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Environmental Evaluation

PETER MANNING*

More than twenty years after Cowan's identification of environmental design as the principal problem of architectural science, today's new buildings seem still liable to cause environmental discomfort. The practical usefulness in building design of knowledge gained from environmental evaluations could be increased if the design means employed to create particular environments are evaluated against detailed design needs of generic kinds. This paper proposes a procedure for evaluations of this kind, includes check lists of environmental needs and design means and presents an example of part of such a completed environmental evaluation.

INTRODUCTION

IN 1966, in the first edition of his outline history of architectural science [1], Cowan proclaimed by the title of chapter 5 that "Environmental design replaces structure as the principal problem of architectural science". Today, more than 20 years later, environmental design is still a problem. While building structures, on the whole, can be designed predictably, the environment within buildings, it seems to be common experience, cannot. Despite enormous amounts of research that have been undertaken into many aspects of building environment, and the store of knowledge that has accumulated, design of the environment too often appears to be a matter of chance. Users of today's new buildings are just as liable as were users of earlier buildings to be uncomfortable. They may be too hot or too cold and still experience draughts; they are often troubled by noises they would rather not hear; auditoria may not provide the distribution and quality of sound their users expect; new kinds of space planning and function seem, inevitably, to lead to unsatisfactory visual environments—as recent widespread use of visual display units in offices has so frequently illustrated [2]. The number of possible examples of environmental problems is endless.

Considering its nature, this uncertainty of the outcome of environmental design should perhaps be expected, for building environment is a subject of many branches that interact in diverse ways. Indeed, every branch of the subject is extraordinarily complex, involving as it does the performance of physical phenomena (light, heat, sound, etc.), the physiological and subjective experience of these phenomena by individuals and groups in varieties of settings, where expectations and standards vary with place and time and wide differences of experience are attributable to different individuals. Additionally, further variations in individuals' and groups' tolerance of environmental conditions depend on such factors as their economic responsibility for the operation and maintenance of those environments.

Another truism that should be accepted as readily as Cowan's is that, in environmental design, the need for new research is less than the need for finding ways to implement the research that already exists. Though much is known from research about the nature and design of (for example) the thermal, visual and aural environments, too many buildings, in their design, exhibit ignorance of this knowledge. This suggests a need for investigation of the successful implementation of environmental research. There are several reasons for this failure to use the results of research in the processes of environmental design. They include the innate complexity and vast scope of the subject; the many participants engaged in the design process for even one moderately-sized building; the range of attributes required of designers of environments and the sometimes totally different ways in which the educations of different design professions are pursued. Most critical, perhaps, is the very nature of the design process itself.

The task that designers of environments undertake is this: they identify (or, more often, have identified for them) a new requirement for shelter and the human, organizational, functional, economic, etc. needs set by that problem. A physical solution is posited and given form. Spatial arrangement, structure, content, surfaces, materials, services, etc. are defined (and eventually communicated to those who will undertake the construction) by analogies of word and line and dimension.

Separately and collectively, environmental designers are involved in the widely different activities and mindsets of analysis, creation, integration, evaluation and communication. If designers are to use research results, then to this list of duties must be added the tasks of knowledge- and technology-transfer: from the technical and precise and qualified writings of scientists to decisions and directions—also technical but sometimes more ambiguous and differently qualified—that will have

*School of Architecture, Technical University of Nova Scotia, P.O. Box 1000, Halifax, Canada B3J 2X4.

meaning in the world of construction, of whose workers only a fraction have much understanding of the world of building research.

Various attempts have been made to ensure greater success for the design of building environments in today's complex technical world. One field of activity that has grown over the last quarter-century has been the systematic evaluation (or criticism, analysis or appraisal) of the performance of completed buildings. Recently the name "post-occupancy evaluation" ("POE") has been used for this activity, though "post-occupancy evaluations, as they have evolved to date, focus primarily on the impacts of designs on (building) users" [3] and thus, strictly, may deal only with a part, though an important part, of the total problem of building performance.

