PROBE: SOME LESSONS LEARNED FROM THE FIRST EIGHT BUILDINGS

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Eight published post-occupancy surveys have focused on building services and energy performance, management, and occupant satisfaction in buildings of technical interest. All the buildings are relatively good; and two of them had unusually high occupant satisfaction: a sophisticated deep-plan air-conditioned office which demanded (and received) a high level of management; and a simple, low energy, largely naturally-ventilated medical centre, in which occupants were prepared to forgive some deficiencies in lighting, ventilation and summertime temperatures. Very good energy performance was delivered by three of the naturally-ventilated buildings, but in the more advanced of them, difficulties with control, commissioning, usability and management - problems which also afflict air-conditioned buildings - had affected occupant satisfaction. The results indicate the need for better briefing; more recognition and discussion of the demands buildings are likely to make on their occupants and management; more robust and sometimes simpler solutions with downside risks considered and minimised; intrinsically efficient systems with more usable controls and feedback; and better industry support to occupiers after handover.

INTRODUCTION

In 1994, the Department of the Environment announced its Partners in Technology (PiT) scheme. This sought proposals for research into buildings which in the process could also improve the linkages between government, industry and academia. Projects were to be timely, relevant to industry (who had to provide at least half of the resource); and include plans for effective dissemination of results.

The building industry tends to be slow to learn from its innovations and mistakes, particularly chronic ones which lead to insidious but not catastrophic problems. This poor feedback is a growing problem today, as changes in technologies and client requirements have become increasingly rapid, and the procurement process increasingly fragmented and price-dominated. Normal conduits of research funding and output also tend to shun such “real world research” and its rapid dissemination.

The PROBE (Post-occupancy Review Of Building Engineering) PiT project aimed to tackle some of these issues. Buildings of technical interest, reviewed in *Building Services Journal* when new, were re-visited for technical, energy, occupant and management surveys, and the results published quickly in the *Journal* - something a reader survey revealed was very much wanted. The methodology, described in [1], uses standardised techniques where possible.

Eight surveys have been published to date, and feedback seminars held, as reported in [2]. This paper outlines how these buildings are performing, and how we might use the findings to improve the quality of occupant satisfaction, energy efficiency, control and operation. It also considers innovation and possible “revenge effects”, and draws some strategic conclusions for briefing, design and management.

THE BUILDINGS STUDIED

Table 1 lists the buildings studied, with their function, treated floor area (TFA) and date of the PROBE article.

- Four were predominantly air-conditioned (AC) offices for financial services companies, representative of completions in the early 1990s. Tanfield House is classed as such: although its openable windows make it mixed-mode (MM) in theory, in its very deep plan few people are close to them, their use is discouraged, and the AC operates all the time.

- Three, all educational (two university and one commercial) had advanced natural-ventilation (ANV), incorporating stack effect and motorised openings. At C&W’s management and technical training centre, which included residential and sports facilities, this applied to the classrooms only.

- One, Woodhouse Medical Centre, with doctors' and dentists' surgeries, was more traditionally naturally ventilated (NV), though with some MM characteristics with its heat recovery mechanical ventilators (now in disuse) and added comfort cooling in two rooms.

TABLE 1 THE BUILDINGS STUDIED, WITH DATE OF PUBLICATION IN *BUILDING SERVICES*

NAME	*ABBREVIATION*	*FUNCTION*	*SERVICING*	*TFA m^2*	*DATE*
Tanfield House	Tanfield	Very deep plan administrative centre	AC	19800	Sep 95
1 Aldermanbury Square	Aldermanbury	Narrow plan speculative office	AC	7000	Dec 95
Cheltenham & Gloucester Building Society Chief Office	C&G	Deep plan headquarters	AC	17400	Feb 96
de Montfort University, Queen's Building	de Montfort	University engineering department	ANV	8400	Apr 96
Cable & Wireless Training College	C&W	Residential training centre	ANV (part)	11400	Jun 96
Woodhouse Medical Centre	Woodhouse	Doctors' and Dentists' surgeries	NV	640	Aug 96
Gardner House	Gardner	Headquarters office	AC	3800	Oct 96
Anglia Polytechnic University Queen's Building	APU	Learning Resource Centre	ANV	5650	Dec 96

