Productivity in buildings: **the "killer" variables**

part two 2

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Introduction

This is part two of a paper on the "killer" variables that have a critical influence on perceived productivity in buildings. In our April issue, the authors identified the five variables that affect perceived productivity the most as:

1. **Comfort, including personal control**
2. **Responsiveness to need, including comfort (from 1), but a host of other ways in which needs should be met effectively**
3. **Ventilation type, which also encompasses attributes such as size, building depth and other allometric properties (how size affects shape, volume, services etc.)**
4. **Workgroups and their layout in the space plan**
5. **Design intent, and how this is communicated to users and occupants**

This month we examine the first three variables in detail.

Keywords: productivity, comfort, ventilation

Comfort, including personal control

Research work in the 1980s into what was then called sick building syndrome (now building-related ill health) 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 22-24], 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 seemed to be more tolerant of conditions the more control opportunities - switches, blinds and opening windows, for instance - were available to them. This is a vital finding to take from pioneering thermal comfort research and is the basis for what later came to be called 'adaptive comfort theory'. People are more forgiving of discomfort if they have some effective means of control over alleviating it. However, many modern buildings seem to have just the opposite effect. They take control away from the human occupants and try to place control in automatic systems which then govern the overall indoor environment conditions, and deny occupants means of intervention.

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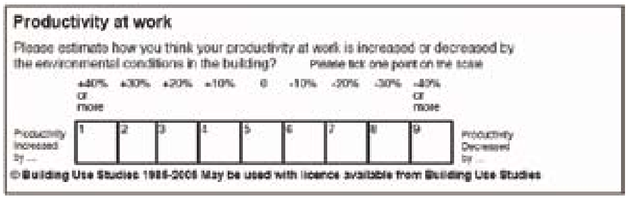
Building photography by Phil Wilkinson and Stuart West

On the rare occasions when such systems can cope with all eventualities, they can work wonderfully well but, often as not, they do not. [Reference 28]

The extent and strength of relationship between comfort and productivity (using the BUS variables 'overall comfort' and 'perceived productivity') is shown in Figure 3. The more comfortable people say they are (averaged for each building in the dataset) the more productive they say they are (again taking the average score for each building). 'Overall comfort' is an umbrella variable which covers peoples' perceptions of heating, cooling, ventilation, lighting and noise taken together in an overall assessment.

Similar results on the relationships between perceived control and sickness symptoms have been reported in, for example, Reference 25. 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 26]. There are numerous other such examples, including the revived interest in the 1990s in adaptive comfort [for example, Reference 27].

Figure 4 has 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. Perception of control is measured by the average of five variables for perceived control over heating, cooling, lighting, ventilation and noise.



Productivity at work

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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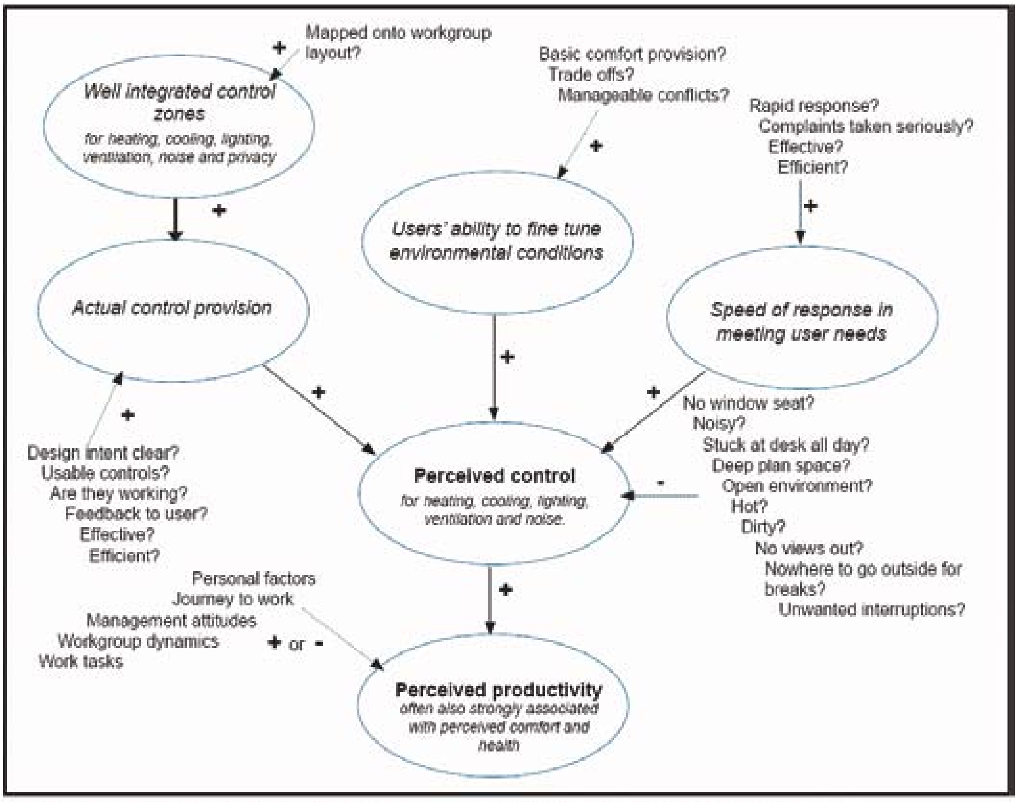
Figure 1 – perceived productivity questions used in Building Use Studies' surveys



