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R. F. Legget and N. B. Hutcheon

Performance Concept in Building

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Performance Concept in Building

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ABSTRACT: The ability to design for any desired result depends upon the ability to predict the result in advance. Performance tests become necessary when relevant theoretical knowledge is inadequate for prediction. Standards must be developed to establish minimum criteria through standard performance-type test methods. The acceptance of the performance concept by the building industry will take place only if it is always associated with the concept of measurement, measurement that is based on standard test methods, the results of which can be communicated without fear of wrong interpretation.

KEY WORDS: testing, performance, buildings, construction, building codes, standards, test methods, design

The performance concept has recently caught the imagination of many in the building world in North America, as if it were the equivalent of a new comet in the building firmament. The idea of novelty is generally found in discussions of the matter by those who are themselves new to the field of building technology. The widespread current interest in the performance concept as applied to building must be, however, an indication of some real need for this sort of approach. This paper is a summary of experience with the performance concept gained by the authors and their colleagues while developing a national research service for the building industry of Canada, in association with necessary support work for the National Building Code of Canada.

The development of building codes, and particularly of model codes, has clearly given rise to some of the current discussion about the performance concept. The old type of so-called "specification code" is held by many to be unsuitable for general application in model codes. This type of rather rigid regulation, so roundly condemned by the uninitiated, has served the building industry well but certainly it can be

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improved in the direction of the "performance code" now so widely hailed as the answer to all code problems. There are, however, some who aver that a performance type of code is impossible of achievement, despite its theoretical advantages.

All this talk is to the good. It represents a desirable stirring of thought in an industry that, in recent years, has been so overwhelmed by the magnitude of the job it has to do that there has been all too little time for thinking about fundamentals. And the concept of the performance of a building is so clearly a fundamental idea that it should permeate much of the activity that goes to make up the technology of modern building. One cannot talk about performance-type codes or about the performance concept (in building) without also talking about simulated service testing. And when this topic is discussed, one has to ask "Simulating what?" A paper such as this accordingly appears to be an appropriate part of this symposium, organized as it is by the ASTM Committee on Simulated Service Testing, a symposium cordially to be welcomed in relation to all the work of developing standard test methods in the many fields now served by the Society.

It may not be too trite a suggestion to indicate that the title of this paper could well be "The Performance Concept in Building—What It Is and What It Is Not." Considering what it is, one of the most recent definitions may be cited first. This was given at the conference organized by the (U.S.) Building Research Advisory Board on the Performance Concept, held in Chicago in October, 1965. In the paper by William Gillett, he gave this thoughtful definition:

True performance is the fulfillment of requirements based upon absolute need for a building or complex of buildings and pertinent structures, regardless of the construction system or the materials used, provided the technical characteristics fulfill the requirements according to scientifically based judgment or by test results from an acceptable evaluative technique.

The Proceedings of this meeting have now been issued² and provide a useful review of current thinking on this subject.

If only by way of contrast, it is of some interest to look at a somewhat earlier definition of the performance concept in building which reads as follows:

All these must be built with due reference to durability, convenience, and beauty. Durability will be assured when foundations are carried down to the solid ground and materials wisely and liberally selected; convenience, when the arrangement of the apartments is faultless and presents no hindrance to use, and when each class of building is assigned to its suitable and appropriate exposure; and beauty, when the appearance of the work is pleasing

² "Report of Proceedings," *Symposium on the Performance Concept in Building*, October, 1965, Building Research Advisory Board, Washington, D. C., 1966, p. 17.

and in good taste, and when its members are in due proportion according to correct principles of symmetry.

This quotation happens to be about two thousand years older than the first definition quoted, coming from Book I of "The Ten Books on Architecture" of Vitruvius, a Roman engineer and architect who lived in the first century B.C. (the dates of his birth and death are unknown). This quotation is taken from the Morgan translation of this justly famous work, another reference to which the attention of readers can be directed.³

Even Vitruvius was a latecomer in this field of interest for about fifteen hundred years before him a famous Babylonian figure, Hammurabi, had given yet another definition, in rather more barbaric, but equally clear terms:

If a builder build a house for a man and do not make its construction firm, and the house which he has built collapse and cause the death of the owner of the house, that builder shall be put to death.⁴

The performance concept, clearly, is almost as old as the art of building itself. It has received varied attention throughout the centuries but it can readily be shown that it has never really been forgotten. What, then, is new about the situation today that has given such renewed interest to this concept? Stated simply, it is the rate at which changes in almost all aspects of building are being introduced, forced by the almost frightening rate of development of modern technology. There are changes in user requirements, in standards of performance and safety, and in materials and methods of construction. These in turn have forced changes in the kind and extent of interaction between the work of designers, regulatory agencies, builders, manufacturers, suppliers, and tradesmen. It may be argued with some justification that many alive today have seen more changes in building than had occurred in all the previous history of building and that what has just occurred in a lifetime will almost certainly be matched in the next two decades.