ENERGY PERFORMANCE

Figure 1 shows annual carbon dioxide emissions by end use, with the associated energy consumption data. It also includes benchmarks from ECON 19 [3] for Good Practice (GP) and Typical (TYP) offices: Type 1 (naturally-ventilated, cellular), Type 2 (naturally-ventilated, open plan), and Type 4 (prestige air-conditioned). Total CO_2 benchmarks for the academic buildings (de Montfort and APU), and C&W are also shown. The building data are sorted by increasing emissions for building services, i.e: up to the right hand end of the white bar for lighting. Further to the right is energy consumption by occupier's equipment (e.g: computer suites, communications rooms and office equipment) plus leisure facilities, Mercury transmitter etc. at C&W.

There is a sixfold variation in carbon dioxide emissions, both as a whole and for building services. Per square metre, the AC buildings were near TYP, while the NV ones designed to be low-energy had significantly improved upon GP benchmarks. The two main exceptions are the relatively high consumption at C&W - particularly for heating and hot water - and low building services energy consumption (for an AC head office) at C&G, owing to tight management of heating and cooling plant and the associated pumps.

Data for the energy efficient - and comfortable - One Bridewell Street [4] is also included. Although not a head office, and with energy use by occupants' equipment similar to the NV buildings, it shows that with careful briefing, design and especially energy management a VAV AC office can approach NV levels of energy consumption. But AC offices which perform like this are very rare.

The components of energy consumption

Heating and hot water. Relatively low except at Tanfield and Gardner (which have full fresh-air systems and long running hours) and C&W (a spread-out form, hotel-like occupancy, and a swimming pool). Heating consumption was very low at the highly-insulated Woodhouse, while its electric water heating incurred relatively high CO_2 emissions. Surprisingly, none of the AC buildings had heat recovery or condensing boilers.

Cooling, fans and pumps. AC consumption varied greatly with design cooling loads and air change rates (often too high), system efficiencies (particularly specific fan power), and annual hours of use - which in turn depend upon management (do the systems run as needed or stay on "just in case"?) and design (do small loads bring on large systems, and if so are these efficient at low loads?).

Steam humidification can incur relatively high energy use (and high costs if electric as in cold weather UK electricity costs more), a particular penalty with full-fresh air systems. Frequently it seems to be operated wastefully, with high set points and needless usage in mild weather.

Lighting. The AC buildings made little use of daylight, and in all the buildings lights were often on unnecessarily, particularly in corridors etc.. Glare was often a problem. Design and performance of automatic lighting controls was frequently disappointing, with systems often defaulting to ON, and sometimes annoying occupants.

Office equipment. Equipment energy consumption was low in the NV buildings, higher in the AC buildings. In both, the average loads to date have been well below the design estimates, but they are rising.

Catering gas and electricity. This was fairly normal in the buildings with catering kitchens. Unfortunately - apart from gas at Tanfield - these kitchens were not sub-metered.

Computer and communications rooms, where present. Electricity consumption is often substantial and 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.

Widespread energy-related problems

The low priority given to energy management in most of the buildings. While there is scope for improvement, it is also important to recognise that management time is in short supply, and where possible to design for manageability.

The almost complete absence of submetering. This hinders not only energy management, but also realistic benchmarking and space charging in these days of internal accounting. However, the main meters and sub-meters that were present tended not to be read routinely either!

The potential of the more highly-serviced buildings to waste large amounts of energy if systems were run liberally or unnecessarily. This often occurs owing to the limited amount of energy management, a focus on service before economy, and poor low-load performance.

Overestimation of internal heat gains. We need better ways of making strategic provision for change without providing unnecessary - or unnecessarily large - air conditioning plant.

Poor usability, performance and commissioning of automatic controls, also affecting occupant satisfaction particularly for lighting and natural ventilation. Many occupants also found BEMS difficult to use; BEMS control of natural ventilation proved troublesome; and systems were seldom effectively set up to monitor performance, energy efficiency, or conformity with design intentions, and to alert management of potential problems.

"Tail wags the dog" and "Default to ON" problems which bring on large systems, often unnecessarily. Systems need to contend efficiently with the increasingly long opening hours and irregular occupancy patterns of buildings today. See also reference [5].

