# Productivity in Buildings: the “killer” variables


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## Introduction

This paper deals with the somewhat vexing question of human productivity in the workplace. It sets out to answer: “What features of workplaces under the control of designers and managers significantly influence human productivity?”. The main theme is how individual occupants are affected. We are seeking building or organisational features which most readily improve or hinder human productivity. The findings can then be used in the briefmaking, design and management processes.

Observations are mainly based on surveys carried out since 1985 in the UK by Building Use Studies and William Bordass Associates (hence the bias in the references), together with new and spin-off projects from the Building Research Establishment and Department of Environment amongst others. Some of this work has been published before but the bulk of data collected still remains to be analysed and reported on in greater detail.

There is also a substantial wider literature, much of it from the US, reviewed by Lorsch and Abdou [References 1-3] and Oseland [Reference 4]. Quite a lot is known about how well people respond to different conditions of temperature, humidity, lighting, ventilation and noise, for example, and regulations for building design are based on many of the findings (although with a considerable time lag).

Most of these studies come from military, industrial and commercial sources. Their findings can be contradictory (although there is a reasonable consensus on key points) and sometimes they can be hard to make sense of when productivity is linked to the indoor environment. For instance, Reference 5 found that young people worked best (and were thus more productive) for short periods when they were uncomfortably cold. Periods of relatively uncomfortable arousal can thus be important. It is unlikely that people will continue to perform well in conditions of prolonged discomfort. Reference 6 shows that large numbers of office staff considered their working environments to be thermally unacceptable despite measured conditions falling within industry-standard comfort envelopes, so perceived and measured conditions can be different. Reference 6 also demonstrated that 23.5°C is the temperature which people in offices prefer, but even with this there is a sizeable minority of about 35 per cent who wanted it to be warmer or cooler, so minority needs cannot be ignored.

Human productivity in workplaces is fraught with difficulty because :

a. studies of individual occupants often miss out the wider context of differences between buildings, and their operational and managerial circumstances;

b. buildings and their occupying organisations are rarely even similar to each other from case to case, which complicates comparisons;

c. methodological and interpretational problems result from a. and b. and lead to begged questions about assumptions and spurious detail so it can be difficult to filter out the most important points from case to case;

d. people behave differently in groups.

On balance, we prefer the approach of “real-world research” [Reference 7] which deals with human activities in their real contexts. This involves smaller surveys (10–15 buildings is ideal), controlling for context through a thorough understanding of prevailing circumstances, detailed occupant, technical and energy surveys (based on Building Use Studies occupant questionnaires and EARM (Energy Assessment and Reporting Methodology) techniques, intensive peer group review and quality control, and reporting based on the "exception proving the rule " (that is, finding the most benign energy case and the happiest occupants and understanding thoroughly why this happens). Laboratory experiments and statistical tests based on experimental designs often try to isolate cause and effects, but in so doing can over-simplify or interfere with the behaviour of the study group. A celebrated example is that people who have greater control over their indoor environment are more tolerant of wider ranges of temperature. Theory based on laboratory tests in climate chambers seemingly understates this effect which is context-dependent. [Reference 8]

Buildings are complex systems made up of physical and human elements and their many associations, interactions, interfaces and feedbacks. Elements and interactions create “emergent” properties (those like aesthetic qualities which are greater than the sum of their parts and consequently harder to pin down). Because of interdependencies, it is often fruitless to try and separate out different variables and treat them as “independent” as many statistical methods require. Characteristics like depth of space from wall to wall, open-plan space and air-conditioning all depend on each other to a greater or lesser extent. As a result, they produce cats’ cradles of statistical interdependencies which can be impossible to disentangle causally. Feedback loops also add to the complex dynamics.

As well as physical complexity, designers, managers and occupiers also have different preferences, priorities and personal agendas. Changing circumstances add to the richness and dynamism of contexts, but also make them less yielding to conventional analysis. Although it is tempting to seek out general theories governing behaviour in buildings (and enshrine principles in design guidance and building legislation), in practical terms constraints imposed by contexts frequently turn out to be more important for the designer, manager or occupier.

Contexts - locational, social, economic, technical and environmental - are always subtly changing, and can sometimes have surprisingly direct effects on local situations. For example, it can be baffling why two schools - identical in design and intake profiles and on adjacent sites - should differ markedly in vandalism damage rates. This can often be explained by environmental strategies - especially with respect to the speed of repair of damage and the extent to which particular individuals take responsibility for (“own”) the problem of repair [Reference 11].

This example might tempt a designer to say that management is the cause, not design. However, as recent post-occupancy surveys show, buildings whose management strategy has been developed from the outset of the design, with a clear understanding of client requirements and management capacity, are more likely to perform better. Hence management and design factors, like many others in buildings, depend on each other and cannot be meaningfully isolated in real situations (see References 40, many of whose hypotheses are being verified in the Probe studies [References 12-25]).

Designers and managers constantly strive to create conditions which bring out the best in people and add value to investments and services. Occupants will also usually want to achieve reasonable conditions for themselves. To further complicate matters, designers, managers and occupiers can all behave perversely as well. For example, in a study of the top floor of an office building we asked the occupants “Why do the lights always seem to be on when you don’t need them, especially as the switches are easy to reach?”. The reply came: “We only do it to annoy the manager. He is obsessive about switching the lights off so we switch them back on again when he goes out just to annoy him.” More seriously, different working groups in the same building can use the lighting to reinforce their team identity.

Too often, though, elements unwittingly interact and conspire to create unforeseen and unwanted chronic problems. In the context of technology and its side-effects, Tenner has memorably labelled these “revenge effects” [Reference 9]. In buildings, technical elements often work reasonably well in isolation or in theory, but when included as part of a wider system of operation induce inefficiencies which ultimately affect the ability of people to perform their work properly. These wider aspects of the design, use management and operation of buildings concern us most here.

