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WORKING WITH THE PERFORMANCE APPROACH IN BUILDING

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Working with the Performance Approach in Building

Summary

This report provides a state-of-the-art review by CIB/W60 of the performance approach in building practice, against the background provided by building science. Main chapters deal with setting performance requirements, testing potential solutions against criteria, the evaluation of solutions in relation to requirements and techniques for application.

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CONTENTS

WORKING WITH THE PERFORMANCE APPROACH IN BUILDING

Preface

CIB Working Commission W60 'The Performance Concept in Building' was set up in 1970, largely on the initiative of the Directors of the four Scandinavian Building Research Institutes. The first meeting was held in Oslo in 1971 under the guidance of the first co-ordinator, Oivind Birkeland of the Norwegian Building Research Institute. In 1974, Dr Eric Gibson of the UK Building Research Establishment took over as co-ordinator.

The Commission has met 14 times since 1971. Although the total membership exceeds 40, the majority of members of necessity work by correspondence only. At present, the frequency of meetings is about one per year, held to date in either Western Europe or the Middle East.

The following reports have been issued:

- 'The performance concept and its terminology'
  (CIB Report No 32 - Ref 1)
- 'Terminology and guidance on the application of performance concept in building'
  (W60 Working papers - Ref 2)
- 'Setting performance criteria for building products'
  (W60 Working papers - Ref 3)
- 'Performance test methods and the interpretation of results'
  (W60 Working papers - Ref 4)
- 'The relative significance of performance requirements'
  (W60 Working papers - Ref 5)

The work has now reached the stage when the Commission can provide a further statement of its views on the development and application of the performance concept as a practical tool for the building industry.

This report, edited by Eric Keeble of BRE, offers guidance on both conceptual and practical problems. Chapter 1 describes the meaning of the performance approach, while Chapter 2 explores the range of interests and applications to which it is relevant. Chapters 3 to 7 give more detailed guidance on the determination of performance requirements and achieved performance, on the evaluation of suitability for use and on specific types of application.

The report is published to coincide with the third joint ASTM/CIB/ RILEM Symposium on the Performance Concept, to be held in Lisbon from 29 March to 2 April 1982.

E J Gibson
Co-ordinator, CIB Working Commission W60

1 WHAT IS MEANT BY THE PERFORMANCE APPROACH IN BUILDING?

The performance approach is, first and foremost, the practice of thinking and working in terms of ends rather than means. It is concerned with what a building or building product is required to do, and not with prescribing how it is to be constructed. This is not to say that means - particular types of construction, products or materials - are not considered; they are, but strictly in terms of whether the means will achieve the ends, and will do so reliably for a defined period of use. There can be no assumption that a design solution, whether traditional or novel, will be satisfactory in service without a quantitative basis for testing and subsequent evaluation of its performance.

In essence, therefore, the performance approach is no more than the application of rigorous analysis and scientific method to the study of the functioning of buildings and their parts. There is little fundamentally new in this concept; indeed, the basic data and methods used in structural and environmental design, which employ the principles of performance though not necessarily its terminology, have evolved over many years. However, the performance approach does break new ground by attempting to define unified and consistent methods, terms and documentation, and by subjecting all parts of the building to systematic scrutiny. In particular, it implies:

(1) Assembling data and criteria from different contributors to the total design and attempting to state them in common terms,

(2) Extending the scope of quantitative analysis to aspects of performance previously taken for granted (particularly important when dealing with innovative designs or products),

(3) Defining all design objectives clearly,

(4) Demanding proof of compliance with requirements via accepted methods of test and evaluation, and

(5) Where products or designs are being compared against performance criteria, defining methods of ranking or weighting individual aspects of performance to give a measure of overall quality.

The practice of defining performance requirements or preparing performance specifications is often contrasted with the use of prescriptive requirements or specifications*. Prescriptive specifications describe means, as opposed to ends, and are concerned with type and quality of materials, method of construction, workmanship, etc.

Prescriptive requirements are perhaps simpler to work with than performance requirements, but they can stand in the way of the most efficient and economical solution to a building problem, since:

(1) By prescribing a restricted range of solutions, they exclude from consideration other solutions which may possibly be better or cheaper (exclusion of innovation) and,

(2) They are only as up-to-date, widely-researched, appropriate and compatible as the specification writer's knowledge permits, that is to say they are not the best means of tapping other people's knowledge or ideas.

The trend towards the performance approach and performance specification arises from the accelerating rate of change of building techniques, from the availability of improved space-planning and design techniques and from higher expectations of the conditions to be provided by buildings. For buildings, performance specifications can provide a quantified, functional brief to serve as a basis for design, whether that design is prepared in the same organisation, delegated under contract or the subject of a competition. For components, performance specifications may provide a means of actively promoting innovation or, perhaps more commonly, a set of criteria for evaluating either innovative or existing products in respect of their suitability for a particular use. The performance approach permits new developments to be exploited, while safeguarding and assuring a level of quality adequate for the purpose in question.

Prescriptive specifications will, however, continue for some time to play a significant but supplementary role. The performance approach depends on the availability of a large and wide-ranging fund of scientific knowledge on each aspect of building function, and on building techniques and materials (to enable requirements for controlling side-effects and incompatibilities to be included). While knowledge is adequate for some aspects of performance it is not yet available for all, so that practical specifications will often need to be expressed partly in performance terms and partly in prescriptive terms.

There may be other reasons for retaining some aspects of a specification in prescriptive terms, eg:

(1) A building owner might want to prescribe or restrict the form or materials of a building, either for aesthetic reasons or to simplify maintenance and limit the range of spare parts likely to be needed, especially where a complex of buildings, erected at different times, is involved,

(2) The cost of a performance evaluation may be too high in relation to the value of the product. An example is the evaluation of ageing. It is usually impossible to assess the natural ageing process by a quick, cheap test, whereas it is nearly always possible to do so by a long, expensive one. In such cases it may well be more cost-effective to use a prescriptive specification,

(3) In parts of the world where professional resources are scarce, or where the local construction industry is not able to respond to a performance specification, prescription of construction details and techniques may be necessary for the practical implementation of building work.

In principle, all prescriptive specifications or design details for general use, eg prescriptive product standards, standard details, and construction guidance in Codes of Practice and textbooks, should state the level of performance expected to be achieved, where this can be confidently predicted from experiment, calculation or feedback from use. This can help to provide continuity and consistency between design decisions taken at different stages of a project, and should also reinforce caution about making untested changes to established details or products, which can have a disastrous effect on their performance.

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*In some parts of the building materials industry, performance specifications are known as 'end result' specifications, while prescriptive specifications are known as 'recipe' specifications.

2 USES AND USERS OF THE PERFORMANCE APPROACH

The performance approach is relevant to a wide range of problems and processes within the construction industry; wherever, in fact, the utility and value* of a particular form, layout, space, product or material have to be considered. In view of this, it is particularly necessary for any study, documentation, or specification based on performance to be absolutely clear about the precise level and scope of problem addressed. This Chapter summarises many of the possible fields and scales of interest, so as to illustrate the various contexts in which building professionals may encounter performance thinking, or be able to apply it with advantage.

2.1 Buildings and their spaces

2.1.1 Building fabric

The functioning of buildings and their constituent parts can be considered from various points of view, eg as illustrated in Figs 1 & 2. Potentially, the performance approach is relevant to all parts of the fabric at all levels of detail, although the nature of the performance attributes to be considered will vary. Note that Fig 1 shows only order of size, and not order of composition. Thus, for example, a single component, product or material may form part of more than one sub-system or element, eg a facade unit may act as part of the structure, external envelope or thermal, ventilation or electrical services.

The way in which materials or products are used may be as important as their intrinsic properties in determining the performance of elements or sub-systems; they may, for example, by either exposed to or protected from aggressive agents. Thus, at any level, the strategy of the design solution both contributes to the satisfaction of higher-level requirements and also implies additional, consequential requirements for lower levels in the fabric hierarchy. Conversely, unco-ordinated decisions at lower levels may constrain the range of possible high-level solutions.

Example:

> A high-level decision to air-condition a building is likely to lead to stringent requirements for the air-tightness of the external envelope, to reduce or prevent air leakage. Conversely, the prior choice of a relatively permeable construction for the external envelope could rule out air-conditioning as a viable option.

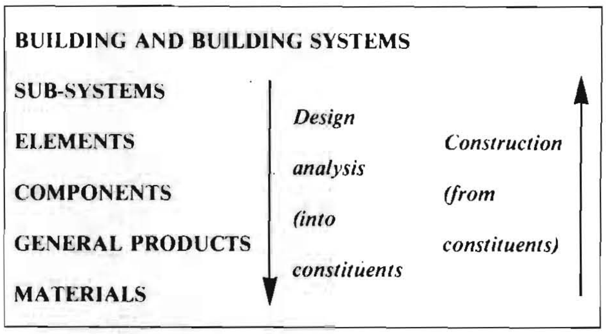

Figure 1 Building fabric — example of classification by size

SUB-SYSTEMS	
Structure	*Foundation* *Carcass*
External envelope	*Below ground* *Above ground*
Space dividers: external	*Vertical* *Horizontal* *Staircases*
Space dividers: internal	*Vertical* *Horizontal* *Staircases*
Services	*Water supply and disposal* *Thermal and ventilation* *Gas supply* *Electricity supply* *Telecommunications* *Mechanical transport* *Pneumatic and gravity transport* *Security and protection*

Figure 2 Building fabric — example of classification by function (from ISO DP 6241; 1982 — reference 7)

*There are close parallels between the performance approach and the technique of value-analysis when applied to building design; value-analysis always involves consideration of the cost of providing different levels of quality or amenity.

2.1.2 Building spaces

Spatial classifications, parallel to those of the fabric and of equal importance, are also useful in performance thinking. Classification by size (Fig 3) can help relate environmental conditions, both planned and unplanned, to the demands made of the building fabric at various levels of detail (eg with regard to functions of separation, insulation, protection from hazard or damage, etc).