Unintended consequences of new techniques and technologies. Trial and error is an inevitable part of technological development. However, the amount of post-occupancy support being given to innovative - and indeed to relatively straightforward - buildings was relatively small, so things which could have been made to work could easily turn into problems. It is telling that the energy consumption and related carbon dioxide emissions of the innovative HVAC systems at Gardner and Aldermanbury were higher than the other two AC buildings with more conventional VAV systems (and considerably higher occupancy and equipment densities). It takes time to climb the learning curve!

OCCUPANT SATISFACTION

Figure 1 shows overall comfort, for which more details are available in reference [6]. In two buildings, this - and perceived productivity - were significantly above national benchmarks:

The AC Tanfield. A deep-plan, management-intensive building clerical and administrative staff at high densities tends to be at high risk of occupant dissatisfaction. However, Tanfield's imaginative design and good management (with rapid and effective response to the relatively rare complaints) worked well, though with considerably more facilities and engineering support than many organisations would be prepared to commit.

The NV Woodhouse, in spite of shortcomings, particularly in ventilation and summertime temperatures. This reinforces the findings of other studies [e.g. 7, 13] which suggest that where systems are easy to understand and people can make simple adjustments, occupants seem to be more prepared to forgive shortcomings in technical performance. This in turn is most likely in quasi-domestic environments with relatively small rooms and individually operable lights, windows, and radiators, a context which in our view is more important to these perceptions than the natural ventilation itself.

Of the other three AC offices:

- C&G performed reasonably well, although with some glare and air infiltration problems.
- Thermal comfort in Gardner was let down by excessive air infiltration, which was being tackled.
- Aldermanbury fell somewhat short on energy performance and occupant satisfaction. The occupiers knew they could do better with more effort, but felt that they had obtained a reasonable compromise, as the system was already receiving considerably more attention than normal.

The satisfaction levels of the permanent staff in the ANV buildings - incidentally all educational - were not quite so good. Various problems seemed to have been getting in the way of their achieving their technical potential:

- Ventilation control systems were seldom operating as intended, owing to both logic and actuator problems, and often resulting in some overheating. Innovative features like this need effort to bring them to life, but this can easily be hindered by contractual arrangements and by a shortage of time generally for “sea trials”.
- As a genre, educational buildings tend to be under-resourced managerially: occupiers have better things to spend their time and money on! Clients and designers may not have appreciated that ANV requires more management attention in use than traditional natural ventilation. In situations where occupants are dependent upon automation and management, slow or ineffective response can cause their satisfaction to deteriorate rapidly. It is well-known that this happens in AC buildings, but the problems are related to the overall context, and not just to air-conditioning.
- Occupants did not always understand how systems should work (this applied at the simpler Woodhouse too). The answer is not only user education, but better ergonomic design of systems and controls to make the desired actions easy, and if possible intuitively obvious.
- Automatic window control was sometimes used with no manual over-ride facilities. As with blinds and lights, if a well-meaning control operation causes discomfort, this can irritate, even infuriate.
- The building, the furniture layouts (often done by others), environmental and controls designs often seem to have reduced the adaptive opportunity [7], which seems to be at the root of occupants’ traditionally higher tolerance of environmental conditions in NV buildings.
- The design and management emphasis had been on the public areas (and indeed visitors spending only an hour or two in any space were significantly happier), while the needs of the permanent staff appeared to have received less priority. PROBE’s AC buildings tended to have been designed and managed with more emphasis on supporting the permanent staff, whatever their grade.

<u>Lighting</u>

In lighting, occupant responses suggested a need for more attention to quality. Glare from natural lighting was often mentioned, particularly in computer screens. For lighting as a whole, occupants only regarded Tanfield’s uplighting - enhanced by wall-washing, high ceilings and light from atria - as significantly above the UK benchmark for occupant satisfaction.

<u>Comfort and energy consumption</u>

Tanfield, the most comfortable building, was one of the highest energy consumers per unit floor area for building services (though per occupant Aldermanbury and Gardner used more), while the next most comfortable - Woodhouse - used the least. The third - C&G - was in the middle, but the most efficient of the AC buildings. As in previous studies, PROBE confirmed that there was no simple direct relationship between comfort and energy efficiency, but that with good design and good management it was possible to obtain the best of both. Indeed, following PROBE, several buildings including Tanfield have significantly reduced their energy use.

