From Feedback to Strategy

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First presented to Buildings in Use '97, Commonwealth Institute, London, February 25, 1997

Introduction

The Probe studies examine the performance of eight British buildings from energy, environmental and occupant perspectives [1,2,3]. They are amongst the most recent of over a hundred surveys we have been involved in over the past ten years. What do the results tell us about building performance and how it is changing? How can the feedback be used to make buildings better?

This paper brings together some of the findings from the previous ones, in particular on comfort, energy, control and management. It considers the innovation process and possible "revenge effects" and draws some strategic conclusions for briefing, design and management.

Overall comfort in relation to HVAC type

Some recent history

Studies of building-related sickness in the 1980s [4] revealed an association between discomfort, ill-health and air-conditioning (AC). AC buildings were also shown to use considerably more energy than naturally-ventilated (NV) ones: albeit some quite legitimately owing to longer occupancy hours, higher office equipment levels (though internal heat gains were found to have been over-estimated [5]), higher design occupancy densities (though again these were found seldom to materialise [6]) and major electricity consumers such as computer rooms.

The knee-jerk reaction to these findings was to see AC itself as the prime culprit, and three simultaneous trends were launched, or at least reinforced:

1. efforts to improve the design, hygiene, management and energy efficiency of AC;
2. efforts to avoid AC and to improve the performance of NV by exploiting natural forces and adding some automatic controls (we call this Advanced Natural Ventilation - ANV); and
3. increasing interest in mixed mode (MM) designs which try to offer the best of both worlds.

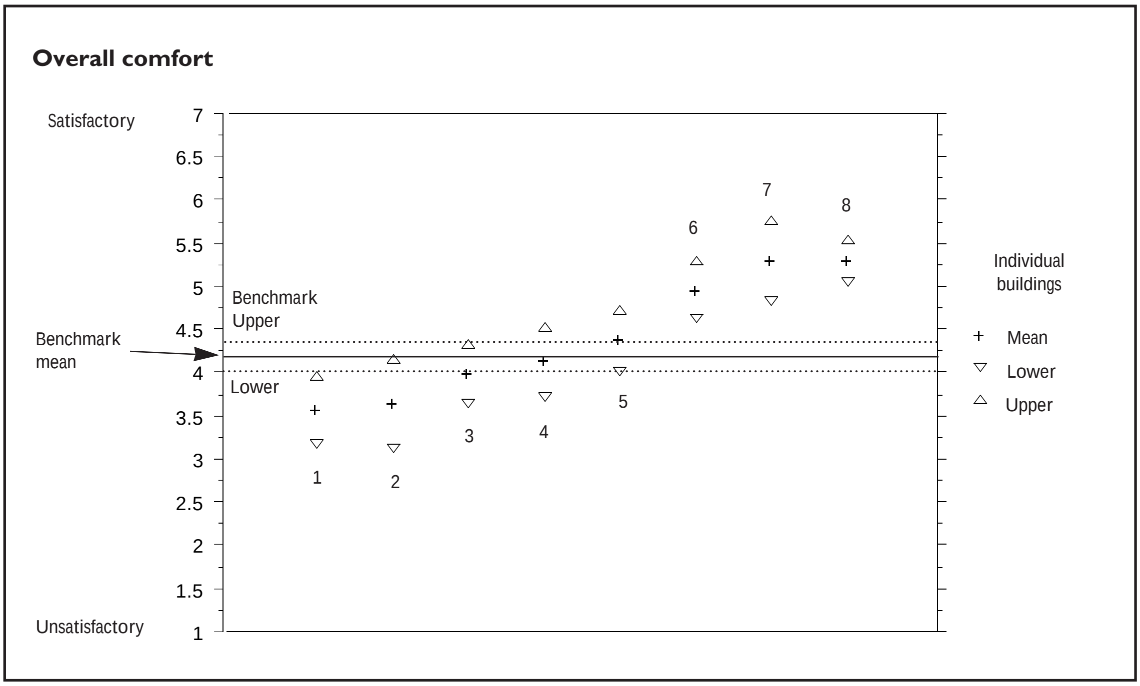
In the early 1990s, further analysis suggested that:

- In general, comfort levels in AC and NV offices were similar, but AC tended to have a broader spread, with some very good and some very bad examples.
- In the poor-performing AC buildings, an underlying problem appeared to be not so much the AC itself, but the gap between the maintenance and management that a complex building demanded and the amount their occupiers were supplying. The cure lay in more management effort, or in simpler buildings, designed for manageability.

Comfort provision or discomfort alleviation?