Interpretation: Perceived productivity, comfort and heath are often strongly associated and may even be surrogates for each other. Usually, but there are exceptions, the more occupants perceive that they have some control over their personal environment, the better the ratings for productvity, heath and comfort. Many factors are involved in the wider picture, some with positive effects (+ sign) and some with negative (-).

Figure 2 – factors affecting perceived control and perceived productivity

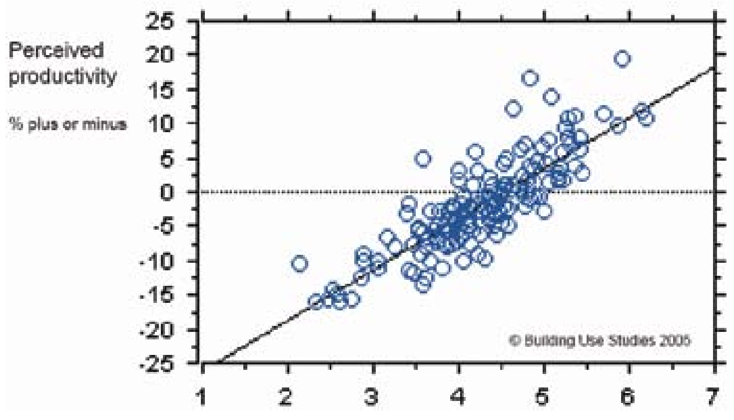


Figure 3 – perceived comfort and perceived productivity. This is based on n=151 buildings from Building Use Studies' international dataset for the variables overall comfort and perceived productivity. This is a strong and significant relationship. r = 0.84, r2 = 0.7, p = < 0.0001

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	

Figure 4 – relationships between control and perceived productivity for office workers in 11 UK buildings surveyed in 1996-97 (see also figure 3)

Definitions:

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

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

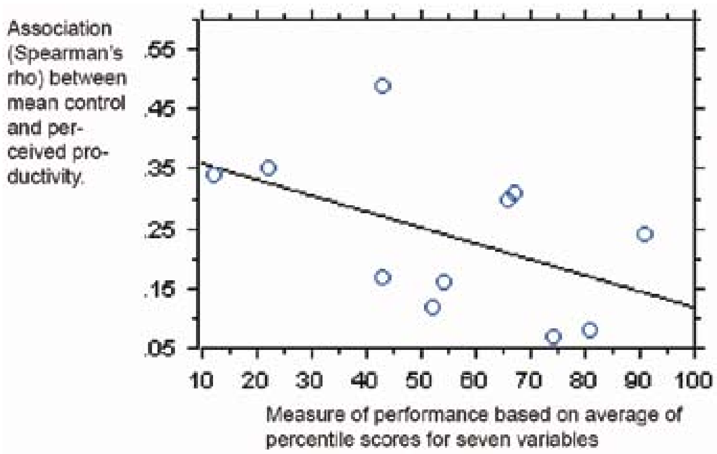


Figure 5 – the strength of relationships between perceived control and productivity decline as buildings perform better. The "average overall percentile" is a measure utilising seven summary variables from the Building Use Studies dataset of 50 buildings. The average percentile score (built from individual 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.

Figure 5 shows that the relationship in Figure 4 probably gets weaker as buildings perform better - that is, there is less need for individuals to have means of discomfort alleviation when base conditions are good.