Consider just a few of the changes in the practice of building in North America that have taken place in the last two decades: the widespread adoption of air conditioning for buildings large and small including humidification in winter and the associated demands that this makes upon building enclosures; the "necessity" today for the inclusion in residential buildings of such items as tiled bathrooms and advanced heating systems; the widespread use of curtain wall construction for even the largest buildings and the corresponding developments in the use of precast

³ *Vitruvius—The Ten Books on Architecture*, Book I, Dover Publications, New York, 1960, Chapter III, paragraph 2.

⁴ Percy Hancock, *The Code of Hammurabi*, MacMillan Co., New York, 1920, p. 35.

concrete cladding panels; and, more recently still, the use of exposed steel as an architectural feature of large buildings.

Even though some of these features may change with changes in architectural fashions, they are now in wide use. They do create problems; their performance should be predictable. How to predict their performance, and the criteria to be applied in such predictions, are questions that go to the heart of the subject under review. When the current state of building technology is viewed in this way it becomes apparent that some changes make others desirable, but that many compensating changes may be resisted or may not be made quickly enough. The time is ripe indeed for such a reconsideration of accepted approaches as the current discussion of the performance concept is promoting.

Designer and Performance

The conclusion that performance of a completed building is fundamentally related to the process of design is inescapable. The designer is the one who must identify what is desired in the way of final performance. He must also delineate satisfactory ways in which the desired result is to be achieved. The designer therefore must take the prime responsibility for the performance of the completed structure.

In the days when the architect or engineer was the master builder, he was the expert in all phases of the work from conception to completion of construction. He was taught under the old master-pupil system in which the accumulated experience and knowledge of the master was passed on to him, to be refined and extended through his own experience. The master builder selected and controlled the quality and use of the materials and so held under his own control all the factors involved in final performance. Any failure in the building, apart from acts of God, was clearly identifiable with the master builder and was his responsibility alone.

There were failures, naturally, since the designer's ability to predict the final performance was necessarily limited, even though the master-pupil system of developing and passing on the cumulative experience of the profession was a good one, being still sound in principle today. Every venture into new materials and new forms which went beyond this accumulated experience and the intuitive knowledge of the architect became an experiment on the job, to be exploited by him, the resulting experience being added to his competence.

The fundamental issue in any approach to performance can be identified clearly. It is that the ability to design for any desired result depends entirely on the ability to predict the result in advance. Design without such ability to predict involves experiment or trial-by-use. In former days the master builder was the man best qualified to predict the performance of all aspects of a building. With the growth of building tech-

nology as it is known today, the modern architect has been surpassed in his ability to predict in various special areas related to current building technology by the structural, mechanical, and electrical engineers, by the manufacturers and suppliers of special equipment, and even by some contractors and builders. He is no longer the universal expert and, although he continues to be the designer, he must rely upon the skills of many others, through the overall building system by which their various interests and contributions are combined, to support him in the design of the total building that will perform as intended.

The architect of today must, in a sense, delegate some of his fundamental responsibilities as a designer, while doing everything possible to ensure that these will be clearly identified, assigned, and accepted by others. Since it is no longer possible to experiment with new materials or components on the job, in ways that may involve the risk of failures, experiments, including various forms of testing necessary for prediction, must be carried out in a laboratory. This is an outline of the situation which must be dealt with in developing and applying the performance concept. It will be desirable to consider next the design process in its modern context in somewhat greater detail than in this introductory review.

Process of Design

Every building design is approached with *some* idea of what is wanted. The concept of requirements at this stage will be partly, if not largely, expressed in performance terms. It will seldom be well defined and must be developed and refined in the course of the design process. There must be continuing reappraisal of almost all aspects of the design as it develops, *keeping in mind what is possible and the ease or the difficulty of ultimately providing what is proposed*. Thus there must be the possibility of reconsideration and modification at any and every stage of design. This is an essential characteristic of the design process making it a most complex and demanding operation whether the designer is one man or, as is now almost inevitable in modern building, a number of individuals or agencies involved in a team effort.