Occupants of AC offices were also found [7] to be less tolerant of non-optimal conditions than in NV buildings. This related back to work in the 1970s by Humphreys [8] on the wider comfort bands in "free running" buildings and by Haigh [9] on comfort in schools, where high occupant dissatisfaction with the more controlled environments was identified. We proposed [7] that good perceived comfort was not just a matter of providing good environmental conditions (as AC buildings attempt to), but of occupants having the facilities to alleviate discomfort when it arises (facilities which tend to be more common in NV buildings). Other authors have called this "adaptive opportunity" [10].

Figure 1: Overall comfort Probe 1 buildings



Key

1 APU, Queen's Building
2 Cable & Wireless College
3 1 Aldermanbury Square
4 De Montfort Queen's Building
5 Homeowner's Friendly Society
6 C&G Chief Office
7 Woodhouse Medical Centre
8 Tanfield House

Notes to Figure 1

Upper and lower ninety-five per cent confidence intervals are shown for 1) individual building means; 2) Building Use Studies dataset benchmark for 49 buildings.

An individual building mean is significantly different from the benchmark mean if the value falls outside the interval range for the benchmark mean (this applies to buildings 1, 6, 7 and 8). A building mean is significantly different from another building if the value falls outside the interval range for that building (for example, buildings 5 and 7 are different).

For full details see reference 3.

Rapid response

It was further deduced that occupant satisfaction with the discomfort-alleviation process was related not only to the resulting conditions (though clearly there had to be a change in the right direction) as to the speed of response when a “crisis of discomfort” [9] occurred. In many NV buildings people could more readily adjust clothing, windows, blinds, seating positions etc., which could not only improve their comfort directly, but increase their tolerance of environmental conditions. In AC buildings, however, people might be trapped in a bad local environment over which they had little or no control, for example under a “dumping” air stream. Further study revealed that perceptions of good control and rapid response did not necessarily require good physical means of local control: a telephone call to an effective facilities manager would do. In the Probe occupant questionnaires, questions on discomfort events, speed of response and effectiveness of response were added for the first time, and the results to date have been consistent with the hypotheses.

HVAC types in Probe

Of the eight Probe 1 buildings:

- Four are predominantly AC (Tanfield House is classed as such: although its openable windows make it MM in theory, few people are close to them, their use is discouraged, and the full-blown AC system operates all the time).
- Three are ANV, though with C&W this really applies to the classrooms only.
- One, Woodhouse Medical Centre, is NV, though with some MM characteristics with the heat recovery ventilators (now in disuse) and some added local AC units.

Figure 2 Probe 1 buildings: productivity and forgiveness scores and relative percentiles

Probe 1 buildings	Productivity %	Percentile		Forgiveness	Percentile
Tanfield House, Edinburgh	8.00	**96**		1.15	**88**
1 Aldermanbury Square, London	-4.20	**36**		0.99	**14**
Cable and Wireless College, Coventry	-8.01	**14**		1.13	**81**
C&G Chief Office, Gloucester	•	•		1.14	**86**
De Montfort Queen's Building, Leicester	-10.00	**8**		1.09	**63**
Woodhouse Medical Centre, Sheffield	10.90	**99**		1.25	**99**
Homeowners Friendly Society, Harrogate	2.10	**84**		0.99	**17**
APU Queen's Building, Chelmsford	-5.60	**26**		1.02	**27**
95% upper	-4.22			1.09	
Benchmark mean n=49	-2.62			1.07	
95% lower	-1.01			1.04	

Notes to Figure 2

Productivity percentages scores are based on building occupants' subjective ratings. Forgiveness is a measures of occupants' tolerance. Buildings with scores above one have occupants who are more likely to tolerate faults. For full details of productivity and forgiveness, see reference 3.

Scores in a solid box are greater than the upper range of 95% confidence that benchmark means fall within the confidence interval. Scores in a dashed box are less than the lower 95% interval

Percentile: Shows how each building scores on the Building Use Studies dataset. Example: a percentile score of 96 for Tanfield House shows that 96% of buildings in the dataset scored less than Tanfield.

Dataset: Data on productivity were not collected at C&G.

Probe buildings with good overall comfort

Occupant satisfaction is discussed in detail in reference [3]. Figure 1 from that paper shows overall comfort. Scores significantly better than the national average were obtained in:

- The AC Tanfield House. On the basis of the 1980s data this is a surprise, because a very deep-plan and management-intensive building, with clerical and administrative staff at relatively high densities (see [1]), would tend to be at high risk of failure. Instead its imaginative design, good management and rapid response has delivered good comfort and satisfaction levels and rapid and effective response to the relatively rare complaints. However, the facilities and engineering staff levels are higher than many organisations would be prepared to commit. The AC C&G performs almost as well, though the problems with glare and airtightness meant that comfort provision was less reliable, and unfortunately we were not permitted to ask the response or productivity questions.
- The NV Woodhouse, in spite of quite a lot of shortcomings, particularly in ventilation and in summertime temperatures. In this quasi-domestic environment, people could nevertheless make simple adjustments and were much more prepared to give the building the benefit of the doubt.

