example many issues addressed by fire protection engineering are regulatory in nature but there are also many issues that go beyond regulations into the area of client expectations such as the protection of historic artifacts found in a museum or mission continuity. Additionally, it is appropriate for a group that deals with regulatory issues to explore such a broad model because in many cases the goals of regulatory systems tend to evolve over time as societies expectations broaden. For instance, sustainability and accessibility are currently evolving into regulatory issues where they were once an individual building owners preference. Having a system that can address a large spectrum of issues encourages a smoother transition when the scope of regulations is broadened. Conversely, some countries are looking at reducing the issues regulated by the building regulations after a review of society's expectations as to what should be regulated. This shift is related to the fact that prescriptive regulations tend to accumulate provisions in areas such as consumer protection that are generally far beyond the intention of minimum building regulations. It is important to note that regulations are only one piece of the overall concept of building performance.

In addressing this need, CIB TG37, Performance Based Building Regulatory Systems, has established a work programme to formalize such a model. The model has been termed a "Performance System Model (PSM)" and originates from IRCC, specifically through the work of Brian Meacham. Meacham and the IRCC expanded on the NKB model (Nordic Committee on Building Regulations, NKB, 1976; NKB, 1978)[i] by adding varying risk (performance) levels to the model. This revision has created a more solid link between the qualitative and quantitative portions of the NKB model. The contents of the structure will be described later in the paper. See **FIGURE 1** for a description of the PSM. The Task Group has several different tasks which focus on this model which are to be completed by the 2004 CIB World Congress. For more information please access the TG37 Website.
(http://www.icbo.org/Code_Talk/Performance_Codes/CIBTG)

This paper and the discussion on the model focus primarily on performance design methods and solutions versus the more traditional prescriptive approaches. It is recognized that in most cases, especially within the regulatory environment, the existing prescriptive solutions will play a strong role and will continue to play a strong role in the future. More on the discussion of the use of the traditional prescriptive solutions within performance building regulatory systems can be found in a paper by D. Bergeron et al.[ii]

MODEL DESCRIPTION

As noted earlier, the concepts embodied within this model originate from the NKB model, with modifications to reflect the need for more quantitative guidance.[iii] One of the key elements of understanding provided by IRCC has been the need to appropriately recognize the relationship between policy issues and technical issues. The technical community needs to understand they are working within a larger system, which must ultimately relate to qualitative goals and functions of buildings. These qualitative goals may or may not be regulatory in nature.

This model can conceptually be divided into 2 portions, qualitative and quantitative. The qualitative portion is often where the goals, functions and level of performance are described in qualitative terms. This portion of the model sets the structure and focal point for the quantitative portion of the model. Although, it should be noted that the qualitative portion of this model recognizes that a performance system is only useful if quantitative methods and solutions are provided. The key to this entire model is that such quantitative methods and solutions must be specifically linked to the qualitative portion of the model to complete the system.

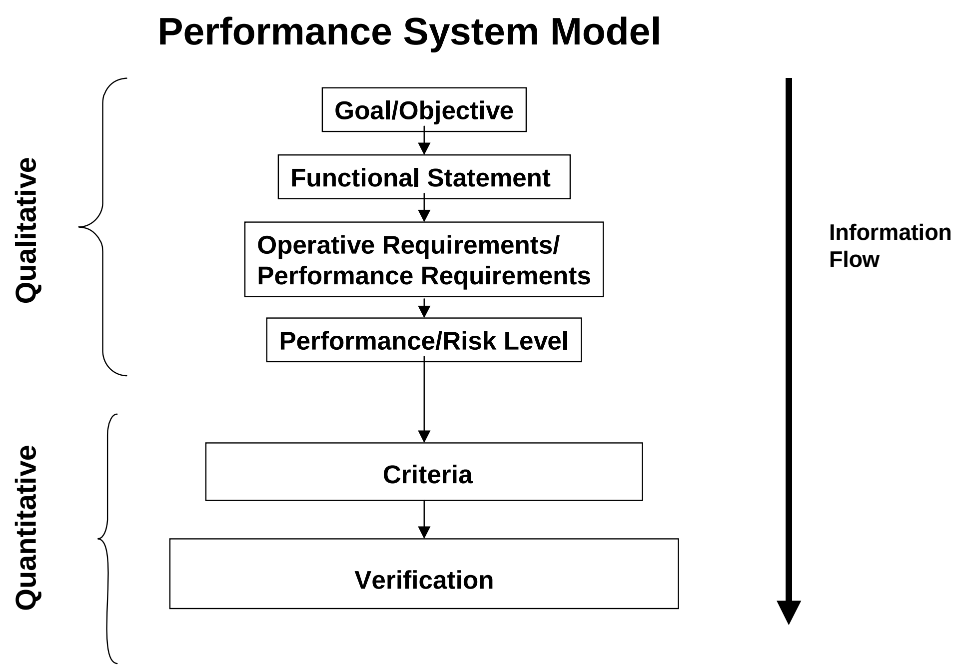

Figure 1

One should be able to view this model from the top down or the bottom-up. In other words, one should be able to start with a goal statement and be able to ultimately link to a specific quantitative requirement. Inversely, one should be able to look at a specific quantitative requirement and link to a top-level qualitative goal. If such linkages cannot be made then there is a disconnect. Generally, it should be remembered that the top-level policy/user need oriented portion of the model sets the scope for the quantitative portion.

Ultimately, when designing and constructing a building, quantitative, measurable methods and solutions need to be used. Such methods have been available in the form of prescriptive codes, standards and design approaches in the past. These approaches have generally been successful, but a key communication tool was missing. Without the qualitative level, society, public policy makers and building owners and users did not understand the full scope and intent of what a particular design or building regulations provide. The NKB approach used to create the qualitative portion of regulations in many countries has helped but still more information regarding the level of performance is needed. Generally, a lack of understanding of this level has led to negative reactions after natural disasters such as earthquakes.[iv] This also makes it difficult to justify new and innovative approaches since it is difficult to determine what is expected. In order for the performance approach to be effective strong communication tools are necessary which link society, public policy makers and building owners and users to the technical community. Therefore, the importance of the qualitative portion of the model is stressed. It is hoped that the communication tools will be strengthened and more closely link all stakeholders.

Qualitative

General

As noted this is the top level of the performance system model and focuses on more general statements of intent which express the needs of society or consumers. Detailed numerical or specific designs methods and solutions are not provided in this portion of the model since that has the tendency to stifle innovative approaches from occurring.

This portion of the model is critical since it provides a mechanism for policy makers and building owners to communicate their expectations in a method that is more familiar and understandable. Presenting technical performance criteria, such as a critical heat flux or specifying Standard XYZ will not be a successful communication tool. Conversely, a qualitative goal and functional statement must be able to link to a measurable approach to be practical.

Goals/Objectives

This is the top level of the performance model. Goals (also termed objectives), with respect to regulations, are intended to reflect societal expectations of minimum building performance. Goals also can apply to non-regulatory issues such as “efficiency in the workplace.” Such issues would be considered individual client expectations but in either case a goal must be drafted to ensure that the solution addresses the building owners needs.

These goals should be the driving force for the entire system. These goals set the stage for the evaluation of what functions the building must provide to accomplish these goals. Also these goals set the scope of issues that are of importance to address when determining to what extent a building shall perform, which will be discussed later in this paper.

Functional Statements

Functional statements answer the question, how does the building need to function in order to meet the demands presented by the goals? The functional statements generally should contain a reference to or link to an appropriate measure of performance. A reference to or a link to an appropriate measure of performance is necessary since the functions of a building ultimately need to be quantified to be constructed. Therefore, it needs to be understood to what degree a building must meet this functional statement.

Operative Requirements (Performance Requirements)

Operative requirements, sometimes called performance requirements, break the functional statements down into more measurable components. For example, an operative requirement would more likely look at fire resistance of a structure versus simply stating a building must withstand fire. These statements will also need to link to a measure of performance to ultimately construct the building.

Performance/Risk Level

This level is one that is not within the NKB structure. This element has been realized, as being essential to qualify to what level a building must address the functional statements and operative requirements to ultimately achieve the goals. Additionally, this level serves as the link between the qualitative goals, functional statements and operative requirements and the quantitative performance criteria and verification methods.

The establishment of a performance/risk level takes into account several characteristics of the building and the approach used in a regulatory system versus an individual building owner's expectations will vary. This portion of the structure will be discussed later in the paper as it pertains to both regulatory and individual client expectations. It should be noted that currently this portion of the model is found within the qualitative section of the model but its location may be debatable. More specifically it may sometimes be a combination of both qualitative and quantitative aspects. This is an issue which must be discussed further. It can be seen within the client expectation portion of the paper that this level is often a combination of both qualitative and quantitative information.

Quantitative

General

This portion of the model is where the building design occurs. There are two important aspects in the quantitative portion of the model that include the criteria level and the verification level. The performance criteria (or simply criteria) sets the acceptability range and the verification level (assessment or indication of performance) ensure that the design does in fact fall within the acceptability range through various methods of assessment. Standards also play a strong role in the quantitative portion of the PSM in that, in many cases, standards contain verification methods in the form of test standards or design methodologies that enable an assessment against performance criteria.

Criteria

The criteria level, often called Performance criteria, create the measure of pass/fail or range of acceptability for performance design and can also set the baselines for the development of standards. Typically in the past such technical criteria has originated from the technical community with little interaction with the policy makers or understanding of the consumer's needs. Frankly without a performance-based system in place the technical community often has had little choice but to be placed in this role. At the very least, in each project, the designers (technical community) should have as many relevant stakeholders together to discuss the needs of everyone involved to derive performance criteria that is most relevant and appropriate for the situation.[v,vi]

This model intends to formalize the need to relate the goals of both building regulations and individual building owner's expectations with performance criteria to ensure when a design meets the criteria that the goals have actually been achieved. These criteria as will be seen specifically in the non-regulatory applications refer to such criteria is indicators.

Verification Methods

Verification methods are intended to play the role of verifying that performance has been met. These methods are generally the design tools and measurement techniques. Essentially, a proposed design is taken through the process of verification, on a systems and more detailed level, to ensure that the criteria for acceptance is met. This verification can be through the use of assessment and design methods.

Standards

Standards play the role of providing a consistant approach. Such consistency facilitates trade and also can have the tendency to improve the quality of life as it increase compatibility and improves designs. There are several different kinds of standards, for example there are test standards, procedural standards and standards which focus on detailed specifications of products. Many standards organizations exist on a national and international level. Standards cover a wide spectrum of subjects and in some cases are specifically related to the building regulatory systems.

These standards have the potential to play a strong role in the verification of performance against a set of criteria. The application may be related to an overall methodology or the measurement of a single component. Currently, such standards are not closely linked with the top-level goals of a performance approach since in many cases the top-level goals and objectives have not been available when standards have been developed. More discussion on some of these issues is being pursued by TG37[vii]

REGULATORY USE OF PERFORMANCE MODEL

This portion of the paper will explore the relationship of the performance system model to the regulatory portion of building performance. In particular the interaction of the performance criteria and verification levels with the qualitative portion of the model will be discussed.

It should be noted that the discrepancies described above are not new to performance regulations; it is simply more obvious since the intent of the regulations are intended to be clearly stated. The need for clear framework in this area is becoming more and more important with the ever-increasing global market place. Without a structure, standards, performance criteria and verification methods may be used which are not reflective of the different cultures and levels of expectations in building regulations. If levels of performance are implicitly included that cannot be directly linked with the qualitative portion of the regulations, inappropriate levels of performance may be used that are inconsistent to the cultural or climatic conditions of different areas of the world. The portion of the performance regulatory system which is mandatory will vary from one country to another.[viii]

Qualitative

Performance/Risk Level

In most performance regulations in existence currently, qualitative intent statements are often provided in the form of goals (sometimes called objectives), Functional Statements (functional requirements), and operative requirements (performance requirements). The Performance System Model takes this structure one step further and provides a mechanism to create a more measurable link to the quantitative portion of the model. This level is called the performance or risk level. This portion of the model addresses several components that include the use of a building, the importance, risks, expectations of users and the types of hazards likely to impact the building. This approach allows the user to better understand the different levels of performance desired from one building over another based on the particular factors addressed above and to take that understanding and form quantitative information for design.

The focus, until now, with regard to the concept of performance/risk levels has been upon event oriented risks such as fire, earthquake and hazardous materials releases. It is recognized that there are other regulatory issues with building regulations that are not event oriented and instead are related to everyday use of a building such as slip hazards, plumbing and access to those with disabilities. These issues will likely be areas of discussion in the future as to how they can be dealt with regard to multiple performance levels.