Classification by use (Fig 4) can be of value for grouping and ordering performance requirements for common building types, especially for the purposes of Building Regulations, eg occupancy classes for imposed loads and fire hazards. In other cases it may be necessary to analyse the specific activities and processes to be accommodated within building spaces.

SPACES BETWEEN BUILDING
OPEN AREAS WITHIN BUILDINGS
ROOMS
ANCILLARY SPACES ***(eg storage)***
SERVICE SPACES ***(eg lift shafts, ducts)***

Figure 3 Building spaces — example of classification by size

TRANSPORT
INDUSTRY
COMMERCE
MEDICAL CARE
RECREATION
CULTURE
HOUSING
CIRCULATION
CATERING
HYGIENE
CLEANING AND MAINTENANCE
STORAGE
PLANT, CONTROL
OTHER

Figure 4 Building spaces — example of classification by use (from ISO DP 6241; 1982 — reference 7)

2.2 Examples of applications

2.2.1 Fields of application

The performance approach may be applied during:

1) The design and construction of a single project

2) The design and construction of a continuing building programme

3) The development and marketing of building products

4) The preparation and structuring of design guidance

5) The control of construction quality through inspection, approval or certification (whether by governmental or private agencies).

DESIGN OF SINGLE PROJECT
DESIGN OF CONTINUING PROGRAMME
PRODUCTS
DESIGN GUIDANCE
CONTROL OF DESIGN AND CONSTRUCTION QUALITY

Figure 5 Fields of application

2.2.2 Purposes served

For specific building projects, applications at various stages may be considered, eg briefing, sketch design, detailed design, component supply, assembly and construction, commissioning, acceptance.

Improving the quality of design data and guidance is of growing importance as design methods develop and the volume of information available to designers increases.

For product development and marketing, appreciation of the added value of superior performance is essential, as is the provision of clear and explicit performance data in product literature.

Quality control provides a major opportunity to obtain feedback from practice on a wide scale, which is essential for the continued refinement of performance criteria and of design and evaluation methods.

SPECIFIC BUILDING PROJECTS

Functional briefing
Design delegation
Design competition
Design and build
Selection of a building system
Selection of building components

DESIGN DATA AND GUIDANCE

Collection of basic data
Validation and consistency of criteria and methods
Structuring and organisation of documents

PRODUCT DEVELOPMENT AND MARKETING

Research and development
Promotion and marketing
Product literature

QUALITY CONTROL

Performance-based building regulations
Certification of products and systems

Figure 6 Examples of purposes served

2.3 Participants and their involvement

2.3.1 Types of participant

Each type of participant has a distinctly different set of interests in building performance, although those of certain participants overlap to some extent. Distinction should be made between those interested in all aspects of performance, ie including ease of construction, operation or repair, together with long-term economics, and those mostly interested in a specific aspect, eg ease of construction (builders) or performance of particular products or materials (manufacturers).

THE COMMUNITY BUILDING USERS CLIENTS DESIGNERS BUILDERS MANUFACTURERS INSURERS

Figure 7 Types of participant

2.3.2 Character and degree of involvement

The participants range from corporations and official bodies building year after year, creating opportunities for feedback and continuing improvement, to the single client commissioning a building once in a life-time. The performance approach is likely to be more relevant, and yield greater benefit in relation to the resources expended, for the 'continuous client' than for the single commission or other 'one-off' involvement. Under some circumstances large contracting organisations will have similar opportunities and interest in using the performance approach.

CONTINUOUS INVOLVEMENT INTERMITTENT INVOLVEMENT ONCE-ONLY INVOLVEMENT

Figure 8 Character and degree of involvement

2.3.3 Responsibilities

Responsibilities are assumed both by those setting performance requirements and those undertaking to meet them. Requirements may be set by individual specifiers or by corporate agencies such as regulatory bodies, standards committees, research institutes or the procurement departments of large organisations. Any decision about a performance level appropriate for a particular purpose carries with it a connotation of risk, in terms both of known sources of uncertainty and of possible errors of judgement. Since a building has ultimately to be operated, maintained and possibly adapted or altered by the occupants, the provision of a manual of instructions, including performance data and explaining the designer's intentions, can help to ensure satisfactory performance in use.

The responsibilities associated with meeting performance requirements vary in degree, according to circumstances. At the simplest level, responsibility can be limited to assuring compliance with prescribed test criteria, subject to considerations of statistical uncertainty. More responsibility is taken if the results of performance tests are interpreted to provide an evaluation (or declaration) of suitability for a specific use. Still greater responsibility is assumed if a performance evaluation or declaration is used as the basis for guaranteeing or assuring satisfactory performance in use, over whatever time-scale design and construction liabilities extend. All or part of these responsibilities may be assumed by several types of participant, eg designer, builder, manufacturer, control or certification authority. Also, with respect to performance in use, it is encumbent upon occupants and owners not to misuse the building, eg by engaging in unplanned-for, detrimental activities, or by neglecting maintenance.

2.4 Documentation

2.4.1 Types of document

Documents may be prepared for any of the purposes described above; their content may accordingly range from the general to the particular. Since documents are likely to originate from various organisations, care needs to be taken to ensure that their technical contents are complementary, consistent and up-to-date.

CHECK LISTS
GENERAL LISTS OF PERFORMANCE REQUIREMENTS
DESIGN DATA AND AIDS
PERFORMANCE SPECIFICATIONS
BUILDING REGULATIONS
STANDARDS
PRODUCT LITERATURE
AGRÉMENT CERTIFICATES

Figure 9 Types of documents

2.4.2 Document structure

No single order is recommended here for presenting attributes in performance specifications or performance declarations, since such presentation may need to vary according to circumstances, eg to reflect differences in the relative importance of attributes for different applications. One recommended order is given in ISO DP 6241 (7)*, while an alternative is contained in the CIB Master Lists (8)*. Such lists may be used for the order itself, or as a means of cross-referencing items placed in a different order, or simply as check lists.

It is also necessary to ensure that the scope of performance documents includes all the considerations essential for practical implementation, eg adequate reference to intended purpose and context, methods of evaluation, etc. ISO 6240 (6) specifies the scope and clause order for performance standards. The headings of the principal clauses are shown, as an example, in Fig 10.

PURPOSE AND CONTEXT OF USE

Role
Relevant agents

PERFORMANCE REQUIREMENTS

Definition of performance
Methods of assessment or verification
Performance values
Commentary

DESCRIPTION OF ACHIEVED PERFORMANCE
APPLICABILITY TO CERTIFICATION

Figure 10 Technical contents of performance standards (from ISO 6240; 1980 — reference 6)

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*In a draft revision of the 1972 CIB Master Lists, currently under discussion, the possibility of integrating the CIB and ISO approaches is being explored.

3 THE NECESSARY KNOWLEDGE BASE

Whatever the range of performance attributes involved in a particular application, effective use of the performance approach depends on knowledge of:

(1) the requirements of building users, eg occupants, owners, builders and the public at large,

(2) the context in which buildings or their component parts have to meet those requirements (ie, all the agents influencing performance, whatever their origin or nature), and,

(3) predictive methods for the evaluation of behaviour in use (ie for modelling the performance of buildings and their parts).

These three types of knowledge are drawn upon in various combinations for particular purposes, as described in subsequent Chapters of this report. For full use of the concept, the knowledge needs to be quantitative, or at least capable of a quantitative interpretation, to provide a workable and unambiguous basis for performance-based regulation, design, appraisal, etc.

The 'knowledge base' applicable to a particular building or product is seldom found in a single publication, and is more likely to comprise material published in textbooks, design guides, data books and data bases, Codes of Practice and Technical Regulations. Some numerical data, especially that comprising the context, may be specific to a particular building on a particular site; in such cases guidance is needed on methods for collecting the necessary data.

Improvements in this knowledge base accrue from research and practical experience (feedback) on many specific topics, and there are today many more proven test methods than were available only a few years ago. For application, some simplification of research methods or findings is usually necessary. It is important always to bear in mind the degree of simplification or uncertainty involved in practical data and methods, so that the apparent precision of a systematic, analytical approach, does not mask the underlying approximations.

When the overall performance of a building or product is being considered (ie involving all the performance attributes significant for a particular use), it may be helpful to use check lists to confirm that all relevant factors have been considered. Various check lists, including ISO DP 6241 (7) and the CIB Master Lists (8), provide sets of detailed sub-headings for user needs, context, and behaviour in use, elaborating the main headings shown in Figure 11.

USER NEEDS (ISO DP 6241)

Safety
Habitability
Suitability for use
Durability/reliability
Economy

CONTEXT (ISO DP 6241)

Climate
Site
Occupancy effects
Design consequences

BEHAVIOUR IN USE (CIB Master List)

Structural properties
Fire properties
Effects of gases, liquids and solids
Thermal properties
Acoustic properties
Optical properties
etc . . . . . .

PREDICTIVE METHODS

Laboratory testing
Full-scale testing
Calculation
Conformity with designs known to be satisfactory

Figure 11 The knowledge base

4 HOW DO WE DETERMINE PERFORMANCE REQUIREMENTS?

4.1 User requirements

The starting point for analysing the functions of a building is to consider the requirements of its users. In this connection, the word 'user' is used in a broad sense and may be taken to mean not only the occupants of the building (which itself includes permanent occupants together with visitors, cleaning and maintenance personnel), but also non-occupying but interested parties. These include owners, financiers, building managers and those in the vicinity, eg neighbours and the general public who might be affected by the building both in its normal and possible accidental states (eg collapse, fire, explosion). Taking all classes of building into account, the 'user' may even include non-humans such as animals or plants in agricultural buildings, or machinery and equipment. If, as is often the case for products, consideration of performance includes factors such as ease of handling and installation, then the builder, too, is added to the list of users.

User requirements may include technical, physiological, psychological and sociological aspects. These are generally first thought of in qualitative terms, when they are perhaps best described as goals or objectives for the building to fulfil, in terms such as, for example:

'To provide a suitable standard of thermal comfort (or lighting, or ventilation, or sound insulation) for the envisaged activities of occupants.'