These two buildings also show the highest perceived productivity increases, see figure 2.

Overall comfort in other Probe AC buildings

The somewhat lower overall comfort levels in the other AC buildings are not unexpected owing to the known shortcomings:

- At HFS, comfort problems owing to the excessive air infiltration problems and the consequent forced operation of the plant. Nevertheless, the result was significantly above average.
- At Aldermanbury, where management considered that the effort devoted to looking after its technologically sophisticated system was more than they would normally have allocated. Although agreeing that more would have improved its performance levels, they felt that it was not justified and that a reasonable balance had been obtained.

Overall comfort in the ANV buildings

The scores in the ANV buildings were average (at De Montfort) and significantly below in C&W and APU, disappointing results for these carefully-designed and much-publicised buildings. What is going wrong?

i Their control systems were seldom operating as intended, owing to both control logic and actuator problems. More recognition is required that these buildings are innovative and need effort to bring them to life.

ii They were under-resourced managerially, hence falling into the same trap as many AC buildings had in the 1980s. There may have been an expectation that ANV was simple and straightforward, but in fact the approach is more “managed” and less self-managing than traditional NV buildings

iii Occupants did not always have a good understanding of how the environmental systems were supposed to work (this applied at the simpler Woodhouse too). There is a communications problem here, not only in “educating the users” but in the ergonomic design of the systems and controls to make the necessary actions easy and where possible intuitively obvious.

iv Frequently automatic control was used without manual over-ride facilities. This can irritate, and in some cases infuriate, as discussed later.

v The building plans, environmental systems designs and controls often seem to have reduced the adaptive opportunity which seems to be at the root of occupants’ higher tolerance of environmental conditions in NV buildings.

vi The design emphasis in these buildings had often been on the public areas, with some permanent staff relegated - by design or by management - to second-class spaces. Probe’s AC buildings tended to be more democratic in this respect: the common tendency for management to grab the perimeter and isolate clerical, secretarial and administrative staff in the core was generally absent. Consequently, perhaps, the Probe AC buildings showed less improvement than normal in occupant satisfaction for those with window seats.

Forgiveness

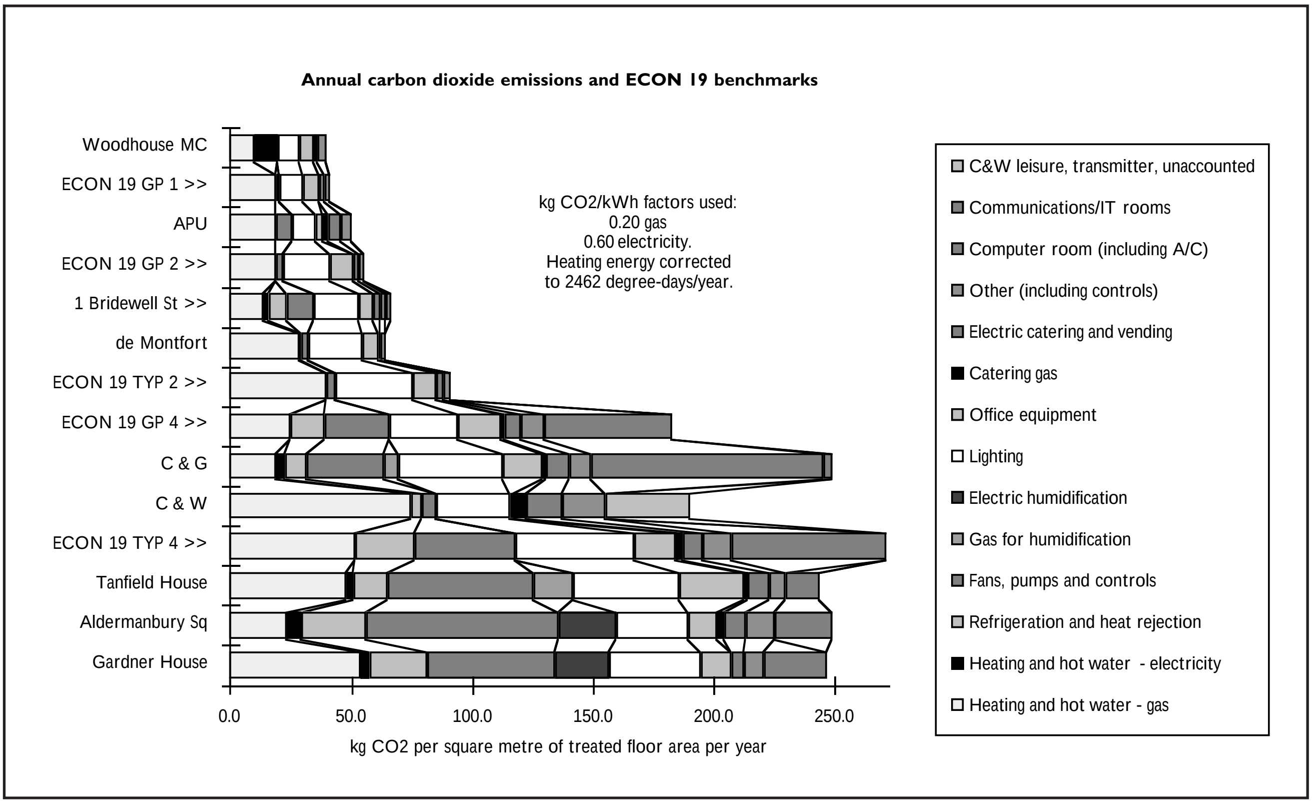
People’s overall impressions of a building are more than the sum of its parts. If the design raises the spirits, and the management and the systems are responsive, people may give specific shortcomings the benefit of the doubt. BUS have developed an index of “forgiveness” [3]: the score for overall comfort divided by the mean of six principal comfort variables (weighted averages have also been tried, but since the results are similar the simplest combination has been used). A forgiveness of more than 1 means that occupants tolerate faults in detailed performance. Forgivenesses significantly less than 1 are rare. In Probe 1, high forgiveness has contributed to the above average overall comfort scores in Woodhouse, Tanfield and C&G, see figures 1 and 10 of reference [3]. Designing (and managing) for high forgiveness might sometimes be more effective than engineering measures in raising comfort scores.

