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Welcome to Part One of our campaign – Benchmarks for Better Buildings. Over the next two months *Building Services Journal* will be calling for CIBSE members to champion real improvements in building services, such as tests for building airtightness, the fitting of energy meters, collective resistance to cost-cutting and greater acknowledgement of occupant productivity and satisfaction during the scheme design stage.

In this introductory feature, we lay down the priorities. What can we do to reduce plant oversizing? Can we include the needs of real people in a building's detailed specification in a way which won't be compromised by surveyors and contractors?

Benchmarks for Better Buildings

Designers rarely have the opportunity to obtain detailed feedback on the performance of buildings they have worked on. While many harbour a genuine interest to find out, pressure of work and lack of remuneration prevents their ongoing involvement in buildings in the post-handover period.

The good news is that we are beginning to learn. Post-occupancy investigations are identifying the strengths and weaknesses in building design, and the professions are gaining access to previously unavailable information.

The PROBE investigations, for example, have delivered significant lessons for both clients and designers, with implications both for the performance of the building and occupant satisfaction.

Those lessons are not just for designers. In many instances problems have arisen where the design team has been unable to persuade a client of the value of an important design feature, which has then been omitted to the detriment of the project. Equally, the PROBE studies reveal several situations in which the clients have supported an unconventional solution which has ultimately proved to be effective.

Much of the feedback from post-occupancy investigations reveals the role that building operators have in ensuring that buildings operate effectively, with reasonable energy consumption and contented occupants. It could be concluded from this that design is of secondary importance, provided that the facilities management is excellent.

In fact this is far from true. Without good building design the building operator may end up running to stand still. Good design can also make a difference to energy consumption, as the three low energy buildings studied under the PROBE project – De Montfort's Queens Building, the Learning Resource Centre at Anglia Polytechnic University (APU) and the Woodhouse Medical Centre – have demonstrated.

Design can also make a difference to occupant satisfaction levels, with relatively simple designs being well received by the users.

The design stage of a project presents the main opportunity to get things right that will often be too difficult or too expensive to correct once the building is built. Details such as the glazing specification and its level of light transmission will have a direct impact on the occupants' perception of the internal environment and the opportunity to reduce the running costs of electric lighting through the use of natural light.

Once specified and installed, such items are likely to remain unaltered for at least 20 years, or perhaps for the entire life of the building.

So which aspects of design are most important? While pressure increases for greater efficiency in the design process it is most important to get the main issues right in order to produce a cost-effective, low energy building which satisfies the occupants' comfort and other requirements.

A number of recurrent themes warrant emphasis: design for low loads, employ passive design with care, beware fragile scenarios for occupancy or operation, avoid "tail wagging the dog" services and, above all else, fight the cuts.

A building with low fabric heat loss and gain, tightly controlled fabric air leakage and low installed building services capacity with appropriate controls will achieve relatively low energy running costs almost irrespective of how it is operated.

The Queens Building at De Montfort University, APU and the Woodhouse Medical Centre all demonstrate that low fabric heat loss can be achieved through good standards of wall insulation and double glazing (or better) at costs well within industry norms.

Achieving airtightness is dependent upon a number of factors, including the chosen method of construction, the quality of constructional detailing and the quality of site construction plus the appropriate level of supervision. Evidence from the PROBE project and other studies shows that it is the junctions, particularly the corners, that require closer scrutiny during the design phase.

Site factors may appear difficult to address at the design stage, but the inclusion in the specification of a requirement for the contractor to demonstrate airtightness by pressure testing could help to avoid problems such as those encountered at Gardner House and Cable & Wireless (see PROBE 9, p37-41).

Few architects, and possibly not many building services engineers, are familiar with the emerging benchmarks for various elements of building services.

For example, the difference between installed lighting power density to achieve the same level of illuminance can be very significant, ranging from 2 W/m^2/100 lux to 5 W/m^2/100 lux.

Similarly, specific fan power can vary from 1 W/l/s to in excess of 5 W/l/s. Ensuring that the lowest practical level is achieved for each of these benchmarks requires, among other things, careful selection of light fittings, adequate sizing of ducts and appropriate selection of fans.

As these benchmarks become better known and more widely accepted, it is then up to clients and architects to question what can be achieved, and for building services engineers to demonstrate an understanding of how best to achieve them.

Building designers are generally at a disadvantage compared to designers of manufactured products. Each new building is effectively a prototype and, unlike a manufactured product, they do not go through a rigorous process of development and testing before being released to the public.

Any design for a new building will involve elements from previous buildings but seldom with any detailed understanding of the performance of those buildings. New buildings can therefore easily repeat the mistakes of their forebears.