<u>Forgiveness</u>

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, occupants may tolerate shortcomings in detailed performance. BUS have developed an index of “forgiveness” [see 5]: the score for overall comfort divided by the mean of six principal comfort variables. High forgiveness was part of the reason for high overall comfort scores in Woodhouse, Tanfield and C&G. Designing (and managing) for high forgiveness could sometimes be more effective (and cost-effective) as an approach than attempting to improve comfort by engineering methods - particularly when these run the risk of confusing or alienating the occupant.

CONTROL

Control is key to better performance and can improve occupant satisfaction [5], particularly if they can change things when circumstances become adverse. It 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.

People like control

People like control and rapid response, particularly when they experience a "crisis of discomfort" [8]. Current trends, however, can tend to take control away from them, for example putting them in open-plan spaces with interlocked furniture which does not allow the working position to be moved (to avoid local glare or draughts, for example), and choosing automated systems with no (or poor) manual over-rides. This can create a dependency culture, in which management has to solve problems which individuals might have been able to deal with themselves. Without good, attentive, and responsive management, this can start to unravel in any building in which occupants are unable to make their own adjustments, and not just AC ones.

Plant control

Control of plant and distribution is often wasteful. For example, when there is little or no demand, it is not unusual to find all the boilers and chillers enabled (and sometimes juggling the load between them) and all the pumps operating. A more graduated response requires both design and management input. Often small demands can bring on large systems, or the response to minor problems is to more liberal control settings and programmes, causing increased energy use. Systems expected to be controllable sometimes malfunction - for example with instabilities or lockouts when variable operation is attempted - causing features to be abandoned.

Integrating user behaviour with automated systems

The industry needs to get better at designing systems to be usable, manageable and controllable, as was concluded in an EnREI study of users and automated controls [9]. With the benefit of PROBE and other studies one can begin to suggest a few rules which may help improve both occupant satisfaction and energy efficiency:

- Automatic systems should provide safe, healthy background conditions economically.
- Where appropriate, any decision to boost or change conditions should be made by occupants as close as possible to the point of decision.
- It should be clear to occupants what control action they should take.
- If the outcome of this action is not obvious, then the system should be designed to confirm its changed status to the user (for example by a position change, a click or an indicator light).
- After boosting, the decision to switch off (or revert to the background state) should be made either manually, or automatically if manual action has not taken place after a reasonable interval.
- The operation of automated control should where possible be imperceptible to the user, avoiding abrupt changes in settings.
- Where automatic operation is perceptible to occupants at their workstations, for example switching lights, moving blinds, or opening windows, user over-ride with rapid response is 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."* The appropriate user interfaces depend on the occupancy context, as is discussed in [10] for lighting controls.

Control systems surveyed often broke these rules. For example, automated windows could swing open and introduce draughts, noise, traffic fumes and insects, but could not be over-ridden. So-called "intelligent" luminaires turned on lights unnecessarily, or did not allow them to be switched off for unusual requirements, e.g showing slides. Abnormal usage required staff to telephone a "help desk", which was only staffed from 9 to 5!

REVENGE EFFECTS

In a recent book [11], Tenner discusses how new technologies can bring new problems, sometimes more severe than those which they were intended to resolve. Buildings contain good examples of this: Table 2 outlines 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. However, a more circumspect approach might deliver more robust and effective results:

- Don't be too optimistic.
- Think carefully about the possible downside risks of a proposal and try to minimise them.
- Keep things simple.
- Seek comment and where appropriate undertake pilot projects.

SOME STRATEGIC CONCLUSIONS

See also reference [14]

For briefing

Too many buildings appear to end up more complicated, more difficult to manage and less appropriately serviced and controlled than they might be. Designers and clients have sometimes unwittingly conspired in this by striving for flexibility or optimum performance without clearly assessing the options and solutions for usability, robustness and manageability.

In its development, the brief should articulate the strategic objectives (the mission statements for the building), fitting into wider corporate, risk, and environmental management strategies. If not, these may be wrongly second-guessed or left unquestioned by the designers. For example, in a recent major project it only emerged well into construction that the designers had envisaged routine occupancy hours while one of the client's key reasons for wanting a new building was to obtain efficient support of irregular, round-the-clock operation!