HVAC type: the strategic lessons

Although the Probe buildings are hardly a random sample, they indicate that:

- In an AC building, excellence in design, execution and management is essential. This expense and labour-intensity may be justified by the greater staff satisfaction, which is associated with higher productivity. The building itself may also reinforce the image of an organisation which sees itself as excellent in managing complexity, quality and service. However, there are relatively few organisations like this.
- If a lower-cost, low management solution is required, then a simple, robust NV solution which attempts to maximise adaptive opportunity may be appropriate. If it is not possible to obtain reasonable conditions in some places or at some times in the year, then a mixed mode approach could be appropriate.
- ANV is not the same as natural ventilation. The new techniques need more development and more management. In seeking optimum performance, one must balance any gains in physical comfort conditions against possible losses in occupant tolerance and adaptive opportunity: otherwise the additional complexity may increase the risk of both technical failure and occupant dissatisfaction.

Figure 3 : Annual carbon dioxide emissions for Probe 1 buildings compared with benchmarks for typical and best practice performance



Notes to Figure 3

ECON 19 Benchmarks are from reference 11, Best Practice Programme, Consumption Guide 19, *Energy Efficiency in Offices*, Department of the Environment (October 1991, reprinted 1996). Also included is the exceptional type 4 AC building, One Bridewell Street.

Energy consumption

A common basis

Figure 3 shows the energy consumption for all eight buildings expressed as carbon dioxide emissions, and broken down into end uses. Energy consumption data can be found in the accompanying papers [1,2]. The histogram also includes some appropriate Good Practice (GP) and - with the chevrons - Typical (TYP) benchmarks from ECON 19 [11] for offices of three Types:

- Type 1 Naturally-ventilated, predominantly cellular.
- Type 2 Naturally-ventilated, predominantly open plan.
- Type 4 Prestige air-conditioned.

The bars are sorted in increasing order of carbon dioxide emissions for building services, that is: up to the right hand end of the white bar for lighting. To the right of this one finds energy consumption by occupier's equipment (in particular computer suites, communications rooms and office equipment) plus the leisure facilities, Mercury transmitter etc. at C&W.

Benchmark data for the exemplary air-conditioned office One Bridewell Street [18] is also included. This building - ten years old in 1997 - although not a head office and consequently with lower energy use of occupants' equipment similar to those in some of the NV buildings - shows that with careful briefing, design and particularly energy management a VAV (variable air volume) AC office can approach the energy profile of NV buildings.. Although this data is from 1990, a recent review [12] has confirmed that overall energy consumption is similar today, though this may mask an increase in office equipment and reduction in building services now there is a new building energy management system. Sadly air-conditioned offices which perform like this are extremely rare. Why?

Comparing energy consumption

Do all these buildings come from the same planet?! There is a sixfold variation in carbon dioxide emissions both for the buildings as a whole and for their building services. Can this really be justified? While the most comfortable building - Tanfield

House - is amongst the highest energy consumers per unit floor area for building services (though not per occupant owing to its high density [1]). The next - Woodhouse - uses the least energy whilst the third - C&G - is in the middle and somewhat below C&W. While the ANV buildings APU and de Montfort fall somewhat short on occupant comfort (but for a fair trial control bugs need to be fixed and management improved), in energy terms they are close to Good Practice levels for often much simpler naturally-ventilated buildings - although the air-conditioned One Bridewell Street comes close.