### Terminology

By "productivity" we mean the ability of people to enhance their work output through increases in the quantity and/or quality of the product or service they deliver. Work output is impossible to measure meaningfully for all building occupants. How do you compare, for instance, the productivity of telephonists in a call centre with their managers? Our answer is to use scales of perceived productivity, rather than measure productivity directly. The question on productivity which has been incorporated into most Building Use Studies questionnaires since the pioneering *Office Environment Survey* [Reference 10] of 1987 is shown in Figure 1.

On balance, advantages with perceived productivity scales outweigh disadvantages. Advantages include:

- a single question covers the topic so it can be incorporated in surveys with wider objectives (although we find that building managers are still wary of the question and sometimes forbid us using it);
- the question is common to all respondents so that fair comparisons can be made between most of them;
- it can be incorporated in questionnaires across different building types (although strict comparability between types may need to be treated circumspectly, for example between teachers and administrative staff in a school where working conditions are slightly different between the two);
- large samples may be surveyed relatively cheaply;
- benchmarks of averages or medians may be used to assess how occupants' perceptions in individual buildings score against the complete dataset;
- data analysis and verification is easier across large samples in many different buildings.

Disadvantages are:

- the nagging doubt that perceived productivity as measured may not associate well with the actual productivity of the occupants (although many agree on the key point that perceived and actual productivity are strongly associated (see the review of sources in References 4 and 31));
- the need for occupants to judge their own reference point when answering the question (they sometimes want to know "Productivity with respect to what?");
- the possible effects of context and other ruling factors at the time of the survey, for example, rumours of possible redundancies.

### Objectives

The main objectives of the productivity parts of post-occupancy and diagnostic studies are to:

- give designers and managers indications of the main factors within their control that might influence human productivity at work;
- help prepare design and management strategies which measurably aim to improve performance for organisations and individuals without compromising individuals' needs and introducing unhelpful side-effects.

Our emphasis is always on appropriate design and management strategies - as expressed in the design briefing process and troubleshooting studies - and the major risk factors affecting productivity. We are not attempting a "theory" of productivity at work, nor a detailed analysis of cause and effect or costs and payoffs.

### "Killer" variables

A "killer" variable - to use hyperbole from the language of computing - has a critical influence on the overall behaviour of a system. With the present state of knowledge we can guesstimate that losses (or gains) of up to 15 per cent of turnover in a typical office organisation might be attributable to the design, management and use of the indoor environment. Fifteen per cent gains/losses as a ballpark figure crops up in the work of Brill [Reference 26] and Vischer [Reference 27] for example. Lorsch and Abdou talk about the productivity of 20 per cent of office workers in the USA being raised simply by improved indoor air quality [References 1-3]. Data from the Probe studies show perceived differences of up to 25 per cent between comfortable and uncomfortable staff, with uncomfortable staff showing consistently lower productivity (as common sense predicts - unless the arousal mechanism is more important) [Reference 20]. The difference gets narrower as overall satisfaction with the building improves.

Whatever the actual figures (no-one knows, of course) there is consensus that indoor environment factors improve output, as well as a lot of evidence to show associations with a cluster of related factors such as perceived health, comfort, and satisfaction. There are also data to show that some of the management, design and use characteristics which improve perceptions of individual welfare also contribute towards better energy efficiency, thereby closing the loop on a potential “virtuous” circle [References 29 and 31].

This said, there are not too many grounds for optimism, because the vast majority of occupied buildings do not exhibit such self-reinforcing qualities and many are unmanageably complex [Reference 29]. From the perspective adopted here - that of strategic guidance for building designers, managers and occupiers - it is sufficient to know simply that there are positive and negative relationships between indoor environmental factors and human productivity. The question then becomes: Which are the most important?

Important factors - the “killer” variables - have been arranged here into four “clusters”. Each represents a group of features which have more connections amongst themselves than with others. There are also connections between the four: as we have implied, there is no such thing as an independent variable in a building! Their relative importance also depends on prevailing circumstances - the stage of the design process, for example. We have not prioritised here, because contexts and interconnectedness alter in different situations, changing priorities as well.

The clusters are:

1. Personal control
2. Responsiveness
3. Building depth
4. Workgroups.

## Personal control

Research work in the 1980s into what was then called “sick building syndrome” (“building-related sickness” is the preferred term now) confirmed to a new generation of researchers what was already well known to an older one - that people’s perception of control over their environment affects their comfort and satisfaction. Work on thermal comfort, notably that of Humphreys and McIntyre in the 1970s [References 34-36], had shown that the range of temperatures that building occupants reported as “comfortable” was wider in field studies than in controlled conditions in the laboratory. People were more tolerant of conditions the more control opportunities - switches, blinds and opening windows, for instance - were available to them.

Similar results on the relationships between perceived control and sickness symptoms have been reported in, for example Reference 37. More recently, in studies on heart disease in civil servants, higher incidence of heart attacks seem to be related to people’s perception of control over their work [Reference 38]. There are many other such examples, including the renewed interest in the 1990s in adaptive comfort [for example, Reference 39].

Figure 2 shows results for office workers in 11 UK buildings examined by Building Use Studies in 1996-97. Self-assessed productivity (see Figure 1) is significantly associated with perceptions of control in 7 out of 11 buildings. Perceptions of control is measured by the average of five variables for perceived control over heating, cooling, lighting, ventilation and noise. Figure 3 shows that the relationship in Figure 2 probably gets weaker as buildings get better - as overall satisfaction gets better there is less need for discomfort alleviation. However, buildings which are designed to *provide* comfort but do not deliver it (through technical, management or usability problems) tend to come out badly.

Figure 4 shows that of the five perceived control variables - heating, cooling, lighting, ventilation and noise - the last, noise, is most strongly associated with perceived productivity, but the relationship is quite weak. Even so, perceived control over lighting is the only one that is not significant.