	Spearman's Rho (corrected for ties) bewteen perceived control and productivity	P value	Significant association?
Heating	0.1	0.0001	Yes
Cooling	0.08	0.0001	Yes
Lighting	0.033	0.2513	
Ventilation	0.06	0.0001	Yes
Noise	0.12	0.0001	Yes

Figure 6 – associations between perceived control and productivity for 11 UK buildings and five perceived control variables.

Figure 6 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.

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!

Figures 4-6 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.” People often oppose the introduction of open-plan working because they suspect that they will lose control and privacy, and it will become more noisy. This might not necessarily actually happen in practice, but people are afraid 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). 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 28]. This point is picked up in more detail later under design intent.

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 with 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 absence 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 with no well-articulated demand. Those who have tried have found success elusive. For example, the promising environmentally-advanced Colt window system was taken off the market as a complete package [Reference 29].

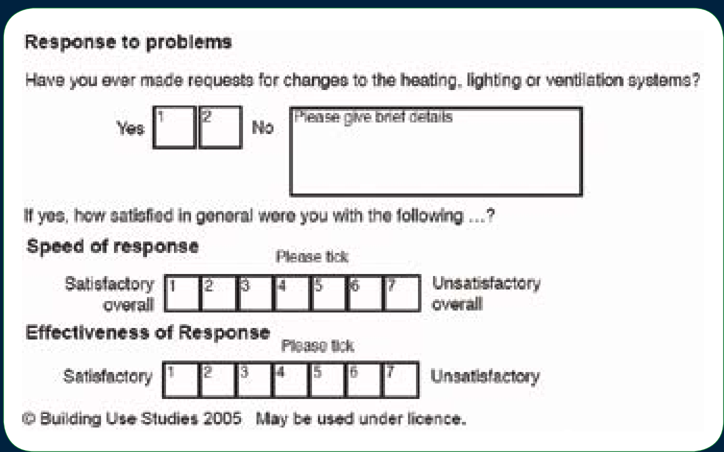
3. Designers do not fully appreciate the important difference between comfort provision and discomfort alleviation. For example, the ability to alter the position of the computer screen - a seemingly trivial feature - can be crucial to office users' comfort. By making tiny changes to their immediate environment to mitigate the worst effects of (say) glare from the winter sun, or down draughts, occupants can turn intolerable conditions into marginally tolerable ones without undue management intervention. Most control adjustments are 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 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. As a result, chronic problems multiply and eventually become difficult to reverse, even though, individually, they may be easy to remedy. For example, a problem which we have observed in building after building is doors which close too loudly because their automatic door closers are set too powerfully and there are no noise dampers in the door frame. The closers also squeak, so that every time anyone uses a door it first squeaks, then bangs shut. This happens countless times, and affects all those unfortunate to be sitting in the vicinity.

Responsiveness to need

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 clear to us in a study in 1992 which included One Bridewell Street, Bristol [References 30 and 31], revisited by Joanna Eley in 1996 [Reference 32]. This building is noteworthy because, although air conditioned, it uses (or at least used to use, circumstances have changed) little more energy than a good practice, naturally ventilated, open plan office. In addition, occupant satisfaction was unusually high. Was this just coincidence or was 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.


Response to problems

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

Yes [1] [2] No — 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

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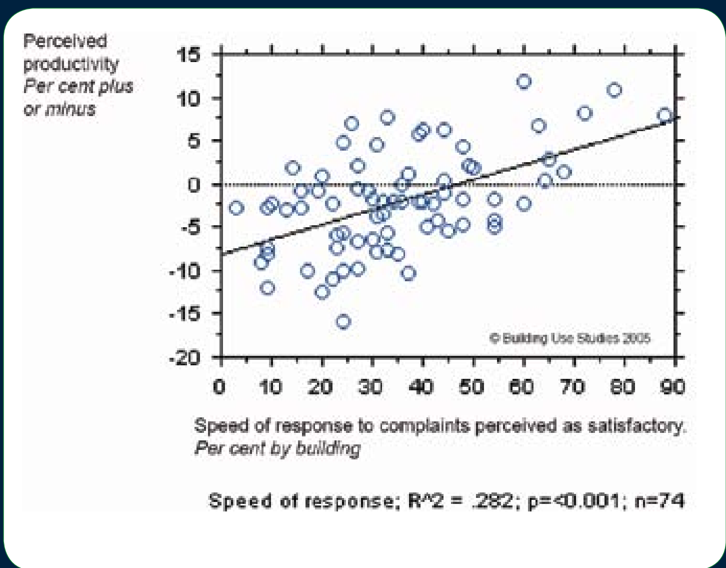
Figure 7 – response time question used in Building Use Studies' surveys