Quantitative

Performance Criteria

In terms of performance criteria, there is a concern, in some cases, that the criterion chosen for design do not coincide with the goals (objectives) of the regulations. In other words, the criteria do not address the issues that the objectives intend, or perhaps are too high or too low for the regulatory expectations. Due to the lack of direction provided, in many cases, the technical community is placed in the role of determining performance criteria with regard to the intent of the regulations. This decision, however, is a policy decision, and should not be left to the technical community alone.

An example of this problem is found with the limit states that a structural engineer chooses: What if they do not match what society expects? This is not necessarily the fault of the structural engineer, but rather is a function of inadequate communication between the technical community and the policy makers. The Northridge earthquake in California, United States was a perfect example of the mismatch between society and the technical community. As far as the technical community was concerned generally buildings performed as expected and within acceptable ranges. Whereas society was not satisfied that buildings needed extensive repairs or had to be rebuilt completely. [ix]

Verification Methods

Verification methods have shortcomings as well, as in many cases they do not provide data relevant to the objectives. The standard fire resistance test such as ASTM E119, for example, simply provides a relative ranking of fire resistance based upon an unrealistic fire conditions. More specifically, a wall rated one-hour in the standard fire resistance test does not directly correlate to an hour in an actual fire. There are many fire test standards that have similar pass-fail criteria. Such information is not useful for performance design and does not relate to the objectives of the regulations. These discrepancies are primarily related to the lack of framework provided by the regulatory systems and the difficulty in understanding the intent of the existing prescriptive methods. If the regulations do not state what is expected, in terms of performance, it is very difficult to determine which tests and corresponding results will help demonstrate this performance. Also, a large gap exists in the ability to communicate the technical aspects of building regulations to the public policy makers. This gap was not as well understood when adopting prescriptive codes since the public policy makers were implicitly adopting a level of safety. In a performance environment the level of safety becomes more explicit and needs to be specifically addressed.

There are currently hundreds of test methods available in many different subjects some regulatory and some focused on consumer goals. Generally most tests currently are structured in a manner that focuses on a pass/fail criteria that does not relate to real world conditions. Instead they tend to provide a relative ranking system. An example would be a standard that measures the char length of cigarettes in upholstered chairs when exposed to a lit cigarette. The standard is looking at ignitability but only as it relates to one chair to specific ignition scenario. A particular fire exposure is used and the length of char is measured. While it is important to have an idea as to which chair is less ignitable than another such data is of little use to someone conducting a fire protection analysis of a building.

It should be noted that over time a demand for tests that provide more relative information for design has grown. This is likely due to the fact that engineers are trying to conduct performance design and are finding little in the way of resources. Also, this may be related to failures experienced in buildings, which generally complied with the building regulations. For example some newer fire tests have focused upon actual heat release measurements or other more relevant measures of performance.

Standards

Standards generally support verification methods by providing testing standards and methodologies to demonstrate compliance with performance criteria.

In some cases, standards exist that may exceed the minimum levels of the regulations. For instance, a manufacturing association may have a standard for a particular building component. This standard provides many specific requirements that are related to the demands of the consumer in addition to the requirements related to the regulatory minimums. This standard is therefore inconsistent with the minimum regulatory requirements.

Standards are generally not adopted directly by the building regulations but instead mandatory references to the standard are made within the regulations. Therefore they become the law indirectly and should, in theory, be held to the same due diligence as the regulations themselves. These standards and verification methods at present are designed to work primarily within a prescriptive system where the standards, generally, are not written in such a way which identifies what they are ultimately trying to achieve. Until the more recent trend towards performance regulations and design internationally there have not been the specific goals in which to link to. Therefore, like the prescriptive codes and other design solutions it is often difficult to determine the performance level provided by the standards. As noted earlier in this paper this level it is sometimes higher or lower than what the regulations that reference such standards require. This gets more complicated when standards developed internationally are applied to cultures that are very different from those involved in drafting the standard. Standards and regulations, especially when drafted in a prescriptive manner, have the tendency to force certain types of construction methods, such as wood frame construction or concrete construction due to the fact that many standards are based upon construction practices in specific locations. These prescriptive standards tend to create a standard of practice to the exclusion of other types of construction found in other countries that have not been heavily involved in the standard writing process. An example of such construction may be bamboo or perhaps rammed earth. It should be noted that there is a movement internationally to address these other building methods in various countries including but not limited to New Zealand, United Kingdom and the United States. Also, different countries and cultures regulate different issues. A standard, which heavily addresses property protection, would be inappropriate to be referenced in a country where building regulations are not intended to address property protection.

Standards which set out certain test methods to verify compliance such as the fire resistance test or perhaps a strength test are not necessarily reflective of real world conditions and the data generated during such tests is generally not the type of data needed for an engineering analysis.

This model is proposing that future standards must be more closely linked into the objectives of regulations in order to more closely understand what the standard is addressing and to fit more closely with the regulations. Essentially, standards need to be more straightforward in there contents as to what the standard addresses. This does not necessarily mean that standards need to be written in performance language. It may simply mean that the provisions need to be sufficiently justified in there contents. In order to assist in the more appropriately linked standards performance criteria needs to be developed in order to form a basis as to which standards can be written.

NON-REGULATORY USE OF THE PERFORMANCE CONCEPT

Roots of the Performance Concept

The performance concept in building, as used by client organizations outside the regulatory system, has roots before World War II in Canada, the United States, and overseas. In the United States in the 1950s and 1960s, the Public Buildings Service (PBS) of the General Services Administration (GSA) funded the National Institute of Standards and Technology (NIST, then the National Bureau of Standards) to develop a performance approach for the procurement of government offices, resulting in the so-called Peach Book publication. [x]

Starting in the early 1980s, the performance concept was applied to facilities for office work and other functions by the American Society for Testing and Materials (ASTM) Subcommittee E06.25 on Whole Buildings and Facilities. Worldwide, in 1970, the International Council for Building Research Studies and Documentation (commonly known as CIB) set up Working Commission W060 on the Performance Concept in Building. In 1982, the coordinator for that commission defined the concept in those terms: "The performance approach is, first and foremost, the practice of thinking and working in terms on ends rather than means. It is concerned with what a building is required to do, and not with prescribing how it is to be constructed."[xi] CIB W060 complements the work of TG37. In 1998, the CIB launched a proactive program for the period 1998-2001 focused on two themes: the performance-based building (PBB) approach, and its impact on standards, codes and regulations, and sustainable construction and development.

Why use the Performance Concept for non-regulatory purposes? For the some of the same reasons that are driving the changes in building regulations: increased flexibility, reduction in the barriers to innovation, greater ability to integrate processes, delivery, services and products, overall cost reductions, and added range of suppliers.

How does the non-regulatory use of the Performance Concept fit in

The Performance System Model applies also to non-regulatory uses (Figure 2). In their "Statement of Requirements (SOR)", clients need to state their objectives and goals in broad terms. These can then be broken into "aspects", "topics" and "functional elements", expressed as Functional Statements that are more and more precise (granularity).

The difference between the regulatory and non-regulatory parts of the Performance System Model is that one is mandated by codes and regulations that have the force of law, whereas those other functional requirements, that are included in Statements of Requirements and defined by a client for a project, are part of what the client requires and is willing to pay for. Functional requirements mandated by Codes and Regulations are included in the Statement of Requirement for a project, at a level of performance either explicitly or implicitly at least equal to the level mandated by the code.

Bergeron notes that "Tools will need to be developed for the purpose of determining the implicit expectation of performance of the acceptable solutions and to transcribe it into quantitative and measurable performance criteria." In the non-regulatory world, "Design Guides" play a role similar to "acceptable solutions."[xii] "Prescriptive Request For Proposals", "Bid" documents which include design concept and specifications, "Solicitations for Offers" are also part of the traditional prescriptive system. Appropriate tools such as the ASTM Standards described below have been used to assess the implicit level of performance of such documents. A similar approach might be usefully applied to assess the implicit performance levels of acceptable solutions.

ASTM Standards for Whole Building Functionality and Serviceability

The ASTM standard scales[xiii] provide a broad-brush methodology, appropriate for strategic, overall decision-making. The scales deal with both occupant requirements (*demand*) and serviceability of buildings and facilities (*supply*). They can be used at any

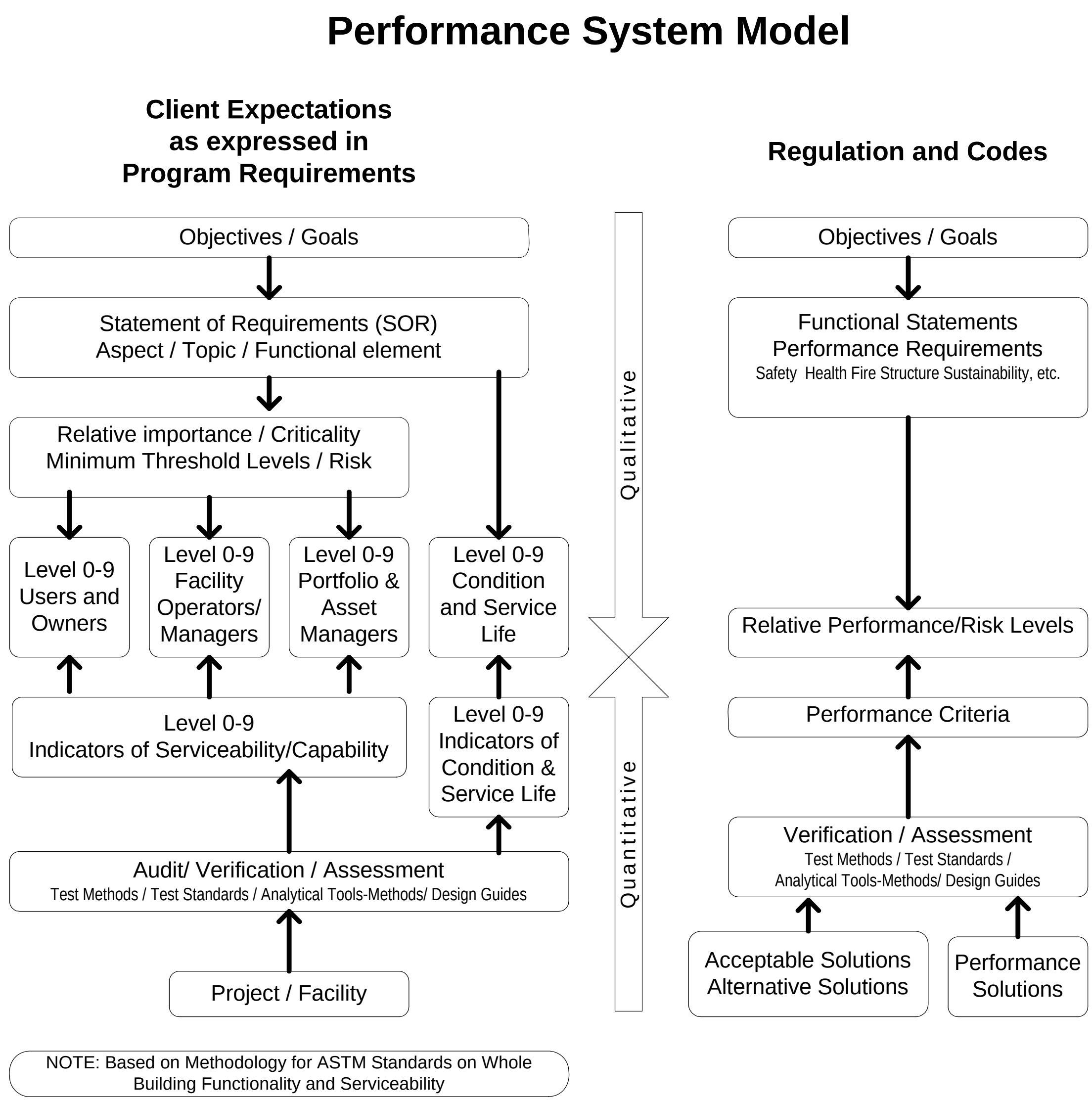

Figure 2 - Regulatory and Non-regulatory Application

time, not just at the start of a project. In particular, they can be used as part of portfolio management to provide a unit of information for the asset management plan, on the one hand, and for the roll-up of requirements of the business unit, on the other.