Figures 2-4 tell a stark statistical story about personal control and productivity. Building users in their personal comments on questionnaires are much more forthcoming. In study after study, people say that lack of environmental control is their single most important concern, followed by lack of control over noise. Taking one typical comment from many in the same vein from a building study carried out in 1996: “Noise has the most disturbing effect on my work. Other factors such as heat and light are not so disrupting.” Many people, some almost instinctively, oppose the idea of open-plan working because they immediately suspect that they will lose control and privacy and it will become more noisy. This might not necessarily actually happen in practice, but people suspect that it will.

In spite of the wealth of research and occupier evidence that high perceptions of personal control bring benefits like better productivity and improved health, designers, developers, and sometimes even clients seem remarkably reluctant to act on it. There are many reasons for this, including the absence of thorough cost-in-use analysis in the calculation of future payoffs (and the problem of who actually receives the benefit), but four are prominent.

1. Environmental control operates at the interface between a building’s physical and technical systems and its human occupants, or, less visibly, automatically and often under the supervision of computer-controlled building management systems. Perhaps seduced by the promise of technology rather than its delivered performance, designers assign more functions to automatic control than are usually warranted and, knowingly or not, make the interfaces obscure. They then often do not seem to make clear to the client the management implications of the technology, and whether these are acceptable to them. Simpler and more robust systems are required, with greater opportunities for users to intervene - especially for opportunities to override existing settings, better feedback on what is supposed to be happening and whether or not the system is actually working [Reference 40].
2. Building design is split into architectural and building services tasks, often with surprisingly little integration between them. Poor attention to detail in building controls is a common symptom of an incomplete design and specification process and gaps between areas of professional responsibility. As well as lack of recognition of the problems here, there is also an absence of tools for specification and briefing, and lack of suitable standard componentry and systems. Manufacturers find it difficult to invest in suitable new or modified products to meet such requirements, owing to a diffuse market and a lack of well-articulated demand. Those who have tried have found success elusive. For example, the promising environmentally advanced Colt window system has recently been taken off the market as a complete package [Reference 41].
3. Designers do not fully appreciate the important difference between comfort provision and discomfort alleviation. For example, the ability to alter workstation position - a seemingly trivial feature - can be crucial to office users’ comfort. By making tiny changes to their immediate environment to avoid the worst effects of (say) glare from the winter sun, or down draughts, occupants can turn intolerable conditions into marginally tolerable ones without management intervention. Most control adjustments will be at margins of discomfort, triggered by something experienced as uncomfortable, rather than in anticipation. The absence of this capability to fine-tune, especially in space-planned offices with fixed furniture systems and little or no user control, can be make the difference between tolerable comfort and dissatisfaction.
4 Sadly, few building occupiers are motivated enough to take the bull by the horns and gain control of systems which are troublesome.

### Responsiveness

To many people, the relationship between better personal control and human performance is common sense; so too is the cluster of variables related to responsiveness. Many of the buildings which work well in post-occupancy studies appear to have the capability to meet people’s needs very rapidly either in anticipation or as they arise. This applies to personal control, but it also works at other levels: the ability to reconfigure furniture, for example, or adaptability of spaces to accommodate change, or speed of response to complaints by the facilities management department.

The importance of responsiveness first became blindingly clear to us in a study in 1992 which included One Bridewell Street, Bristol [References 42 and 43], revisited by Joanna Eley in 1996 [Reference 44]. This building is noteworthy because, although air-conditioned, it uses little more energy than a good-practice, naturally-ventilated, open-plan office. In addition, occupant satisfaction is unusually high. Was this just co-incidence or is there something more profound at work?

At One Bridewell Street high occupant satisfaction seemed to be related to the speed with which the facilities management department dealt with complaints of discomfort: the response was exceptionally fast, and occupants were told exactly what the outcome was. The facilities manager also learned to anticipate common problems and to deal with them, often before anyone noticed. Personal control for the occupants was not high, with just infra-red “zappers” for the lights and limited ability to change workstation position.

To test the possible influence of response time, a new variable was added to the Building Use Studies questionnaire in 1995 (Figure 5). The relationship between perceived speed of response to complaints and perceived productivity is shown in Figure 6 and people’s perception of “quickness” (the speed with which occupants think that heating, cooling, lighting, ventilation and noise needs are met) in Figure 7.

With the usual interpretational caveats relating to small, non-random samples, the results in Figures 6-8 are strong grounds for developing this line of of analysis further. The association between speed of response and productivity in Figure 6 is positive and significant. Eight out of 11 buildings in Figure 7 shows significant positive associations between perceived quickness of response and perceived productivity. Figure 8 indicates that, just like perceived control, the strength of correlation between quickness and productivity increases as the buildings’ overall performance decreases. An obvious conclusion from this is that quickness and control are also strongly and significantly associated and this indeed is the case (for individuals rho=0.60, p=0.0001; for building means rho=0.75, p=0.0125).

As measures of response time and personal control are themselves related, are we dealing with two sides of the same coin? To some extent, yes, because responsive control delivers rapid response by definition. But in some buildings a lack of individual control facilities is more than compensated by the excellence of the facilities management arrangements.

Conversely, if designers try to add control in a complicated building which already lacks management resource then their efforts may well be defeated as there will be an inability to manage the added complexity which will induce further chronic failures.

Most buildings tend to have poor levels of perceived control *because* they also have relatively low levels of building management: it has been incorrectly assumed at briefing and design stages that building services technology will automatically deliver what the occupants require without undue extra management intervention or, alternatively, that management will be superhuman.

As the Probe studies [References 12-25] show, these assumptions are wrong. The buildings that came out best overall either managed technological complexity with high levels of expertise [eg Reference 12] or deliberately rid themselves of gratuitous complexity [eg Reference 17] and a dependence on management.

So designers and managers should consider both personal control and response time implications, rather than think that they are the same. Building Use Studies finds that when something goes wrong occupants give building managers the benefit of the doubt for a honeymoon period of up to three days, then get upset or give up! [Reference 47]

The implication is that real-time responsiveness is something to be considered in the briefing and specification processes, and that different response time standards could be set for different occupier needs. For example, glare and severe overheating need to be dealt with and corrected immediately, whereas a three-day threshold could be used for the replacement of components which directly affect interfaces - simple things like blinds, chairs, luminaires and suchlike.