This article is an abridged version of a paper delivered at the Buildings in Use '97 conference by Paul Ruyssevelt, associate director of HGa Consulting Engineers and Rab Bennetts, principal of architect Bennetts Associates.

Real world solutions

benchmarks for better buildings

Everyone agrees that post-occupancy research is providing designers, clients and facilities managers with a rare insight into the real performance of buildings. But how can we transform the findings into practical guidance? In the wake of the PROBE conference in February, delegates met at a one-day workshop to hammer out some strategies for improvement.

BY RODERIC BUNN

There are two sides to post-occupancy building reviews. The downside is the very public discussion of shortcomings in design practice – the equivalent of holding a mirror up to the construction industry – while the upside is the identification of the real effects of briefing, designing and operating strategies, and the practices that should be improved if the construction process is to deliver better buildings.

With all these issues in mind, delegates attending the Buildings in Use '97 conference were invited to attend three workshops covering the topics of energy, occupancy and design. The objective was to develop a new set of best practice benchmarks for developers and designers, aimed fair and square at improving the quality of both building construction and operation.

Based on the findings of the PROBE project, the lessons for design were defined as:

- ☐ design for low loads;
- ☐ employ passive design with care;
- ☐ avoid fragile design;
- ☐ avoid "tail wagging the dog" design;
- ☐ fight budget cuts.

Issues relating to the energy efficient design of buildings and building management were categorised as:

- ☐ designing for manageability;
- ☐ good management techniques;
- ☐ influence/role of organisational culture;
- ☐ intrinsically efficient systems;
- ☐ effective controls;
- ☐ methods of energy assessment.

The main factors determining occupant satisfaction were defined as:

- ☐ user versus central control;
- ☐ the importance of response times;
- ☐ matching management to the building;
- ☐ the balance between services provision and user tolerance;
- ☐ productivity;
- ☐ the value of occupant surveys.

Around 100 delegates split into small discussion task groups to brainstorm these issues, and devised strategies whereby the findings from PROBE might influence the briefing, design and operation of buildings.

At the end of each consultation period, each group reported what they thought the construction industry should be doing. What follows here are the main findings from the workshops, with outline action plans for improvement.

Designing for low loads

Two major issues relating to designing for low loads arose from the PROBE studies: the seemingly perennial problem caused by the overestimation of internal heat gains, and growing difficulties caused by extended hours of building operation.

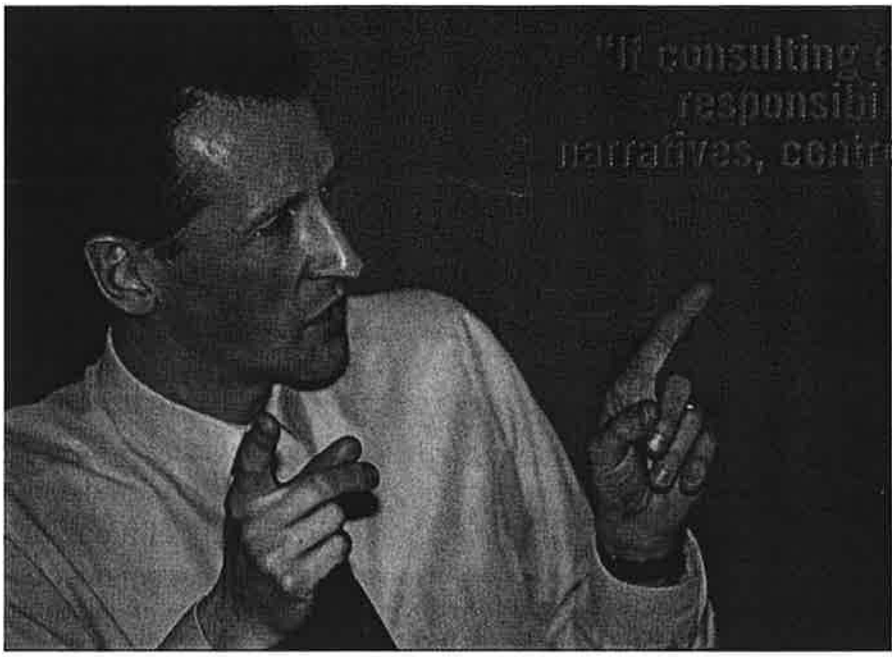
In many of the buildings studied under the PROBE project, the predicted heat loads were not being met, which led to inefficient systems and raised energy consumption.

As Neil Beaumont of BT Group Property pointed out, the problem faced by clients is being able to predict operational requirements after they have moved into a building. "The reality of running property today is that no organisation, particularly one which is global, really knows what is going to happen next."

But ECD's John Doggart sprang to the defence of property owners, arguing that the design professions should be able to take the unpredictability of business into account.