Evaluations of building performance have at least three major purposes [4]:

(1) to learn from existing buildings and their users how buildings actually perform and are used (rather than how they are thought to perform and be used) so to provide knowledge for use in the formulation of user-requirements (i.e. "design-briefs" or "design programs") for proposed new buildings;
(2) to evaluate the possible consequences of design alternatives, enabling choice of the most appropriate;
(3) to check, in a completed building, whether and to what extent the conditions predicted to result from design action did in fact occur.

Among the earlier attempts to evaluate environmental performance in buildings was the work on assessment of "the agreeable luminous environment" carried out in the early 1960s by a working committee of the International Commission on Illumination (CIE) [5]. Much of the CIE's work on the evaluation of lighting installations was carried out by people knowledgeable in lighting who made judgements with the aid of prepared questionnaires. Use of that technique became more widespread and has continued.* A different technique, the checklist, allied to a very simple scoring device, was developed in the late 1960s and used in a number of contexts, but originally to appraise the total environment in schools [7, 8].

Although, from the earliest days, a main intention of evaluation activity was to make the design processes of future buildings better informed, there were inevitable difficulties in translating knowledge gained from evaluations of single buildings to the generalizations needed for effective design in different circumstances. However, it was widely recognised that a useful outcome of such activity was the educational experience gained by the individuals and groups who did the work [9, 10]. One product of this interest, in the 1960s, was the establishment at Strathclyde University in Scotland of the Building Performance Research Unit, publication of that unit's text [11] and, indirectly, much other material.

From the late 1970s as "POE" in North America and elsewhere, building evaluation has assumed a wider interest and become a more widely practised basis for passing judgement upon the successes and demerits of completed buildings. A bibliography of "POE", published in 1983 (and restricted to sources published since 1970) [12] listed some 200 references, which are by no means all that had appeared. Indeed, rather curiously, one of its omissions was of an earlier bibliography in the same series [13]. One useful contribution to this subject that, despite the increasing literature, seems to have evolved little in the last quarter of a century is from Australia's Experimental Building Station [14]. This document brings together a variety of material from different sources that can help provide structures for organising the search for and assembly of information and judgements obtained from building evaluations.

Despite the widespread intention that building evaluation should enlighten and improve the design process, it seems clear that no ready method is known by which the results of an evaluation of one building may be applied directly to the design of others. Generally, the evaluation methodologies that have been described do not attempt to do more than provide specific knowledge of the performance of particular aspects of particular buildings. A few have attempted statistical treatments [15] but there have rarely been large enough samples, nor has there been sufficient agreement on an evaluation structure related to the design process, for this to be worthwhile. Published reports on evaluations of buildings have been expected to increase the fund of general knowledge and awareness of reader-designers as to the common consequences to be expected from design activities. They have not been expected to provide direct guidance on what might be done and what should not be done in response to particular design assignments.

EVALUATION ON THE BASIS OF DESIGN REQUIREMENTS

This paper attempts to enlarge the usefulness of evaluations by postulating a procedure of evaluating on the basis of design requirements (or "needs"). Evaluation surveys of buildings in use are carried out with the object of determining the success of the physical design solutions that have been employed by analysing them in terms of their response to detailed design requirements of generic kinds. Evaluations of this kind may be used to assess the value of particular buildings, compare the performance of similar buildings or compare different evaluations. More importantly, the results may be used to build up data banks of specific information relating design needs and means (solutions). This knowledge can then be used in design processes that employ basic systematic methods: stating needs, posing alternative means of satisfying those needs and evaluating means to choose those most suitable. Such a systematic approach is not an invariable part of the design of buildings (at least, such an approach is not invariably evident), but it is a common way for many design professionals to work, even if they do not always do so consciously [16]. It is,

* A recent C.I.E. Journal [6] carried the latest version of that international organisation's work on building lighting evaluation in the form of a questionnaire to be used to increase interaction and understanding between lighting designers and other building design professionals.

moreover, a manner of working that is certain to become essential the more that systematic methods, and computers, are used in design practice. The approach is, for example, directly applicable to the method of procuring buildings by means of performance specifications [17].

PROCEDURE

Step 1

The evaluation procedure for a particular building (or, more commonly, a particular space or spaces within a building) is begun by listing the environmental requirements that its existence demonstrates have needed to be fulfilled. Few statements of such environmental needs are to be found, apart from those of the International Council for Building Research Studies and Documentation (CIB Working Group W-65), which has produced two: one, in 1971, for housing [18] and another, in 1978, for schools [19].

