Design for manageability

UNMANAGEABLE COMPLEXITY IS A MAJOR SOURCE OF CHRONIC PROBLEMS IN BUILDING PERFORMANCE

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Drawing evidence from studies of the performance of buildings in use, the authors explore the consequences of unnecessary complexity especially for usability and environmental efficiency. Briefing and designing for management and use raises strategic issues of how human and physical systems interact, how uncertainty and inefficiency in systems' operation and use can develop; how human behaviour is affected and how chronic failures occur. Attributes for more successfully briefing, designing, researching and evaluating buildings are discussed in terms of improving performance in use.

A partir de preuves extraites d'études sur les performances de bâtiments en exploitation, les auteurs explorent les conséquences de complexités inutiles, notamment sur le plan de l'usage et de l'efficience par rapport à un objectif environnemental. L'information et la conception en vue de la gestion et de l'usage suscitent des questions stratégiques sur les interactions entre les systèmes humains et physiques ainsi que sur l'incertitude et l'inefficacité de l'exploitation et de l'usage de systèmes, qui peuvent se développer. Une autre question porte sur la façon dont est affecté le comportement de l'homme et dont se produisent des défaillances chroniques. Les auteurs examinent en termes d'amélioration des caractéristiques d'utilisation les attributs nécessaires à de meilleures méthodes d'information, de conception, de recherche et d'évaluation des bâtiments.

Keywords: building performance, feedback, manageability, risk reduction, briefing

Introduction

Recent studies of building energy performance and of management and occupant satisfaction suggest that too many buildings deliver less than they promise. Pathological characteristics are too widespread, for example avoidable wastage of fossil fuels; poor indoor environments; chronic low-level illnesses of occupants; and low user morale. Most of these may also lead to productivity losses and absenteeism. The problems tend to reinforce each other: once standards slip they can become increasingly difficult and expensive to regain. Since the features of the building and the culture of the occupying organization are inter-related, it then becomes difficult to attribute direct causes.

Designing with management and use clearly in mind should help to make things easier. However, this seems to be much more easily said than done. Indeed, in striving for improved flexibility and efficiency, both designers and their clients often appear to under-estimate or ignore:

1. how systems – physical and human – can conflict with each other, thereby pulling performance levels down to the lowest common denominator; and
2. how uncertainty and inefficiency in systems' operation and use can readily develop through lack of attention to detail for occupants' requirements.

This paper considers how things might be improved, particularly in strategic thinking at the briefing stage about building design for use. It suggests that many problems can be traced to unmanageable complexity, a feature of modern buildings which arises from the tendency, first, to require too much of the building and its services and then too much of its management. It considers desirable attributes in buildings, postulates that designing for manageability may need to become an important criterion, and identifies new areas for research.

Much of the data referred to here is from studies in which Building Use Studies and William Bordass Associates have been involved over the past decade,

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including post-occupancy evaluations of offices, schools and museum buildings; building services and energy performance in a range of non-domestic buildings; and surveys of occupant comfort, ill-health and control behaviour.

Design, occupancy and management of buildings

Different perspectives

A building consists of things that occur in space and time, and have a certain level of performance, Fig. 1. Although both designers and users usually try to create flexible buildings that respond well to changing requirements, their perspectives are different and often incompatible:

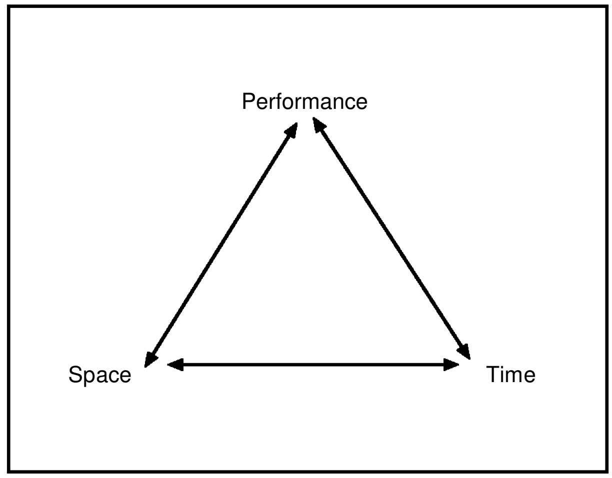
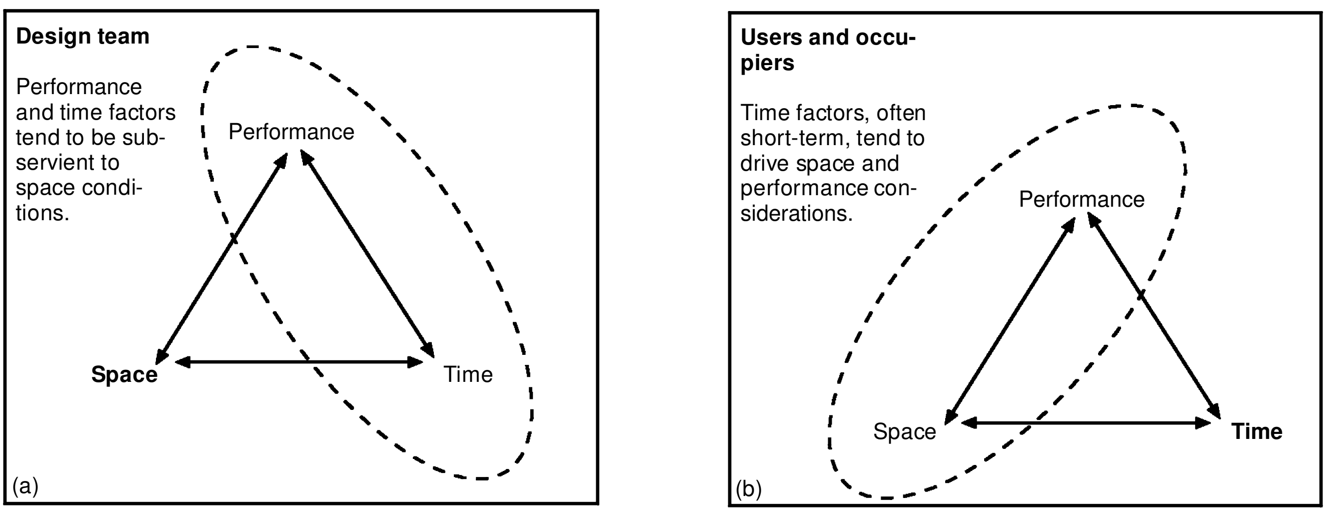


Fig. 1. Related aspects of building performance.

- The design team, in providing the artefact, are clearly most concerned with the spatial. However, they must also give the building the potential to meet changing needs over time, both from minute-to-minute (as, for example, the building services respond to changes in the weather, internal heat gains, use, and occupant requirements), from day-to-day (with changes in working patterns, space use, equipment, furniture etc.), and from time-to-time (with changes in organizational structures, requirements, tenancy and even function) (Fig. 2(a)).
- Occupiers are most concerned with the time element: they want the building to support them in their activities – now! – and with as little effort as possible {5} (Fig. 2(b)).
- General management, be it of the developers, the owners, the users, and even among the designers, has yet another viewpoint: the performance factors. How much will it cost per square metre to buy and to operate? What will the rental be? How many people will fit in? What heat gains can it accommodate? How much energy will it consume? Performance requirements may also be regulated by legislation and by corporate or professional norms (Fig. 2(c)).



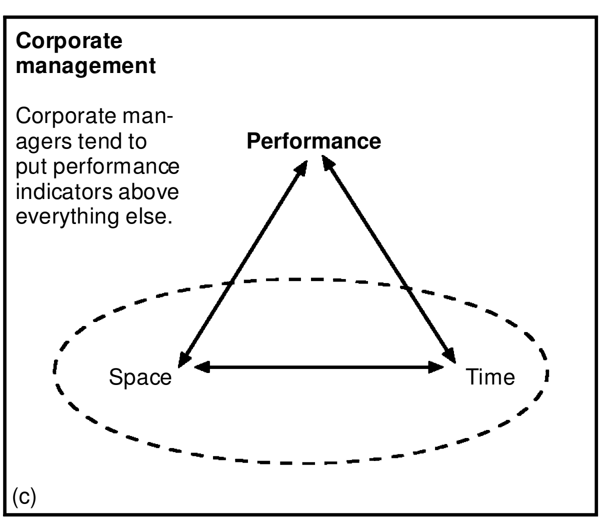


Fig. 2. Different viewpoints on performance aspects. (a) Design team, (b) Users and occupiers, (c) Corporate management.

At the design stage, problems often seem to arise when one party expects another to solve their problems completely. Flexibility is a common culprit, see Table 1.

A strategic diagram

Figure 3 is a diagram which has helped us and our clients to review some of the issues. Buildings can be seen as integrated systems (vertical axis), including both physical (top half) and behavioural (bottom half) elements with interfaces between them ({1} chapters 1 and 5). Physical systems (such as the building structure, walls and enclosed spaces, windows and ventilation systems) tend to be tightly coupled (meaning that there is relatively little slack or give between them ({2} p. 90). Behavioural systems are loosely coupled (meaning that certain parts express themselves according to their own logic or interests ({2} p. 92)).