### Building depth

The third cluster is building depth. The crucial depth-of-space threshold is some 15m from wall-to-wall, around the normal limit of natural ventilation. In the past, we have found that:

- the deeper buildings get, overall satisfaction and productivity tend to go down;
- a depth of about 12m across the building seems about optimal for human performance variables;
- shallower plan forms tend to cost about £50/$m^2$ more, assuming similar cost levels per unit area of envelope and for building services. However, shallower-plan buildings may lend themselves to cheaper, more domestic envelope construction and cheaper services. Unfortunately, cost calculations often find it difficult to consider such trade-offs; economic calculations tend to be more precise at minimising envelope-to-floor-area ratios than building services costs, about which they tend to be less well informed [Reference 48].

Looking at differences in perceived productivity between naturally ventilated (ie less than 15m across) and air conditioned buildings (usually, but not always, deeper than 15m) in the current Building Use Studies dataset, the mean perceived productivity is minus 0.19 per cent for NV and minus 4.25 for AC ($p=0.0097$). This comparison is based on 40 buildings, but does not include either mixed-mode or advanced naturally-ventilated which are harder to classify by depth.

This does not necessarily mean that naturally-ventilated buildings are better than air-conditioned. The pointers are that occupants prefer natural ventilation as the default - in winter, spring and autumn - and air-conditioning, not surprisingly, in the hot, humid parts of summer [References 32 and 46]. Depth of space is also a correlate for other variables which affect human performance. Many of these have been assessed, although not necessarily in working buildings or conclusively. They include:

- occupants' preferences for window seats (studies usually show that people with window seats tend to be more comfortable [eg References 32 and Figure 10] but this effect tends to decrease as overall building performance improves [Reference 12]);
- ill-health, with the statistical association of chronic, building-related ill-health symptoms (like dry eyes or stuffy nose) with larger buildings leading to wider speculation about the role of air conditioning as a cause [Reference 10].

Building depth is also a correlate for complexity. Buildings have allometric (size) properties which make them disproportionately more complicated as they get bigger. This is not just a matter of building services like mechanical ventilation and air-tempering, which are always needed with depths greater than 15m., but also spatial and behavioural complexity - there are many more activities and much greater likelihoods of conflicts, in bigger floorplates with higher populations, and a higher dependence on technology and management.

Katsikakis and Laing [Reference 51] is a rare example of a study that measures actual occupational densities, and compares them with design densities. A selection of London offices have been measured for occupied densities, which turn out almost invariably lower than design densities, some substantially so (these findings have more recently been confirmed with a bigger sample by Gerald Eve Research (Reference 58). Figure 11 is a secondary analysis of data in Reference 51 (excluding two buildings with very low occupant densities). It shows how the measured-to-design density proportion varies significantly with both the amount of primary circulation space and the amount of support space. The more primary circulation and support, the higher the measured-to-actual ratio (that is the measured density of staff drops with more circulation and support space).

Does this mean that occupiers are compensating for greater complexity by being much more generous with floorspace, or are standards just going up, so that office staff are getting the best of both worlds - lower densities and more support space? Unfortunately we do not really know and do not have productivity data to match with findings on density. As with many other aspects of this tantalising subject we need a little more information!

Building depth introduces a double-edged effect. As buildings get bigger, they are able to perform more functions and pack more people in, but the penalty is increased operational complexity which creates a greater likelihood of failure - especially chronic performance problems - which increases the cost of management to reduce relative risk. On the other hand, people do not like working at high densities (with the exception, perhaps, of financial dealers who seem immune!) but higher densities are often perceived to be needed to “save” on office costs. Reference 51 possibly shows that when this trade-off is made in reality, building users opt for lower densities because this gives them sufficient degrees of freedom to deal with the consequences of dysfunctional conflicts. What do you prefer: an aircraft with 70 per cent of the seats filled or completely full up?

### Workgroups

The fourth variable cluster relates to workgroups, remarkably, along with personal control, one of the least understood topics in modern buildings. [Reference 52]. In offices, perceptions of productivity are higher in smaller and more integrated workgroups. Like control, this will be obvious from personal experience: given an unrestricted choice most will opt for their own room, for instance, or a small workgroup with close colleagues. This said, there is little research data to back it up and, like density and size, needs more work. For example, on the rare occasions when Building Use Studies has looked at workgroup dynamics, productivity has not been measured as well (usually, because the client did not want to).

Figure 12 has preliminary data from a rare case building where both productivity and workgroup topics were studied. In this case, workgroup size could explain differences in overall comfort (smaller is better), but there was no association between size of workteam and overall perceived productivity for the individuals in the study building.

Our confidence in including workgroups as a killer variable comes from work in 1987 [Reference 10]. Room size is a correlate of perceived control for temperature, lighting and ventilation [Figures 13-14], with perceived control declining with workgroups bigger than about 5 people. As perceived control is a correlate of perceived productivity, it is fairly safe to assume that workgroup size is also a contributory factor (but so are technical factors).

From a design and management point of view, workgroups are seen as desirable both for space saving reasons (possibly spurious, see above) and for better communication between colleagues. There is always a trade-off to be considered between the risk of degrading performance in open plan and cutting people off from each other by putting them in their own rooms. Designers and managers both tend to opt for the open plan approach, but for different reasons. The evidence we have indicates (but does not prove!) that well-integrated workgroups of four to five people will probably be acceptable, but the risks of lower productivity in bigger workgroups can increase substantially thereafter. To support the claimed business benefits it is therefore necessary to put in a much higher level of expertise in building and services design, and facilities management. While we all know this to some extent, the degree of improvement necessary can be much higher than one would think.