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 5 or more on a seven-point scale). The vertical axis has the average 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. The data are from n=74 buildings, mainly from the UK, in the Building Use Studies 2005 dataset

Figure 8 – relationship between perceived speed of response in dealing with heating, lighting and ventilation complaints and perceived productivity for the UK dataset

To test the possible influence of response time, a new variable was added to the Building Use Studies questionnaire in 1995 (Figure 7). The relationship between perceived speed of response to complaints and perceived productivity is shown in Figure 8 and people's perception of "quickness" (the speed with which occupants think that heating, cooling, lighting, ventilation and noise needs are met) in Figures 9 and 10.

With the usual interpretational caveats relating to small, non-random samples, the results in Figures 8-10 are grounds for developing this line of analysis further. The association between speed of response and productivity in Figure 8 is positive and significant. Eight out of 11 buildings in Figure 9 shows significant positive associations between perceived quickness of response and perceived productivity. Figure 10 shows 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 for by the excellence of the facilities management arrangements. Conversely, if designers try to add control in a complicated building which already lacks management resources their efforts may well be defeated as there will be less capability 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 [Reference 1] show, these assumptions are wrong. The buildings that came out best overall either managed technological complexity with high levels of expertise (eg. Tanfield House) or deliberately rid themselves of gratuitous complexity and over-dependence on management intervention [eg. Woodhouse Medical Centre].

So designers and managers should consider both personal control and response time implications, rather than think that they are the same. Building Use Studies has found 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 33]

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

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	0.4	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

Figure 9 – relationships between quickness and perceived productivity for office workers in 11 UK buildings surveyed in 1996-97. 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 controls meets their needs.

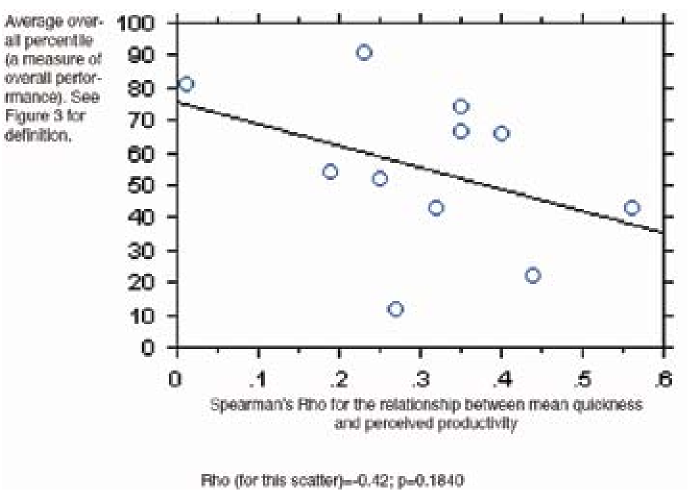


Figure 10 – the relationship between perceived quickness and perceived productivity

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.

As the relationship between perceived quickness and productivity gets stronger, overall performance decreases. This implies that quickness of response is more important to users in poorer performing buildings.

Figure 11 – perceived productivity ratings by ventilation type (UK, 2004)

	All	Air conditioned AC	Mixed mode MM	Natural ventilation NV	Advanced natural ventilation ANV
Perceived productivity %	-2.1	-2.4	0.0	-2.5	-2.4
Std. Error	0.8	0.8	2.1	2.4	2.9
Number of buildings	63	32	10	12	6
Worst %	-15.5	-12.4	-11.1	-15.5	-10.0
Best %	10.9	8.0	9.4	10.9	7.7

These are perceived productivity scores for 63 UK buildings from the Building Use Studies dataset split by ventilation type.

Source: Building Use Studies 2005

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.

Ventilation type

The third killer variable is ventilation type. 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 optimal for human performance variables;

-shallower plan forms tend to cost about £50/m2 (approx. AUD$120/ m2)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 34].

Ventilation type is closely related to building depth because mechanical services have to be added whenever buildings get deeper than about 15m across, the limit of simple natural ventilation. Buildings have allometric (size and depth) properties which make them disproportionately more complicated to service 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.