A closer look

Looking at the components of the annual consumption:

Heating and hot water. A wide range, but with low energy consumption in the majority of the buildings. The exceptions are Tanfield House and Gardner House (with their extended running hours and all-air systems) and C&W (with its spread-out form and hotel-like occupancy). Surprisingly, none of the AC buildings had heat recovery or condensing boilers.

Cooling, fans and pumps. These are the major areas in which NV buildings score. However, the consumption in the AC buildings is very variable, depending upon design cooling loads and air change rates (often too high), system efficiencies (particularly specific fan power), and particularly annual hours of use. The hours of use in turn depend upon management (do the systems run "just in case"?) and design (do small loads bring on large systems, and if so do the systems work efficiently at low loads or do many of their components default to full-on?)

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Steam humidification. A relatively new arrival and one which can incur relatively high energy use (and even higher costs if electric because its use often coincides with peak demand periods) and a particular penalty with full-fresh air systems. Our impression is that these systems are often operated wastefully, with unnecessarily high set points, control sensor inaccuracy, and needless usage in mild weather. An area for attention in design and in energy management.

Lighting. The AC buildings generally made little use of daylight, the ANV buildings used more but glare was often a problem. Automatic lighting controls design and performance was frequently disappointing, with systems often defaulting to ON or annoying occupants, and with generally long running hours, particularly in the AC buildings and in corridors etc.. For most buildings there still seems to be more emphasis on lighting quantity than quality. Tanfield's uplighting scheme, enhanced by wall-washing, high ceilings and light from atria, was the only one significantly (and very much) above average for occupant satisfaction.

Office equipment. Equipment energy consumption was particularly low in the NV buildings, in spite of much higher design estimates in some of them. While higher in the AC buildings, energy consumption and installed loads were well below design estimates.

Catering gas and electricity. This was fairly normal in the buildings with catering kitchens (high at C&W owing to its residential use) but - apart from gas at Tanfield - the kitchens were not sub-metered. Metering is important not only for energy management and to give information and incentives to catering contractors, but also for re-charging in these days of internal accounting.

Computer and communications rooms. Where these are present, electricity consumption is often substantial and of course highly variable depending on the extent of the facility and the efficiency of its air conditioning. By now one would expect people to have independent meters on computer rooms, and preferably separating the equipment and its AC … but nobody did!

Other end-uses. These are generally quite small and within normal benchmark levels, except at C&W with its leisure facilities and Mercury transmitter. Again, these were not submetered.

Energy: strategic conclusions

On a square metre basis, the energy profiles of the Probe AC buildings are close to Typical for their Type while the NV ones approach and sometimes exceed Good Practice levels. The two main exceptions are a relatively high consumption at C&W - particularly for heating and hot water - and low at C&G, owing to tight management of heating and cooling plant and the associated pumps.

Important messages are:

- The low priority given to energy management in nearly all the buildings. In recent years, customers have clearly been influenced more by trends to fuel industry competitiveness than to incentives to save energy and the environment. While there is scope for improvement in energy management, in design the stress must also be on manageability.
- The high potential of the more highly-serviced buildings to waste energy if systems run liberally or unnecessarily. But at present this often happens owing to the limited amount of energy management and in these buildings a focus on service before economy.
- The almost complete absence of submetering, even in buildings which deliberately set out to be low energy! The lack of such information is hindering not only energy management, but also realistic benchmarking and space charging.
- Overestimation of internal gains. While nobody likes to be caught short, there must be better ways of making strategic provision without providing unnecessary - or unnecessarily large - air conditioning plant.
- Poor controls performance, particularly for lighting and natural ventilation, see below.
- Unintended consequences of new techniques and technologies. While trial and error is an inevitable part of technological development, the amount of support being given to innovative buildings after completion is relatively small, often leading to things which might have been coaxed into working well turning vicious, usually with adverse effects for energy consumption. It is telling that the more innovative HVAC systems at Gardner House and 1 Aldermanbury Square created more CO2 than any of the others.
- "Tail wags the dog" and "Default to ON" problems which bring on large systems, often unnecessarily. It is important that systems can contend efficiently with the increasingly long opening hours and irregular occupancy patterns of buildings today. Further problems of this kind have been identified in [13].

Control

Introduction

A key to better performance and occupant satisfaction lies in control. Control allows:

- systems to operate efficiently according to need;
- management and occupiers to intervene where necessary to adjust programmes and settings;
- individuals to obtain the services they require, when they require them, and to take action if they experience a "crisis of discomfort".