'To provide a suitable level of reliability in respect of structural failure (or accidental damage, or the incidence of fire and its consequences) in relation to the people and capital at risk.'

At this level of detail, the concepts are very much those that would be included in an explicit, functional brief for a building, discussed and agreed between a client and a designer (acknowledging that, for matters of safety and health, it is often sufficient to conform with the objectives laid down by society as a whole, and implemented through Regulations or similar controls on building quality). Correspondingly, these will also be the terms in which the degree of success of a completed building will be judged by its users.

To convert such qualitative statements of user goals into quantitative user requirements is a specific stage in the design process, drawing on the accumulated knowledge and experience of the environmental conditions and facilities, including space and layout, needed for various user groups (eg children, adults in active or sedentary work, old people), engaging in various activities. At this stage certain practical qualifications may need to be introduced:

(1) It may have to be admitted that, in certain respects, it will never be possible completely to satisfy 100 per cent of possible users, due to the variation in individual responses to, for example, thermal and lighting levels; a practical compromise is to seek a reasonable 'fit' with the needs of, say, 95 per cent of users.

(2) For some aspects of performance, it may be impractical to expect the goal to be completely met; it will be necessary instead to accept a reasonable degree of satisfaction. A prime instance is the level of intrusive noise permissible in a particular room or space. In some circumstances this level might ideally be very low, approaching zero, but in practice it is accepted that economical forms of building construction cannot achieve this. Accordingly, user requirements for this type of attribute are set at levels known to be achievable and generally acceptable.

4.2 Performance requirements and context

User requirements defined in this way express measurable quantities; a building in use could be appraised to ascertain the extent to which such criteria are met. However, for many attributes they do not, on their own, constitute performance requirements for a building. This is because a building performs not in isolation, but by resisting, controlling or exploiting the features and agents that comprise its context - the climate and site in which it is situated, the incidental effects of occupancy (such as water vapour, surplus heat or abrasion) and, particularly for products and materials, the 'design consequences' of basic decisions about built form and the principles on which the building functions (eg high or low thermal inertia).

Thus, by way of definition, for whole buildings:

User requirements define conditions and facilities to be provided by a building for a specific purpose, but independent of where it is located,

while

Performance requirements define in quantitative terms the conditions and facilities to be provided by the fabric and services of a building, usually for a specific purpose on a specific site and reflecting particular design decisions.

Examples:

Thermal comfort in winter

User requirement: a minimum internal air temperature of 20°C shall be achieved on all but 3 days per year, on average.

Performance requirement: a minimum internal air temperature of 20°C shall be achieved when the daily mean outside air temperature is -2°C or above (assuming this to be the low extreme reached or surpassed on an average of 3 days per year on a particular site).

Intrusive noise from sources outside the building.

User requirement: the maximum equivalent noise level, L_{eq}, during the working day (08:00 to 18:00) shall be 40 dB(A).

Performance requirement: the maximum equivalent noise level, L_{eq}, shall be 40 dB(A) when the external noise level is 75 dB(A) (assuming this to be the value in the vicinity of the building between 08:00 and 18:00).

It is clearly more difficult and therefore costlier to provide a particular level of comfort, convenience or other facility where the environment is unfavourable. In some cases, this may have to be reflected in a lowering of the standards adopted as user requirements. Data on performance requirements may be given directly where more convenient, eg in a design specification for a particular project. In documents of a more general character, it is more probable that user requirements and contextual factors will be found separately, eg national Building Regulations or Codes may prescribe minimum internal temperatures for different occupancies or activities (user requirements), as well as minimum design temperatures for different regions of the country (context). The user then combines these as appropriate to determine the performance requirements for a particular building.

For sub-systems, components and materials, performance requirements can be defined either for specific applications or for generalized uses and locations, as in product performance standards. As noted in the following sections, certain performance requirements at these levels will not stem directly from user requirements, but will depend on decisions about the form and design strategy of a particular building or building type.

4.3 Performance of fabric and services

Many interdependent decisions have to be taken in the design of a building. There will often be several options about shape, form, fenestration, thermal behaviour, etc, implying a multitude of different ways of satisfying the same set of performance requirements. At 'sketch design' stage, widely different solutions might be contemplated and examined, each perhaps providing a different 'mix' of advantages - better performance in certain respects offset by poorer performance in others. The decision taken at this overall, strategic level (generally in favour of the solution offering potentially the best overall value for money) will determine what performance requirements are imposed on the elements and sub-systems that make up the building's fabric and services. The 'design consequences' of this decision complete the definition of the 'context' in which the fabric and services have to perform.

The same process of decision-taking and the generation of design consequences applies to subsequent decisions about the performance required of subsidiary or constituent parts of the fabric or services, eg components, materials, joints. However, in reality, the process is not usually an uninterrupted progression from the general to the particular, but has a more cyclic character, with the consequences of detailed decisions reflecting back on subsequent decisions (see Fig 12). Also, within the same cyclic process, the consequences of different possible decisions may be explored tentatively before each final decision is taken.

4.4 Performance requirements for products

Discussion so far has been primarily in terms of a unique functional analysis undertaken as part of the design of a particular building. At some point, however, these requirements have to be interpreted in terms of the actual products from which buildings are created - ranging from large-scale industrialised components to basic materials - and reflecting the ways in which elements of construction can be designed and built in practice. Custom and practicality dictate the form of most components so that, although one of the aims of working in terms of performance is to encourage imaginative solutions, for products these opportunities are most likely to be realised in terms of alternative materials or detailed design. In other words, the requirements derived for fabric and services have ultimately to be resolved into specifications for recognisable components and construction features.

At this stage it may be realistic to limit the number of performance attributes considered. Whether products are being chosen from the market or specially commissioned, the practical problems of evaluation and assurance of performance mean that effort must be concentrated where it is most effective. It will generally be feasible to consider in depth only the primary performance attributes of products, which determine their basic suitability and for which test methods and data on existing products are likely to exist. A different situation obtains when the performance approach is used for product development or for a highly innovative building design, when a more exhaustive approach may well be necessary.

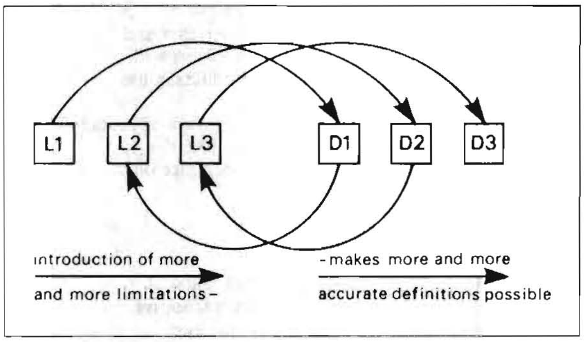

Figure 12 Cycle of performance definition

Table 1 Methods of selecting criteria

Method	Activity	Advantages	Problems	Applicability
1 Subjective selection	– intuitive selection of a set of criteria or – systematic listing of criteria followed by subjective selection	– not resource – intensive – good results with 'right' expert(s)	– no direct user involvement – takes into account only one person's experience	– applicable only to problem areas where experts are available
a) by an individual expert	– selection based on the individual's knowledge and judgement		– justification of selection often not documented – difficulty of selecting expert	
b) by a group	– selection based on group's knowledge, discussion and concensus	– based on several experts' experience	– subjective	
2 Selection based on the availability of test methods	– review of existing test methods, and selection among these by an expert or group of experts	– easy to evaluate (methods available) – easy to set levels (quantify) – moderately resource-intensive	– no direct user involvement – problems of validity – methods often based on existing products (not innovative) – acknowledged lack of test methods in many fields	– a pragmatic way of selecting criteria often used in performance specifying – applicable only to well-established problem areas
3 Selection based on functional analysis	– definition of the main function of a product and subdivision of this into subfunctions, leading finally to a list of criteria related to the function, and to selection among these (or to various other methods, eg 1 or 2)	– aid in structuring available knowledge – use-orientated – helps to identify gaps in knowledge – easy to use/not resource-intensive	– no direct user involvement – presupposes a certain type of product – does not provide any new information – subjective selection often used	– often used in product development to create ideas to improve existing products. A structurning aid in performance work
4 Selection based on feedback from products in use	– collection and analysis of experience and problems with products in use	– user may be directly involved	– based on existing products (not innovative)	– often the basis for existing norms
a) complaints and records of failures	– collection of problems and negative experience only	– inadequate products may be eliminated	– defines negative, not positive characteristics – time lag before problems are identified	– not recommended for developing performance specifications
b) surveys of products in use	– collection of representative experience (positive and negative) – may use a functtional analysis (3) as a framework (eg for a questionnaire) – may lead to recognition of need for user studies	– both positive and negative characteristics are identified – it may be possible to determine the order of importance of attributes to the users – may identify redundant attributes	– may need to wait for a period of familiarisation with the product before results are representative	– can be used to validate and develop a functional analysis (3), and aid performance work
5 Selection based on the study of user requirements (research carried out at the time of selection)	– direct user participation in product specification, – or systematic research studies of user requirements and transformation of these into criteria	– user directly involved – gives the basic criteria against which to evaluate performance related to use – innovative	– often resource-intensive (getting in touch with the user, etc) – methodological problems – transformation into more technical language generally needed	– generally the task of research; needed when established information base is not available

4.5 Selecting criteria

Performance requirements may need to be selected by designers when specifying products to be used in a building, by manufacturers when developing new products or when preparing product information, or by governmental or other agencies when drafting Building Regulations. The importance of particular requirements varies according to circumstances, but often it will be both possible and desirable to concentrate on the relatively few 'prime' attributes which decide the character and acceptability of a solution.