The ASTM standard scales include two matched, multiple-choice questionnaires and levels. One questionnaire is used for setting workplace requirements for functionality and quality. It describes customer needs—*demand*—in everyday language, as the core of front-end planning. The other, matching questionnaire is used for assessing the capability of a building to meet those levels of need, which is its serviceability (range of performance over time). It rates facilities—*supply*—in performance language as a first step toward an outline performance specification. Both cover more than 100 topics and 340 building features, each with levels of service calibrated from 0 to 9 (less to more). These standard scales are particularly suitable to set the requirements as part of the front end for a design-build project, to compare several facilities on offer to buy or lease, or to verify if requirements have been met during the contracting process, design reviews and commissioning. The scales can also be used to compare the relative requirements of different groups.

This set of tools was designed to bridge between "functional programs" written in user language and "outline specifications and evaluations" written in technical performance language. Although it is a standardized approach, it can easily be adapted and tailored to reflect the particular needs of a specific organization or the particular features of a specific facility. For organizations with many facilities that house similar types of functions, the functionality and serviceability scales capture a systematic and consistent record of the institutional memory of the organization. Their use speeds up the functional programming process and provides comprehensive, systematic, objective ratings in a short time.

Benchmarking and comparisons

The ASTM standards include two sets of scales in recognition of the need for comparison between what is required and what is provided, and to allow for the audit and verification that what is provided to the client in fact meets the stated requirements. Such scales include "statements of functional requirements" in order to make explicit these so-called "non-measurable" requirements. In order to measure the levels of serviceability, "indicators of capability" are included in the second set of scales, and matched to the levels of functionality.

The scales include 9 levels from LEAST to MOST (0-9), or Hazardous to NEW (0-9), because, as is pointed out by Bergeron (2002), functional requirements are not "absolute, and differ from one situation to the other. Equivalent levels between the stated requirements and the solution provided, or the indicators of performance, is one of the hallmarks of the ASTM standards. These levels can be graphed as bar charts and used to create a "Requirement Profile" or a "Rating Profile". Profiles can be compared to each other. Facilities can be compared to each other. They can be compared to "generic" profiles of requirements. (Figure 3)

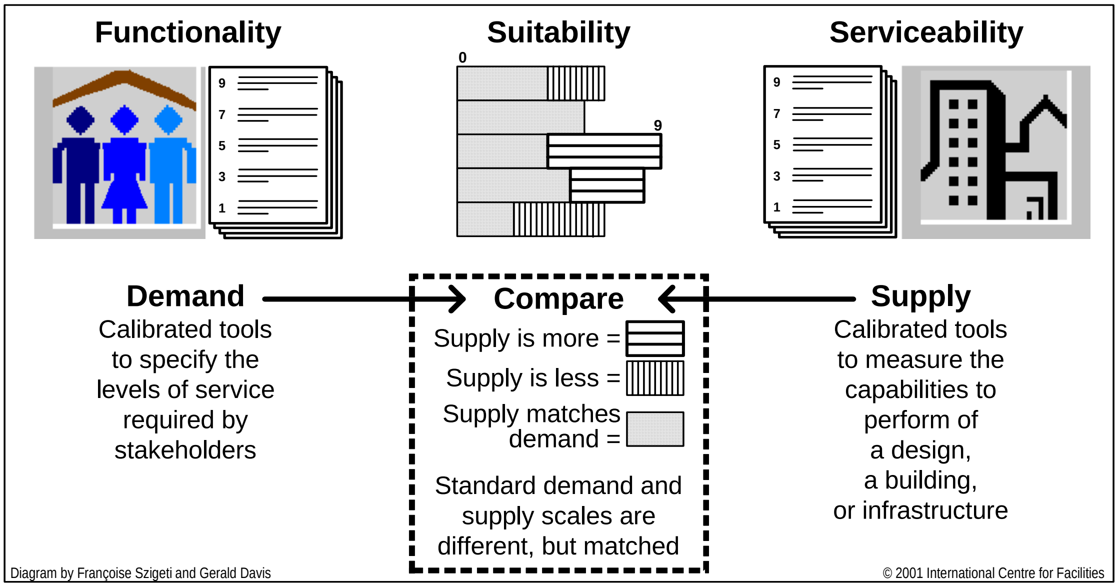

Figure 3 - Comparing What is Required with What is Provided

Trade-offs

Different situations can have a different "profile of requirements" for the same occupancy category. If a requirement cannot be met by a design or existing facility, the profile of requirement includes "threshold" and relative importance/criticality, so that trade-offs can be proposed, analyzed and costed, as a basis for informed decisions. This is particularly important when dealing with historic structures which cannot be brought up to code without destroying their unique qualities.[xiv] It is also useful when there is a need for budget adjustment and during value engineering reviews.

Methodology is currently in the ISO balloting process

The methodology used to create the ASTM scales is currently being balloted in ISO and under the authority of Technical Committee 59 / SC3. A new WG14 has been established within SC3 to further develop related standards. For further information about this methodology, readers can refer to the papers and documents listed.[xv]

CONCLUSIONS

This model is the next step forward in the evolution in the performance of buildings. The Performance System Model (PSM) is now officially introduced. This model is the result of a combination of the NKB model with a risk/performance levels by Brian Meacham[xvi] and the IRCC. It is hoped that this introduction will lead to a better communication tool to those involved with both performance based building regulations but also with performance based design in general. Also, this model clearly points out a problem with general references of criteria, verification methods and associated standards from one regulatory system to another and from one project to another. It is hoped that this model and an explanation of these discrepancies will provide direction for standard development in the future

Additionally looking at the full spectrum of performance from the basic regulatory minimums to the area of client of expectations shows how performance regulations are simply one aspect and the applicability of the model to all areas of design. This understanding should provide more insight to disciplines such as structural engineering and fire protection engineering related to regulatory minimums. Such design disciplines in many ways have had the primary focus on regulatory minimums for compliance without a greater understanding of the overall level of performance and how such design should look deeper than minimum compliance.

In exploring both the regulatory and non-regulatory issues different approaches were presented. In the regulatory environment there is a push to compare directly to technical performance criteria to show that the goals/objectives are met. Whereas in the non-regulatory arena, the use of scales to indicate the serviceability (performance over time) are used. The scales are a relative measure of performance where the technical performance criteria tend to provide a more specific independent indication of performance.

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ROLE OF ACCEPTABLE SOLUTIONS IN EVALUATING INNOVATIVE DESIGNS

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Introduction

Building regulatory systems around the world are going through dramatic change in response to changing stakeholder needs and political environments. The common element resulting from the changes however is the introduction of greater flexibility for the building code users. This is achieved through the explicit statement of the goals/objectives of the regulations and an increased use of performance-based requirements. This characteristic of these new building regulatory systems is an important feature for those wanting to encourage innovation and the advancement of new technologies.

In the past the prescriptive code provided the code users with solutions which were considered acceptable to the regulatory system. The knowledge was lacking as to how to express the desired outcome in performance terms so it was provided in the form of specification-based acceptable solutions.

A common characteristic of these new regulations, generally referred to as performance or objective-based, is that they include or are supported by at least one set of acceptable solutions which are deemed to deliver the required performance. An increase in the number of acceptable solutions will likely occur over time as new approaches and methods are employed in building construction. They will not necessarily all perform at the same level but they will all be considered to deliver at least the minimum level of performance expected by the building regulation in all areas covered by the regulation.

A point of departure within countries which have implemented performance-based or objective-based building regulations is how innovative designs are handled. Innovative designs are methods of complying with the regulations which differ from the acceptable solutions, usually but not necessarily project specific. Generally speaking there are two ways these innovative designs can be assessed for compliance against the regulations: assessing against the goals/objectives and performance requirements (first principles approach), or comparing against the stated acceptable solutions (benchmark approach). There are pros and cons to the two approaches and they can co-exist. The decision as to which approach or combination of approaches is employed in a specific country is governed by broader aspects of the legal system and desired regulatory framework being pursued.

Some areas of building regulations already benefit from sufficient knowledge to support the expression of performance requirements in measurable and verifiable terms. Examples include energy conservation, structural design, and some aspects of fire safety. In such instances, assessing innovative designs against performance requirements would seem a logical approach that could provide greater design flexibility while clearly specifying in quantitative terms the minimum level of performance expected by the regulations.

However the complete knowledge to express the performance requirements in measurable terms that can be verified at the time of construction still does not currently exist in all areas of building regulations. This paper will describe typical areas where performance requirements currently do not benefit from sufficient knowledge to be expressed in measurable and verifiable terms. Examples include sanitation, comfort, accessibility, and some other aspects of fire safety. These areas are often characterized by the significant impact of human behavior on the establishment of minimum levels of performance.

This paper will show how the role of the acceptable solutions has become very important in today's performance-based regulations. These acceptable solutions often implicitly determine the level of performance expected by the regulations. Acceptable solutions can play two roles:

1. in those areas where efforts are made to express performance requirements in quantitative terms, acceptable solutions can be viewed as an implicit statement of the performance level expectation of the regulations and their analysis can be used in developing quantitative performance criteria;
2. in those areas where performance requirements are not expressed in quantitative terms, acceptable solutions can be used to establish the baseline against which innovative designs can be compared to determine compliance with the regulations.

There are many issues and questions surrounding acceptable solutions, which must be addressed by those implementing performance-based building regulatory systems. CIB TG37, Performance-Based Building Regulatory Systems, is working to gather information and experiences related to these issues and questions. TG37 works closely with the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) consisting of several countries engaged in building regulatory system reform. In many of these countries, the reform takes the form of a performance-based building regulatory system and IRCC focuses on identifying key issues for implementing such systems[xvi].

This paper will answer the following questions regarding acceptable solutions:

1. What are acceptable solutions?
2. What is the relationship between acceptable solutions and the goals/objectives and performance requirements?
3. What is the role of acceptable solutions in a performance-based building regulatory system?

This paper will present the work to date of TG37 in studying these issues and questions. This paper is a further development of earlier work accomplished by TG37 in analyzing acceptable solutions. This earlier work was expressed in a paper[xvi] presented at the CIB World Building Congress 2001 in Wellington, New Zealand.

The information offered in this paper results from discussions and responses of TG37 members to questionnaires on issues related to acceptable solutions. This paper attempts to reflect current understanding of the majority of members involved in these discussions and may not necessarily represent the position of any specific member.

Performance Based System[xvi]

Although the concept of performance-based building regulatory systems is relatively new, most countries engaged in such a reform agree, with some variations, on a performance system model[xvi] which can be simplified for the purpose of this paper into two components:

1. a qualitative expression of the goals/objectives of the regulations and of the functional requirements to be met by the building as a whole, and/or for its systems, components and elements;
2. quantitative and measurable performance criteria and verification methods.

The qualitative portion of this model is the regulation expression of the needs and expectations of society to be met by the performance of the building or facility. The quantitative portion of this model contains the tools offered to the construction community for the design and construction of buildings. This quantitative portion is key to the performance system model.

Quantitative Performance Criteria

Some areas of building regulations already benefit from sufficient knowledge to support the expression of performance requirements in measurable and verifiable terms. Examples include energy conservation, structural design, sound insulation, and some aspects of fire safety. In such areas, quantitative performance criteria are available to the building design and construction community. Even in these areas, the term "performance" can have different meanings. In some areas, performance criteria can set the performance expectation of society to be met by the building as a whole. An example could be energy conservation regulations where the performance target to be met by the whole building may be set in terms of the total energy consumption without stipulating the individual contribution of the various building components and systems. In other areas however, performance targets will be set for building components and systems and regulations will not clearly establish the overall performance expectation of society to be met by the building as a whole. An example could be fire safety, more particularly in those areas related to fire growth (design fire characterization), fire spread (standardized test methods for flame spread and smoke contribution classification), fire resistance of building components (standardized test methods for fire resistance rating), smoke management, fire suppression systems, etc.

Qualitative Performance Criteria

It is however recognized that knowledge may not be readily available in all areas of building regulations to allow the expression of performance expectations in measurable and verifiable terms. Examples include personal hygiene, comfort and well-being of people, access and movement of people - including people with disabilities, safety of people from injury, aspects of fire safety - more particularly those related to prevention of fires and human behavior in fire emergencies.

Most building regulations have provisions aiming at reducing the risk of injuries to building users as a result of trip and fall accidents. Stair geometry and handrail design requirements are part of most building regulations. These requirements are generally prescriptive: stair rise and run dimensions (min./max. or ratio), handrail height (min./max.), etc. Sufficient knowledge is not available to support the expression of these requirements in performance terms. Past performance of stairs and handrails designed with such prescriptive specifications has proven to be acceptable. Embedded in these prescriptive requirements are performance levels that can be deemed to meet society's needs and expectations. Expressing such implicit performance levels in quantitative and measurable terms may prove to be a very difficult task. What aspects of performance should be defined? Rate of accidents in stairs? Nature and severity of accidents? Consideration for age groups?