The systems have attributes, on the horizontal axis:

- Context-free attributes (left-hand side of Fig. 3) can apply to buildings more-or-less independently of their operation. They include technical features, often passive ones, which are normally taken for granted in everyday use; and much habitual behaviour. They are very appropriate for application of standards and legislation.
- Context-dependent attributes (right-hand side), need to be tailored to suit the needs of the occupants, and generally require regular attention.

Table 1. The downsides of flexibility

At the design stage

1. To avoid altering the building in use . . .
2. one asks for it to be flexible.
3. Designers respond with complex systems . . .
4. which in use demand management time.

In use:

5. If not enough resources are devoted, or if response is not fast enough, failures occur . . .
6. directly or indirectly affecting staff satisfaction. comfort, health and productivity.

In use, alternatively:

7. Enough time and effort is spent; but . . .
8. the cost of looking after the complex systems intended to provide flexibility may exceed those of adapting a simpler building to meet new needs as they arise; and . . .
9. the demand is relentless; and . . .
10. the systems that were initially intended to provide the flexibility may themselves obstruct the change which is then found to be required!

The four quadrants

The two axes divide Fig. 3 into four quadrants.

A Physical and context-free

Characteristics which are predominantly spatial, can be taken care of physically, and do not alter with operational context: for example location (except perhaps for transportable buildings); and passive features such as structural stability, fire compartmentation and insulation, which are largely 'fit and forget'. This is traditionally the main territory of designer, setting the major physical parameters for the occupier: the results in use may be regarded as anything between insuperable constraints and helpful, simplifying disciplines, depending how appropriate they are to the requirements. Ideally they should be made unnoticeable.

B Physical and context-dependent

Here designers and occupiers meet, the occupiers having to look after the systems the designers have provided, and adapt them to ever-changing demands, e.g. equipment needs operating, servicing, adjusting and replacing; furniture needs to be moved about; and engineering systems react to changing weather

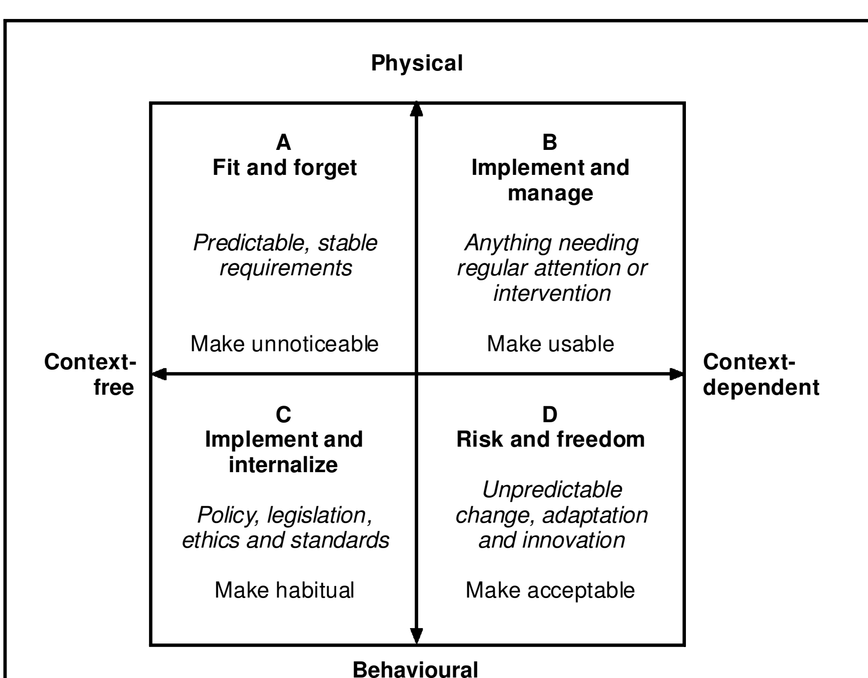


Fig. 3. A strategic diagram for assessing building performance.

and occupancy. These things need to be implemented and managed, but what this may truly entail is seldom fully considered at the design stage. Ideally thay should be made usable, preferably by those most directly connected with them: it is better if you can move your own table, adjust your own thermostat and light, and for the engineer get at the item needing maintenance or adjustment without having to take lots of other things out of the way.

C Behavioural and context-free

Things one would like to take for granted in (or at least reasonably expect from) people, and have implemented and internalized. They are ingrained in social structures, ethics and value systems, and supported by written and unwritten rules: national laws, habits, practices and expectations, overlaid by those of the occupying organization and of the particular user groups. As a rule, designers as professionals do not share the occupiers' culture, lack understanding of their habits and priorities, and may expect them to behave in unfamiliar ways (for designers as individuals, there may be less of a behavioural gulf!). If change is really necessary, then a strategy must be carefully worked out, agreed and implemented. Better still if what you want fits the way people already do things, if it is intuitively obvious, and can be made habitual.