This section of the report focuses on the process of selecting criteria and not on the use of criteria to assess proposed solutions. A criterion is a standard of performance against which the adequacy of a performance attribute can be judged. Various methods or procedures may be used for this process of selection, some more systematic and based on greater 'in-depth' knowledge than others. Table 1 groups the methods into categories, but these are not mutually exclusive; method 1 is always used to some extent, in combination with one or more of the others.

There is a dependent relationship between methods 1, 2, 3, 4 and 5. Subjective selection (1) and functional analysis (3) are likely to reveal deficiencies in knowledge about some user requirements, and hence point to the need for direct user research (5). Conversely, the results of user feedback or surveys (4) will need processing in order to make them usable in design, including the selection of priorities. In passing it may be noted that method 1 is essentially that of the individual building designer applying his own knowledge and judgement, in lieu of the users themselves expressing their needs.

Whether or not suitable test methods are available (2) may be largely an accident of history. In considering their suitability for performance testing, the origins of existing test methods should be examined critically. It is quite likely that a test method will not be valid for circumstances of use other than those for which it was designed. The development of new test methods, where none exists, could arise naturally following the use of methods 1, 3, 4 or 5.

All the processes described have one fundamental aim - the proper satisfaction of user needs. The mechanics of the process may differ, but the essential task of correctly matching solution to requirement remains the same. Since the methods are not complete alternatives to each other, two or more methods may be used in combination (either simultaneously or in sequence), to tackle a particular problem. For example, it may be that

(1) different methods are used to select different types of criterion for a particular product, or

(2) the methods applicable will vary according to the state of knowledge in particular fields.

In general the aim should be to use method 3, tempered by methods 4 and 5. Method 2 is likely to be useful only for well-established criteria. Method 4 should be of particular value in programmes of continuous development, for confirming the validity of choices made. Feedback has a wide scope, providing information on how components actually perform in buildings and on the techniques and economics of their manufacture and installation. Some of the methods used to obtain feedback are listed in Table 2.

It is of little use defining requirements unless they can be satisfactorily tested, and this is examined in the next section.

Table 2 Some of the methods by which feedback can be obtained

1	SURVEY	national, selective or small scale, including product manufacturers' records
2	PANEL	skilled or informed observers
3	COMPLAINTS	systematic investigation and analysis of specific problems about which advice is sought
4	NATURAL EXPOSURE	measurements of performance in use under conditions which can be accurately measured at the same time
5	CAPACITY OF USERS	measure what the occupants of building can do or perceive
6	INDIRECT (environmental)	analyse suitable existing statistics and interpret these in relation to the performance attribute
7	INDIRECT (products)	equate situations where product performance in use is known to be satisfactory with measured performance of same products under laboratory tests

5 HOW DO WE PREDICT THE PERFORMANCE OF SOLUTIONS?

5.1 Models of building behaviour

In actual use, a building is subjected to an endlessly varying sequence of influences and stresses. The aim in developing models of building behaviour - which may be realised through either physical testing, calculation or judgement - is to distil the pattern of actual use into criteria simple enough for practical evaluation in building design, product development or product selection. Just how simple the models and corresponding test methods can become while still giving dependable results is explored later in this Chapter.

It is helpful to make a basic distinction between two types of model:

5.1.1 Static models

In static models the influence of an agent or stress is analysed at a single point in time or, for some types of problem, a period of time is aggregated into a single 'case' for modelling. Static models are normally adequate for problems involving agents that have constant values, or values that change relatively slowly, ie when the variation itself does not induce a significant time-related response in the building, or a part of it (over and above the static response). In the latter case, the models may be described as 'quasi-static'. Static or quasi-static models may be used to represent the behaviour of the building under extreme conditions, eg, many types of structural load, or average conditions, eg most types of accelerated ageing test.

5.1.2 Dynamic models

In dynamic models an attempt is made to mimic, to some degree, changes over time in the magnitudes of agents or stresses, and the associated response of the building, sub-system or element under consideration. Dynamic modelling is appropriate when the dynamic response of a system gives rise to critical extremes or modes of behaviour, eg when a natural frequency or the inertia of the system interacts with the rate of variation of the agent.

Dynamic models may be applied to extreme-value problems, eg structural or environmental loads, driving rain simulation in weather-tightness testing, or to average-value problems, eg prediction of energy use by computer simulation.

5.2 Testing and types of test

Testing is the means of arriving at an objective decision about a performance attribute or a property of a product or of a building. While there are several, apparently distinct ways of predicting performance, ie physical testing, calculation or judgement, even the latter two must in essence be based on previous knowledge obtained by observation or test.

Testing nearly always involves some approximation or simplification of real conditions of use. In general, less simplification is possible for test methods designed to simulate behaviour in use - hereafter referred to as performance test methods (PTMs) - than for other types of test, eg those intended to detect variations in the properties of mass-produced items. Thus the different purposes of different kinds of test need to be recognised, eg:

(1) PTMs for research purposes,

(2) PTMs for general development of products or systems, and

(3) Quality control test methods for production control.

Most work on performance testing has concerned building products and components. However, in principle testing is equally applicable to whole buildings, and to elements comprising a number of different components. There has been some successful research involving type-testing whole buildings and the spaces within them. In general, performance tests on whole buildings are very expensive and are most likely to be used:

(1) for research, eg to refine models of building behaviour,

(2) to provide feedback to designers, eg to improve cost-effectiveness or reliability, or,

(3) to check performance against Regulation requirements, or more generally to resolve contractual problems involving building performance.

Because they can be undertaken only after components have been installed in a building, in-situ performance tests are of little help for developing purpose-made components for that building. However, systematic test regimes on buildings are potentially a powerful tool for developing general-purpose components of high performance and reliability.

5.3 Objective procedures are needed for performance testing

Before a method of test can be accepted as a PTM and thus a means of assessing whether a product, component or building meets stated performance requirements, it must fulfil several criteria. In particular, the conditions of test under which the behaviour of the article is being assessed must be realistic in relation to the expected conditions of use, or related to them in some known way. This implies a knowledge of conditions of use, often on a statistical basis, to represent the intended extreme or average value.

Since conditions for testing frequently need to be simpler than those experienced in practice, there needs to be a clear scientific basis for relating the results of performance testing under simplified conditions to conditions in practice. Often studies relating the behaviour of similar articles in real buildings to those under test can be used for this purpose (see Fig 13). However, the level of stress appropriate to the conditions of use may vary between different countries or regions, particularly due to climate. Care must therefore be exercised in transferring methods of tests and levels of stress from one situation to another.

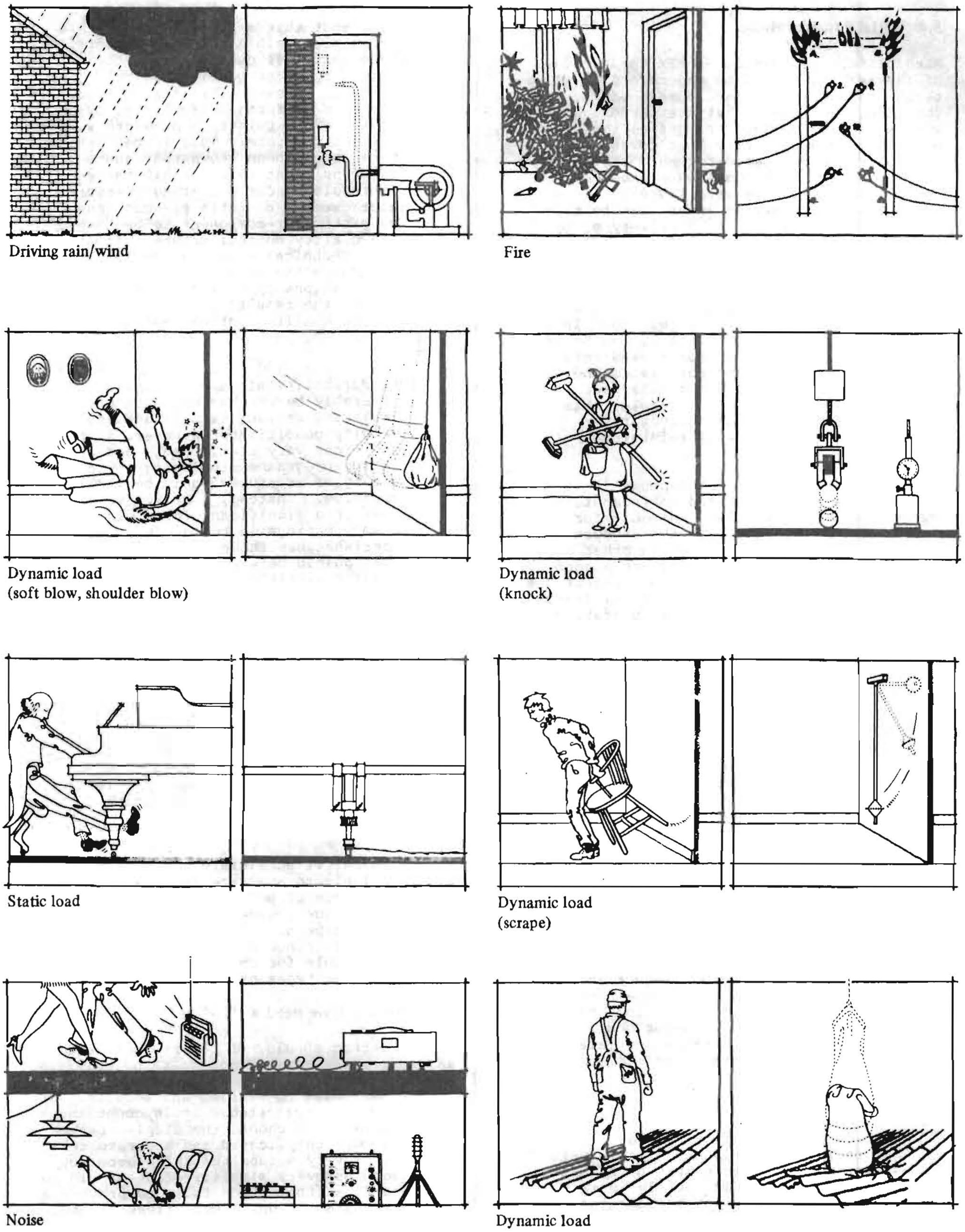

Figure 13 Examples of stresses for which there are outwardly similar test methods

5.4 Initial considerations

When planning to develop a PTM the purpose of the testing should be understood by all those engaged in the development work. It should be made clear that the purpose of the work is not to measure properties that have been decided arbitrarily, but to estimate the behaviour of a specific part of the building (eg a component) when exposed to conditions simulating actual use. Estimation of behaviour in use can be made either by testing in the laboratory or by field-testing in a partly finished or completed building.