This paper focuses on such building regulation areas where performance expectations are not easily expressed in measurable terms and where acceptable solutions can play an important role. The work done by TG37 on a case study is first briefly described in order to introduce the discussion on acceptable solutions later in this paper.

Case study

Two approaches in performance-based building regulations are referred to at the beginning of this paper. The first principles approach assumes that quantitative performance criteria are available or can be developed, while the benchmark approach relies on acceptable solutions (prescriptive specifications) to evaluate innovative designs. An apparently simple case study was used by TG37 to examine how these two approaches could be used in evaluating an innovative design solution in a performance-based building regulatory system.

The case study deliberately stayed away from fire or structural engineering examples because of the multitude and complexity of design and evaluation tools available, which would turn the attention away from the main topic being presented. The following case involving sanitary facilities was therefore developed and submitted to CIB TG37 and IRCC representatives from several countries with the purpose of describing what would the decision-making process be in their respective country for each of the two approaches: first principles and benchmark.

CASE:
In order to save space for the construction of a new concert hall, a design team proposes to reduce the number of available water closets (from what is required by prescriptive specifications) in close proximity to the spectators seating area. In order to demonstrate that this proposal is satisfactory, the design team puts forward the following argument: Studies have demonstrated that many people spend unnecessary time using public sanitary facilities. The proposed washrooms and water closets will incorporate several new features that will reduce the amount of time a person is likely to spend using these facilities: annoying background music, unpleasant odours, aggressive colours, uncomfortable appliances, bare minimum circulation space, etc. People will spend less time using the public washroom facilities and the sanitary needs of the occupants will therefore be met with fewer water closets.

QUESTION:
Could you briefly describe what would be in your country the decision-making process for evaluating this proposal - keeping in mind the two approaches described in the paper: first principle and benchmark - especially with respect to:

1. establishing what is the acceptable level of performance of sanitary facilities in a concert hall,
2. checking the proposal against the goals/objectives, functional requirements/statements, performance requirements, etc.
3. using the acceptable/deemed-to-comply solutions.

The results of this consultation were quite surprising. It appeared that no country could readily apply the first principles approach to this case and that the qualitative nature of the goals/objectives, functional requirements and performance requirements made it necessary to use other tools to evaluate the proposed innovative design. None of the building regulations consulted had been able to express the design criteria for sanitary facilities in quantitative and measurable terms. Related performance statements remained qualitative with ample use of non-measurable terms such as suitable, convenient, appropriate, etc.

First Principles Approach

Some members nevertheless explored the possibility of using a first principles performance-based decision-making process for this case. This exercise raised a number of concerns without identifying a clear direction. The following is a list of some of the concerns raised. It represents some of the issues that could be required to be addressed and documented by the proponent in order to provide sufficient evidence that the innovative design is acceptable and satisfies the goals/objectives and functional requirements of the regulations:

1. The designer should present design load, the parameters used and the final solution should be documented.
2. Establishing the acceptable level in a concert hall would have to consider parameters regarding health, hygienic standards and possibly comfort and amenities. It would also have bearing on related items like ventilation requirements and noise reduction affecting each individual.
3. For building products there are durability requirements, and sanitary appliances may be chosen according to expected use.
4. Relating this to a more engineering like approach a type of risk analysis method (as a product of consequence and frequency of occurrence) may be used and the «risk» level established. This should again refer the material factor (the failure or breakdown of the appliances) and the load factor - population, demographic parameters, time assessment etc.
5. Checking the proposals against the goals/objectives would have to consider the cumulative effect of the solution.
6. What are the physical limits to what is necessary time spent in a washroom, and what time is desirable for secondary functions like washing hands.
7. The use and the load on the facilities shall be considered. The number of persons, demographic patterns the uses (rock or classical concerts), the level of catering or serving drinks and assessing periods of intervals.
8. Consider the likelihood of alternative patterns of behaviour and possibility of changed behaviour. This would relate to whether the public would be familiar with the facilities and if so the likelihood of being prepared for alternatives.
9. Consider the secondary effects of the proposed solution: aggressive colours may lead to violent behaviour, unpleasant odours may have a negative effect on occupants of adjacent spaces, etc.

The general reaction to the use of a first principles approach in this case study was that questions on the performance expectations of the existing regulations remain unanswered. The broad range of concerns raised is an indication that several aspects of the proposed solution need to be examined and that no guidance exists in the qualitative goals/objectives and performance requirements. This fairly long, although partial, list of concerns is also an indication that a first principles approach in this case may rapidly lead to a very complex and expensive design and decision-making process. Looking at each of the concerns listed above also reveals that they raise questions in areas where scientific knowledge, statistical data or information on past performance are not readily available. This otherwise very simple case study seems to identify an area of building regulations – sanitary facilities – where more research and studies are needed in order to support the expression of the performance requirements in quantitative and measurable terms. Another aspect may simply be the lack of cost benefit or need to even approach this topic from first principles. This may be why such technical information has not been generated.

Benchmark Approach

Comparison with the prescriptive specifications of the acceptable solutions was identified as a viable avenue. The benchmark approach process was generally perceived as simpler and more straightforward than that of the first principles. It was suggested that the proposal could be assessed by comparing the amount of queuing time taken for the patrons to use sanitary facilities complying with the prescriptive specifications with the numbers being proposed under the performance-based solution. This would provide the necessary benchmark for the assessment to take place. If the queuing times to use the proposed performance-based solution resulted in equal or less queuing times than the current prescriptive specifications of the acceptable solutions, then it could be argued that the proposed solution meets the performance requirements. It was also argued that concerns over legal liability could refrain designers and building officials from considering a solution for which clear evidence cannot be provided that it will offer a level of performance at least equivalent to that of the acceptable solutions.

One of the conclusions of the work of TG37 on this case study is that acceptable solutions can play an important role in a performance-based building regulatory system, more specifically in areas where performance requirements are not expressed in quantitative and measurable terms.

Acceptable solutions

Traditionally the prescriptive approach was to write a code with a single method that had to be followed. Implicit in these prescriptions was the level of risk or performance, which was acceptable to society. These prescriptions would frequently be the first acceptable solutions.

What are Acceptable Solutions?

The term “acceptable solution” means many things to many people and is used indifferent ways around the world. From the perspective of the building regulatory structure, an acceptable solution is considered to be a set of provisions which when met will deliver the desired performance as intended by the goals/objectives and performance requirements. Acceptable solutions are examples of compliance with the regulation. In this paper, the term “acceptable solution” is used in a broad sense and shall include prescriptive solutions as well as those expressed in performance terms, including their verification methods. In most countries the body that develops the code usually establishes the acceptable solutions. The name given to acceptable solutions and their relationship to performance requirements vary from one country to another. Acceptable solutions are sometimes referred to as deemed-to-satisfy solutions and are often included in approved documents or guidance publications, which form an integral part of the building regulation. It is anticipated that over time the number of acceptable solutions will likely increase so that code users will have more ready-made options to choose from.

The different ways of "packaging" acceptable solutions can be cause for confusion. In at least one country, the body responsible for the development of the building codes will publish two building codes that are offered as equivalent alternatives: one is called the performance-based code, while the other contains a full set of essentially prescriptive specifications covering the same areas as the performance-based code. Although not specifically identified as such, the latter prescriptive code is equivalent to what is called "acceptable solutions" in other countries that do not have a dual code system. In another known case, a building code will contain one chapter describing the performance-based approach while the other chapters contain prescriptive specifications that are deemed to provide solutions equivalent to those that would be developed using the performance-based approach. Again, the packaging is different but the prescriptive chapters of this building code play the same role as acceptable solutions and are included in the term "acceptable solutions" for the purpose of this paper.

What are Innovative Designs?

An innovative design (also called alternative solution) is anything that differs completely or partially from what is described in the acceptable solutions. This concept does not exist in a performance-based design process with quantitative performance criteria. But, as shown earlier, many areas of building regulations do not benefit from sufficient knowledge to support the expression of performance requirements in quantitative terms. In those areas where performance requirements are expressed in qualitative and non-measurable terms, acceptable solutions may become a viable option for evaluating innovative designs. It is only in this context that the term "innovative designs" is used in this paper.

Innovative designs present ways of complying with the building regulations that differ from the specifications contained in the acceptable solutions. They can be a unique solution for a specific building or be a solution which represents a type of construction that is repeated in different buildings or locations. The solution can just meet the requirements or be significantly better than the minimum. In many countries, these solutions must be accepted by the local authorities or by some established organization acceptable to the building regulatory authority. This is where some confusion comes up because the solution would be "accepted" by a local authority as an alternative to the corresponding acceptable solutions in the building regulations. That acceptance by one local authority is not legally binding on anyone else. That contrasts with the corresponding acceptable solutions, which is part of the building regulations and is binding on all local authorities administering the building code.

What is the Role of Acceptable Solutions?

1. Acceptable solutions have become an important part of the new performance-based regulatory systems. What has happened in the transition to performance-based regulations is a majority of the designers and builders continue to want to follow the acceptable solutions they have become more familiar with. Even though there is greater flexibility if a performance-based design is chosen, anything more than comparatively minor departures from the acceptable solutions is viewed as a higher risk or more costly approach and is only used in certain kinds of projects. Consequently, when looking at performance-based regulations today, most countries will have some form of a more prescriptive option available for their stakeholders.

2. As illustrated in the case study discussed earlier, many areas of building regulations rely on qualitative and non-measurable performance criteria to determine the acceptable level of performance of building solutions. It is recognized that acceptable solutions can play an important role in evaluating innovative designs in such areas of the regulations. The implicit level of performance of acceptable solutions can be used as a baseline against which innovative designs can be compared to determine equivalency. Unlike the efforts placed in the development of performance design tools, models and methods, little work has been done internationally towards the development of tools for the purpose of benchmarking the implicit expectation of performance of the acceptable solutions. In Canada, the Fire Risk Management program of National Research Council has developed computer-based decision-making tools in support of this role of acceptable solutions (see discussion below under Canadian Approach).

3. Under prescriptive codes, policy makers were adopting solutions that were deemed to meet society's needs and expectations as they relate to building performance. Embedded within the prescriptive specifications are implicit levels of performance: adopting the solutions also meant adopting these implicit levels of performance. Seen from this angle, acceptable solutions of the building regulations contain society's performance expectations.

In performance-based regulatory systems, the goals/objectives and performance expectations are more explicit. Determining and quantifying the level of performance through measurable performance criteria should be the role of policy makers as an expression of society's expectations. One possible way of determining what level of risk or performance is acceptable to society is to examine the acceptable solutions with their past performance record. The implicit level of performance of acceptable solutions can be used by policy makers in developing acceptable performance criteria for performance-based systems. If policy makers do not play this role, the technical community (designers, manufacturers, builders, etc.) will be placed in the role of determining what is an acceptable level of performance to society.

Canadian Approach

During a strategic planning exercise that lead to the articulation in 1995 of the objective-based code concept in Canada[xvi], the Canadian Commission on Building and Fire Codes first examined the possibility of embarking in a performance-based building regulatory reform. The Commission quickly realized that sufficient knowledge is not available in several building regulation areas for the expression of performance expectations in quantitative, measurable and verifiable terms. The Commission considered that development of performance-based codes with qualitative and non-measurable performance criteria would be too disruptive to the construction process and was not acceptable for Canada. A transitional approach called objective-based was approved and is currently being developed. The first objective-based national building, fire and plumbing codes of Canada are scheduled to be published in 2004.

Objective-Based Codes

The fundamental concept behind objective-based codes in Canada is the recognition that the acceptable solutions represent an implicit expression of the levels of building performance that are acceptable to society. Objective-based codes are articulated around acceptable solutions[xvi], which play all 3 roles described earlier in the discussion on the roles of acceptable solutions.

1. In objective-based codes acceptable solutions are maintained and represent one of the two compliance options. Following pertinent specifications of the acceptable solutions is deemed to meet the goals/objectives and performance expectations of the regulations. Acceptable solutions consist of essentially – but not exclusively – prescriptive specifications that have been developed over time under the code development system in place before the introduction of objective-based codes. Acceptable solutions will continue to be developed and updated under objective-based codes and will continue to offer to code users an easy way of complying with building regulations.

2. The second compliance option under objective-based codes is through the use of alternatives, i.e. innovative solutions that differ from the specifications of the acceptable solutions. To be acceptable, an alternative must however provide a level of performance at least equivalent to that of the acceptable solutions. This very important feature aims at preventing an unintentional reduction or increase in the level of performance and quality of construction that could result from the introduction of objective-based codes. This is a clear statement that the acceptable solutions (specifications developed over the years) do set out the level of performance deemed to be acceptable to society and that objective-based codes shall not inadvertently facilitate the use of building solutions with a lower performance level. A reduction or increase in the acceptable level of performance is possible under objective-based codes and can be achieved by the

introduction or revision of acceptable solutions against which alternatives will be compared.