Table 1 in this paper presents a tentative generic check list of environmental needs, that should be applicable to many building types and spaces. For convenience, the list is divided into three columns: functional needs, human needs, aesthetic needs. These categories are not hard and fast and, in an evaluation, do not need to be identified. But, generally, evaluators should begin with the list of *human* needs. This is because, in a majority of building or space types (housing, educational and office buildings, for example), the environmental needs of the building or space type are predominantly or wholly those of the people who live or work there and use the building or space. It is only a minority of building or space types (buildings or spaces to house animals or some manufacturing processes, for example) where the function dictates the environmental needs and where the human users may have to adapt themselves (e.g. by protective clothing) to the conditions dictated by factors external to their own needs. For building and space types with critical environmental requirements of this kind the listing of needs should begin by reference to the column headed "functional".

Step 2

Against each listed "need" should be attached a criterion to indicate the conditions under which the need will be satisfactorily met. For some needs the appropriate criteria may be quite precise (e.g. for "air temperature", something like "within range 20–22°C" might be appropriate); for some other needs (for example, that the environment represent a particular mood: say, the aura of "progressive education" or "high technology"), it is unlikely that the criteria could be expressed exactly.

The bulk of preparation for Steps One and Two should be undertaken before beginning the actual evaluation survey in the building.

Step 3

For each "need", the "means" used to satisfy it should be listed. Since it may not be possible (and anyway, for the purposes of an evaluation, it is not necessary) to know what means were *intended*, the list should include those factors of the physical design situation that knowledgeable inspection indicates contribute to the satisfaction of the need—or, alternately, serve to work against it. For example, in an auditorium, the features of building design ensuring achievement of a need for "audibility at all seats of sounds emanating from the stage" could include the distance from the stage to the furthest audience member, the insulation of distracting sound from outside, the directness of sound- (and sight-) lines, the absence of delayed reflections determined by such matters as volume, positioning of absorbent and reflecting surfaces, and so on. In preparing this list reference may be made to the checklist at Table 2. This, it will be seen, goes beyond physical design factors to include some matters of administrative kinds that can influence the perception and function of environments.

Step 4

The last column is for entering an evaluation, a judgement of the success with which each "need" has been resolved. In what must by now be one of the classical pieces of writing about building evaluation Canter, in 1966 [20], said that "Essentially, the act of appraising a building consists of placing the building's attributes on a scale or series of scales . . ." He went on to describe some important properties of scales: validity, reliability, level of measurement, precision (or sensitivity), convenience of use, objectivity—that he considered particularly relevant.

In today's circumstances tests for these properties that are more than elementary remain an interest of building academics, who properly search for refinements beyond the level of practicality needed by building owners and designers. For most purposes the essential need of environmental evaluations is to state whether or not the criteria have been met. The greater concern is for the general rightness of the answer than for its nuances.

If the criterion is met with substantial room to spare this is worth remarking and quantifying, perhaps to indicate a use of resources that might have been better applied elsewhere. If the criterion has not been met, if the design to satisfy the particular need has been defective, or insufficient, then the evaluation should make this clear. It should also indicate by how much the criterion has been missed besides, perhaps, what might be needed to make good the difference. The significance of the shortfall to the remainder of the building's design and performance would then be clarified in the course of the evaluation.

EXAMPLE OF AN ENVIRONMENTAL EVALUATION FOCUSED ON NEEDS

An example of part of a completed evaluation, of the auditorium of a university teaching theatre that is also used for public performances of plays and chamber music, is shown in Table 3. This is arranged in the tabular form suggested: environmental needs, criteria, design means, evaluations. Such a tabular presentation can then be summarized in a paragraph or two. A summarizing section of this kind is a useful device for drawing attention to critical issues and attempting evaluation and integration of the performance of the building or space as a whole. An example (in this case of a courtroom) is given

Table 1. Checklist: Some desirable environmental attributes ("needs")