Looking at differences in perceived productivity in the 2004 UK Building Use Studies dataset, the mean perceived productivity score for all UK buildings is minus 2.1 per cent (Figure 11). Broken down by ventilation type the scores are minus 2.5 per cent for natural ventilation (NV), minus 2.4 per cent for air conditioned (AC) and minus 2.4 per cent for advanced natural ventilation (ANV). Mixed-mode (MM) (0 per cent) gives better perceived productivity scores. Note that none of these averages is greater than zero. Overall, only in some 30 per cent of buildings in the dataset do occupants, on average, report scores above zero. The naturally ventilated buildings have higher standard errors, implying that their range of performance is wider.

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 [Reference 35]. Ventilation type 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 but this effect tends to decrease as overall building performance improves);

- ill-health, with the statistical association of chronic, building-related ill-health symptoms (like dry eyes or stuffy nose) with larger buildings leading in the 1980s to wide speculation about the role of air conditioning as a cause. It turned out to be more a matter of how much management an occupying organisation was prepared to put into a building to deal with chronic problems that arose in circumstances where people were more dependent on the quality of the building, its systems and its management.

Building depth introduces a double-edged effect. As buildings get bigger, they are capable of performing more functions and more people can be packed in, but the penalty is increased operational complexity which creates a greater likelihood of failure - especially chronic performance problems - which in turn 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. 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 or theatre with 70 per cent of the seats filled or completely full up? [Reference 36] We had a clear case of the cocktail party effect (where conditions rapidly worsen as densities rise) in a case study in 2004. People were moved in to a new building sequentially. Early movers reported that they liked the building for the most part, but that once planned densities had been reached after about twelve months conditions had become noticeably worse.

Next month we will conclude the study with an examination of the final two killer variables - stay tuned!

References

[1] A comprehensive list of downloadable articles about the Probe studies may be found by following the Probe menu item on www.usablebuildings.co.uk

Probe articles used here are:

BORDASS W. and LEAMAN A., From Feedback to Strategy, Buildings in Use '97: how buildings really work. London, Commonwealth Institute, 1997, Feb 25

LEAMAN A., Probe 10: Occupancy Survey Analysis, Building Services Journal, 1997, May, pps. 21-25

LEAMAN A., BORDASS W., COHEN R. and STANDEVEN M., The Probe Occupant Surveys, Buildings in Use '97: how buildings really work. London, Commonwealth Institute, 1997, Feb

[22] HUMPHREYS Rev. M., Field studies of thermal comfort compared and applied, Building Services Engineer, 44, 1976, pps. 5-27

[23] HUMPHREYS Rev. M., Thermal Comfort in the Context of Energy Conservation, in ROAF S. and HANCOCK M. (eds), Energy Efficient Building, Oxford: Blackwell Scientific Publications, 1992, pp. 3-13

[24] McINTYRE D., Indoor Climate, London: Applied Science Publishers, 1980, p. 154

[25] RAW G., ROYS M. and LEAMAN A., Sick Building Syndrome, Productivity and Control, Property Journal, 1993, August

[26] MARMOT M., Report on Perceived control over work, British Medical Journal, July 1997. also Marmot, M., Economic and social determinants of disease. Bulletin of the World Health Organization, 79, 906-1004, 2001,

[27] BAKER N., The Irritable Occupant: recent developments in thermal comfort theory, Architectural Research Quarterly, Vol 2, Winter, 1996, Winter

[28] BORDASS W. LEAMAN A. and WILLIS S., Control Strategies for Building Services: the role of the user, Buildings and Environment Conference, BRE, 16-20 May, 1994

[29] LLOYD-JONES D., Windows of Change, Building Services, 1994, January

[30] Energy Efficiency Office, Best practice programme: Good practice Case Study 21: One Bridewell Street, Bristol, Brecsu, 1991, May

[31] Building Use Studies Ltd, User and Automated Controls and Management of Buildings, London: Building Use Studies Ltd. Unpublished report for Building Research Establishment, 1992 (Phase 1) 1993 (Phase 2)

[32] ELEY J., Proving an FM Point: One Bridewell Street, Facilities Management World, 1996, September

[33] Building Use Studies Ltd, Post-occupancy survey findings, Unpublished, 1996.

[34] William Bordass Associates, Specification and Design for Building Depth, internal note, 1992, July

[35] ROWE D., FORWOOD B., DINH C. and JULIAN W., Occupant Interaction with a Mixed Media Thermal Climate Control System Improves Comfort and Saves Energy, AIRAH meeting, Sydney , 1998

[36] LEAMAN, A., Window Seat or Aisle?, Architects' Journal, 3 March 1999

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