Test development work should only be undertaken if there is an obvious need for a test method to permit correct evaluation. In some cases fairly simple calculations can be used instead of a test method for assessment, particularly when a good correlation between theoretical calculations and behaviour in use has been established. For example, this applies to evaluating the structural performance of traditional reinforced concrete structures.

In the early stages of development it is important to consider - and to reconsider - whether the method will be suitable for predicting the behaviour of the product under real conditions of use; in other words, whether the test method has a good validity. It is customary to proof-test the heating and air-conditioning systems installed in buildings, ie run them under operating conditions to see whether they match their designers' intentions. This is not, strictly speaking, the kind of PTM discussed here, where the emphasis is on an artificial test regime external to the items being tested.

5.5 Alternative test methods for quality control

Some PTMs may be so complicated and costly that it is unrealistic to expect them to be used for quality control, eg in a factory producing building components. However, if a simpler, alternative method is to be feasible, it is very important that the correlation between the original PTM and the alternative method be proven and well-documented. A test method which measures a property, but not a performance attribute, should never be referred to as a PTM.

A simple quality control test method will be valid only for a particular product and only where the relationship between the test and some essential aspect of performance has been clearly demonstrated. Any major modification to the product may mean that a new relationship between the two methods has to be established.

Example:

> When developing a test method simulating the onslaught of rain onto an external wall component or element, the apparatus should ideally contain not only a water spray arrangement but also provision for creating static and pulsating air pressure, as well as air movement perpendicular to and parallel to the surface. The control of air movement in different directions during a test with driving rain is possible in a few laboratories, especially those engaged in research. For practical development work, however, most driving rain apparatus is, for economic reasons, equipped only for creating static and pulsating pressure and wind velocities perpendicular to the vertical surface. Experience over a number of years has shown that this simplification of the PTM is permissible when testing ordinary window and wall components in the laboratory. For quality control purposes, however, this test procedure can often be further simplified by replacing the pulsating pressure with a constant pressure. This is permissible where it has been shown that there is a consistent relationship between the results under pulsating pressure and those under static pressure for the particular component to be tested in a quality control scheme. If any major technical modification is is made to the window component, a new relationship must be established between the results from the PTM and the quality control test method.

Example:

> The durability of plywood should preferably be checked by means of a PTM simulating ambient temperature and humidity conditions. However, such conditions vary considerably and a testing programme simulating a wide variety of exposures would be very expensive. Instead, a boil test can be considered significant for a wide range of applications in buildings, since experience has shown a reasonable relationship between test results and actual durability for the types of adhesive in current use.

5.6 Can test methods be independent of material or construction method?

Although it may theoretically be desirable that a PTM should be independent of the material or construction tested, it is difficult to respect this principle in all cases, mainly due to the lack of knowledge. This means that at present it is often necessary to carry out 'performance testing' specific to different types of material.

Example:

> A number of accelerated test methods are available to evaluate the weather-resistance of polymeric materials. However the choice of method(s) depends on the type of polymeric material involved, since different mechanisms are responsible for degradation in the different types of material.

5.7 How accurate need a PTM be?

A test method should, of course, not require any more sophisticated equipment or qualified staff than necessary. Sometimes the appropriate test will be simple, and sometimes it will be more complicated. If in doubt the rule should be to choose the simpler rather than the more complicated and accurate test, since it is very seldom that high accuracy is required. However, simplification should not go so far that the method fails to provide a reasonable simulation of conditions of use.

Example:

> The impact strength of a partition will depend on the elastic properties of the partition (total as well as partial) and the elastic properties of the impact body. Nevertheless a sandbag test method, where the elastic properties of the impact body are neglected, is used in most countries because an 'elastic approach' is somewhat complicated and does not give significantly better results.

5.8 Relationship between value and cost of information

A PTM must be looked upon in exactly the same way as any other test method. This means that the general rules of statistics should be used to deal with problems of sampling, repeatability and reproducibility*. This may lead to expensive testing programmes when simpler methods would be more realistic. In such cases, simple cost/benefit analysis may reveal the most realistic test procedures.

Ideally PTMs should be fairly simple, but information that cannot be obtained by simple means may still be necessary. Thus, if it gives sufficiently important information, a PTM should be used even if it is expensive. A sophisticated and very realistic PTM may often be necessary during the early stages of research, but may be replaced later by simpler methods which have been shown to give results of sufficient validity.

Example:

> Relatively simple spread-of-flame test methods have been developed on the basis of full-scale fire tests. Instead of performing very realistic but also very expensive tests on whole buildings (or parts of buildings), it is arguably sufficient to test in a small apparatus. (It can be said that a true relationship remains to be proved for this particular example.)

5.9 The need for soundly-based PTMs

Before spending much time on the development of a PTM, considerable effort should be devoted to analysing conditions of use to make sure that the tests will be relevant and also that the necessary scientific background exists. Neglect of this last requirement can be a weak point in the whole performance testing approach, since our objective knowledge of conditions of use is somewhat limited. In many cases more effort should be devoted to studying activities and stresses before work on developing PTMs is accelerated. It is equally important to consider how systematic feedback from real buildings can be obtained and applied in laboratories developing or revising PTMs.

5.10 Statistics

It is important to establish the relationship between the results of tests on a few articles, selected from a large population, and the performance to be expected from the population as a whole. This depends on the variability of apparently identical products, the variability inherent in the test procedure, the number of samples tested and the degree of certainty required for the result.

It is not satisfactory to evaluate results from performance testing when only one test is carried out. However, the limited availability of adequate test facilities, together with the high cost of testing, make it very difficult to perform sufficient tests to establish statistical significance for the results. The variability of the product or system under laboratory test conditions may be of an entirely different order of magnitude from the variability and performance that will be achieved in buildings. This is due to many other contributory variabilities such as installation, weatherproofing and finishing or other factors such as movements in service and ageing. These uncertainties should be reflected in the factors of safety applied to determine design values for performance requirements.

It might be considered that a statistical approach would need the development of a new theory in the performance context. Fortunately this is not the case, since traditional statistical methods in general use apply also when performance test results are evaluated. From the test results a characteristic value* for each attribute tested should be determined at a particular level of significance** (say 75 per cent). To be acceptable, the characteristic value for each attribute, in some cases modified by a factor of safety, must satisfy the performance requirement.

It has been found in practice that, for many attributes, tests on as few as (say) 5 samples are adequate for determining characteristic values. However, to allow for the low level of confidence from so few tests, the resulting characteristic values will tend to be conservative, and achieved performance may be underestimated. If the performance requirement is not satisfied, statistical techniques may be used to infer whether testing further samples, to give a better estimate of achieved performance, is likely to be worthwhile (see, for example, papers 4 and 5 in reference 4). Thus a balance can normally be obtained between the need to minimise the costs of testing and the benefits obtained from testing a larger number of samples.

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*Repeatability is a measure of the variability in results when the same specimen is tested more than once by the same operator on the same test apparatus. Reproducibility is a measure of the variability in results when the same specimen is tested by different operators and/or on different examples of the test apparatus.

* The characteristic value of a random variable is any value which has a defined probability of not being exceeded (based on the known probability distribution of the variable).

** The significance level denotes the level of confidence that can be placed in the characteristic value.

6 HOW DO WE EVALUATE SUITABILITY FOR USE?

6.1 The principle of evaluation — scales

Evaluation of the suitability for use of building designs or products involves matching the performance of potential solutions with the applicable performance requirements. However, the nature of the choice between alternative solutions may be somewhat subtler than is at first apparent, especially where the evaluation spans a range of attributes. One fact to bear in mind is that the advantages of superior performance may differ between different attributes. In some cases better performance will bring useful benefits, while in others, once certain thresholds have been reached, there may be little advantage in further improvements in performance.

There are a variety of other reasons for adopting a flexible approach to the expression and comparison of performance levels. Performance requirements themselves cannot always be determined with great precision, due to deficiencies in understanding and lack of data. Also, even the best test methods are not so accurate as to justify over-rigid boundaries between performance categories. In many cases acceptability will depend not on an individual attribute but on overall quality; since a number of factors are reflected in such a decision, great accuracy in any one is unlikely to be critical. Also, excessive elaboration of criteria is likely to prove counter-productive to both busy practitioners and cost-conscious manufacturers.

In general, therefore, it is preferable to express both required and achieved performances not as single values but as bands between upper and lower limits. This can be done whether one or several attributes are being considered. It helps to avoid unjustified precision in defining acceptability and has the further advantage that less demand may be placed on manufacturers for a wide variety of products differing only in small degree. Instead, a product can be designated and chosen by reference to the band in which its performance falls, and not by a closely defined threshold. In consequence, the criteria in performance specifications can with advantage be expressed as graduated scales, divided into fairly broad bands.

In use, the various bands of performance for a product can ultimately be given a qualitative interpretation (value judgement), but only in the context of a specific type of application. The value judgement may take the form of designations ranging from, for example, 'barely acceptable' to 'extraordinarily good', for the context in question. As described later, general specifications and lists of performance requirements should not include value judgements; these should be left to users to determine, in the knowledge of the location, scale, form and design strategy of particular buildings.