In preparation for the development of objective-based codes, the technical committees responsible for the development and updating of acceptable solutions have examined each and every code specification with the mandate of determining their goals/objectives and intents. In objective-based codes, each specification of the acceptable solutions is tied to well defined objectives and functional statements. When evaluating innovative solutions for compliance, the areas of performance to be examined are clearly identified by the objectives and functional statements attributed to each specification of the acceptable solutions.
Innovative solutions are not limited to "prescriptive" solutions. Both prescriptive and performance design options are permitted but their common denominator is that any alternative shall provide a level of performance at least equivalent to the acceptable solutions it replaces.

3. Objective-based codes may be perceived as a transitional approach towards the introduction of performance-based design criteria in building regulations. As more knowledge becomes available, areas of the codes may be developed into a performance path with quantitative, measurable and verifiable performance criteria, including their verification methods. This could become a third compliance option in addition to the two options described under points 1 and 2. One area of the current codes that appears to be a good candidate for such development into a performance option is structural design.

In developing performance criteria, the implicit level of performance embedded in the acceptable solutions and deemed to be acceptable to society shall be analyzed to ensure that a performance option will not inadvertently lead to a general reduction or increase of this accepted level of performance. Tools will need to be developed for the purpose of determining the implicit expectation of performance of the acceptable solutions and to transcribe it into quantitative and measurable performance criteria.

Decision-Making and Fire Risk Assessment Tools

FiRECAM™ and FIERAsystem are computer-based fire risk assessment tools that can be used to evaluate fire protection options and costs for office, apartment and light-industrial buildings. FiRECAM™ and FIERAsystem are developed by the Fire Risk Management group at the Institute for Research in Construction (IRC) of National Research Council Canada. These tools do not establish the level of performance in absolute terms but allow the benchmarking of current codes and can be used to determine if different fire protection options would have an impact (reduction or increase) - and the relative importance of such impact – on the overall level of fire safety performance of a building. These are decision-making tools that can be used to compare the impact of such features as sprinkler systems or smoke detectors on life safety and property preservation.

FiRECAM™ and FIERAsystem are examples of the research that IRC is conducting to support Canada's move from a prescriptive to an objective-based system of construction codes. IRC is planning to extend its modeling capabilities to evaluate fire protection systems in other types of buildings, such as industrial plants, arenas and shopping malls.

Conclusion

A lot of efforts has been invested internationally in support of the introduction in several countries of performance-based building regulatory systems. A performance-based system relies on clearly expressed goals/objectives and functional requirements, which are generally expressed in qualitative terms. Key to a performance-based system is a set of quantitative and measurable performance criteria appropriately linked to the qualitative portion of the system. Some areas of building regulations such as energy conservation, structural design, sound insulation, and some aspects of fire safety currently benefit from sufficient knowledge to support the expression of performance criteria in quantitative and measurable terms.

Several areas however do not benefit from such knowledge, namely those areas of building regulations related to personal hygiene, comfort and well-being of people, access and movement of people - including people with disabilities, safety of people from injury, aspects of fire safety - more particularly those related to prevention of fires and human behavior in fire emergencies. The absence of quantitative and measurable performance criteria is these areas creates a need for alternate methods and tools to determine – and verify - the acceptable level of performance in order to satisfy society’s expectations as expressed in the goals/objectives and performance requirements of the regulations. Several methods and tools have been developed and their use varies from one country to another. Expert judgment, historical in-service performance, statistical evidence, approved calculations, test methods, models and simulations are examples of such methods and tools that may be used to determine and verify performance of a building design. Another method relies on comparison of a proposed building design with acceptable solutions, those solutions (essentially - but not exclusively - prescriptive specifications) that are deemed to comply with building regulations. This is the method privileged by Canada in developing its objective-based codes concept.

Canada will publish in 2004 objective-based national building, fire and plumbing codes. Canada’s objective-based approach is articulated around the fundamental principle that acceptable solutions do reflect the level of performance acceptable to society. Based on this principle, acceptable solutions will continue to be developed and updated and will play the following roles in an objective-based building regulatory system:

1. As one of the compliance options, acceptable solutions will offer to the construction community an easy and cost-effective way of meeting the goals/objectives and performance expectations of building regulations;
2. Acting as a benchmark for determining the level of performance that is acceptable to society, acceptable solutions provide excellent guidance for assessing equivalency of

innovative solutions. Computer-based fire risk assessment models FiRECAM™ and FIERAsystem are developed at National Research Council of Canada in support of this role of acceptable solutions in objective-based codes;

3. The implicit level of performance embedded in the acceptable solutions can be viewed as representing society's expectations of building performance. Converting this implicit level of performance into quantitative terms can help in the development of measurable and verifiable performance criteria that would closely reflect society's expectations. This is an area where research is needed to develop tools and methods that would allow to quantify the implicit level of performance of acceptable solutions.

TG37 recognizes the dependence of important areas of building regulations on the prescriptive methods and will continue its work in studying these issues and questions.

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This paper was developed by a member of CIB TG37 as one of a set of papers related to the implementation of performance based regulatory systems. While the words are the author's the ideas have sprung from detailed discussions at several meetings and from the cumulative experiences of the members, many of whom are authorities who are directly involved in the enforcement of performance based regulatory systems in their own countries. It is important to mention the contribution of the members of the Inter-jurisdictional Regulatory Collaboration Committee (IRCC) to these discussions.

QUALITATIVE VERSUS QUANTITATIVE ASPECTS OF performance-BASED REGULATIONS

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ABSTRACT

Performance-based codes distinguish themselves from their prescriptive counterparts by specifying objectives (or goals) and functional requirements (also, functional statements or objectives), which are qualitative, and either specifying or referencing performance (or operative) requirements (or criteria) that can be used to assess whether or not the objectives have been met. The criteria can be either qualitative or quantitative, although one might expect them to tend to be quantitative, as quantitative criteria are ultimately needed for the rational development of methods of building design and construction. The issue of whether or not quantitative criteria should be part of the mandatory portion of a performance-based code is a constant focus of discussion. Some countries have extremely quantitative criteria written directly into their legislation. In other countries, however, the regulations are extremely qualitative and specify few quantitative requirements, which are mainly found in “approved” or “deemed-to-satisfy” documents, “acceptable methods” or other reference standards, guides or documents.

As can be imagined, there is considerable debate as to where, when and how building regulations should be quantitative. This paper provides an overview of the topic, indicating the range of approaches that could be taken: specifying criteria in the regulations, and thereby making them mandatory; referencing them in another document, so that they may be mandatory or not; or providing only qualitative criteria. A summary of the different approaches will be examined and presented after a review of the various practices from around the world.

KEYWORDS:

Performance-based building regulations; performance requirements; quantitative criteria, mandatory provisions.

INTRODUCTION

Many of the countries that have decided to pursue the development and promulgation of performance-based building regulations have used the Nordic Five Level Structure (NKB, 1978) as the model for their regulations. Figure 1 (Meacham, et. al., 2002), developed through the efforts of the Inter-jurisdictional Regulatory Collaboration Committee (IRCC), is an expansion of this model that includes risk (performance) levels which provides a critical link between the qualitative and quantitative portions of the NKB model. In this paper, “regulations” is used to mean the totality of documents that make up the mandatory technical provisions of a building regulatory system.

The model shown in Figure 1 can be adapted by regulation development agencies to reflect the desires of the local, affected or interested parties and the regulatory system within which they operate. In true performance fashion, however, no single model will address every country's needs. Because of this, differences will arise in the provisions of performance-based regulations developed by various organizations around the world.

One of these differences is concerned with the criteria used to measure whether or not a performance-based design complies with the mandatory requirements of the building code and may therefore be permitted as an "alternative solution" (a "performance-based design" is a design that is not in accordance with "approved" or "deemed-to-satisfy" documents, "acceptable methods" or other reference standards, guides or documents, and that cannot be assessed by comparison with those documents). The issue regarding these criteria that will be explored in this paper is whether or not quantitative criteria should be placed in the regulations and, if so, where. "Where" in this case refers to the "mandatory line" in that the quantitative criteria can be either enforceable or not.

BACKGROUND

The IRCC structure of Fig. 1 consists of a hierarchy, with either goals or objectives at the top. The goals/objectives are broad statements of what the building regulations are intended to provide. These goals may, for example, address the issues of safety, health, accessibility, and protection of buildings (CCBFC, 2000). Other examples of objectives are safeguarding people from injury and from loss of amenity, and protecting other property (NZ, 1992).

The next level down in the hierarchy are functional statements. Functional statements have been defined as "a statement which describes how a building achieves the Objective" (ABCB, 1996) or as "those functions which a building is to perform for the purposes [i.e. objectives] of this Act" (NZ 1991). As such, functional statements can be a qualitative way of indicating what steps must be undertaken to achieve the stated goal or objective.

Operative requirements are the next step down the hierarchy. Operative requirements address specific topics within the regulations, e.g., structural stability, fire safety, sound transmission, etc. Therefore, an operative requirement is "a requirement which states the level of performance which a Building Solution must meet" (ABCB, 1996), or "those qualitative or quantitative criteria which the building is to satisfy in performing its functional requirements" (NZ 1991). Operative requirements are typically stated in qualitative or descriptive terms, but in some countries they also contain some quantitative aspects. It is these quantitative aspects that are needed for the next level down in the hierarchy.

Acceptable solutions form the lowest levels of the IRCC structure. An acceptable solution is considered to be a set of provisions which when met will deliver the desired performance as intended by the objectives and operative requirements. In this paper, the term "acceptable solution" is used in a broad sense and shall include prescriptive, deemed-to-satisfy solutions as well as those expressed in performance terms, including their verification methods. In general discussion, and in this paper, the phrase "acceptable solutions" is used to mean any documents, including verification methods, that are officially recognised as deemed-to-satisfy documents prescribing methods of complying with the mandatory requirements of the building code.

The focus of this paper is primarily on the operative requirements. The difficulty associated with operative requirements is that they lie at the interface between the qualitative, public policy aspects of the regulations and the quantitative, technical needs of verifying that a proposed design will comply with the regulations. There are several competing effects at work.

THE PROBLEM WITH QUANTITATIVE STATEMENTS

The mandatory provisions of building regulations ("the law") are public policy documents and as such tend to be qualitative in nature. The mandatory provisions provide the means of describing "what" must be done. Therefore, mandatory provisions tend to emphasise the upper two or three levels of the hierarchy discussed above: goals, functional statements, and performance criteria. These mandatory levels define "what" society requires from buildings. In essence, the upper two levels provide the broad intent and more specific "sub-intents" of the building regulations. Mandatory provisions might be drafted by code writers but they are made into law by legislators.

Once established, the law is not expected to change significantly over time. This is the argument most often used to keep the qualitative provisions of building regulations separate from the quantitative aspects that determine "how" compliance with the law will be accomplished. Mandatory provisions may take many months or years to change, depending on the legislative process employed by the adopting jurisdiction. Tools, methods, and information used by designers can change at a greater rate than this and therefore quantitative provisions in building regulations may be obsolete when they are adopted and possibly result in unsafe conditions.

However, there might be a perceived difficulty in not mandating some quantitative values in performance-based building regulations. This problem arises when safety is the major concern, as opposed to an amenity. For example, if the building regulations of a given jurisdiction address both structural stability and sound transmission, the former can be considered a safety issue (i.e., the building will remain standing long enough to allow occupant evacuation) while the latter is an amenity (i.e., internal walls will provide some resistance to sound transmission but only to a reasonable level, not necessarily total elimination of sound transmission). Because the structural loading of a building is a safety issue, it is more likely that quantitative values for the possible loads a building may be subjected to will be included in the building regulations as minimum requirements. Conversely, quantitative values for sound attenuation may be viewed as overly prescriptive if included in performance-based regulations. Placing the minimum loads (i.e., safety related quantitative values) in the building regulations makes them non-negotiable. "Non-negotiable" in this context means that a minimum requirement has been established by legislators and, therefore, a societally acceptable minimum level has also been established.