Functional needs	User/human needs	Aesthetic needs
External Environment		
Economy, low maintenance Ease of access Protection from weather Legal and quasi-legal requirements satisfied Adaptability to changing needs and uses	Convenience; safety Protection from weather Availability of daylight Availability of view Availability, controllability, of sunshine Protection from noise	Appropriate mood, character Symbolic representation Sense of: openness; enclosure
Spatial Environment		
Space for operational functions, work, related activities Maximization of "useful" space Adaptability to changing needs and uses Economy of spatial arrangement Economic, safe circulation Legal and quasi-legal requirements (e.g. for minimal space) satisfied	Space for individual activities: e.g. for lying, kneeling, sitting, standing, reaching, bending Space for furniture, equipment, seated activities Space for movement: in rooms, passages, stairs Space for group activities Comfortable, safe, dimensions of stairs, doors Postural comfort: e.g. when sitting Separation of private and public spaces Economy of effort in movement	Appropriate "mood", character Amplitude of space Spatial: order, organization Spatial status Sense of security Sense of: scale, proportion
Thermal Environment		
Thermal conditions for operational functions Rapid heat-up Maintain, control, thermal conditions Avoid condensation Economy in provision of thermal environment Legal and quasi-legal requirements (e.g. for energy conservation) satisfied	Thermal comfort: in winter, in summer, in "shoulder seasons" Thermal comfort: in sedentary, in active, situations; in light clothing, in outdoor clothing Controlled variability of thermal environment Radiant temperature approx. same as air temperature Sense of air movement; absence of draughts Clean air; absence of odour Temperature gradients minimized Absence of horizontal variations in thermal conditions	Appropriate mood, character Sense of warmth, coolness Sense of freshness (as against "stuffiness")
Visual Environment		
Visual conditions for operational functions Illumination for visual tasks Constancy of illuminance Minimize horizontal variations in visual conditions Provision for darkness Colour rendition Reveal form, texture Sun control Energy conservation Legal and quasi-legal requirements (e.g. for minimal illuminance) satisfied	Visual comfort Visual efficiency Visual privacy Controlled variability of visual environment Adequacy, constancy of illuminance on horizontal, other, planes Brightness patterns emphasizing specific features, foci Availability of daylight View; link with outside world Sun control Absence of glare, veiling reflections Colour rendition; texture rendition; modelling Absence of flicker, stroboscopic effects Sense of orientation within building	Appropriate mood, character Visual order Sense of lightness (as against "gloominess")
Aural Environment		
Isolation of, control of transmission of noise from or to a space Control of noise and vibration from equipment Required sound distributed to all listeners Intelligibility of desired sound Appropriate resonance, quality of sound Reverberation time appropriate to function Controlled variability of aural environment Legal and quasi-legal requirements (e.g. maximal sound levels) satisfied	Audibility, intelligibility of desired sound Freedom from: distraction (e.g. reading) or interruption (e.g. of sleep) by noise Aural privacy Ability to create noise without disturbing others	Appropriate mood, character Contribution to spatial comprehension Appropriate quality of sound Sense of "liveliness" or "deadness"

Table 2. Checklist: aspects of building design that might be used to influence the design of the internal environment ("means")

Location and the External Environment
Geography, latitude, climate type
Landscape forms, contours, berms, shields
Site selection, siting, shelter, exposure; elevation; availability, quality of views
Orientation
Nearby buildings and other structures
Ground surfaces: reflective, absorptive
Existing plant materials, trees; planting
Existing water surfaces

Planning and the Spatial Environment
Building shape
Space type; Plan type (e.g. deep, shallow) shape, degree of openness or enclosure; screening by planning, by internal distance
Sizes, proportions and shapes of spaces
Perimeter
Interconnections of spaces
Number of floors
Floor-to-floor and room heights
Building volume, volumes of spaces
Room depths from windows
Staggering of doors, other openings

Construction and materials
Constructional system, e.g. heavy, light; jointed, continuous, separated; floating, solid, void
Choice of materials, components, e.g. reflective, absorptive
Cladding system
Wall, roof, etc. thickness
Thermal insulation
Thermal capacity
Air spaces, seals
Control of infiltration
Wall surface: colours, textures—reflectance, absorption, diffusion
Weather stripping

Fenestration
Windowless or daylit
Extent, pattern, orientation
Window type, position, frequency, construction, size, fixed, sealed, operable
Glazing—glass type, weight, thickness, single, double, multi
Window reveals: splayed, lined
Blinds, curtains, brise soleil