D Behavioural and context-dependent

All is going well and something breaks down, or a telephone call changes everything! This is an area of risk, but of freedom and of opportunity too. Most hazards can be reduced by a combination of physical, behavioural and managerial measures in the other three quadrants, together with risk management procedures, but if these are taken too far the results may be over-regulated, over-bureaucratic, and poorly adaptable either to change or to the real needs of individuals. Many cannot be entirely eliminated, at least at sensible cost (spending too much on reducing one kind of risk can divert funds from better and more cost-effective measures) and without unreasonable restrictions on freedom: instead they need to be met acceptable. Risks also have a nasty habit of being shunted around: people in safer cars kill more pedestrians and cyclists {3}, or force them off the road!

Trapping the fantasies

Designers tend to inhabit the left-hand side of Fig. 3; users, the right-hand side. Many problems seem to occur because people either put things in the wrong quadrant, or fail to evaluate interactions between features and quadrants. Naturally clients want to avoid potential problems in use by referring them to the designers. Designers, in turn, often offer solutions which pretend to be in the top left of the diagram; but possible leakage back into other quadrants, and the true implications of occupiers, is seldom reviewed carefully: it is assumed that the occupants will do whatever is necessary to make the solution work. In developing the solution, occupant behaviour is often stereotyped or ignored ({4} Chapter 1), and if things go wrong later the usual defence is that the problems could not have been foreseen and that the occupiers are not behaving in the way that the design assumed and required.

As buildings become more complex, designer and user perspectives are more likely to 'fight' each other {5}. Indeed, the rapid growth of the facilities management profession can be seen as partly a response to the need to cope with the consequent conflicts and inefficiencies, and the insights this is generating can now begin to be fed back upstream. Clients often misunderstand or ignore the spatial, technical, cost and legislative constraints within which designers must operate, and it is easy for everyone to conspire in fantasies that solutions are 'fit and forget', while 'fit and manage the consequences' (top left and top right of Fig. 3) would be more like it.

Many difficulties in practice can be traced to the quest for 'flexibility' and subsequent problems with the 'solutions', for example as outlined in Table 1. In practice, it might have been better to start off with something simpler, which made fewer routine demands of management, even though it might require more substantial *ad hoc* intervention from time to time – which could itself be made easier with the right sort of design. At present, however, there seems to be a general tendency to try to force as much as possible into Quadrant A, whether it belongs there or not, some symptoms being over-reliance on technology, burgeoning legislation (designed in part to deal with technological overkill), more standards and codes to be followed, and less scope for discretion in design and management.

A way forward?

Introduction

If we expect too much of the building in the hope of reducing risk or making things easier for its management, the consequent demands of a different kind upon management may actually restrict opportunities for appropriate and effective compromises, and in turn reduce overall performance. This trend could become self-perpetuating as designers, managers and legislators continue to seek technological solutions to what should more properly be considered as human management problems, and which in turn make buildings harder to manage effectively, and less easy to change.

Instead we consider that more attention should be given to understanding outcomes of human behaviour in real contexts, especially:

- in risky, abnormal or dangerous circumstances;
- when individual actions are further constrained by group behaviours, including how individuals and groups respond to sub-optimal internal environmental conditions;
- change, flexibility, adaptability and responsiveness of conditions to new situations;
- effects on behaviour and decision-making of changing work tasks;
- usability of control interfaces.

All these fall properly in the right-hand part of Fig. 3, and all are seldom given due weight.

Improving performance in use

Table 2 summarizes eight fundamental attributes of building and their management which studies have

Table 2. The best buildings

1. Optimize relationships between physical and human systems over their lifetimes.
2. Keep resource inputs and undesirable effects to the necessary minimum.
3. Are simple but capable of upgrading, avoiding unnecessary complexity.
4. Are economical of time in operation.
5. Respond rapidly to change.
6. Have sufficient management resources to deal with both routine requirements and unpredictable consequences of physical or behavioural complexity.
7. Are comfortable and safe most of the time, but use properties 5 and 6 if difficulties occur.
8. Try to avoid introducing failure pathways.

shown to benefit performance in use, and which could be used in strategic briefs for new or remodelled buildings. They will be discussed in turn in the eight sections below. Supporting evidence can be found in the references: we must apologise for about one-third of these being our own, but these in turn do also refer to the wider literature!

Attribute 1
Optimize relationships between physical and human systems over their lifetimes

Buildings and their occupying organizations are recognizably complex systems, with many levels of interaction and feedback between sub-systems. However, many are designed, built and occupied as if they were independent systems with simple causality. It is commonplace to hear designers plead for their specialism (lighting, security, furniture and so on) to receive priority in the design process. This way they can avoid or minimize constraints deliberately or unwittingly imposed by others, and perhaps pass on some of their own for good measure!