6.2 Stating single values is seldom satisfactory

If a statement like 'the partition should be $\frac{1}{2}$-brick' is replaced by performance requirements, for example, strength, fire resistance and sound insulation, the performance approach has of course been applied in principle. Experience has shown, however, that it is seldom satisfactory to state only a single value for each performance requirement. Performance statements of this type can become as inflexible as the old prescriptive statements, and a more flexible approach is desirable both when evaluating performance for a specific use and when expressing a range of performance classes for different applications.

As an example, the air- and rain-tightness of a window placed under a large overhang in a one-storey house does not usually have to be as good as that for a much more exposed window on the tenth floor of a high building. Another factor making a single-value statement inappropriate for this aspect of performance is regional differences in rainfall intensity and wind velocity.

6.3 Performance levels must reflect the accuracy of the evaluation method

Precise limit values for performance requirements may be given in Building Regulations or Codes, when they must obviously be complied with. However, inflexible criteria of this type are not usually the best basis for comprehensive performance evaluations, whether based on testing, calculation or judgement. As a rule, even the best performance test method will not justify evaluations 'accurate to the fourth decimal place' or thin, accurate border-lines between quality or performance categories.

6.4 Banded levels of performance

One means of reflecting the above-mentioned factors, adopted in some national applications of the performance approach, has come to be known as the use of 'banded levels'. This may have been the subject of some misunderstanding in the past; the term merely implies dividing a scale of possible performance requirements into bands sufficiently coarse to provide the minimum number of performance classes or levels, consistent with the needs for different conditions of use (see Fig 14).

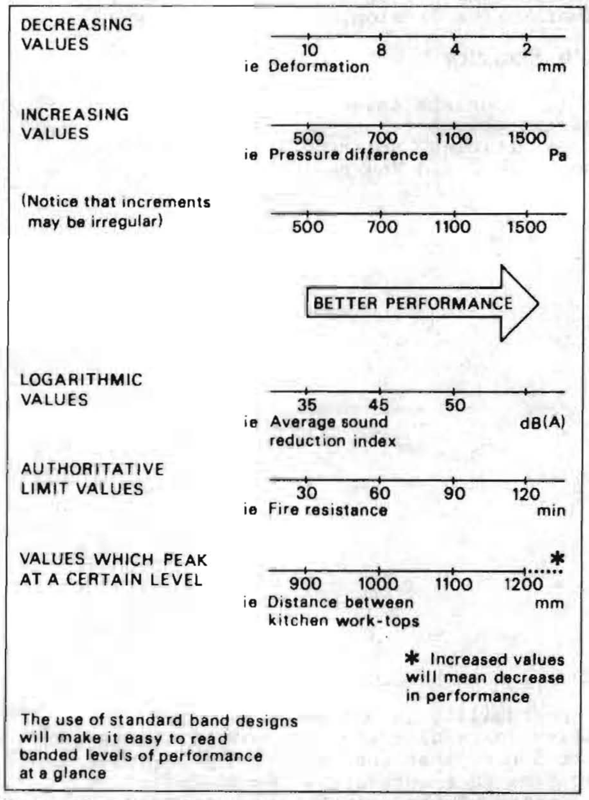

Figure 14 Standard band designs applied to different types of value

The use of banded levels can simplify the expression of both required and achieved performances. For example, standards, general specifications and general lists of performance requirements* normally need need to be expressed in simple terms, since they are applicable to a multitude of different - and unknown - projects. Correspondingly, manufacturers and contractors usually want to use simple means to describe solutions or products providing various levels of performance at different prices.

6.5 Open-ended scales — truncated for use in practice

Scales containing banded levels should in principle be open-ended, because until they are applied to specific projects it is not usually possible to decide the appropriateness of specific levels or values. At the equator thermal insulation (to prevent heat escaping from a building) can be nil, while under permafrost conditions requirements for human survival necessitate extreme thermal insulation to be applied regardless of cost. However, in most countries or regions it will normally be possible to choose from an open-ended scale a group of bands which contains sufficient levels or values.

The 'lowest' band on the scale should start with a performance level or value which will normally be just below the acceptable, while the 'highest' band should end with the level or value beyond which it will normally be uneconomic to increase quality.

In countries subject to considerable climatic variations, either because of their size or their topography, scales for, eg precipitation or wind, may have to be wide in order to include a sufficient number of levels. On the other hand, there are probably other scales which could be universal without being particularly wide. For example, it seems as if certain space requirements and also some requirements for dimensional compatibility are much the same all over the world.

6.6 Value-loaded designations of levels must be avoided

A value designated 'barely acceptable' for the air- or rain-tightness of a window in normal applications might be quite 'good enough' if the window were positioned under a large overhang in a one-storey building; at the other end of the scale a very high performance might be necessary to achieve a satisfactory result. Also, it would hardly be acceptable to manufacturers if they were asked to market any solution described as having a 'low' or 'barely acceptable' performance, even when it could be argued that for some purposes such a performance was quite good enough.

6.7 Designations of bands must be easy to print, read and understand

A band can be designated using either a phrase, a word, a letter, a figure or a symbol. Phrases and words can be understood immediately but, as mentioned above, they tend to become value-loaded and they may take up considerable space; this is undesirable, especially in performance specifications and product information. They are also language-dependent.

Designation by letters or figures will be an advantage in printing and also easy to read, but understanding may require further, time- and space-consuming explanations.

Symbols can be easy to read and understand, but may have shortcomings when 'printing' is based on typing, as it would seem difficult to find a usable set of symbols on normal typewriter keyboards.

A special case can be argued for the use of simple characters in product information, because they can make it easier to compare a number of similar products whose characteristics have to be presented in a very confined space. On the other hand, where the numerical value of a performance band conveys its level clearly and without value judgement, eg for ranges of strengths and similar properties, this may be preferable to arbitrary designations.

6.8 How to express banded levels

This report recommends that, for many purposes, the best method of designating bands is to use a standard series of capital letters, drawn from the middle of the alphabet. The normal range of performance requirements for typical buildings in temperate zones can often be expressed in 3 principal bands, with the scale reading (K)LMN(O). In some cases 5 principal bands, (J)KLMNO(P) may be necessary (See Fig 15). The extreme bands (K and O, or J and P) are intended for situations in which less, or more, stringent requirements apply.

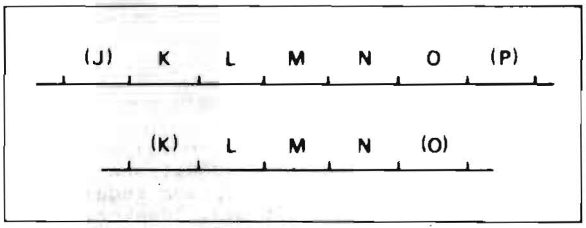

Figure 15 Preferred method of designating bands

The bands are labelled in this way, and not A,B,C or 1,2,3, in order to reduce the impression that one grade is better than another rather than more appropriate, since this could lead to specifying qualities higher than are necessary for a particular purpose. Also, the scale can be added to at either end for conditions where requirements are more extreme.

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*A 'general list of performance requirements' is a form of 'design aid', published in some countries, containing guidance on the principal performance requirements for a particular element or component, eg external walls, doors.

It is recognised that other methods of designating banded levels may sometimes be appropriate. For example, easily memorable numbers can be preferable to letters, especially where their use is established, eg standard fire ratings of doors in hours. As a further example, the International Agrement Union (UEAtc) uses a system in which bands are denoted by numbers, with a capital letter prefix for the performance attribute involved (See Fig 16).

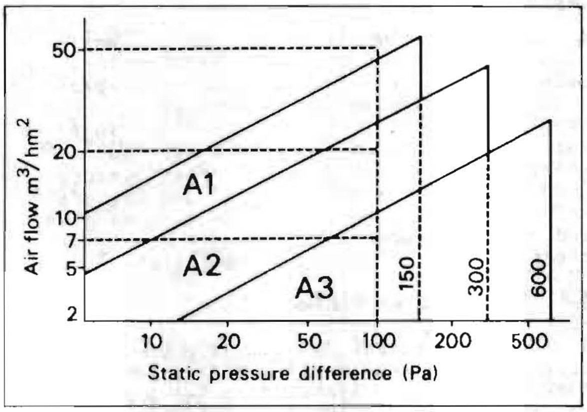

Figure 16 Designation of bands for air permeability in the UEAtc Common Directives for Windows

Fig 16 also shows that the full description of performance attributes may involve compound quantities, in this case air flow in relation to pressure difference. The sound reduction of elements over a range of frequencies is a further example. In such cases, a single linear scale cannot represent the full range of possible combinations, although for some purposes a simplified scale, derived from the compound data, may be useful, eg for the comparison and weighting of different attributes, discussed below.

6.9 Comparison and weighting of attributes

Whenever several attributes are considered, the comparison of products or solutions against a performance specification requires a measure of judgement. It can, however, be helpful to use numerical methods to combine the separate performances into a single index of overall worth or quality. Such methods involve factoring or 'weighting' the individual performances and converting their combined 'score' to a figure on a simple scale, eg from 1 to 10, or per cent. The methods need not be rigid, and can incorporate preferences about weighting expressed by individual clients or users for buildings on particular sites. There are a number of national appraisal systems of this type, especially for evaluating housing designs and components (See Bibliography), but so far no method has been endorsed internationally.

An alternative technique is illustrated in Figure 17, which shows the possibility of combining banded scales for different attributes of an item into a single diagram, sometimes termed a performance profile.

This technique can be used to visualise the overall worth of different products or solutions, both to compare them against requirements and to choose between them. It reflects the flexible approach to criteria advocated above, since failure to achieve a particular banded level for one or two attributes may be offset by superior performance for other attributes. Where numerical methods for combining the performance for several attributes into overall indices of quality are not available, a performance profile can provide a 'feel' for the best value for money among competing solutions.