A key reason for this is the “mapping” between the workgroup’s activities, the available environmental controls and zones of services. Where the relationship is one-to-one (ie everything coincides as it should in a single room) the sole occupant will have full control over lighting, blinds, ventilation, heating, cooling, privacy and noise, and is able to fine-tune to exactly suit needs. Here there will be perceived productivity benefits for the occupant who will be able to prevent undesirable impacts like distracting noise or overheating. Supervising managers may be rather less keen on individuals with high levels of privacy and productive interactions may also be reduced but modern technology is permitting close work integration with less face-to-face contact.

As workgroups get larger, three characteristics affect the occupants:

1. the mapping between environmental controls, services zones and activities disintegrates (for example, the lighting may be switched for the whole floor rather than for workgroups alone);
2. occupants also have to consider their colleagues’ wishes when they want to make changes. As a result, the likelihood that everyone will be satisfied with the prevailing settings will reduce as the workgroups get bigger. This is an inevitable consequence of a) size and allometry; b) differences in individual preference ranges.
3. Long-distance effects become important: for instance, glare from a remote window, possibly even through a glass partition, or draughts of uncertain origin owing to com-

plex movements of air in both naturally-ventilated or air-conditioned spaces

The best strategies for the designer and managers are thus to:

- keep workgroups as small and well-integrated as possible;
- make sure that zones of activities map onto the service zones, especially for productivity killers like irrelevant noise, glare and draughts;
- keep sources of unwanted distraction down to a minimum - we have found that up to 60 per cent of staff sitting in open-plan offices can be located directly next to a source of random distraction like the end-doors which may squeak and bang when closing, the photocopier or the tea/coffee area; but
- do not interfere with sources of wanted information, that is information that is needed and relevant to worktasks within earshot and lines of sight, so that people receive reinforcing, relevant data by default; and
- design and manage the overall worksetting so that the default (ie normal) setting is reasonably comfortable, safe and healthy and does not rely on excessive amounts of technological or management input to make it work acceptably.

## Conclusion

We have dealt with productivity in the workplace from the perspective of things within the control of building designers and facilities managers. Necessarily this means missing out aspects of productivity largely or entirely outside the influence of building professionals. These include considerations like workplace stress (which we once tested to see whether stress was building-related, and found that for most intents and purposes it was not [Reference 53]), management attitudes and job satisfaction [Reference 54].

Although productivity begs many definitional and methodological questions, we think that the available data tell a clear story which designers and managers can practically incorporate. Buildings, especially offices, work best for human productivity when there are:

- many opportunities for personal control, providing a background for healthy, comfortable and safe operation as well as adaptive comfort;
- a rapid response environment, not necessarily only for personal control, but for the many other aspects of a buildings' operation that might compensate for absence of personal control, such as an excellent complaints monitoring and feedback system;
- shallow plan forms, preferably demanding less technically complex and less management-intensive systems (with the added benefit of better energy performance);
- activities which properly fit the services which are supposed to support them, not only in spatial capacity, but for the zoning and control of heating, cooling, lighting, ventilation, noise and privacy.

In some contexts, these will not be possible or desirable. This is perfectly acceptable, but clients, designers and managers then need to appreciate the extra levels of core and support services that will be needed to produce good performance.

Of course, like everything else with buildings, the attributes above are all really aspects of the same thing. Ideally, simple, shallow plan forms, small work rooms, robust and manageable controls and domestic levels of servicing work best. In fact, Raw and Aizlewood show in Reference 56 that building-related chronic illness was signficantly lower (and perceived comfort higher) in homes than in offices - just what would be expected from our findings.

However, such "ideal" design forms (characteristic of offices in the UK up to the 1960s) have long since been superseded. The relentless trend is now towards intensification (and diversification) of building use [Reference 56] with much greater attention paid to:

- risk/value payoffs not just in rental or property investment terms as in the past, but for the wider canvas of human and environmental resources as well;
- business benefits and consequential environmental disbenefits which have to be managed if overall performance improvement is to be achieved;

- design strategies linked far more closely to business missions to improve strategic advantage in the market place;
- greater interest in “generic” spaces and forms of servicing which allow rapid switching between different occupier activities.

Bigger and more complex buildings demand subtler strategies for managing this complexity and different design strategies and technologies to support them. Where this is successful, performance gains are possible, but where management does not properly compensate for the extra diligence that technology needs, chronic problems usually result.

The trend towards mixed-mode buildings (with mixtures of natural ventilation and air conditioning) is a case in point. Treating early findings from Probe and other recent studies very circumspectly, it seems that mixed mode can offer the best of both worlds - better occupant satisfaction and better environmental performance - and occupants can detect the differences. Studies by Rowe and colleagues in Sydney [References 49-50 and Figure 9] suggest that mixed-mode offices not only give performance advantages through better thermal comfort and better perceived ability to perform work (ie better productivity), but they are also better for perceived air quality and overall satisfaction with workplace. As with British studies, the work also confirms that this delivers better perceived control and leads to much improved energy efficiency. By monitoring the switching behaviour in mixed-mode buildings, Rowe has shown that a control-rich, naturally-ventilated environment is the preferred default - even in subtropical conditions in Australia - and this preference is only abandoned on the minority of occasions when both temperature and humidity exceed tolerance thresholds.

Although we can be upbeat and report these findings optimistically, we have also tried to show where things work and where they don’t. Unfortunately, the design and construction industries are much more coy, especially about failures. There is an inclination, even in research and development agencies who should know better, towards reporting just the good news and forgetting about the downsides, which often turn out to be the very things that affect human productivity the most. Many of the issues we have dealt with in this paper have been known about for generations. Poor human productivity in buildings is a function not just of our four “killer” variables but also poor professional feedback, lack of integration in design processes, lack of care for the primary occupants, weak or non-existent briefmaking and the convenient but disturbing tendency to forget the bad news.

Our experience with monitoring and troubleshooting studies of UK buildings is that the key to success with building performance lies with managing downsides effectively. Generally this involves:

1. understanding contexts, especially by bringing ruling constraints to the fore at briefing stage, and making sure that everyone shares assumptions early on;
2. identifying possible downsides and knowing risks for what they really are, so that we are not “optimising the irrelevant” [Reference 57];
3. keeping technology within thresholds of affordable manageability, so that the inevitable revenge effects can be identified and coped with before they develop into insidious chronic defects;
4. taking occupants’ complaints seriously and dealing with them quickly and sensitively.