True integration, with attention to detail and avoidance of unnecessary conflicts, comes through a well-developed briefing process which does not compromise specialists' roles. Later in the building's life, the brief should become the yardstick for post-occupancy surveys which objectively test whether it was met – and whether it was relevant! The information may then be fed into new building briefs, closing the quality improvement loop. The now extensive literature on 'total quality' offers many suggestions for building managers. For instance, techniques used in small-scale product development seem particularly appropriate to use at the larger building-system level {6}.

For building and environmental services, it is important that the point of control is as close as possible to the appropriate point of need. Anything else will require access to management resources: which is at best wasteful, and usually means that an undesirable state becomes the default state because it is the most convenient {7}.

Attribute 2
Keep resource inputs and undesirable effects to the necessary minimum

Buildings are undergoing a demand-side revolution, of which the rapid growth of the facilities management profession is an important part. Emphasis on systematic building evaluation techniques is increasing, in an attempt to give potential occupiers a clearer understanding of strengths and weaknesses in advance of committing themselves to development, lease or purchase. Good buildings match demand and supply, while keeping 'just-in-case' provision to a necessary minimum. From the somewhat extravagant 1980s – both in appearance, specification and over-provision (for occupancy, structural loadings and in particular cooling loads – one now hears calls for 'no frills', 'lean and mean', and more recently 'lean and fit' buildings. However, whether the economies have been made in the right places has yet to be demonstrated!

With wider understanding of building performance – through investment, costs in use, technical features and human factors – clients are more aware of the questions to ask their design teams. Faced with an informed client, and more focus on problem definition, designers must repond with better predictions of what their buildings will deliver. That architects and engineers have less influence over briefs and strategic agendas for buildings is not necessarily a bad thing: potentially more attention to needs and requirements will permit better problem definition in the building brief, to which designers can then give a better response.

For day-to-day running, the resouce inputs include manpower, technology, space, materials, management and energy. While economies are being sought in all six, this can be done in the context of adding value rather than penny-pinching, and under good management virtuous circles are possible. The results are encapsulated in phrases like 'environmental sense makes business sense'.

In user surveys we see a microcosm of this. For example, some buildings which worked best for human comfort and satisfaction were also energy efficient {7, 8} probably because a good match of demand and supply was achieved through more effective building procurement and management, careful performance monitoring, attention to users' complaints and relatively rapid feedback loops and well-defined diagnostics. This was helped along by robust, well-designed, user-friendly systems, effective cleaning and maintenance, and efficient energy management. The cleaning or the energy saving may not be the most important part of these activities, but the active monitoring of performance and the culture which causes it all to happen {9}. Interestingly, the three best buildings from the users' point of view happened to be pre-lets: while not statistically significant this suggests that the occupiers, while able to influence the buildings, were less distracted by the mechanics of having to build them, and could concentrate more on what they really needed from them as users.

Attribute 3
Simple but capable of upgrading, avoiding unnecessary complexity

This is a development of Attribute 2. The desire for (or promise of) 'flexibility' often leads to complex solutions which are reliant on energy-dependent technologies such as air-conditioning. However, in practice the flexibility may not be as great as was initially hoped, as can be seen by all the nearly new materials which end up on the skip when many air-conditioned offices are fitted out.

Almost invariably, when buildings are altered to suit new requirements, the altered space will be more densely occupied and accommodate a wider range of activities, for example, in higher education which needs to change uses from daytime to evening and from termtime to vacation; or in converting offices from cellular to open plan.

The best buildings are able to accommodate higher densities and more functions operating simultaneously. However, in recent solutions one has fears about more rapid obsolescence. An alternative route may sometimes be to provide simpler, but potentially adaptable, buildings which are easily altered as needs change. If properly thought through, this can potentially reduce both initial and in-use costs. 'Mixed-mode' services concepts, which allow natural ventilation and mechanical systems to work together, are examples of this {10}.

However, designers and clients seeking flexibility, or energy efficiency, may unwittingly add to complexity and the management resource requirement and hence sow the seeds of failure – and new ideas (including mixed-mode) could be as prone to this as the old ones. For example {11, p. 9} noted that 'complex energy systems may not be operated as the designers intended, and saved heating and cooling energy may turn up instead as parasitic losses from pumps, fans and unforeseen control problems'. It goes on to say that 'the greatest savings nationally are likely to come from simple applications of available technology in a manner which integrates architectural, engineering and user requirements, and provides control and management systems to suit,.