One of the major problems that must be solved is how the building regulations provide the link between the qualitative statements (i.e., goal/objective, functional statements, and sometimes performance requirements) and the quantitative criteria which might be needed to assess a proposed performance-based design. In order to develop a design, numbers must be used. If the numbers used for a design are not stated in the mandatory requirements of the building code, and cannot be justified by comparison with the acceptable solutions or derived from the verification methods, then it is difficult to assess the acceptability of that design. In such a case, the building regulations do not provide a sufficient link between their public policy qualitative statements, which represent the values of society, and the quantitative aspects of the designer's job. If so, then the designer must attempt to interpret what the society values, choose quantitative values appropriately, and then convince the responsible building official or building control authority that the design does in fact comply with the building code. The problem in this case is that the designer may choose, and the official or authority may accept, values that are contrary to the desires of society.

Conversely, a problem with specifying mandatory requirements in quantitative terms is that it is very difficult to cover all possible future situations. Furthermore, quantitative requirements must cover the worst case, so that there is a danger that they might be unnecessarily restrictive for other cases. One way of dealing with this is for the system to allow building officials the flexibility to waive or modify the mandatory requirements, but of course there would need to be safeguards against misuse of such flexibility.

A final problem with specifying quantitative values in building regulations is that human beings are individuals and therefore not necessarily susceptible to the same level of a given hazard. For example, people of differing heights will be subjected to a smoke layer developed by a fire at different times if they are all standing. Compound this problem with differing respiratory rates (i.e., uptake of smoke,) various levels of general health (e.g., marathon runner, elderly, infant,) and the rate at which the products of combustion are metabolised. Therefore, the time at which an individual will succumb to the effects of a given fire will vary and specifying a single value of smoke exposure in the building regulations is not an optimal way of dealing with exposure to a fire's products of combustion. The same argument applies to almost all the operative requirements of any building code, and is particularly obvious if one of the objectives of the building code is to provide for people with disabilities.

BOTH ARE NECESSARY

The title of this paper has actually established a false dichotomy. The question is not to include qualitative statements in building regulations at the exclusion of quantitative ones, or vice versa. The fact is that both types of statements are necessary in the context of performance-based regulations, but at different points in the process. The performance-based process establishes a continuum between the expectations of society and the design that is proposed to meet those expectations. As a minimum, the building regulations qualitatively define what society expects from the structures that result from its provisions. At some point in the performance-based process those qualitative statements are translated into numbers and the designer is thus able to complete a design. The point in the regulations at which quantitative statements are found is a function of the body developing the regulations and the jurisdiction that adopts them.

A country-by-country overview of how the qualitative/quantitative issue has been addressed is now presented and is followed by a summary discussion of the main issues.

APPROACHES OF VARIOUS COUNTRIES

AUSTRALIA

The Building Code of Australia, BCA, (ABCB, 1996) is published in two volumes: one for residential classes of buildings and one for all other types of buildings. The BCA is comprised of objectives, functional statements, performance requirements, and building solutions. The objectives and functional statements are defined as guidance level provisions and the performance requirements and building solutions are defined as compliance level provisions. The building solutions are the means to comply with the performance requirements and may be either deemed-to-satisfy provisions (i.e., prescriptive provisions) or alternative solutions which require assessment methods to determine that a building solution complies with the performance requirements. A combination of deemed-to-satisfy and alternative solutions may be used in the same design.

In the BCA, the performance requirements are qualitative statements which define the required level of performance. For the structural provisions of the BCA, the deemed-to-satisfy provisions are a number of Australian Standards which define various structural loads. If the structure is designed to resist the loads stipulated in the referenced standards, the performance requirements is satisfied. If the deemed-to-satisfy provisions are not used, then the designer must demonstrate that the performance requirement is satisfied by using one of the available assessment methods: documentary evidence, verification methods, expert judgement or comparison to the deemed-to-satisfy provisions.

Thus, the BCA has qualitative performance requirements that facilitate their satisfaction by referencing quantitative values in established documents.

CANADA

The Canadian Commission on Building and Fire Codes is providing the leadership to move the Canadian family of construction codes (building, fire and plumbing) to an objective-based structure. The target completion date of these codes is 2003 at which time authorities having jurisdiction will be able to put them into force. Current plans call for each code to be published in one document with two major divisions – Division A and Division B. There will be mandatory linkages from Division A to Division B and vice versa.

Division A will set out the objectives that the code addresses and the functional requirements (in qualitative terms) that solutions must satisfy. Its prime purpose is to state as clearly as possible what it is that society seeks to achieve with the code. This is best achieved by a structure based on the "tree" of objectives, sub-objectives and functional requirements of the code. Division A of the code is expected to remain relatively stable over time.

Division B will set out the quantitative performance criteria (where these are available) with which solutions must comply and provide deemed-to-comply solutions drawn from the current version of that code. (In this context, "solution" means any product, combination of products, system or spatial configuration which is proposed to perform a function regulated by one of the National Code Documents). Such solutions will be generic in nature.

The general objectives and qualitative requirements of a code do not change very frequently. Keeping these separate from the quantitative criteria and solutions opens up the possibility that authorities, such as provinces and territories, will be able to adopt Division A in their code legislation and not have to change that legislation very frequently.

Division B of a given code would change more frequently than Division A as new acceptable solutions are added and existing acceptable solutions are improved. It is envisioned that it would follow a regular cycle of revisions and be published in dated editions as at present. Division B could then be adopted as regulations, which need not involve the provincial/territorial legislatures.

Division B of the new codes, which is the division most likely to be used on a day-to-day basis by code users, will closely follow the current organizational structure of the codes. This can be thought of as a structure based on disciplines. For each requirement in Division B there will be a reference to the Division A objectives and functional requirements it addresses. The “intent” of every Division B requirement will be provided as guidance material only and will not form part of the formal structure. Such material will aide in the interpretation and general understanding of the code.

JAPAN

The Building Standard Law (Japan, 1998) adds performance-based codes for the first time in the Japanese building regulatory system. They deal with such topics as fire safety, structural safety and building equipment safety, where technological knowledge and experience are available. The Building Standard Law, which must be examined and amended in the Diet; i.e. the Japanese Parliament, only states objectives and functional (qualitative) performance requirements. The Law also declares that both quantitative (technical) criteria and deem-to-satisfy (prescriptive) solutions are given as acceptable solutions by the Cabinet Order (the law enforcement order) and/or the Construction Minister's Notification, which is relatively easy to change. The performance-based building codes consist of these legal documents suggesting a mandatory line. Thus, it can be said that Japanese approach is a quantitative one. However, there always exists an argument that the benchmark approach might exclude innovative and unique solutions, which fail to meet quantitative performance requirements but can satisfy functional requirements. In order to avoid this argument, there are such special provisions that solutions to which the Minister of Construction gives approvals after performance evaluation are regarded as acceptable solutions.

NETHERLANDS

In the Dutch building regulation system, in force since October 1992, the Building Decree is the central document for the technical building rules. Based on the Housing Act, that does not contain technical rules, the Building Decree is a general administrative order, issued by the central government. The Decree has been changed twelve times till now; two of them are not in force.

In the Building Decree, standards play an important role. Wherever possible the Decree refers to standards ('NEN's') or parts of standards of the Dutch Standardisation Institute. These standards have been adapted to the Building Decree requirements and contain the determination methods intended to check if the work complies with the Building Decree requirements. There are 55 standards the Decree directly refers to.

The technical regulations of the Building Decree are expressed in performance requirements. In a clause, the performance requirement is based on a functional description. This description expresses the intention of the performance requirement. The performance requirement consists of a limit value and a determination method. The limit value indicates the minimum level of performance that has to be attained. As stated above for the determination method, the Decree usually refers to a standard of the Dutch Standardisation Institute. The presentation of the Decree doesn’t follow the format of any other country or system. The Decree has all elements of the Nordic System and of the recommendations of CIB/TG11. The elements are split into:

a. the titles of the chapters (usage function and relates to works to be built and existing works);
b. the titles of the division (starting points: safety, health, usefulness, energy economy and environment);
c. the titles of the paragraphs (e.g., like structural safety, users safety, fire safety, social safety);
d. the titles of the sections (e.g., like strength of the structure, floor boarding); and
e. the content of the clauses (performance requirement based on a functional description).

Not all clauses have been formulated in terms of performance requirements because of incomplete discussions between government departments and the building industry. So far utility buildings and works, not other buildings, have some clauses which are only functionally formulated. Such a clause doesn't have a quantified level to fulfil. By the end of 1998 an alternation of the Building Decree had been published with performance-based clauses for all clauses which were functionally formulated in 1992. These alternation did not came in force. The reason of this decision was the wish to present the Building Decree by scheme-presentation. This project is still ongoing.

The Decree doesn't refer to codes of practice. Codes of practice give solutions or simplified determination methods. Codes of practice are linked to standards. Codes of practice may be used if there is a relation between the code and a performance-based clause. The user of the code has to check whether or not there is such a relation.

Also, quality assessments may be used to prove that a solution fulfils the Decree. There is a list of assessments, recognised by the Minister of Housing, Physical Planning and Environment, which have a relation to one or more clauses of the Building Decree.

NEW ZEALAND

The performance-based New Zealand building code was introduced as part of a new building control system established by an Act of Parliament (NZ, 1991).

The building code itself is part of the building regulations (NZ, 1992) and represents the minimalist approach to performance-based regulations. The code consists of topic specific objectives, functional requirements, and performance requirements specified mainly, but not entirely, in qualitative terms. The topics covered by the building code are similar to those of other countries and include stability, fire safety, access, services and facilities (including plumbing and drainage, gas, and electricity), and energy efficiency. All of the New Zealand code is mandatory.

The code is supported by 35 "Approved Documents" (authorised by the Building Act as "documents for use in establishing compliance with the building code"), one for each topic.

SPAIN

The performance-based Spanish building code is currently under development. It was established by the Building Act, Act 38/1999 of 5 November 1999 (Spain, 1999) that the Government will approve it within two years after the act became enforceable, which occurred in May 2000. The Building Act establishes three categories of basic requirements related to the safety, habitability, and functionality of buildings.

The Code will develop those requirements that ensure building safety (structurally, in case of fire, and during use) and building habitability (hygiene, health and protection of the environment, protection from noise, energy conservation, thermal insulation and other functional aspects). The requirements on functionality (defined in the Act as Utility, Accessibility and the Access to telecommunications, audio-visual and information services) are and will be regulated by other jurisdictions such as the Autonomous Communities (Regions) having authority on the matter.

The Code will adopt the approach of performance (or objective)-based codes in order to promote innovation and technological development. The Code will be divided into two parts.

PART I is compulsory and comprises the:

> Objectives, which express the essential interest of the user with regard to buildings, taken from Article 3 of the Building Act. Also, on a secondary level, objectives determine the conditions of the building that make it fit for the intended use. The purpose of objectives is to identify the response of the building's functions and its parts in accordance with human, social and economic needs that will be detailed in the requirements themselves.
>
> Requirements (articles of the code) are the specific conditions (performance) that the building's design and construction must fulfil. This includes verifying that the building systems and products used will comply with objectives. Requirements will have a technical content and will generally be expressed in a qualitative form, though in some cases it may be quantitative.

PART II is of an instrumental (non-compulsory) nature that comprise the:

> Verification Methods, the tools for verifying and showing that a solution meets the relevant Objectives and Requirements; can be in the form of calculation methods, practical rules, tabulated values, etc.
>
> Accepted solutions, which are regarded as being in compliance with the Requirements.

Part II will be comprised of the so-called Code Application Documents (DAC) that revise and re-arrange existing compulsory norms and try to close the existing normative gaps, using the experience gathered under the traditional norms. The DACs could contain prescriptive solutions and, in those fields where possible, performance rules.

UNITED KINGDOM

In England and Wales, building regulations are based on functional or goal-based, requirements. The Building Act 1984 provides the enabling legislation for the Building Regulations 1991 (as amended), which set out the functional requirements to be met.

Supporting this mandatory legislation, acceptable solutions are provided in Approved Documents (which indicate minimum standards to achieve compliance). These Approved Documents are non-mandatory and may refer to British and European Standards to support them. Approved product test certificates such as British Board of Agrement certificates and European Technical Approvals may also give guidance. Approved Documents contain both prescriptive and, where possible, performance solutions. Alternative methods which achieve the minimum standard can also be accepted by the control authority.

In Scotland there is different legislation and variations to the England and Wales system, but they are at present carrying out a comprehensive review of the whole regulatory system.