Lighting
Electric lighting system (direct, indirect, etc.)
Kinds of lamps: filament, fluorescent, HID; ballasts
Luminaires: type, size, number, position, light distribution
Lighting controls

Servicing Systems
Air conditioning
Heating: continuous, intermittent; solar, convective, forced, radiant
Ventilation
Humidity control: humidification, dehumidification
Filtration
Servicing outlets (e.g. heater outlets)
Background noise, music
Sound reinforcement
Loud speakers: location

Servicing Facilities
Plant rooms: location, size, number
Ducts: location, size; vertical, horizontal; lining, closing
Control systems
Vibration damping
Fuel delivery, storage
Flues: height, position

Building Users
Functions, activities: kind; clean, dirty; numbers
Clothing specified; dress and appearance
Use of equipment controlled
Use of services (e.g. lighting) controlled
Managerial attitudes
Internally-produced heat gains controlled
Use of window blinds controlled

Other aspects
Furniture: design, quality, condition
Furnishings: carpets, curtains, hangings
Construction budget, costs
Operational costs
Maintenance, cleaning standards, costs

by the following:

Example of a summarizing section

"The courtroom's thermal comfort requirements are similar to those of many other types of room. Its unique requirements are in the spatial, aural and visual environments. Aural privacy is of paramount importance. No noise may penetrate to outside halls or rooms and no noise should be admitted. Furthermore, room acoustics must be conducive to speech, and the judge must be able, aurally and visually, to dominate the room. Moreover, there must be a degree of visual formality which reflects the significance of the court. The judge must be perceived to be the focal point of the proceedings and must, in turn, be able to view the entire room. The jury must be directed towards the court proceedings without being distracted by the public. All of this must be enveloped in a space which allows freedom of movement for participants.

I examined courtroom number 8 while a trial was in progress. When the room was empty I was able to measure levels of heat, light, sound and space. The courtroom was perceived to be well appointed in every respect, except that there were shortfalls in comfortable public seating and creation of a suitable mood. The environmental character of the space was more sombre than I thought appropriate. It could better have reflected the nature of a Canadian Court of Law by changed lighting . . . (etc.) . . ."

CONCLUSION

An evaluation of the environment within a building presented in the form suggested in this paper provides opportunities to employ the results of building environmental research in a very constructive way. The most up-to-date research knowledge can be used to provide the standards by which to review buildings' performance in terms of the extent to which they satisfy the environmental needs of the buildings' functions, and of their human users—workforce, customers, management, owners, visitors, etc.

Table 3. Example: part of an evaluation of the auditorium of a teaching theatre

Environmental requirements	Criteria	Physical means employed by design team	Evaluation
Spatial			
Space for seated audience	460 mm min. width of chair space 920 mm min. seatback to seatback	Average width 490 mm Back to back 900 mm	Space more than adequate laterally but cramped longitudinally
Comfortable seating for 2-hour periods	Satisfy basic ergonomic requirements of dimension, height, slope, support, etc. for relaxed sitting	Typical uptight "classroom" type chairs of tubular steel frame and canvas back and seat	Seating uncomfortable for more than short periods (e.g. half hour max). Not designed for relaxation. With use over several years, some seats and back supports have stretched and some wider patrons find themselves spanning the framework
Adequate circulation space for access to seats	Min. aisle widths of 1100 mm (main) and 920 mm (secondary)	Aisles are 1200 mm and 1050 mm wide	Adequate, though not spacious
Economical arrangement of seats	Max. 15 seats between aisles	Typically, there are 15 seats between aisles	Maximum number of seats possible within space provided. Provision appropriate for type of theatre
Thermal			
Comfortable thermal conditions: temperature	20°C effective temperature for light sedentary activities	Air conditioning thermostat control. Air temperatures 21.5°C at front of auditorium, 26°C at rear	Thermal conditions vary within the auditorium; too high at rear
consistent temperature	Within ranges: About ±2°C during performance	Temperatures increased, typically, by about 1°C during performance	1°C rise in temperature is entirely acceptable
relative humidity	About 30–60%	Measurements 45–55%	Acceptable
Some air movement; absence of draughts	Preferably variable air movement, never to exceed 0.5 m s^{-1}	Air conditioning	Requirements met. Good air movement just perceptible. No draughts experienced
Freedom from odours	Absence of odour during a performance	Air conditioning	No odours experienced
Fresh air supply	Min. 0.4 m/person h^{-1}	Air conditioning	Not measured but appeared adequate (see below). Wall surfaces seem warmer than air. Air temperature felt cool at beginning of performance but increased substantially. However, no sense of stuffiness
Sense of coolness and freshness			