Attribute 4
Economical of time in operation

While buildings operate over time as well as in space, far more attention has been given to performance in relation to spatial variables. As a result, space and time systems are often poorly integrated and physical solutions are often proposed where operational approaches might have been better, and sometimes vice versa. In future, more thought should be given to the way buildings work dynamically, especially to overcoming inefficiencies of space or time (efficient use of space is not necessarily good: sometimes what looks like 'waste' space may be useful redundancy which saves time in operation and may be cheaper to build, or to retain, and to service).

Understanding time involves not just considering gluts and famines of occupancy, but also how habits, attitudes and behaviours influence the way systems really work.

The best buildings keep the time wasted by occupants to a necessary minimum. The point is closely related to response times (Attribute 5) – the faster a need is met, the better. This applies not just to more obvious facilities such as say the location of meeting rooms or toilets, but to activities such as photocopying, where there may be major inefficiencies in queuing, machine downtime and travel time to the machine location, and to the ease with which the building may be altered. Economy of time in fact unites many of the Attributes in Fig. 3. A simple rule is to make 'the bad difficult and the good easy', which means comprehensible devices correctly located, easily operated, and configured to give rapid response while avoiding unnecessary waste.

Attribute 5
Respond rapidly to change

Speed of response is widely discussed in management science {12} but rarely in the building literature. However, the faster a building (meaning the whole system, human as well as physical) can respond to requests for change from occupants, the better people like it and the more productive they say they are {13}. Response time applies in obvious ways in lifts answering calls, or computer systems responding to a log-in-request ({14} says four seconds is the tolerance threshold!). More emphasis is now being placed on the speed with which furniture systems can be reconfigured, and possible cost savings by much more efficient relocation logistics.

Management which reacts promptly to occupants' complaints is appreciated, even where the source problem cannot be completely solved. Surveys of comfort and occupant satisfaction {15}, reveal more positive and appreciative occupant perceptions where quick response is the norm, whether this is provided by physical control systems such as adjustable blinds or manually adjustable thermostats, or by building management support services, or combinations of the two. One reason why when surveyed occupants say that they like the conditions in naturally ventilated buildings more than one would anticipate from the monitored values is that openable windows give fast response and intuitively obvious control, even though they may not always deliver optimal or even reasonable conditions.

Rapid response is most commonly found in buildings which have enough management resources to deal with problems when they arise. Good management will set up self-reinforcing virtuous circles of causation which consistently 'deliver' quality and responsiveness. However, most buildings are victims of vicious circles which can become increasingly expensive to halt or reverse as they spiral into decline {16}, as with vandalism, which tends to escalate unless an environment is cared for, with immediate repainting or repairs {17}.

Technical systems also need to give rapid response to failures, see also Attribute 8. While automatic alarms are usually provided for critical faults like fires and boiler lockouts, chronic faults which affect efficiency but not service frequently persist for long periods. Examples include:

- wasteful operation of heating and air-conditioning systems, sometimes even running continuously;
- malfunctions of energy-saving systems, like heat recovery, free cooling and night ventilation.

Attribute 6
Sufficient management resources to deal with both routine requirements and unpredictable consequences of physical or behavioural complexity

As often as not, the true manpower requirements of running buildings are under-estimated or ignored altogether by designers and by senior management, forcing many buildings into vicious circles from move-in day. Budgets are also soft targets for cutbacks, partly because line managers do not have convincing data with which to defend themselves against attack from above (for example, {18} and {19} suggest that, as a rule of thumb, expenditure on energy and on building services maintenance should be similar). But much can be done in good briefing and design to reduce the management task by making things less complex and more self-managing.

Early work on sick building syndrome (SBS) in UK offices led many, including the authors, to regard SBS as primarily a design problem (with the main explanatory variable being physical features such as type of ventilation system or depth of space). As understanding grew, it became clearer {20, 21} that problems usually surfaced where the building's demands for management and maintenance were well in excess of the resources provided.

In general, management and maintenance leaves a great deal to be desired, either from knock-on effects of chronic long-term underfunding (as in many British schools for instance); through bad habits and practices (including poor selection and supervision of outside contractors); and because the building's demands were too great for the resources available, often a result of wishful thinking at the design stage.

Attribute 7
Are comfortable and safe for most of the time, but use Attributes 5 and 6 if difficulties occur

One of the best kept secrets of work on thermal comfort is that alleviating discomfort is just as important for occupant satisfaction as providing comfortable conditions in the first place {22–24}, and that people can exploit opportunities to adapt themselves and the internal environment to meet their needs {25, 26}. Occupant dissatisfaction with the indoor environment is directly related to occupants' perceived productivity {27} – with a stronger link between dissatisfied staff and lost productivity than between satisfied staff and better productivity. On this basis, it may be better to give building occupants more capability to fine tune their environment than to rely upon fully automated systems which in theory can deliver better conditions but may not be perceived as doing so {13}.