People like control

People like control and rapid response, particularly in conditions they do not like. From the British Gas cooking ad, via the anonymous quotation "If I'm in a machine for living, I want to be in the driving seat", to a widely-publicised recent research report in the British Medical Journal that civil servants who feel more in control of their work are much less likely to suffer heart disease. Unfortunately, however, designers and managers often regard occupants as a nuisance - acting perversely and fiddling with things - and seek to take control away from them, by putting them in open-plan spaces with interlocked furniture that cannot be moved, and choosing automated systems in preference to manual ones. In doing so, one can create a dependency culture, in which management has to solve problems which individuals used to be able to solve for themselves. With good design and good management - as at Tanfield House - such solutions can work, though they are often better at delivering comfort than energy efficiency. Without good, attentive, and responsive management,they can start to unravel and turn vicious.

Plant control

Control in the plant room is often wasteful. For example, it is not unusual to find all the boilers and chillers enabled (and sometimes juggling the load between each other) and all the pumps operating when there is little or no demand. A more graduated response is essential, which requires both design and management input. Often the tail wags the dog with small demands bringing on large systems, or minor problems leading to a massive widening-out of the control envelope and a loss of many of the anticipated savings. Systems which might be expected to be controllable sometimes malfunction - for example with instabilities or lockouts when variable operation is attempted - which then can easily lead to these features being abandoned.

Integrating automated systems with the individual user

Unfortunately we do not seem to be very good yet at designing systems to be usable, manageable and controllable. Some of the issues were explored in an EnREI study [14], which predicted problems in ANV buildings. With the benefit of Probe and other recent studies, one can begin to formulate a few rules. Briefly:

1. Automatic systems should aim to provide safe, healthy background conditions as economically as possible.
2. Where appropriate, the decision to boost conditions should be made by the occupant as close as possible to the point of decision.
3. After boosting, the decision to switch off (or reduce power) should be be made either manually, or automatically if manual action does not take place.
4. The operation of automatic control should where possible be imperceptible to the user.
5. Appropriate user interfaces depend on the occupancy context, as discussed in [15] for lighting controls. Where automatic operation is perceptible to occupants at their workstations, for example in switching lights, moving blinds, or opening windows, then facilities for user over-ride are essential. As one occupant of one of the ANV buildings commented "The computer is supposed to know what is best for us but, unlike me, it does not sit in the draught it causes."

Many of the control systems surveyed in Probe and in other buildings broke these rules. For example, automated windows could swing open and introduce not only draughts but also noise, traffic fumes and insects, but could not be over-ridden. So-called "intelligent" luminaires not only turned off lights when not required but also turned them on unnecessarily.

Revenge effects

In a recent book [16], Tenner discusses how new technologies can bring new problems, sometimes more severe than those which they were intended to resolve. Buildings contain some good examples of this: Table 1 summarises some revenge effects identified in the Probe buildings and in other recent post-occupancy surveys.

Designers, naturally enough, tend to look on the bright side of their innovations, but often it seems that considering and minimising the downside risk would be the more robust and effective strategy. The following observations might be helpful:

- Don't be too optimistic: think carefully about the possible downside risks of a proposal.
- Try to minimise this risk.
- Keep things simple.
- Seek comment and where appropriate undertake pilot projects: designers are not users, though they often think they are [17].

In buildings it is generally felt that one should get things "right first time". However, sometimes only in hindsight is the downside apparent: and only a practical test will expose any chinks in the armour. While pilot tests can - and where appropriate should - be done, they will not always cover every aspect. Apart than this, and especially where innovation runs ahead of the knowledge base, it is important to take account of feedback - as in these Probe surveys.