The design process always poses multifactored problems and multiple considerations which are often incompatible or in conflict, so that compromises must always be made. The need to compromise in the interests of cost is almost always present. It may be said with some justification that every building design is a *major exercise in the art of compromise*. The making of the right decisions, so that an optimum overall result will finally be obtained, can be difficult even when all the facts about the issues in conflict are available and well understood by the designer. The task of the designer or the team leader is vastly more difficult when the judgments of two or more individuals on whom he must rely for expert assistance are in conflict.

It is possible to recognize in this context the basic role of safety regulations. These include building codes which are primarily concerned with safety from structural, fire, and health hazards. They establish the minimum levels below which any compromises involving safety may not go. They establish also the "authority having jurisdiction" who has the power to ensure compliance with the regulations and to make and enforce final decisions in cases of doubt.

The task of the modern designer is still further complicated not only by the applicable codes and other regulations with which he must be familiar, and by the increasing number of sources of expert advice to which he must turn, but also by the increasing number of choices of materials, systems, techniques, and methods of construction now available to him. He must finally describe what is wanted through his plans and specifications in ways which are meaningful and capable of being interpreted clearly by all those who subsequently become involved in the provision of the completed building conforming to his design.

The designer is thus faced ultimately with a group of decisions that are fundamental to the performance concept—whether to make a choice in each case and specify it or, alternatively, to describe the qualities, function, and performance required. In the former case, he accepts implicitly full responsibility for the choice he has made as to cost, performance, and general suitability. In the latter, he leaves to others the specific choice, subject to his control through the performance specified and probably also to his final approval. The choices which he must make are basically the same as those which face code writers—whether to employ a rigid specification or a performance-type approach. In actual practice, most architects make much use of the former procedure but may employ the performance approach in some instances. In either case, they must make use of the results of test methods and standards. These now merit discussion since they are of such vital importance to the performance concept.

Tests and Testing

The need for accurate communication of technical information and for the clear designation of requirements is very great and pervades all phases of design and construction. Much of this information must be quantitative, and so measurement becomes necessary. This is easily recognized when such elementary quantities as length, weight, and number are involved. The determination of even such simple quantities, however, may involve some difficulty. Recognized methods of test may become necessary in order to remove any ambiguity as to the meaning of the value quoted as, for example, the thickness of an insulation board or the volume of a concrete block.

The measurement of physical properties such as thermal conductivity may pose even more difficulty. It becomes even more necessary to follow

carefully designated test methods in order to obtain comparable results for different materials, these always being related to the test method employed. It must, however, be recognized that if knowledge is adequate, some properties may be calculated from simple measurements. In the case of fibrous thermal insulation, a complete knowledge of the cause and effect relation between k value, the size, orientation, and type of fiber, and the ability to measure these factors, would make it possible to calculate the k value. As it is, the necessary knowledge is incomplete, and so it becomes necessary to employ the guarded hot plate test method in actual practice. This is a performance test, involving performance under a carefully designated set of conditions, so that meaningful and comparable results can be obtained.

To follow this typical example further, when knowledge of heat flow is adequate, the overall heat flow through a wall can be predicted from known conditions of exposure, and the dimensions, arrangement, and basic properties of the component parts. When relevant knowledge is not adequate, a large-scale wall thermal test becomes necessary. Again, in order to make the results meaningful and comparable with others, the conditions of the test must be carefully specified and controlled, in accord with some agreed test method. This is also a performance test. If it is not known how to relate the thermal performance of a wall in the standard test to the actual performance of the wall in practice, then measurements *in situ* may have to be considered. Thus it can be seen that performance tests become necessary when, but only when, the relevant theoretical knowledge available is inadequate for prediction.

When existing knowledge is inadequate for prediction and testing must be employed, it might be necessary in the extreme to test every new or different form or size of product proposed. This could pose a continuing need for testing which would be in the long run both cumbersome and costly. In the case of the walls previously referred to, there are a large number of ways in which a relatively few materials may be combined. Fortunately, in most cases, the thermal properties of walls can be predicted from a limited number of measurements made on the basic materials so that it is not necessary to test every different type of wall. It is this "fact of life" that forces the development of knowledge through research, so that the performance results for specific cases can be predicted as far as possible from the use of theory in conjunction with simple measurements of primary quantities.

Windows—an Example

Windows provide a good example of the problem of predicting performance, and also of the designer's problem in specifying them. Windows are very complex units. Performance tests may cover strength, mechanical properties, air leakage, rain penetration, and thermal proper-

ties. Thermal testing of windows alone will be considered in this discussion (and even this in a partly hypothetical way) since thermal test methods for windows are only now being formulated in Committee E-6 of ASTM.