Designers often assume that comfort can be achieved solely by systems which are designed to 'keep the measured variables within the required tolerances' and leave out the other features. However, to provide both comfort and energy efficiency the best buildings require all four features shown in each of the quadrants of Fig. 4. They need automatic control (top half of diagram) plus manual control (bottom half) and if possible should anticipate likely change (right half), and not just operate in response mode (left half). However, gratuitously adding more controls may introduce conflicts between different sub-systems and increase complexity beyond manageable bounds.

User control is also important because people are often better than pre-programmed systems at dealing with unusual or unpredictable situations – which are also likely to increase as space use is intensified. For example, open-plan offices trade off the greater personal controllability normally found in cellular spaces for greater inter-personal communication in the open areas. However, the productivity gains from better communication may not always outweigh the productivity losses caused by more distracting, less controllable environments, which are frequently perceived as less comfortable too.

Like airline pilots who normally fly under autopilot but take control in difficult, unusual or emergency circumstances, building users need the capacity to make adjustments; and their tolerance of conditions increases as perceived control rises. For example, users seem to accept 'poorer' conditions in naturally ventilated than in air-conditioned buildings {9}. Similar considerations apply in the arena of safety and health, and especially in the rapidly growing subject of risk assessment. Table 3, adapted from {28}, briefly illustrates some of the considerations. See also Attribute 8 and {2}.

Unfortunately, some engineering and energy-saving systems may create rather than alleviate discomfort. As a general rule it appears that:

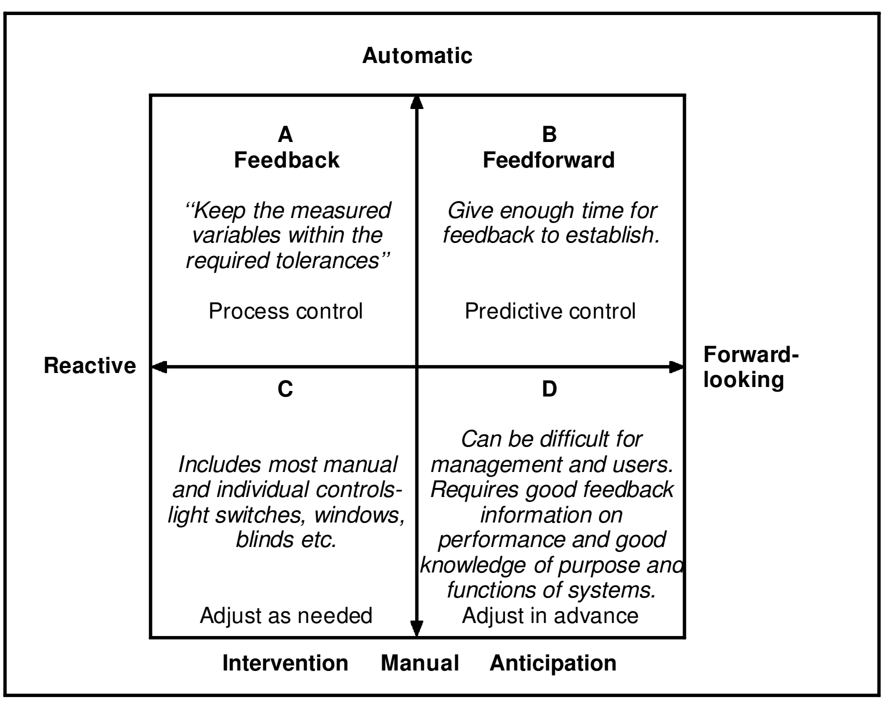


Fig. 4. Fundamental attributes of buildings.

Table 3. Risk estimation considerations (adapted from [22])

Failure to consider the ways in which human errors can affect technological systems
Example: Obscure and difficult to operate Building Management Systems resulting in energy wastage and discomfort.
Over-confidence in current scientific knowledge
Example: Failure to take unproven scientific evidence seriously or develop precautionary strategies (e.g. global warming).
Failure to appreciate how technological systems function as a whole
Example: Overlooking importance of control interfaces in buildings, especially manual controls.
Slowness in detecting chronic, cumulative effects
Example: Building-related sickness
Failure to anticipate human response to safety measures
Example: Windsor Castle fire where emergency telephones were not seen by those wishing to raise the alarm
Failure to anticipate common-mode failures, which simultaneously afflict systems which are designed to be independent.
Example: Failure of innocuous window components like friction hinges in naturally-ventilated offices simultaneously affecting noise, ventilation and heating performance.

- manual systems should operate perceptibly and give immediate response, if not by performing the intended function then at least by giving a click or lighting an indicator;
- automatic systems should operate imperceptibly: if not, whatever they do is sure to be wrong for some occupants.