Visual			
Ability of audience to find seats	50–100 lx on floor	Overhead incandescent lamps 10–90 lx on floor. No aisle lights	Floor illuminated very unevenly
Ability to read program notes	100–300 lx at reading level	20–100 lx	Reading is rather difficult, especially in balconies
Capability of dimming lights to complete blackout	Controlled transition from light to darkness: instant variable to slow	No windows; light-tight doors; dimmer and switch(es)	Requirements met
Adequate sight-lines; ability to see performance	Unobstructed view of stage from every seat. No sight-line more than 20° above horizontal	Seats in steeply-tiered auditorium (each row 460 mm higher), staggered on plan. Farthest seat 12 m from stage	All seats have unobstructed view of stage. Front row eye-level above stage floor. Views generally as good as could be desired but galleries less satisfactory since line of sight at angle of approx. 40° to centre line of seating. However, number of gallery seats small
Illuminated exits signs	Low luminance signs visible from all seats	Illuminated signs located over exit doors. No obstructions; signs visible to all members of audience	Legal requirement satisfied. No significant distraction from performance
Aural			
Low ambient noise level	NC 20–25	Location near centre of university area. No heavy traffic. Heavy (RC) construction; no windows; heavy, tight-fitting doors. Air conditioning	External noises inaudible but some "hum" from luminaires and possibly some fan noise. NC 35 measured: too noisy, but generally accepted
Appropriate liveliness/resonance of human voice heard from stage	RT of 1.2–1.4 s	Room shape, volume; exposed concrete (reflecting) surfaces near stage and on much of ceiling. Back walls (absorbing surfaces) panelled and covered fabric. RT calculated to be about 1.3 s	Good. Voices heard clearly and with some fullness
Audibility and intelligibility of human voice	Actors on stage clearly audible and intelligible to all seats	Direct (and short) sound paths from stage to all seats due to stepped seating. Maximum direct distance less than 12 m. Appropriate RT	Requirements met adequately
Reduce aural impact on neighbours (theatre located in mixed university/residential neighbourhood)	Few or no complaints	Reinforced concrete construction	No transmission of sound to outside discovered during performance. No known complaints of too-loud performances, applause, etc. Theatre almost certainly not an aural nuisance

The method is adaptable to the degree of sophistication appropriate to particular purposes. Evaluations may be undertaken, for example, by design professionals for the self-examination of their own work. Alternatively, they may be performed by user groups to assess their working conditions, or by building owners to assess the efficacy of their buildings as working instruments. Evaluations are a useful tool for the education of future designers. Evaluations published as critical reviews in journals are a potent means of disseminating understanding of environmental design among professional designers and their clients.

Obviously, the quality and authority of an evaluation is influenced by the amount of time, the depth and amount of professional or research competence and experience that is committed to the task. Nevertheless, useful evaluations can be undertaken very simply. An evaluation may, for example, be conducted by a lay individual within the space of one hour, or by a single professional designer or a building research scientist within the same time. Alternatively, the evaluation may extend over several days or weeks and involve multi-disciplinary investigative teams of engineers, social scientists, experts in the building function, architects, ergonomists and others. The depth and degree of expert insight that have been employed will be evident from the detailed tabular statement. The advantages of this form of environmental evaluation are that: (i) by providing a general structure for evaluations it maximizes the effectiveness of the evaluators, whoever they may be, (ii) it presents the analysis and results, and causes and effects, in the clearest possible manner and (iii) basing the evaluation activity upon generic design needs should make clear any omissions that might exist (and therefore, what may need to be done to correct them), besides providing clear pointers to the statement of design requirements ("the brief", or "the program") appropriate to future similar needs and environments.

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