For design

"Designers are not users, though they often think they are" [12]. Designs need regular review against strategic objectives for the building and the needs of occupants, or possible occupants. For example, in seeking optimum performance, added complication or unfamiliarity may increase the risk of both technical failure and occupant dissatisfaction: simpler, more robust, intrinsically efficient solutions may sometimes be better. In seeking to improve comfort, one must balance any predicted gains in physical conditions against possible losses in occupant tolerance, adaptive opportunity, or increases in management-dependence. In many circumstances, design (and management) options which aim to improve "forgiveness" could potentially be more effective, cost-effective, comfortable and energy-saving, and less unsustainable.

For construction

Not enough can be taken for granted, from airtightness to controllability. We need to develop better and more appropriate standards, procedures and benchmarks, and means of demonstrating compliance. We need to design controls for better usability and convey this insight more effectively to management and users. Present contractual arrangements often seem to hinder rather than help to resolve teething problems, which then get worse as confidence is lost. We must try to improve them, and to demonstrate to our clients that any additional costs are rapidly repaid in better performance and fewer nasty surprises.

At and beyond handover

Optimum performance requires both good design and commitment in use. The commendable ambition to get things "right first time", however, can implicity stop people making sensible plans to nurse the building through its infancy. While standards and specifications can be improved, and pilot tests can - and where appropriate should - be done, they cannot always anticipate every eventuality. Sometimes only in hindsight can problems and unintended consequences be identified. Where innovation runs ahead of the knowledge base, it is especially important to set objectives and benchmarks, to undertake appropriate monitoring (including metering), and to seek and take account of feedback (including post-occupancy surveys!).

For facilities management

In an AC building - and others where performance is critically dependent on engineering systems and automated controls - excellence in design, execution and management is essential; and rapid and effective management or system response also appears to be key to maintaining good occupant satisfaction. Some organisations (as at Tanfield) will face up to this and even welcome it as reinforcing an image of excellence in managing complexity, quality and service; and find it affordable through greater public awareness, staff satisfaction and productivity. On the other hand, many occupiers, when talked through the management implications at the design stage, might prefer to consider lower-cost, low-management approaches, which aim to maximise adaptability and occupant forgiveness. Designers, builders and occupiers must recognize that innovative (or at least unfamiliar) "greener" solutions such as ANV may require significant management input to fulfil their potential, particularly at the early stages when problems with both technical (and particularly control) performance, occupant understanding, and unintended consequences might easily occur.

When outsourcing contracts

Routine activities like maintenance, cleaning and security are important monitoring and feedback mechanisms, which can reinforce policies of continuous improvement. When outsourcing, it is important to maintain this feedback - both formal and informal - in support of the facilities management task, and for contracts to be drafted and managed accordingly.

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FIGURE 1: ANNUAL ENERGY CONSUMPTION AND RELATED CARBON DIOXIDE EMISSIONS