UNITED STATES OF AMERICA; ICC

The International Code Council (ICC) has published a "Performance Code for Buildings and Facilities." The performance code contains three parts: administrative, building and fire. The administrative part applies to both the building and fire parts and contains a unique section which discusses design performance levels. This chapter discusses the Use Group of the building (e.g., hospital, detention, power generation, etc.), and the Performance Group the building should be placed in, depending on identified risk factors (e.g., on-site hazardous materials, capabilities of occupants, etc.). Once a Performance Group has been established, the Maximum Level of Damage to be Tolerated is determined, based on the Magnitude of Events the building can be expected to experience at some time in its lifetime. The maximum level of damage can then be translated into performance criteria which is quantitative in nature. Also, there is a section titled "Acceptable Methods" which does not directly reference the prescriptive code but essentially deems it to satisfy the performance code. The key element of this document is instead of providing specific references to codes and standards or other applicable methods, criteria are provided to assist in the selection of an appropriate method for design.

The remaining chapters of the ICC Performance Code contain topic specific objectives, functional statements, and performance requirements. These topics include building stability, fire safety, and safety of users, among others. With the exception of some of the expected loads discussed in the performance requirements of the Stability chapter, there are no quantitative values in the ICC Performance Code. In this regard the ICC Performance Code is similar to the New Zealand building code in that acceptable solutions and other means of verification are not contained within the regulations. The main difference is found in Chapter 3 where further qualitative detail is provided in the form of levels of acceptable damage as they relate to different types and magnitudes of events.

UNITED STATES OF AMERICA; NFPA

The National Fire Protection Association (NFPA) is advancing codes by providing the design option of either prescriptive-based development or performance-based development. This option can be found in *NFPA 101® Life Safety Code®*, 2000 Edition. There are several other documents which do, and in the future will, have the same option, including *NFPA 5000 Building Code*™, which is currently under development with an expected release date of September, 2002.

NFPA develops and maintains a set of integrated ANSI accredited documents which fall into four categories: codes, standards, recommended practices, and guides. Codes and standards (i.e., which can be adopted as regulations) are divided into the text of the code or standard and informational material. The text of the code or standard consists of the mandatory requirements. All nonmandatory or informational text appears in one or more separate annexes. The provisions of NFPA codes discussed below are contained in the text and are therefore mandatory requirements, unless otherwise noted.

The provisions provided in the *Life Safety Code* address the construction, protection, and occupancy features necessary to minimize danger to life from fire. The code's goal is to determine the minimum criteria for the design of egress facilities to enable prompt escape of occupants from buildings or, where desirable, into safe areas within buildings. The *Life Safety Code* is set up in such a manner that the life safety design must meet the stated goals and objectives using either the prescriptive-based provisions or the performance-based provisions.

Performance-based life safety designs are based on an engineering approach to fire protection design which first establishes goals and objectives. The next step is to apply accepted engineering tools and methodologies (i.e., deterministic and/or probabilistic analysis) to the fire scenarios stipulated in the *Life Safety Code* and then to compare the quantitative assessment of the design alternatives to the criteria, as discussed in an annex to the *Life Safety Code*. The criterion in the *Life Safety Code*, while qualitative, facilitates the calculations required to demonstrate that the proposed design can meet the goals and objectives.

A similar approach has been taken with *NFPA 5000 Building Code*. The goals and objectives address safety, health, usability, and public welfare issues. Performance criteria, scenarios, and other pertinent provisions are provided in other sections of the code, with supporting informational material placed in annexes. The criteria are expressed in qualitative terms with references to methods of determining how they may be met.

CONCLUSION

Table 1 summarizes the qualitative and quantitative aspects of the building regulations of the countries presented above. The hierarchy columns provide a cross reference among the regulations considered regarding how the upper levels of the NKB/IRCC hierarchy are defined. The "Quant in Regs?" column is used to indicate whether quantitative values are within the regulations and are therefore enforceable. The final column, "Structure" indicates how the various regulations have been structured and other information.

As is evident from this table, there is no single way to deal with the issue of whether or not quantitative values are placed within building regulations. There is no doubt that they are needed at some point in the process. This is shown by the "Quant in Regs?" column of Table 1. At the two extremes, the regulations can have quantitative design values or not. Canada has opted to place them in a part of the regulations that is relatively easy to change, while New Zealand (and to a certain degree the ICC in the USA) considers the building regulations to be strictly a public policy document and therefore numbers are not desirable. There are also approaches between these two extremes. Some countries (e.g., Australia) have decided to provide a reference to the quantitative design values (i.e., Australian standards) in the regulations. Another approach is that taken by the NFPA *Life Safety Code*, in that the criterion is readily determined based on the qualitative description of the criterion: "No occupant not intimate with [fire] ignition shall be exposed to instantaneous or cumulative untenable conditions." (NFPA, 2000). Embedded in this criterion is the basis for predicting, numerically, a level of untenable exposure established by the regulators and designers, together.

Quantitative values do indeed have a place in the building design process. However, whether or not they are placed within the building regulations is a choice that is left to the organization developing the regulations and is a function of the both the local political processes and the people that are being regulated.

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THE ROLE OF STANDARDS In a Performance-based Building Regulatory System

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INTRODUCTION

Building regulatory systems consist of regulations adopted into law through whatever legislative or administrative procedures are appropriate to the legal system in place, supported by standards that provide the detail on what is considered necessary or sufficient to be considered in compliance. Regulations embody the public expectations for how buildings and facilities are expected to perform and as such represent public policy. Regulators, who develop and enforce regulations, are empowered to act in the public interest to set this policy and are ultimately responsible to the public in this regard.

Standards can provide details of methods and evaluation criteria too complex to include within the regulations themselves. Standards, as more technical documents, rely on significant input from technical experts and often are developed by private groups who may have financial interests in the items covered. Standards employed in regulatory contexts should be developed in a fair and open manner and many countries have mechanisms in place to ensure that standards do not restrain trade or limit competition. In recent years the importance of harmonized standards is recognized in the context of facilitating international trade.

This paper is one of a series of discussion papers developed by the Interjurisdictional Regulatory Collaboration Committee (IRCC) and the International Council for Building Research and Innovation (CIB) Task Group TG37, Performance Based Building Regulatory Systems intended to address evolving issues related to building regulatory reform. The IRCC members are the chief building regulatory officials or drafters of a number of countries that are developing or have implemented, performance-based building regulations. IRCC activities involve the sharing of common experiences and developing issues involving public policy and regulatory framework and infrastructure. With a somewhat broader membership, CIB TG37 works closely with the IRCC on related technical issues. A set of papers was presented at the CIB World Building Congress 2001 in Wellington, New Zealand and these topics are developed further in a set of papers (including this one) presented at the 4th International Conference on Performance-Based Codes and Fire Safety Design Methods, Melbourne, Australia, 2002.

THE TRADITIONAL ROLE OF STANDARDS

Standards have traditionally played an important role in building regulations. Standards are frequently cited in regulations as either mandatory or advisory references as a condition on how a specific requirement can be satisfied. Standards used in building regulation cover a range of topics but are usually in one of the following categories:

- Test or measurement standards that provide information on the acceptability (pass/fail), performance category usually under some standard condition (e.g., Class A, 1-hour), or to provide data that can be used to determine acceptability or performance.
- Procedural standards that detail with how products or systems are to be installed, used, maintained, tested, or operated to be fit for the intended use, safe or reliable.
- Interoperability standards that set out a procedure or arrangement that allows products to fit or work together.
- Standards of professional practice, generally accepted methods of analysis or design, qualifications, processes and documentation thereof.

Standards traditionally provide the detailed criteria for acceptability or compliance with the intent of the regulation. For example, regulations will require the provision of fire protection systems or fuel gas systems that are installed, maintained, and used in accordance with some (cited) standards that assure the safety and reliability of these systems. The citation avoids the need for providing detailed criteria within the regulation, and allows for the technical details to be developed and maintained by technical experts in the field in support of the regulatory objectives.

Standards themselves are not adopted as regulations but rather become law indirectly by mandatory reference within regulations. In legal systems such as in the United States, mandatory references are to specific editions of standards to avoid illegal delegation of legislative authority to the standards development bodies. This assumes that the regulatory development or adoption process includes a review of the standard and certification of its applicability, which may or may not be the case. But in general, in the traditional (prescriptive) building regulatory system the code official responsible for the determination of compliance with the regulations also has the authority to accept or reject any portion of mandatory references to standards.

DEVELOPMENT OF PERFORMANCE-BASED REGULATORY SYSTEMS

As building regulatory systems undergo the fundamental change to performance-based, standards will take on a more integrated role that will require changes in the standards development and adoption process of a similar, fundamental nature[xvi]. Where standards are generally "best practice" documents that are interpreted both by the user and by the regulatory official, regulations are an embodiment of public policy in law and must be enforced by the public officials. Where standards cross this line to regulation, the documents themselves as well as their development process will need to meet a higher level of public involvement than even the so-called "consensus" standards process provides.

Performance-based regulations specify outcomes rather than specific solutions. They are typically formatted as a hierarchical structure (figure 1) in which the top level contains objectives expressed as qualitative statements. These objectives break down into functional statements (also qualitative) of sub-objectives that must be achieved to attain the objective. Following this are performance requirements that provide quantitative measures of when the functions, and thus the objectives, are satisfied. Finally come acceptable methods that can include verification methods recognized as appropriate for verifying the required performance or "deemed to comply" solutions that generally include the former, prescriptive solutions. Where standards are unavailable or inappropriate, such as for the acceptance of innovative materials or methods, there exist systems for *technical approvals* to give guidance on meeting functional requirements. These technical approvals are issued by special bodies such as the British Board of Agrèment or, in the US; by the Evaluation Services organizations affiliated with the model code development bodies.

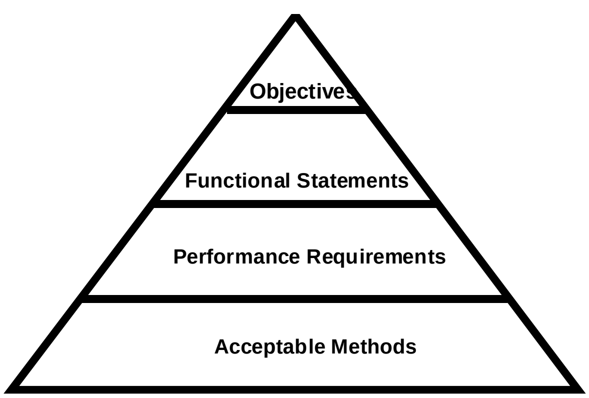

Figure 1

CHANGING ROLE OF STANDARDS

Standards will play a crucial role in these performance-based systems in providing the links from the qualitative statements to the quantitative criteria[xvi]. Standards will provide the performance metrics for materials, products, and systems by which their performance in the context of their use can be determined. Standards will also provide "deemed to comply" solutions for specific functions cited. These roles are fundamentally different from those of prescriptive systems and these differences will require changes in the standards development and adoption methods.

The provision of performance metrics is another new role for standards in performance based regulatory systems. PBRS are based on the ability to evaluate the performance of buildings (and their components and systems) in the context of their use. Such evaluation can be performed at various levels, including testing, expert judgment, experience, and prediction. Where performance prediction is employed it is usually based on models or calculation methods that incorporate product-specific data taken in some standard apparatus (performance metrics). An important role of standards development organizations that is currently undressed is the need for such performance metrics for materials, products, and systems that are coupled to predictive models or calculation methods.

Where standards are cited as verification methods, test or measurement methods, or in the measurement of performance metrics, they do not themselves provide a distinct solution to a function or objective. Rather they provide data to be combined with judgment by a designer or regulator, and the role of the standard is no different than today. However, when standards are cited as acceptable (deemed to comply) solutions to demonstrate compliance with a performance level cited in the regulation, in most performance-based regulatory systems these solutions *must* be accepted by the regulator. Here, the standard itself becomes a regulation and must follow a similar development process including the "due diligence" criteria normally applied in regulatory development[xvi,xvi].

REFERENCES TO SOFTWARE

This concept also applies to references to software and calculation methods in standards and regulations. Proprietary software can be cited as a verification method but could not be an acceptable (deemed to comply) solution because of the previously mentioned problem of illegal delegation of legislative authority. That is, proprietary software can be changed by the developer without the possibility of the thorough public review required of regulations. Openly documented software referenced by specific version could be an acceptable solution if it provides a complete solution for the purpose. For example, hydraulic calculation software results in all of the design parameters for a fire sprinkler system and thus provides a complete solution. Fire models require assumptions and judgment that can affect the outcome and these must be reviewed and approved by the regulatory authority for appropriateness. Thus, fire models would not qualify as acceptable solutions but can be used as verification methods.

As countries adopt PBRS many of the prescriptive standards currently in place will continue to be of value as verification methods or acceptable solutions, but others will become obsolete. There will be a crucial need for standards that address performance metrics for materials, products, and systems that are associated with predictive methods that can assess performance in context. And the standards development process itself will need to change where standards have the status of regulations. If the traditional standards development bodies do not adapt, others will spring up to fulfill these needs. The national and global benefits or PBRS are too great for any other outcome.