What is the designer's problem? He may specify in simple terms that he wants a *good* window, thermally, for the conditions of the particular application. This is a performance-type specification, but it is clearly quite inadequate since it does not provide any clear basis for interpretation of what is really wanted. The designer may (and often does) encourage suppliers to make recommendations from which he will later make a specific selection. This procedure leads to wasted effort and many uncertainties. It confuses the bidding and may lead to long delays in procurement. The most serious objection, however, is the possibility of delayed decisions on other important matters which should have been reconciled at an earlier stage in the design. It is becoming increasingly necessary to identify all such possibilities and to face them, as part of the design process, before they become irrevocably committed by prior decisions.

Another practice, that of specifying a particular product by name, need not be discussed in any detail except to note that it removes any question as to what is wanted at the expense of the practical certainty of other difficulties. It has one other significant feature since, implicitly at least, a decision *has* been made by the designer that the specified product will provide the required performance.

Some of the difficulties resulting from restricted choices may be avoided if the designer has available to him a standard for windows, in this case the thermal aspects of windows, which he *knows* will result in a window having suitable performance. Failing this, and proceeding further on a performance basis, he may identify all the important performance features and proceed to specify them. If common knowledge of window thermal performance, including his own knowledge, were entirely adequate, he might proceed to do this quite readily, in the expectation that others could also identify what is wanted. This requires, however, that the designer and all others concerned be familiar with *all* the pertinent relationships between the various factors involved in the thermal characteristics of a window and of its final performance, or at least that all those involved possess the ability to predict accurately what will happen when any selected window is used.

This is the ideal situation. Unfortunately, it cannot be applied at present to the thermal performance of windows. Not even the specialists can predict, out of present knowledge, the final thermal performance of a window in place. This will be affected not only by the materials used and by the configuration of the window itself but also by its connection with the wall, the properties of the wall, the nature of the exposure to

outdoor weather elements including wind and sun, and the inside environment including temperature, radiation, and air motion as determined by the thermal characteristics of the room, its occupancy, and the heating and cooling system.

An understanding of all these considerations and their effect on thermal performance is being steadily developed. At any given time, however, ways must be sought to achieve the best possible prediction of performance despite all the deficiencies in knowledge. This can only be done by testing.

One can devise and describe a separate method of test for use in connection with every new practical situation as it is encountered, and use it as a basis for a performance approach for each particular case. In the case of windows, all manufacturers and suppliers who may have an interest must then test according to this particular new method in order to determine whether their product will meet the requirements. This can clearly be a costly and very time-consuming approach.

Clearly if a *standard* method of test can be devised which will be widely accepted and regularly used, a much more orderly and less costly approach becomes possible. Different laboratories may then produce results that can be compared at any time. Manufacturers and others can determine in advance what the performance of their product will be, as measured according to that particular standard test method. A great deal of testing and retesting in accord with a variety of methods will thus be avoided.

A significant compromise must usually be made in order to gain this advantage. The method of test cannot on the one hand be "standard" and at the same time provide an entirely adequate basis for evaluation of performance for all possible practical situations. In all such standard methods of test, including the ASTM window thermal test method now being prepared, it is necessary to select one particular set of test conditions. Thus the standard window test method will be basically one by which windows can be compared rather than tested in association with their actual surroundings. The final step of predicting performance *in situ* on the basis of an interpretation of the test results must still be accomplished.

It is always necessary to take into account the differences between the test conditions and those that pertain to the particular application on the job. This is a task for the expert. Where knowledge is inadequate, it becomes necessary to rely upon experience and judgment. In specific situations it may even be appropriate to carry out further testing of a special kind, despite the difficulties with specially devised methods already described. The adequacy of this approach is limited by the ability to anticipate the pertinent conditions which will finally exist and to simulate them adequately in the test or tests. This also requires the best

knowledge and judgment of a competent professional worker, but with such aids he should be able to provide improved prediction of *in situ* performance, as compared with earlier empirical selection.

This, then, is the answer to the man who complains that the designated product met the requirements set out in some standard test but failed to perform adequately in practice. There is no magical way of arriving at final performance prediction. It can only be built up out of the knowledge available, aided by such performance test information as it is possible and practicable to obtain for the purpose, all interpreted with sound judgment based upon experience.

Development and Use of Standard Test Methods

The ASTM window thermal test method (being developed by Committee E-6) will of necessity have to be based on some standard "surround," probably an insulating material, to simulate the way in which the window will be used in a wall. The inside and outside conditions of radiation and air flow will have to be very carefully specified in the interests of reproducibility of results. They may, in consequence, appear to be quite unrealistic to the uninitiated.