Table 1: Examples of revenge effects in buildings

Measure	Intended consequence	Revenge effect	Possible solution	Comments
GENERAL:				
Improve comfort provision and energy efficiency	Automated windows, blinds, lights etc. can be controlled to provide optimum conditions.	Reduced occupant tolerance. Increased dependence on management. More complaints.	Include occupant over-ride facilities.	Imposition of automatic control can be very irritating. Try not to sacrifice adaptive opportunity.
Increase technology to provide added "flexibility"	Less management input necessary to make alterations from time to time.	More management input to look after the additional systems. Still requires some alterations too.	More realism. Better integration between physical and human systems.	Careful discussion of brief and design options to avoid fantasies.
Increased BEMS control	Better control and management information provided.	More load for operator, who may not be fully familiar. Local interventions more difficult.	Don't over-centralise. Allow for local decisions on over-rides etc..	Particularly important to have local over-rides in mult-tenanted buildings.
Outsourced facilities management and BEMS operation.	Professional service. Leaves occupiers to concentrate on their core business.	Business requirements for environmental services not so well understood, so systems run generously, wasting energy.	Tighter contractual requirements or retain in-house control of operation.	Third parties often not on site out-of-hours when anomalies tend to occur. Don't outsource the feedback loop!
LIGHTING:				
Occupancy-sensed lighting in offices	Lights switched off when people absent.	Lights switch on unnecessarily when occupant does not need it, or for passers-by.	Include manual ON switches, except where lighting is required for safety or convenience.	Also include manual OFF switches if possible. Control lighting of circulation routes separately.
Occupancy-sensed lighting in meeting rooms.	Lights come on only when required.	Can't switch lights off for slide presentations etc.	Include local over-ride switches.	Local manual control plus absence sensing only may be preferable.
Automatically dimmed lighting	Reduces artificial illuminance level when daylight is sufficient.	Increases artificial illuminance level when daylight fades.	Bring on at a low but reasonable level. Try to leave adjustments to increase brightness to the occupants.	Constant illuminance may also bring dissatisfaction owing to eye adaptation. Photocells sometimes confused by reflections.
Local switching of lighting	Greater responsiveness to need	Difficult to switch off lights left on inadvertently.	Absence sensing or "last out-lights out" facility at the exit.	The switch at the entrance should only activate circulation and safety lighting.
High intensity discharge lighting	Efficient point source.	Run for extended hours owing to extended run-up and particularly restrike times.	Use instant restrike ballasts or substitute fluorescent lighting.	Compact fluorescent fittings can also take some time to run up to reasonable brightness.
Lighting to suit VDUs	Reflected glare minimised.	Dreary-looking environment.	Added wall-washing etc.	Uplighting also worked well.
HVAC SYSTEMS:				
Displacement ventilation	Reduces cooling loads	Increases air tempering loads	Heat recovery	Minimise parasitic losses and avoid recovering unwanted heat.
Generous provision of cooling capacity	Deals with possible increases in internal gains.	Oversized systems can operate inefficiently and may cause discomfort.	Contingency planning, or systems which work effectively and efficiently at low capacity.	Needs care in design and management.
Full fresh air systems	Improves air quality	Increases heating loads and makes humidification likely.	Avoid over-ventilation and consider heat recovery, including latent.	Cleanliness may be more important. Don't operate ventilation just to provide heating or cooling.

Conclusions

Introduction

It is perhaps obvious that good buildings need to be well-briefed, well-specified, well-designed, well-built and well-managed. A good and extended handover is also becoming increasingly necessary for the more innovative and technologically sophisticated buildings, to allow the occupier to understand the design intent, the designer to appreciate the occupier's requirements, and for problems to be solved and useful feedback obtained. Good control is important too. To sum up, each of these seven requirements is reviewed in turn in relation to Probe and other related findings.

A good brief

Most buildings can no longer be precise responses to measured briefs, they must accommodate uncertain change. They nearly always did, but in today's world change can happen much more rapidly. But the buzzword, flexibility, can lead to problems, problems which need to be correctly "owned". Clients, naturally enough, hope that a new building will magic many of their building-related problems away and leave them to concentrate on their businesses. Designers sometimes collude in this fantasy and do not make it clear that many measures require vigilance in use, sometimes more than the measure deserves. "No begged questions", "Keep it as simple as possible, but not more so"; "Make it adaptable"; "If in doubt, leave it out"; and "What if...so what?"; can be appropriate rallying cries.

One aspect of this problem has been the overspecification of cooling loads. Frequently these requirements were based on guesstimates and fashions, and did not seem to have been queried rigorously by designers, even where better information could have been (and sometimes even had been) collected. We need both more routine availability of good information and contingency planning techniques which can prepare for the worst without over-specifying now.

Another problem has been the intensification of usage of many non-domestic buildings, with longer operating hours and more diverse occupancy patterns. Where the design assumption has been routine occupancy and typical tasks, problems have occurred. Engineering systems have defaulted to ON, with considerably more energy use than anticipated. We need to plan to accommodate more diverse use economically.

A final issue has been that some of the briefing intentions have become diluted during the design and construction process as a consequence of inevitable change, cost-cutting and misunderstandings. The outcome can be very significant for the usability and manageability of a building, especially in unfashionable areas like occupant controls, security, storage, cleaning and maintenance - all of which have vital integrating functions and tend to fall outside areas of design responsibilities.. It is important to manage and review the brief throughout the process.

An appropriate specification

Buildings and their systems can have Achilles' heels with severe repercussions. Major ones revealed in Probe and other investigations include excessive air infiltration; control problems (see below); the effect of glare on daylighting strategies; and the effect of cleaning and security on night ventilation and lighting energy use.