PERFORMANCE STANDARDS

Within the framework of a performance-based regulatory system, standards are needed to fulfill two important functions. First, are needed standards for methods to determine or evaluate the performance level of buildings, systems, or products, which might be called *performance statement standards*[Error! Bookmark not defined.]. Second are standards that give specific performance levels of buildings, systems, or products that can be classified as a type of product standard, which might be called *performance specification standards*.

Both types of standards may be utilized within a performance-based regulatory system. The involvement of regulators is crucial to the development of performance standards due to the public policy aspects represented. Performance statement standards need to be based on an understanding of the relationship between the performance aspects of the standardized methodology and those required in the regulations. That is, the compatibility or equivalency between the performance requirement in the regulation and the performance delivered by the standard must be maintained where different aspects of performance are applied. Performance specification standards may become acceptable solutions for performance-based regulatory systems by providing examples of acceptable systems or products. Other appropriate performance specifications using different performance metrics should also be allowed.

While performance standards are crucial to the practicability of performance-based regulation their misapplication could result in problems when they arbitrarily limit the range of acceptable solutions. Performance standards need to be sensitive to national and cultural norms and practices where these are not inconsistent with the regulatory objectives. An example is the use of indigenous materials in construction. Marble is a common building material in Italy, stone in the UK, wood in the US and Canada. An Italian standard on flame spread on finish materials that assumes marble to be used would be out of place in the US where such materials are traditionally uncommon.

Standards and the Performance System Model

The Performance System Model (PSM)[xvi] represents a refinement of the hierarchy shown in Figure 1 that adds an explicit specification of the performance/risk level as a link between the qualitative goals, functional statements and operative (performance) requirements and the quantitative performance criteria and verification methods. The addition of this link is in part in recognition that the expectations of the owner or even of a society for a particular building, can vary.

The concept of varying expectations for building performance is not new. Agricultural buildings characterized by low (building and contents) value and low life safety risk (usually due to only occasional occupancy) are often unregulated. Conversely, buildings like hospitals and schools are highly regulated both due to the value of the building to society and to the special concerns for their more vulnerable occupants. In structural engineering these concerns have traditionally been addressed through a safety factor multiplier called *importance factor*.

The addition of the performance/risk level makes clearer the need for performance standards that can be used to assess the performance of buildings, systems, or products at the levels demanded by the regulators and society. Culture and tradition often dictate methods and performance levels for buildings and the constraints thus imposed cannot be ignored in the name of international harmonization. Technological solutions common in developed countries are often impractical in the developing world because of a lack of infrastructure. Performance standards should provide the flexibility of alternate means to meet their objectives under a range of such constraints.

The PSM highlights the need for more communication between the regulators and the standards developers. If performance standards are to address the appropriate level of regulatory expectation the regulators need to provide clear direction and linkages to the goals and the intent of the regulations. If this is not provided the technical community sets the performance criteria, usually based on historical practice. More appropriate is the process outlined in the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*[xvi] that involves the key stakeholders; owner, manager, tenant, regulator, insurance, designer, emergency responder, etc. in making the decisions.

Standards for Global Acceptance

One of the advantages to performance-based regulatory systems is the universality of the description of needs or requirements in terms of measurable performance. Nowhere is this more evident than in the regulation of the fire performance of building materials and systems.
Until recently fire was not well understood and fire test methods were designed more for repeatability and reproducibility rather than rigor and robustness. Such test methods only produce a measure of the performance of materials and products in the test rather than in

use. Such political solutions are not useful in a performance-based regulatory system and are inappropriate as standards for global acceptance.

In a recent position paper from the FORUM for International Cooperation in Fire Research, Croce[xvi] suggests a set of options for "end use approval of products and services in ascending order of sophistication and effectiveness are:

1. Ad hoc tests
2. Use of small and/or intermediate-scale tests correlated with large-scale tests
3. Property data coupled with a first-principle model of an intermediate-scale test that can be correlated with large-scale end-use tests
4. Property data combined with models of the end use application."

The first represents the current state of many fire tests referenced in building regulations and which is "widely recognized as inadequate."

The second describes the approach most often used in current test method development. While better than the first Croce cautions, "results can still be misleading if the correlation with large-scale test results is not adequately broad in range and/or end use."

The third, "makes better use of scientific knowledge than do the first two options, does not rely on difficult correlations between small-scale and large-scale results, is achievable in a reasonable time frame and may serve adequately until option 4 is available. It also should be easy to understand by the user, the practitioner and the regulator."

"The fourth option is the ideal approach, using material properties and other scenario-based quantities as input to comprehensive end use computer models. Currently, we do not know enough for most situations to use this approach. Temperature-dependent material properties are proving to be quite difficult to measure, existing models are relatively limited and broadly applicable end use computer models are becoming more complex. Hence, validation and verification is extremely critical. As computing power advances, this option should become easy to use for the practitioner."

The paper concludes with a FORUM position:

"The FORUM position for evaluating products for global acceptance is as follows:

- Approval tests become ingrained. Once established, it is difficult if not impossible to remove or even revise them. They also create burdensome legacy issues.
- FORUM members should encourage and advocate use of the most practicable scientifically-based technology.
- In moving from prescriptive towards performance-based codes and standards, more scientifically-based tests are required to provide data needed for predictive models.
- The intent is to move towards the provision of tools – accurate data, tests, models – as a basis for equitable performance levels needed to support performance-based codes and standards.

- Rather than acceding to tradition, researchers and practitioners bear the responsibility to demonstrate the value of using most practicable technology.
- Research laboratories need to serve the interests of all stakeholders – product manufacturers, product users, practitioners, testing laboratories, insurers, regulatory agencies, society.
- Research laboratories have the further responsibility to advance science needed to progress toward the most scientifically-based approach for accepting products.

The FORUM takes this position because it recognizes that adoption of an inadequate test doesn't necessarily improve safety, can add an unreasonable burden of cost to manufacturers of products and eventually adds to the panoply of ad hoc tests. Globalization, though not complete, is coming fast. Currently there are three major markets – the European Union, the Americas and Asia/Pacific. Failure to press the FORUM position in one market may preclude options for others, resulting in a continuation of parochial/preferred tests in different market areas and the often-wasteful search for a meaningful way to compare different tests."

THE REGULATORY STANDARDS DEVELOPMENT PROCESS

As standards take on the characteristics of regulations, either by mandatory references or deemed-to-satisfy status, it may be legally necessary for the standards development process to incorporate some of the "due diligence" aspects of regulatory development. While different legal systems and legislative responsibilities in different countries will affect what steps must be taken, there are some common issues that will generally apply. The following borrows heavily from a recent publication for EU titled *Legal Aspects of Standardization in the Member States of the EC and EFTA*[xvi].

Participation

The standards development process must be generally open and transparent. While limits may be placed on direct participation based on demonstrated expertise in the related technologies, maintenance of a balance of represented interests, and practicalities of committee size, the process usually incorporates an unrestricted means for public proposals and comments and the documentation of technical reasons for rejection or modification. Such open processes are even more important where the standard is a mandatory reference in regulation or is the basis for international trade.

In the United States, the Office of Management and Budget Circular A-119 (1998) states that "Consistent with Section 12(d) of Public Law 104-113, the ``National Technology Transfer and Advancement Act of 1995'' (hereinafter ``the Act''), this Circular directs agencies to use voluntary consensus standards in lieu of government-unique standards except where inconsistent with law or otherwise impractical. It also provides guidance for agencies participating in voluntary consensus standards bodies. The circular also states that "A voluntary consensus standards body is defined by the following attributes: (i) Openness; (ii) Balance of interest; (iii) Due process; (vi) An appeals process. (v) Consensus, which is defined as general agreement, but not necessarily unanimity, and includes a process for attempting to resolve objections by interested parties, as long as all comments have been fairly considered, each objector is advised of the disposition of his or her objection(s) and the reasons why, and the consensus body members are given an opportunity to change their votes after reviewing the comments. See http://ts.nist.gov/ts/htdocs/210/215/fr-omba119.htm

Public access to standards

Traditionally standards developers have derived a significant faction of their operating revenue from the sale of standards and this revenue stream is protected by obtaining copyrights on the documents. Catalogs and newsletters or official journals provide public notification of the existence of new or revised standards. However it can be argued that the full texts of mandatory standards must be publicly available. Depending on the legal system and the scope of the standard accessibility in the offices of the standards developing body and in public libraries may be sufficient.

Public Review

The ability of the public to participate in the standards development process and to have access to the standard is necessary but not sufficient when the standard becomes a regulation. Due diligence in the development of regulations requires either as part of the development or the implementation (depending on the mechanisms of legal adoption used and the legal system in place) public hearings and debate, notification and education of the public and of authorities to provide consistent enforcement. These regulatory processes have not normally been practiced with standards but may be legally required when standards take on regulatory power. The U.S. regulatory procedures require publication of the intent to reference or use a standard in the Federal Register and the provision of a specific comment period for public review.

Good practice

Design professionals such as licensed or registered engineers and architects are ethically bound to follow the current, best practice generally accepted in the profession (state-of-the-art) but are not bound to employ methods that are generally considered experimental or not fully developed. Standardization may be one method by which a methodology moves into generally accepted practice; that is, when a standard is agreed and published the subject is no longer considered developmental. This may then represent one more method by which standards take on mandatory or regulatory authority.

STANDARDS IN INTERNATIONAL TRADE

Standards are increasing recognized as crucial to international trade. The European Union (EU) continues to invest significant resources in the harmonization of standards among member countries as a prerequisite to free trade. International trade agreements (World Trade Organization Technical Barriers to Trade Agreement) deal with standards by giving preference to international standards over national norms for products and services in international trade. International standards are not defined, however, as being developed by a specific body.

National Standards Bodies

Most countries have a single, national standards developing body, creating standards that are assumed to represent the national position. These bodies may or may not be affiliated with the national government. Examples are British Standards Institute (UK), AFNOR (France), DIN (Germany), and Standards Australia. EU created CEN (Comitè Europeèn Normalisation) and CENELEC to represent the collective EU view (but the individual national bodies continue to function) and member countries are forbidden to develop national standards where CEN standards are under development. Likewise, CEN is expected to defer to international standards, usually interpreted narrowly as ISO (International Organization for Standardization). IEC has a similar agreement with CENELEC.

The situation in the US is different and this may lead to problems in the international standards arena. While the US has a national standards body, the American National Standards Institute (ANSI), most US standards are developed by a myriad of private organizations. There is a public consensus process whereby a standard can be designated the "American National Standard" by ANSI and only one such designation is granted on any topic, there is no consensus that this represents a national position. Thus, since several variations of similar standards often exist there is no clear US position evident in international standards work.

Harmonized standards

Much of the effort in EU has been to harmonize existing standards. In some cases completely different standards existed for the same purpose. Where attempts to correlate them failed it was necessary to develop completely new approaches. An example is with material flammability tests. Several countries had very different test methods and they could not be correlated. The UK, Germany, and France held tenaciously to their traditional tests. Eventually the Single Burning Item (SBI) test was developed and is now on track to become a CEN standard. While the SBI has been criticized on technical grounds it serves the purpose of a harmonized test to regulate the flammability of building materials in European trade.

A potential problem exists with the movement of the CEN standard for the SBI into ISO. This would mean that the SBI would become (in theory) the preferred test method for regulating material flammability in international trade both within and outside of Europe. Non-European countries are not interested in abandoning their traditional test methods for a European political solution with outstanding technical criticisms.

This highlights an important issue with respect to the mandating of international standards in trade. Not all solutions are technically sound and political solutions can collide with cultural norms and customs. A well-known example comes again from the EU when they issued harmonized regulations for food safety that included mandatory temperature limits for food storage. The regulation set limits for meat and for dairy products in which there was no overlap in the acceptable range of temperatures for each class. As a result, is a traditional Italian food made of braided meat and cheese that, under the new rules, could not be sold because there was not a common, allowable storage temperature.

CONCLUSIONS

Standards are evolving as a part of the movement toward performance-based building regulatory systems. Demands placed on standards to link explicitly to both the performance goals and to the operative (performance) requirements are resulting in standards for performance metrics that are scientifically rigorous and robust. At the same time performance standards must provide the flexibility to accommodate cultural and traditional practices where they provide appropriate alternatives that meet the societal objectives embodied in local regulation. This is especially important where standards take on special status under international trade agreements. Finally, standards that take on regulatory authority through mandatory reference or as deemed-to-satisfy solutions must follow regulatory ‘due diligence” procedures consistent with their new status.

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