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**Figure 1: Perceived productivity question used in Building Use Studies’ surveys**

Please estimate how you think your productivity at work is increased or decreased by the environmental conditions in the building? *Please tick one point on the scale*

| | +40% or more | +30% | +20% | +10% | 0 | -10% | -20% | -30% | -40% or more | |
|---|---|---|---|---|---|---|---|---|---|---|
| Productivity Increased by … | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Productivity Decreased by … |

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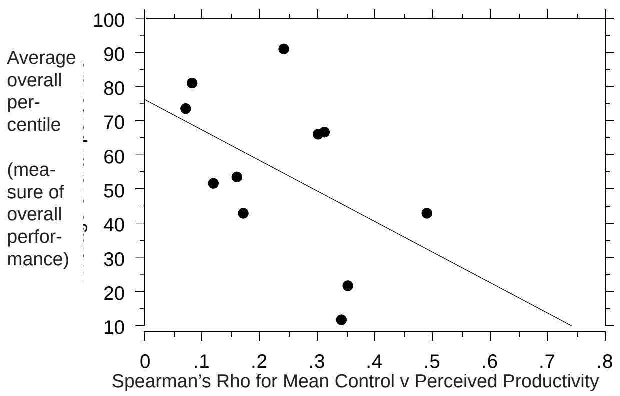
**Figure 2: Relationships between control and perceived productivity for office workers in 11 UK buildings surveyed in 1996-97**

| Building | Type | Average overall percentile | Spearman's Rho (corrected for ties) between mean control and productivity | P value | Significant association between perceived productivity and mean control? |
|---|---|---|---|---|---|
| A | AC | 52 | 0.12 | 0.4133 | |
| B | AC | 43 | 0.17 | 0.0043 | Yes |
| C | NV | 81 | 0.08 | 0.4469 | |
| D | NV | 12 | 0.34 | 0.0348 | Yes |
| E | NV | 66 | 0.30 | 0.1546 | |
| F | AC | 67 | 0.31 | 0.0053 | Yes |
| G | MM | 91 | 0.24 | 0.0425 | Yes |
| H | ANV | 43 | 0.49 | 0.0002 | Yes |
| I | ANV | 22 | 0.35 | 0.0033 | Yes |
| J | NV | 54 | 0.16 | 0.0031 | Yes |
| K | NV | 74 | 0.07 | 0.6356 | |

*Interpretation*
*Buildings*: 11 studied by Building Use Studies in 1996-97 for which productivity data are available.
*Type*: AC=Air conditioned; NV= conventional naturally ventilated; MM=mixed mode; ANV= advanced natural ventilation.
Average overall percentile: Average from percentile score for seven variables from BUS dataset (see Reference 19 for further details).
*Spearmans’ Rho*: Correlation between scores for individual occupants between the mean of five perceived control variables (mean control - heating, cooling, lighting, ventilation, noise) and perceived productivity (see also Figure 1).
*P value:* P value less then 0.05 indicate a significant association.

**Figure 3: Relationships between perceived control and productivity decline as buildings perform better**




Average overall percentile = 76.44 - 89.68 * Spearman's Rho; R^2 = .24

*Interpretation*:
The “average overall percentile” is a measure utilising seven summary variables from the Building Use Studies dataset of 50 buildings. The average percentile score (built from individual percentiles for each of the seven variables) shows how a particular building scores relative to all others. A percentile score of 50 is in the middle of the range. The best buildings - those with higher percentiles - tend to have lower correlation coefficients. The association is verging on significance (p=0.06 for rho), and quite strong ( rho=-0.58). A larger sample of buildings will help test this more thoroughly.

**Figure 4: Associations between perceived control and productivity for 11 study buildings and 5 perceived control variables**

| | Spearman's Rho (corrected for ties) | P value | Significant association? |
|---|---|---|---|
| Heating | 0.10 | 0.0001 | Yes |
| Cooling | 0.08 | 0.0001 | Yes |
| Lighting | 0.03 | 0.2513 | |
| Ventilation | 0.06 | 0.0001 | Yes |
| Noise | 0.12 | 0.0001 | Yes |

*Interpretation*:
Giving that perceptions of mean control are related to productivity, which of the five variables making up the mean control statistic are most important? This table shows that noise produces the strongest association with productivity, significant but relatively weak. Heating is the next strongest. Control over lighting is not significant.

The order of these variables tends to confirm earlier work by Building Use Studies which showed that lighting, which is the easiest to change in a building, also is the least effective in its impact!

**Figure 5: Response time question used in Building Use Studies’ surveys**

**Response to problems**

Have you ever made requests for changes to the heating, lighting or ventilation systems?

Yes [1] [2] No
*Please describe in box (right)*

*Please give brief details*

If yes, how satisfied in general were you with the following …?

**Speed of response** *Please tick*

Satisfactory overall [1] [2] [3] [4] [5] [6] [7] Unsatisfactory overall

**Effectiveness of response** *Please tick*

Satisfactory [1] [2] [3] [4] [5] [6] [7] Unsatisfactory overall

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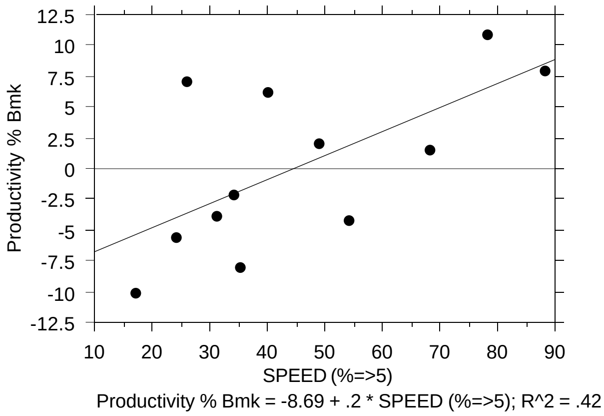
**Figure 6: Relationship between perceived speed of response in dealing with heating, lighting and ventilation complaints and perceived productivity for 12 study buildings.**