Regarding energy efficiency, over-specification must of course be avoided. Often it may be best to set a standard to suit the majority (say 80-90%) of requirements and allow the exceptions to be treated as such, with additional task lighting, spot cooling etc.. Again this is part of the move to allow the building to pick up some of the problems and the management others. In addition to whole-building energy targets, there needs to be emphasis on the individual components: the capacity of the plant; its efficiency in handling air, producing light or whatever; its anticipated annual hours of use; and the effectiveness of control and management. This will assist development and application of useful benchmarks and help to avoid incompatibilities.

Without good information, effective management and feedback is impossible. Specify those submeters, particularly to energy-intensive areas (like kitchens, computer rooms, swimming pools and other anomalous items), to large items of plant, to individual buildings on a site, and to other significant and identifiable cost centres.

Surveys including Probe suggest that comfort standards are affected by context. While this has long been appreciated in applying different temperature standards to AC and NV buildings, the components of this in terms of adaptation, tolerance and responsiveness are now beginning to be understood. More dialogue is required during design development of the standards appropriate to the evolving building and its control and management strategies. A move that aims to improve adaptive opportunity [10] and forgiveness may sometimes be more robust and cost-effective than one which aims to improve physical comfort standards, particularly if the latter threatens to make the design less robust and the occupants less tolerant.

A good design

Design issues are covered in an accompanying paper [19] so only a few points will be made here:

- Keep things simple, efficient, robust and usable where possible.
- While a design should be integrated, often the best form of integration is at the strategic level which then allows different individuals and systems to operate in their own terms.
- Increasing technological complexity must be accompanied by better integration between human and physical systems, or it may well prove to have been in vain.
- Plan for change whilst avoiding over-specification, over-complication, energy-wastage and increased burdens of vigilance upon management.
- Be alert to possible Achilles' heels, downside risks and revenge effects.
- Avoid tightly-coupled interactions which can lead to systemic failure.

Well controlled

Many controls operate in the background and are largely taken for granted. But are the systems controllable, are they controlled and operated efficiently, and are problems being detected? Frequently not. In spite of major advances in control technology, effective human application of controls in buildings requires care, skill and understanding.

One particular problem is the efficient operation of plant to suit variable - and sometimes very small - loads and give a graduated response, not defaulting to full ON. Another to warn when "embedded" systems - often included to improve economy but whose operation has little or no effect on service delivery - are actually working properly [13].

Controls also form the vital interface between the building's environmental control and engineering systems and its occupants and management. Even the smallest thing, for example a window control which is inaccessible or gives insufficient fine adjustment, can lead to major shortcomings in performance and occupant tolerance. It is vital to make controls comprehensible, effective, responsive, and in the right place; and to be sure that in their operation they will assist and not annoy. Careful analysis is required but is often absent: frequently the BMS specialist is told very little about the design intentions and how the building is likely to be used.

Well built

This goes without saying, but can be difficult in today's competitive market, with an increased range of products (plus the disappearance of some traditional skills and products), and in which designers often also have less power on site. This tends to throw the burden back on design and specification, on the basis that if one hasn't asked for something one is unlikely to get it. But new things will need specifying, like pressure testing for air leakage, component energy efficiency benchmarks, usability criteria, and post-completion support. This will require some new infrastructure of standards, acceptance procedures and so on.

Well managed

Good management can procure a good building and make it better in use. While such paragons are rare, they are increasingly evident, particularly in today's air conditioned buildings. Probe indicates that nevertheless they have a lot of work to do and that customer (i.e: occupant) service comes much higher than energy management on their priority list. However, a few have been able to complete the virtuous circle and to provide both satisfied occupants and low energy bills. On the other hand, in the more advanced naturally-ventilated buildings, managers (and possibly designers) seem to be taking too much for granted and are not yet aware of the increased vigilance that such a building may demand, perhaps especially now, whilst the concepts and techniques are still unfamiliar.

The conclusion is a plea not only for better management, but:

- more realism on behalf of designers and their clients about likely management burdens;
- the importance of designing for usability, so that - where they can - individual occupants and tenants can sort out their own problems; and also
- designing for manageability.

An extended handover

Some basic or repetitive buildings can be handed over to the client at practical completion and that is that, bar the snagging or unexpected problems. But many of the more sophisticated buildings we see today need more than this. Designers, clients and occupiers need so be aware that teething problems are a normal part of innovation, and should be planned for.

At present it can be very difficult to get even a trivial problem fixed once a building has been occupied: nobody has a budget, the problems and the potential within the building to solve them may not be clearly diagnosed, and there can be massive inertia and growing misunderstanding. But if not nipped in the bud, niggles can easily turn vicious.

A plan and a budget for "sea trials" and reviews during the first year of occupation could be extremely rewarding. This would include hand-holding during occupancy and fitting-out - a process which can often ride roughshod over the environmental control opportunities and constraints, and can be disastrous for advanced but fragile concepts. It would improve mutual understanding and provide grist to the post-occupancy feedback mill. Who knows, it might even make exercises like Probe redundant!

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