FIGURE 2: Annual carbon dioxide emissions and ECON 19 benchmarks

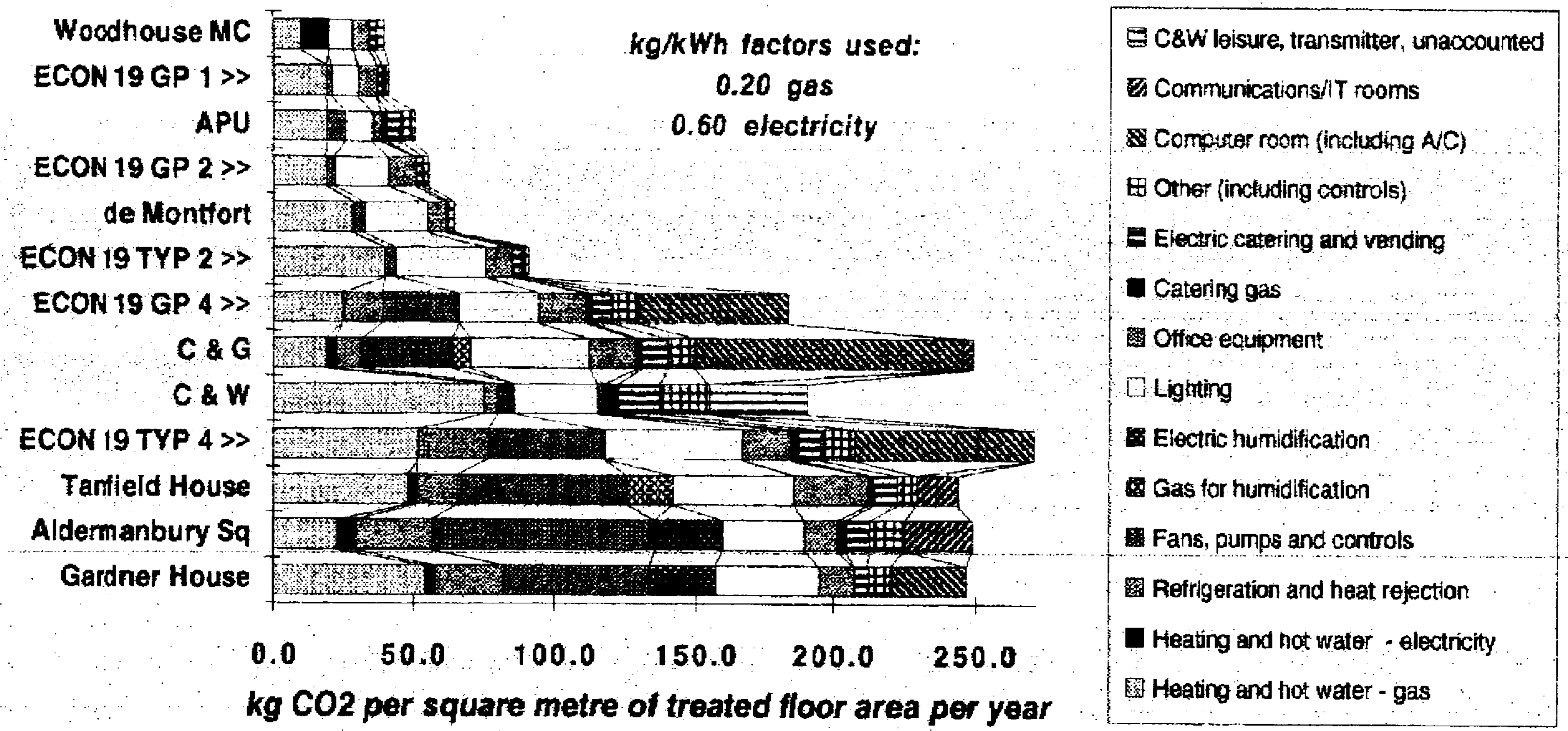


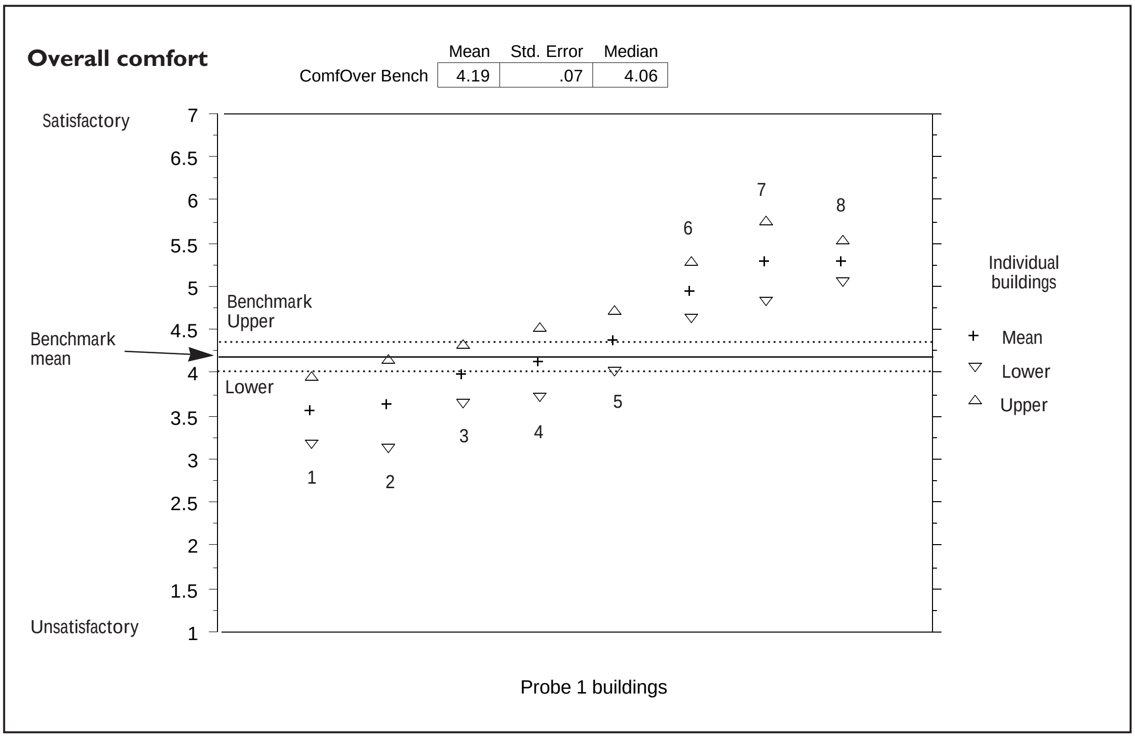
FIGURE 2: SCORES FOR OVERALL COMFORT BY PERMANENT STAFF

ANNUAL ENERGY CONSUMPTION: kWh/m2 of treated floor area	Gardner House	Aldermanbury	Tanfield House	ECON 19 Typ 4	C&W	C&G	ECON 19 GP 4	ECON 19 Typ 2	de Montfort	Bridewell	ECON 19 GP 2	APU	ECON 19 GP 1	Woodhouse
GAS:														
Heating and hot water - gas	271	117	242	259	395	95	124	200	143	70	95	97	95	49
Catering gas	0	15	9	14	26	8	8					11		
Gas for humidification	Elec	Elec	80	Omitted		32	Omitted							
ELECTRICITY:														
Heating and hot water - electricity	6	10	5	Incl	4	6	Incl		1	3				17
Refrigeration and heat rejection	40	45	23	41	8	15	24			13				
Fans, pumps and controls	87	132	101	69	10	53	45	6	6	19	5	11	3	
C&W leisure, transmitter, unaccounted					59									
Humidification	38	40	Gas	Omitted		Gas	Omitted							
Lighting	63	50	73	82	50	71	47	53	37	31	32	16	16	14
Office equipment	21	20	45	29	3	28	29	16	11	9	16	5	11	10
Catering and vending	8	14	14	14	25	16	12	5	1	5	4	8	3	3
Other	13	20	11	20	29	15	16	5	4	5	4	8	4	6
Computer room (including A/C)	44	None	None	106		160	88							
Communications/IT rooms	Incl	40	24	Incl		6	Incl			4				
Total gas	**271**	**132**	**331**	**273**	**421**	**135**	**132**	**200**	**143**	**70**	**95**	**108**	**95**	**49**
Total electricity	**321**	**371**	**296**	**361**	**188**	**370**	**261**	**85**	**60**	**88**	**61**	**48**	**37**	**50**
NORMAL BUILDING SERVICES:														
Building services gas	271	117	322	259	395	127	124	200	143	70	95	97	95	49
Building services electricity	235	277	202	192	72	146	116	59	44	66	37	27	19	31
Building services CO2 emissions	195	190	186	167	122	113	94	75	55	54	41	36	30	28

TABLE 2: SOME REVENGE EFFECTS IN BUILDINGS

Measure	Intended consequence	Revenge effect	Possible solution	Comments
GENERAL:				
Improve comfort provision and energy efficiency	Automate windows, blinds, lights etc. in order 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 time to look after the extra 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 familiar. Local intervention more difficult.	Don't over-centralise. Allow for local decisions on over-rides etc..	Particularly important to have local over-rides in multi-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 occupants do not need it, or for passers-by.	Include manual ON switches, except if lighting is required for safety or convenience.	Also include manual OFF switches if possible. Light circulation 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 dissatisfy owing to eye adaptation. Photocells can be 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.	In large spaces, this switch at the entrance should only re-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 adequate 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. Don't recover 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 well 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.

Figure 1: Overall comfort Probe 1 buildings



Key

1 APU, Queen's Building

2 Cable & Wireless College

3 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.

A building mean is significantly different from the benchmark mean if the value falls outside the interval range for the benchmark mean. A building mean is significantly different from another building if the value falls outside the interval range for that building.

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