Automatic control of lighting and blinds are common offenders here {29}: the blinds close either just as you are enjoying the sun or long after you have become fed up with it; the lights come on when you enter the room whether you think you need them or not; and other people's lights flashing annoy you. Automatically controlled windows in new 'green' buildings may create similar problems. For such systems, individual user over-rides are not costly luxuries, they are essential.

Attribute 8
Avoid introducing failure pathways

Few buildings fail catastrophically in a technical sense. Many more fail economically, functionally, aesthetically or socially and exhibit chronic problems of one kind or another which often persist for the lifetime of the building. With hindsight, some of these once latent faults seem blatantly obvious, but they can be hard to detect beforehand unless thorough briefing and design management disciplines are in place, plus appropriate review and testing of solutions where practicable. With risk analysis techniques, which help prevent accidents in complex and dangerous systems like nuclear power plants {2, 30}, one can now target problem areas and put prevention strategies in place early in the design process. For example, in a naturally ventilated building, the window is one crucial building element, so it is imperative that its components should operate reasonably effectively and in sympathy with associated systems, or apparently trivial difficulties or oversights can be very costly in the long term.

Buildings too often default in performance to undesirable states which are extremely hard to alter. For example, many run with all their lights on all day because the first person who arrives in the morning in the half-light of dawn will switch all the lights on (at the gang switch near the door). Maybe they have no option, maybe the switching is incomprehensible, or maybe they just want to 'cheer the place up'. As successive people arrive, it becomes harder and harder to switch any lights off because of the difficulty of agreeing among everyone that this should happen. The building will thus tend to run 'lights on' by default, whatever the daylight conditions outside. The combination of habit, poor control design, and the difficulty of making small-scale trivial' decisions in groups leads to unnecessary inefficiency and sub-optimal working environments. Here, lack of integration between spatial factors and time factors (location of light switches, times of arrival) leads to buildings running 'just-in-case', that is, inefficiently and insensitively to true demand. Automatic daylight-linked controls are not the complete answer to this problem. Human and automatic systems need to be sensitively combined {31}.

A review of case studies {11, pp. 8–9} found that office energy use depended more on the detailed design, commissioning, control, operation and management than on the technical features adopted. Human management was at least as important as technology in securing good energy performance, particularly in the air-conditioned buildings which had more potential for wastage. We are now finding that the more complex designs being developed in an attempt to avoid air-conditioning are often similarly afflicted {10}, and that much of the energy waste previously attributed to air-conditioning can be laid at the door of unmanageable (or at least unmanaged) complexity! Typical energy-related failures include:

- Default to ON. Systems operating unnecessarily.
- Tail-wags-the-dog. Large systems operate inefficiently to meet small demands.
- Antagonistic operation, e.g. heating fighting cooling.
- Embedded system failure. Breakdown or faulty operation of systems designed to save energy not detected because comfort and service are not sufficiently affected.
- Parasitic losses. Excessive energy consumption by items intended to save energy but not directly involved in service delivery (for example heat recovery pumps).

Conclusion

We have explored a range of issues which affect building performance in practice, often through the inter-relationship of space- and time-dependent variables, and of design and management. Many of these have received less attention in briefing, design and research than we think they deserve. We have begun to use them ourselves in briefing and design reviews, with positive responses, particularly from clients who can envisage integrating their buildings more closely with their business needs; and from designers who have simplified their proposals, reviewed their usability and considered how potential operational failures might be avoided or trapped.

However, each of the eight attributes could merit a research programme of its own, or at least some changes in the emphasis of ongoing research. In some areas we feel that solutions are close: indeed many answers may already be available in related areas like management studies, risk analysis and ergonomics. However, their applicability to buildings has not yet been clearly considered.

If there is a single conclusion from the work to date it is: avoid unnecessary complexity and design for manageability. While what this means exactly requires more study, provisionally we make the following suggestions:

- The fewer demands a building makes on management services, the better.
- Passive is better than active. Make sure that things which are designed to operate in the background do so properly.
- Things which needs changing or looking after should be usable, preferably by those who are most directly concerned with them. Responses should be rapid and understandable.
- Simple is better than complex, but when complexity is necessary try to package and isolate it wherever possible, and provide simple interfaces.
- Cater where possible for people's preference ranges rather than averages or norms. Try to foresee risky situations and consider how people may compensate.
- Potential failure paths should be identified and if possible avoided; if not, appropriate indicators should be monitored to help identify, and deal with, incipient problems.
- Try to assess risk cost-effectively, so that resources are spent realistically on avoiding the costliest and most risky events.
- Beware unsubstantiated promises of 'flexibility' which may bring unforeseen management costs. Recognize that all situations are subject to constraints, which will reveal themselves sooner or later.
- Remember that designers are not users, although they often think they are {14}!

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