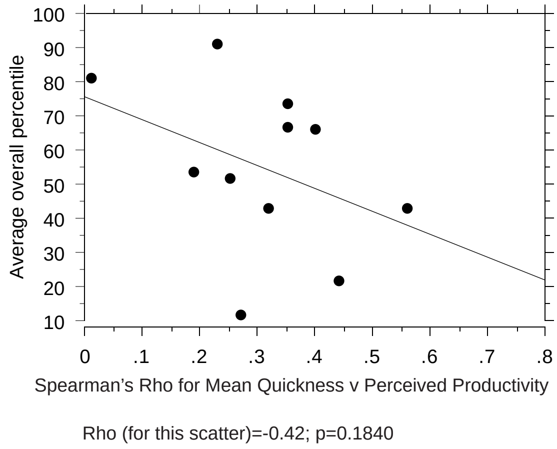

*Interpretation*:
The bottom axis shows the percentage of staff complaining about heating, cooling and ventilation systems who thought that the speed of response by management was satisfactory (a score of over 5 on a seven-point scale). The vertical axis has the perceived productivity for all the staff in the building (including those who did not complain). Perceived productivity and perceived speed of response are significantly associated.

**Figure 7: Relationships between quickness and perceived productivity for office workers in 11 UK buildings surveyed in 1996-97**

| Building | Type | Average overall percentile | Spearman's Rho (corrected for ties) between mean quickness and productivity | P value | Significant association between perceived productivity and mean quickness? |
|---|---|---|---|---|---|
| A | AC | 52 | 0.25 | 0.0433 | Yes |
| B | AC | 43 | 0.32 | 0.0001 | Yes |
| C | NV | 81 | 0.01 | 0.9084 | |
| D | NV | 12 | 0.27 | 0.0961 | |
| E | NV | 66 | 0.40 | 0.0805 | |
| F | AC | 67 | 0.35 | 0.0025 | Yes |
| G | MM | 91 | 0.23 | 0.0274 | Yes |
| H | ANV | 43 | 0.56 | 0.0001 | Yes |
| I | ANV | 22 | 0.44 | 0.0004 | Yes |
| J | NV | 54 | 0.19 | 0.0005 | Yes |
| K | NV | 74 | 0.35 | 0.0176 | Yes |

*Interpretation*:
See Figure 2 for definitions. Column 4 has Spearman's rho for mean quickness and perceived productivity. Mean quickness, like mean control, is a composite variable made up from respondents' perceived view of the "quickness" with which heating, lighting, cooling, ventilation and noise control meets their needs.

**Figure 8: Relationship between perceived quickness and perceived productivity**




*Interpretation*:
See also Figures 2, 3 and 7. As buildings get better (vertical axis), the relationship between perceived quickness and perceived productivity seemingly weakens. This scatter is approaching significance but is NOT significant. A larger sample would clarify this either way.

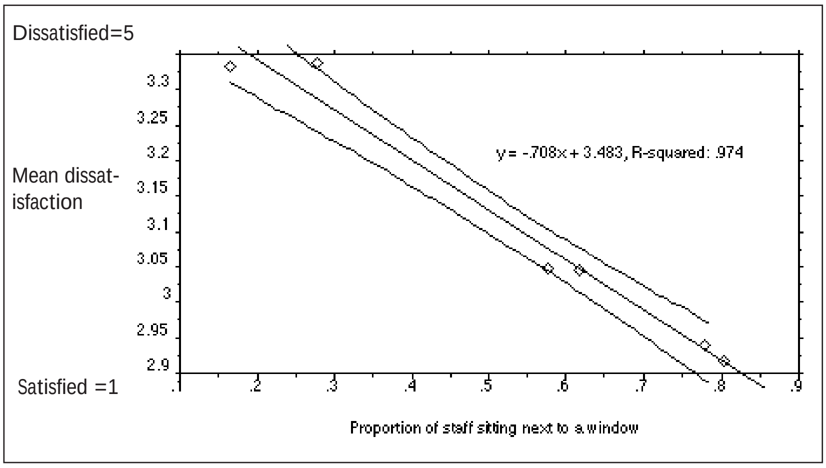
**Figure 9: Performance means by ventilation type for 12 Australian office buildings**

| | Ventilation type | Overall satisfaction with workplace | Impact on ability to perform work | Thermal comfort | Air quality |
|---|---|---|---|---|---|
| 1 | MM | 4.0 | 3.7 | 3.5 | 3.4 |
| 2 | AC | 2.0 | 1.9 | 3.3 | 2.4 |
| 3 | AC | 3.5 | 3.4 | 3.1 | 3.2 |
| 4 | AC | 3.3 | 3.4 | 3.2 | 2.9 |
| 5 | AC | 2.6 | 2.8 | 2.6 | 2.5 |
| 6 | AC | 2.8 | 2.9 | 3.0 | 2.9 |
| 7 | NV | 3.1 | 3.3 | 2.7 | 3.1 |
| 8 | AC | 2.4 | 2.5 | 2.3 | 1.7 |
| 9 | AC | 3.0 | 3.1 | 2.9 | 2.3 |
| 10 | AC | 3.1 | 3.2 | 3.1 | 2.7 |
| 11 | MM | 3.7 | 3.7 | 4.4 | 4.0 |
| 12 | NV | 2.0 | 2.9 | 2.5 | 2.6 |

Source: Reference 50: Rowe D, private communication to authors, July 1997.