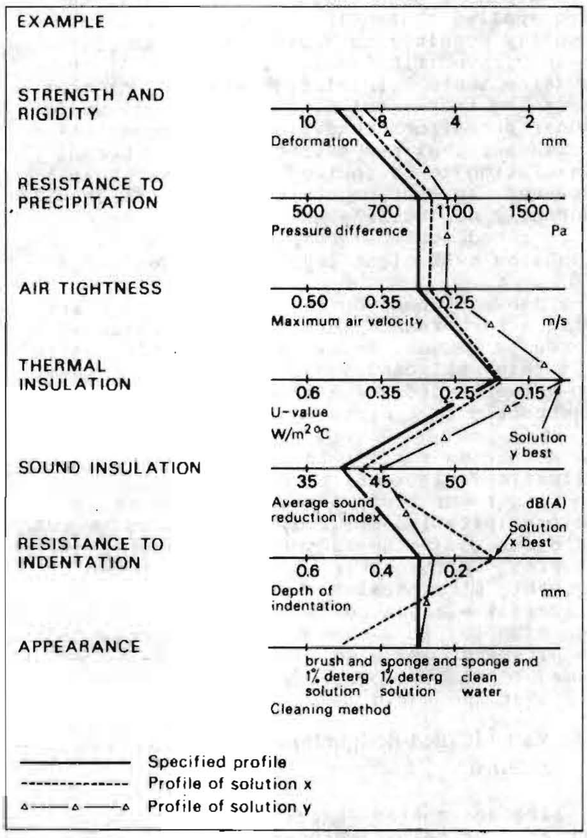

Figure 17 Comparison of performance profiles

6.10 Durability/performance over time

It is essential that the performance of buildings and their parts should be considered not only in their new condition, but also over their service lives. However, the knowledge available at the time of design or selection is often far from complete, both with respect to through-life requirements and to the likely degradation of materials and components. Service conditions may change during a building's lifetime, and even standards of acceptability may alter. Very much more work therefore needs to be done before these requirements may be covered with any degree of confidence, and this section is merely a reminder that performance over time should not be forgotten.

The service life of a building is subject to a wide range of influences. Unless details or materials are badly chosen, resulting in a basically unsound design, the amount of maintenance received and the willingness to invest in periodic rehabilitation to restore or raise performance may have a greater influence on useful life than original design decisions (except for intentionally temporary buildings). Even economic factors, such as loan repayment periods, can be misleading, since the location and architectural quality of buildings can have a decisive influence on their actual lives, which can range from much shorter to much longer than originally planned. At the extreme, when old buildings assume archeological value, strenuous efforts are made to preserve them at all costs.

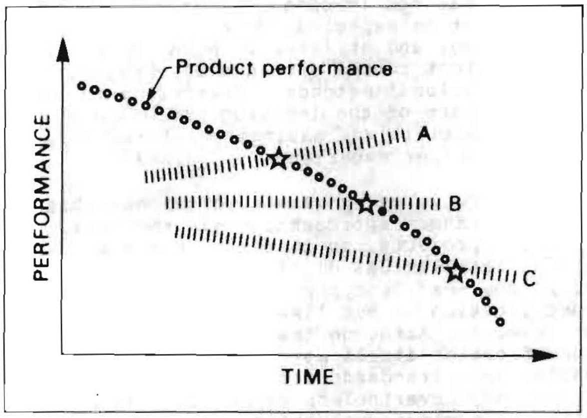

Figure 18 Acceptability of declining performance

For individual performance attributes, performance over time may be represented graphically. Figure 18 shows how a gradual decline in performance, typical of many types of product, results in unacceptability (starred points) after various periods, according to circumstances. The lower limit of performance may not change, as shown by line B. Alternatively, increasing expectations may result in higher targets being set (line A), reducing the time to replacement or restoration. Conversely, it may be decided that normal performance cannot be expected from something old (line C), with consequent prolongation of service life.

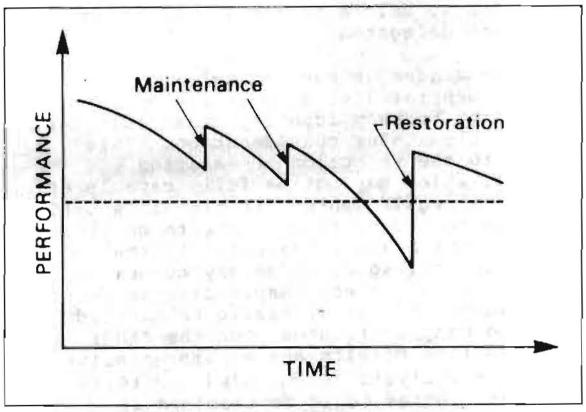

Figure 19 Influence of maintenance and restoration on declining performance

Figure 19 develops this theme by illustrating how maintenance can partially restore performance and delay the moment when the threshold of unacceptability is reached. When performance eventually becomes unacceptably low, the more thorough process of restoration, often including replacement of certain parts, may be necessary.

The way in which a product is incorporated into a building design may have at least as large an influence over its life as the chemistry and physics of the materials used; for example, a dado rail (protective horizontal strip) on a wall or a kicking plate on a door can substantially prolong the service life of finishes. Another aspect of the use of products in design is ease of replacement. In general, inherently durable or reliable products need not be designed for easy replacement (which can impose a penalty in terms of cost, convenience or performance in use). Conversely, ease of replacement of short-lived products is essential to avoid high repair costs and disruption in the use of buildings.

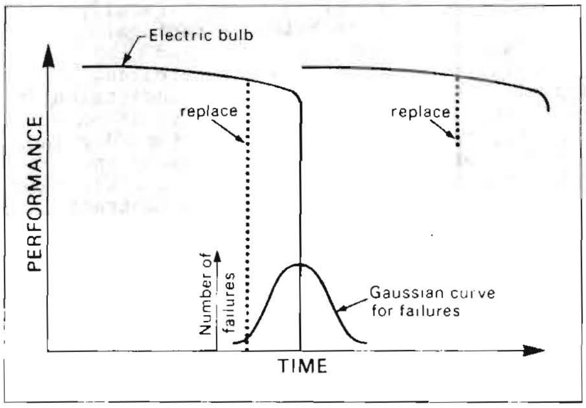

Figure 20 Example of failure pattern and replacement strategy

Even when the factors affecting product life are known, durability nevertheless needs to be considered in probabilistic terms, since the service lives of notionally identical products used in the same circumstances will vary. A simple example is the electric light bulb - a product which performs admirably, even without maintenance, until it suddenly fails. Figure 20 shows how replacing bulbs somewhat before their average time of failure will avoid most failures in service, which may be unacceptable to the user, or at least waste labour on individual replacement when this could be done more efficiently in groups. A similar approach could be used for other types of short-lived components or materials where the consequences of failure are severe.

7 APPLICATIONS

7.1 Performance specification for whole buildings

As noted earlier, a performance specification can provide a functional brief for the design of a building, irrespective of who prepares the design. Many firms and authorities with extensive building requirements develop their own standard specifications, based either wholly or partly on performance. Where design is delegated under contract or is the subject of a competition, the specification needs to be comprehensive and can become very long; cross-reference to national standards and Codes of Practice and other design guidance can help to reduce this length.

Because sponsors need considerable resources to prepare performance specifications and to appraise submitted designs, the practice of commissioning buildings by this means has generally been confined to larger projects, or linked series of developments. Where only part of the specification is expressed in performance terms, this has typically embraced heating, lighting, structural requirements, sound insulation and weathertightness. For some attributes, appraisal and acceptance may be undertaken in two stages: firstly based on calculation or possibly prototype testing, and secondly in the form of tests or observations of the completed building, as the basis for ultimate acceptable and completion of the contract.

In addition to consideration of minimum performance requirements, the choice of an acceptable design may be based on a global appraisal, combining weighted evaluations of performance in excess of the minima, of the predicted total cost of buying, running and maintaining the building over a defined period of use and of architectural qualities which cannot yet be expressed in terms of performance.

7.2 Performance specification for components

The problems of specifying performance for components are in many ways less forbidding than those for whole buildings; there are numerous examples of comprehensive standards and specifications which include methods of test as well as criteria. Criteria for components forming part of a building's services such as air-conditioning equipment, which have been developed through advances in technology, have been produced more readily - or perhaps just earlier - than criteria for components which form the fabric of the building and which have 'emerged' from traditional building practice.

At the component level, the performance approach has been very widely used, sometimes rigorously. Almost every component has been the subject of performance specifications, examples ranging from doors and windows to structural steelwork and heating convectors, and some building systems have in total almost half their superstructure specified by the performance of separate components.

The procurement of building components against performance specifications has in the main been confined to large purchasing authorities who could command the expertise to draw up the technical specifications and carry out evaluation to an acceptable standard. The cost, time and expertise required for the evaluation has often proved substantial. Adoption of the thinking embodied in this report should help to reduce the effort required to mount such programmes in future.

Experiences of component procurement have been mixed, with some examples recording success and others failure. The aim of sponsors has varied widely, including for example pump-priming exercises stimulating the development of industrialised systems, the economical bulk purchase of components, and programmes for erecting large numbers of buildings while keeping professional staff input to a minimum and placing competition between contractors on an equitable basis. Some sponsors are now into their third or fourth generation of specifications.

Most successful applications have had the backing of considerable research resources; where this has not been the case there has generally been disappointment in the results. At this stage in the development of the subject, savings in sponsors' staff time, which might be expected, do not necessarily materialise, and at least as much professional effort can be expended as when using more traditional methods. However, this is probably part of the learning process and, as in other activities, savings should materialise as further experience is gained.

While there is every reason to suppose that the performance approach can aid the designer of small projects, in that it imposes a useful intellectual discipline, procurement of purpose-made components by performance specification is not likely to be economic at present. Although the preparation of the specification itself may be simplified as performance standards are agreed, excessive effort may nevertheless be required to deal with performance evaluation, quality assurance and contractual liabilities.

7.3 How can designers use the performance approach?

Designers have opportunities to use the performance approach at all stages in the design process, from initial concept to working drawings. Although product selection and specification have been emphasised, opportunities may also arise at the stages of briefing, conceptual design, detailed design, and post-occupancy appraisal and feedback. Not only does use of the performance approach enable the designer to discipline his own contribution, perhaps more importantly it gives the potential for clearer definition of responsibilities when parts of the design/build process (including the supply of products to suit a particular building design) are delegated.