Some such standard test method is essential, however, for the reasons that have been given, if designers are to have even the most simple of yardsticks against which to judge how the components they select will perform. Clearly, a standard test method by itself will be of little use to the designer. In simple terms, the use of standard test methods for measurement of the particular property with which they are concerned is comparable to the use of a ruler or a yardstick for measurement of length. It is possible with such an aid to measure unambiguously to some graded and generally accepted scale.

The question of the minimum or desirable value on the scale provided by any standard test method for measuring a characteristic of performance is not an essential part of the method. It must, however, always be questioned whether the kind of measurement that will be produced is the one that is wanted, just as it is appropriate to ask, before using a ruler, whether it is a measurement of length that is wanted and whether the units of measurement are needed in centimeters or inches.

It follows that the availability of a standard test method by itself is not going to be of very much assistance to designers. They must be able to interpret the significance of the results obtained from the test. Since these results will be measurements expressed in precise units, the *ranges of values* within which test results should lie must be known if they are to be regarded as satisfactory. Such limits are what are generally described as "performance criteria."

There are some who dislike this term when used in association with results from standard tests, but it can be seen that some such guide is

essential if standard test methods are to take their proper place in the process of building design as an aid (but no more) in the preliminary assessment of probable performance. The final stage in the overall process is the development by mutual agreement (through the consensus principle) of a *standard* that will establish what the minimum criteria must be, but this can be done only against a background of long experience, and within well-defined limits.

When it is recalled that the preceding discussion has related to windows only and that windows, important as they are, are but one of the many groups of components that must be incorporated in modern buildings, the challenge ahead of ASTM, and of its Committee E-6 in particular (charged, as it is, with the development of "Tests for Building Constructions"), is difficult to describe in temperate language. With the explosion in the volume of building that can already be foreseen for the years immediately ahead, it is safe to say that never in its history has the Society been faced with such a pressing, urgent, and vast demand as it now has in connection with the immediate development of performance tests for a wide range of building components and the development of the associated performance criteria. Only with such standard test methods available, and the means for their interpretation, does the "performance concept in building" begin to have meaning.

Conclusion

This, then, is the direction in which thinking about the performance concept must move, if this valuable—and indeed essential—idea is to be fully applied in the buildings of the future. To talk about the performance concept without, at the same time, talking of the standard performance tests that are imperative, is equivalent to speaking about an automobile without any engine. To talk of performance-type codes without realizing that all such codes *must* include clauses defining the test methods that must be used to equate the performance of one set of components with that of more conventional types is comparable to discussing a financial contract which does not contain any provision for payment.

Without standard performance-type test methods available, devised along the best possible well-defined lines and based upon all the research results that can be used, and in the absence of sound experience, talk about the performance concept is not very meaningful. Correspondingly, appreciation of the significance of performance tests results is essential to the designer so that he may know the criteria that he must apply in using test results in his design process.

In the same way, as will now be clear, there can be no such thing as a "performance code" but only a performance-type code, unless one is willing to go to the absurdity of regulating that "buildings must perform

satisfactorily." Systems of measurement of performance, even though subject to all the limitations outlined in this paper, are essential aids whereby the idea of performance may be embodied in building regulations, and permit of a reasonable selection of materials and components while safeguarding the integrity and safety of the structures to be built.

The performance concept in building is here to stay. It is greatly to be hoped that it will become more accurately, more widely, and more completely appreciated throughout the building industry. This will take place only if it is always associated with the concept of measurement, measurement that is based on standard test methods so that it cannot be misunderstood, measurement the results of which can be communicated to others without fear of wrong interpretation. This means standard test methods for building components on a scale never before seen or even visualized. In general, these will have to be laboratory tests. The significance of the results so obtained must be capable of assessment in relation to well-accepted and well-tried criteria. But in the final analysis, the most critical step of all is in applying in design the results of such tests, excellent as they may be, and this depends on the professional judgment of the designer—and for this there is no substitute, not even computers.

This, too, has been said before—two thousand years ago. Words of Marcus Vitruvius Pollio can most appropriately bring this paper to its conclusion, so clear was he in his thinking about modern building, so imbued was he with the performance concept in building. At the very outset of his great work he says⁵—and the authors beg leave to associate themselves with his most pointed opening words:

The architect should be equipped with knowledge of many branches of study and varied kinds of learning, for it is by his judgment that all work done by the other arts is put to test. This knowledge is the child of practice and theory.

⁵ *Vitruvius—The Ten Books on Architecture*, Book I, Dover Publications, New York, 1960, Chapter I, paragraph 1.