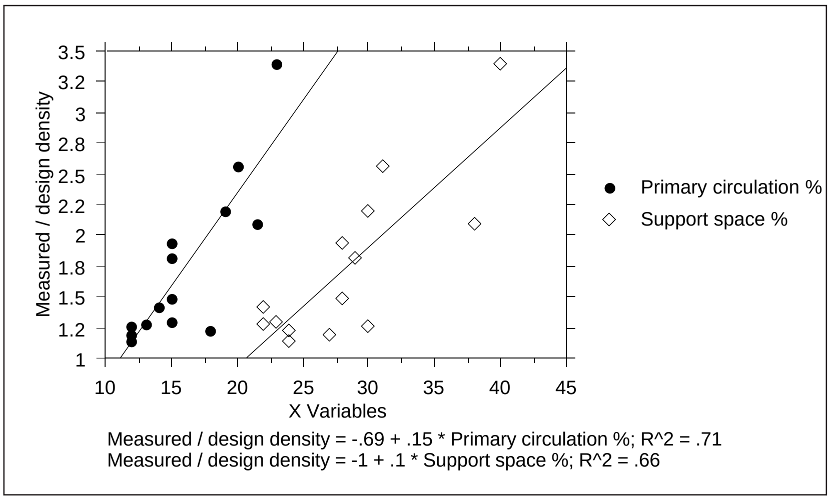
*Interpretation*:
Performance means are for five-point scales: 1=low; 3=average; 5=high.
See also Figure 2 for ventilation types.

**Figure 10: Dissatisfaction and window seats**




*Interpretation:*
This comes from a survey of 6 London office buildings carried out by Building Use Studies Ltd for a private client in 1991. The bottom axis shows the percentage proportion of staff with window seats; the vertical axis the mean scores for overall dissatisfaction on a 5-point scale (a method now discontinued on surveys). For these six buildings, there is a significant and strong relationship: the greater the number of staff with window seats, the less dissatisfaction.

**Figure 11: Ratio of measured to design density by primary circulation and support space for 14 office buildings**




*Interpretation:*
This is a secondary analysis of data first published by Katsikakis and Laing in 1993 [Reference 51]. Two outlier buildings (with extremely low densities) have been removed from the original dataset of 16 buildings.

**Figure 12: Overall comfort scores by size of workteam for a single office building**

| | DF | Sum of Squares | Mean Square | F-Value | P-Value |
|---|---|---|---|---|---|
| WKTEAM<=5 | 1 | 11.76 | 11.76 | 5.63 | .0183 |
| Residual | 302 | 631.24 | 2.09 | | |

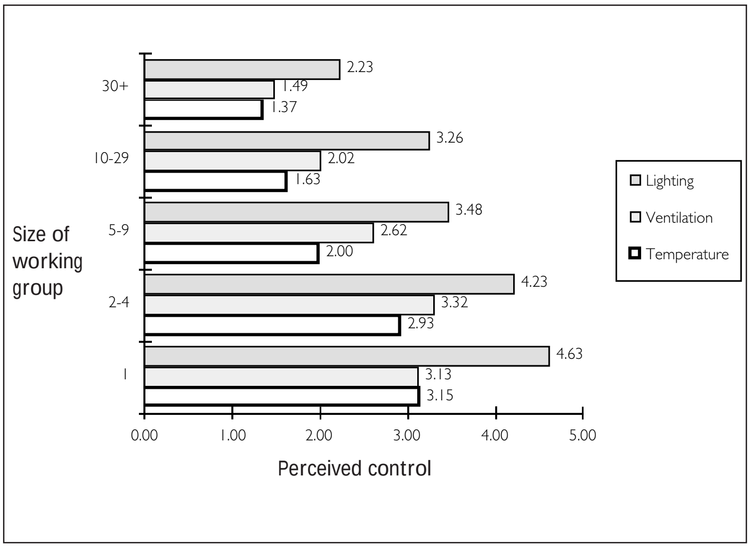
Model II estimate of between component variance: .06
52 cases were omitted due to missing values.

| | Count | Mean | Std. Dev. | Std. Err. |
|---|---|---|---|---|
| Five or less | 143 | 4.58 | 1.51 | .13 |
| Six or more | 161 | 4.19 | 1.39 | .11 |

52 cases were omitted due to missing values.

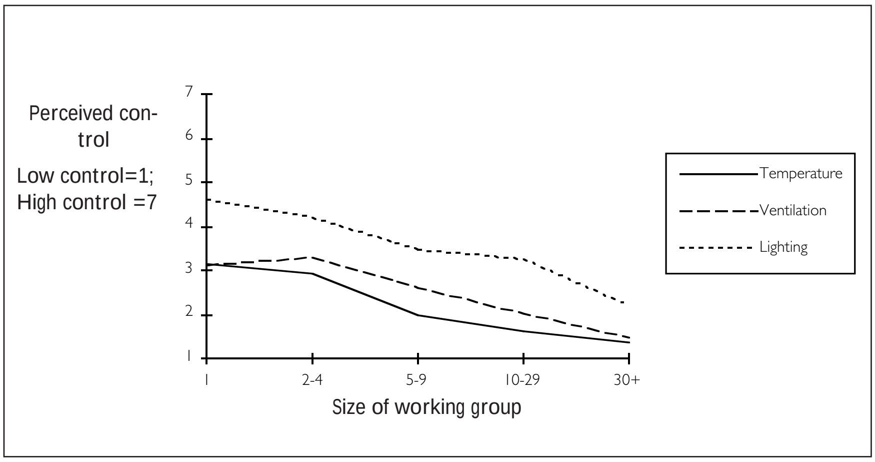
*Interpretation:*
These are data for size of workteam for an office building studied in 1996. The analysis of variance shows that workteams of less than 4 people were more comfortable than those with more than four people. The analysis, though, *does not* take into account any possible effects of grade.

**Figure 13: Size of working group and perceived control #1**




*Interpretation:*
This is data from the Office Environment Survey [Reference 10] showing means of values for perceived control for lighting, ventilation and temperature. The OES used a sample of 50 UK office buildings.

**Figure 14: Size of working group and perceived control #2**




*Interpretation:*
See Figure 13

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