At various stages it may be useful to consult a general list of performance requirements to help identify items relevant to the problem under consideration. This may lead to the rejection of existing solutions, which may not be fully capable of meeting the requirements. If time is short, it will be necessary to concentrate on those attributes which are fundamental to the performance envisaged, which may number no more than two or three. Rapid assessment becomes impossible if it has to be carried out on too many attributes. On the other hand, when time permits and a comprehensive performance analysis is demanded, up to, say, 25 attributes could be examined in depth.

It is always important to check that decisions about performance requirements are consistent with the levels of design above that under consideration. This may be a difficult task in practice, since assumptions made at earlier stages of design may not have been explicit. Ideally, systematic records should be kept of the intended performance of the design and the strategy for achieving it, with provision for eventual feedback data on the actual performance of the building in use.

7.4 How can manufacturers use the performance approach?

Manufacturers have opportunities which are the counterpart of those already mentioned for designers. Thus the performance approach may be used to as the basis for developing new products for the open market, or alternatively manufacturers may respond to an invitation to tender for the supply of components for a specific building project or programme. In both cases there will need to be an explicit statement of the performance of the offered product, referring to the evaluation methods used. It is vital that specifiers and manufacturers use the same language and standard methods of evaluation. For the open market, performance attributes will need to be declared on product data sheets, when the presentation of data needs careful consideration (see Clause 2.4.2).

While building designers might be inclined to see advantages in having available a wide range of products, with various combinations of performance levels, this is not usually practicable for manufacturers. A measure of control needs to be exercised over product variety, and one means is to work in terms of bands or grades or performance rather than specific values, as described in Chapter 6. In this way limited product ranges can achieve wider application. Designers may also be able to think more in terms of using an available product by adapting the design strategy, instead of allowing a preconceived design to dictate the use of a special product.

One of the main difficulties in applying the performance approach is the cost of performance tests. In general, these costs may be minimised in three ways, by using either:

(1) Calculations based rather remotely on physical tests (eg, as at present used for structural requirements),

(2) Technical documents presenting systematic analyses of former test results, which may be used to predict the performance of 'traditional' solutions, and

(3) Certification of quality (including Agrement), for which prototypes or samples are performance-tested and which is usually conditional on the maintenance of production quality through quality assurance.

7.5 Mixed-character specifications are useful

As matters stand, it is probably better to accept the use of mixed-character specifications, that is to say part-performance, part-prescriptive, rather than to stretch present knowledge to its limit in attempting a specification expressed solely in performance terms. However, explicit statements of performance requirements are of great benefit in reducing the amount of abortive design, in guiding innovation and in making judgments of value for money. They also release designers from the constraints of tradition, while providing the basis for an appropriate and adequate design.

It would be unrealistic to expect that rigorous and complete application of the performance concept will be widespread in the near future; there is not enough professional experience to enable complete performance specifications to be drafted for the average building project, even if there were sufficient contractors willing to tender on that basis. There is, however, growing experience of using the performance approach in commercial design and building contracts. In this context, there are differing views on whether or not the performance specification ought to be made a contract document. Some users insist on contractual status for performance specifications while others, apparently preferring the latitude for negotiation when performance criteria are not made binding, insist that performance specifications should be supplementary documents, not invoked in the conditions of contract.

The contractual problems that arise through the use of performance documents as a basis for tendering and purchase may prove to be a hindrance, but this ought not to inhibit unduly the use of performance thinking in drawing up specifications. The performance approach involves a more consistent intellectual discipline for the design field than at present, and this should be helpful in guiding new thinking about building design and in obtaining buildings which meet the purposes for which they are designed both better and at a reasonable cost. Important benefits are likely to emerge through the use of this discipline and the consequent increase in that part of the design amenable to quantification. At the component level there are already signs of a much more rigorous form of specification being used in practice, including its use as a basis for purchase, and this ought to lead to better control of quality.

The rate of progress will depend on opinions about the balance between the potential value of the new approach and the short-term cost of adopting it. It would seem that, with so much changing, a clearer statement of what is desired from a building or a component is highly desirable as a reference point, and that this alone provides an incentive for the more rigorous use of the performance concept.

7.6 Responsibilities for performance in use

Contractual procedures and the responsibilities and liabilities of designers, manufacturers and contractors vary from country to country; in some, statutory obligations are not always fully explicit and are still being tested in the Courts. By throwing the technical basis of fitness for purpose into sharp focus, use of the performance approach may lead to changes or clarifications to these responsibilities.

There is a growing volume of guidance which expresses the current state of knowledge of design and, in the law of certain countries, the designer ought to be aware of it all, and apply such of it as is relevant to the job in hand, if he is to be free of the possibility of action for negligence in the event of a design failure. Of necessity, designers probably employ a disproportionate amount of time in meeting those aspects of function subject to Regulations, leaving still less for the remainder.

There is, too, a growing world-wide consumer protection movement with an accompanying tendency to seek legal redress, not only for negligence in design, but also for what are currently classed as normal risks inherent in the practice of design. Although the law relating to the quality of products supplied for buildings is patently different from country to country, there are, commonly, gaps in legislation as it affects performance specifications and hence ultimate responsibility for fitness for purpose. In the experimental phase during the last ten years, undoubtedly some risks have been taken by both sponsors and suppliers. Where there is explicit law requiring fitness for purpose, this may serve as a 'safety net' if some less critical requirements are left out of a performance specification.

Among the matters which need consideration if the performance approach is to be more widely used are:

- The extent and duration of design liability,
- The exact share of responsibility when design and selection duties are shared;
- The definition of fitness for purpose, with particular reference to briefing, product supply and quality assurance;
- The influence of different contractual forms and agreements; and
- The implications for the insurance of designers, manufacturers, contractors and building owners.

7.7 Improved Building Regulations based on performance

Many existing Regulations for building are based on the functions to be fulfilled if life and health are to be safeguarded. These may be supported by specific types of construction which are deemed to comply with the Regulations. In recent years the range of 'deemed-to-satisfy' types of construction has tended to widen, thereby strengthening the argument for performance-based Regulations to replace them all.

In consequence, the performance approach has been examined by both national and international bodies as a means of reducing the restrictive nature of Regulations based on types of construction, while retaining the essential elements of control. Furthermore, international bodies have recognised the opportunities provided by performance thinking for simplifying the international harmonisation of Regulations and in consequence facilitating international trade in building products. The thought here is that, by having a common basis of requirements set out in performance terms, it could be easier to incorporate the traditional solutions in the various countries. There have also been attempts to use performance as the basis of Regulations in the developing countries, where none have existed up till now.

7.8 The performance approach and Standards

There is keen interest among national and international Standards bodies in the development of Standards dealing with many aspects of building and component performance. These are seen as an important tool for reducing barriers to trade in both products and designs, and for stimulating innovation while retaining the important benefits of interchangeability. There is a particular need for performance Standards to serve as technical references for Building Regulations that are expressed in performance terms (following the declared policy of 'reference to Standards' endorsed by many regulating agencies).

Performance Standards for building products serve as a more flexible and preferred alternative to traditional, prescriptive product Standards, without necessarily replacing them. However, Standards specifying performance requirements (grades or levels) are not enough, and need to be augmented by other types of Standard to provide an operational system. In particular, Standards are needed for evaluation methods and for the format of declarations of the achieved performance of products complying with a performance Standard, eg in product data sheets. Together, these documents will enable the potential user of a product to be provided with dependable information on its performance and suitabilities.

Taken more generally, the scope of a system of Standards concerned with building performance is wider still. In addition to the types of Standard mentioned above it could embrace the provision of basic data on site, climate and occupancy; the classification of building use and form; the harmonisation of design methods in performance terms; the treatment of reliability and quality assurance; and documentation and units of measurement. The International Organisation for Standardisation, ISO, foresees the eventual coverage of many of these areas by Standards. A first series of International Standards, showing how to use the performance approach in preparing documentation for the construction industry, is being developed under ISO/TC59 'Building Construction', as follows:

ISO 6240	Performance standards in building - Contents and preparation. (Published)
ISO 6241	Performance Standards in buildings - Principles for their preparation and factors for inclusion (Draft proposal - DP)
ISO 6242	Building Construction: Expression of functional requirements of building users - thermal comfort, air purity, acoustical comfort, visual comfort and energy saving in heating. (Draft International Standard - DIS)
ISO 6243	Climatic data for building design - Definitions and symbols. (DIS)
ISO 7162	Performance standards in building - Contents and format of standards for the evaluation of performance. (DP)
ISO 7164	Performance of the whole building - Definitions and means of expression (DP)

It is the agreed policy of ISO/TC59 that its International Standards on particular performance attributes should be confined to the means of expression and, in some cases, recommended increments for values, but stop short of prescribing actual levels or grades of performance for particular purposes. That task is seen as best performed by regional or national Standards bodies, in the context of local cultural and economic conditions. ISO/TC59 also has a promotional and co-ordinating function with respect to work on performance requirements and test methods in other ISO Technical Committees.

It is worth noting that the adoption of performance Standards for building products or elements can produce repercussions for prescriptive Standards, which sometimes have their origin several decades earlier. While the notional performance of a prescriptive product or solution may correspond to a grade in a performance Standard, its actual performance under test could prove to be different, due perhaps to changes in materials or workmanship or test methods. It can prove difficult to prohibit an established prescriptive solution, and it has happened that a 'deemed-to-satisfy' solution continues to be accepted, while alternative solutions have to satisfy a more stringent and up-to-date performance Standard.

As noted in ISO 6241, it is helpful to indicate in each prescriptive standard the performance likely to be obtained when a product or design complying with the Standard is tested in accordance with the appropriate performance evaluation Standard. Inclusion of such predicted performance values can considerably simplify the day-to-day work of checking the performance of 'traditional' building products against requirements.

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