"We should not be designing buildings that require constant recommissioning," claimed Doggart. "We should be moving towards buildings which are more flexible and don't place the onus on clients that have to make major changes to the building services and the building fabric just because there happens to be a change of use.

"There is a tendency for designers to demand of the client a specific set of values and then blame him if it goes wrong," added Doggart. "Perhaps we should try and reverse our way out of that, and present the user with a range of scenarios, saying: 'If you operate



"If consulting engineers took back the responsibility for writing the bems narratives, controls systems may end up being much simpler"

Chris Twinn

the building here you will save so much, but if you go here you will lose so much'. We should investigate the level of risk clients would be prepared to take and help them see the consequences of their actions."

That, said HGa director and PROBE investigator Paul Ruyssevelt, might be difficult given designers' tendency to overdesign if only to protect themselves from litigation. "Perhaps the emphasis should be on designing plant to run efficiently and effectively at 10% capacity."

Ove Arup's Chris Twinn argued that services designers could at least admit openly where margins have been added and explain clearly to the client why they are there.

Recognising that uncontrolled air leakage was a major factor in the poor performance of building services, airtightness testing was a major point of discussion, a straw poll revealing that 80% were in favour of an airtightness clause in the *Building Regulations.*

action plan

Designing for low loads

- A CIBSE design code covering airtightness requirements, with guidelines on detailing and air pressure tests.
- Development of feedback mechanisms to brief designers, perhaps via a non-attributable database.
- Development of an industry database, using a standard method of presentation, for building energy consumption. Possibly mandatory and championed by PI insurers.
- Possible mandatory requirement through the *Building Regulations* for all new buildings to be pressure tested prior to handover.

The problem, said Chris Twinn, is that government is no longer prepared to legislate. "Even if there was a mandatory air leakage test in the *Building Regulations,* inevitably it would be a value equating to the lowest common denominator. More could probably be achieved if the CIBSE were to promote a useful value.

"Perhaps we are looking at European legislation, or at least something similar to the ASHRAE *Standard 90* (Energy Conserving Design)," said the BSRIA's Gay Lawrence-Race. "Even if it were a voluntary code, clients could still insist on compliance," she added. "It might even reduce PI premiums if risk was perceived to be significantly reduced."

This, said the task group, meant better feedback mechanisms so designers can find out whether or not their designs have worked.

"What we need is a central building performance database," added Gay Lawrence-Race. "All buildings could be required to publish their energy data, or at least contribute to a central database in a non-attributable way, so we can use it for design purposes."

"Greater knowledge of building performance leads to greater accountability," said Alan Palmer of Kyle Stewart. "If you accept that you have the knowledge there is no excuse for not taking account of it.

"Perhaps the answer lies in making schemes like BREEAM tighter, based on an infra-red survey and a leakage test. You wouldn't be able to get the BREEAM certificate until you have proved that certain standards are met," added Palmer.

The BRE's Colin Ashford suggested a Lloyds Register-type indemnity scheme based on a defects database, where it would be in the insurers' interest to ensure that defects did not occur twice.

"The support of the professional indemnity insurers could entice designers to support a defects database," said Ashford. "There could also be premium reductions for those designers prepared to work with an awareness o defects, promoting such a database.

"Another solution could be framewor agreements between clients and designer which include 12-months' maintenance wit independent verification of the building's op eration at the end," suggested Ashford. "Tha would help to ensure that the building wa operating properly during the maintenanc period, with handover being achieved at th verification stage."

Passive design

Passive design is often characterised as unu sual or unconventional. On the contrary, th basic elements of passive design – natura ventilation, the effective use of natural ligh and the use of a building's thermal mass were fundamental elements of design unt early on in this century. Several aspects of th way we use buildings (eg more people an computers) and some characteristics of the locations (eg air and noise pollution) can un dermine passive design features.

The most difficult aspect of passive desig is achieving real reductions in lighting energ costs through use of natural light. There ar many reasons for this. They range from th fairly obvious, where tinted glass, continuou horizontal shading and two layers of blind reduce the daylight levels from very larg areas of glazing to exceedingly low levels, t the more subtle problems where the contro do not work as anticipated.

Based on findings from the four natural ventilated buildings studied under PROB (see PROBE 9, p37), single-sided ventilatio seems to work reasonably well, but the mor advanced forms of natural ventilation – stac effect or wind-driven – were less robust. D signers, it seems, are fond of imagining th the air will go where the computer prograr says it will, but in reality that is rarely the cas

The trend towards daylighting also create some major problems. Daylight is used rath less in practice than designers believe, largely due to inadequate detailing of glare control and poor control of the artificial lighting systems. The latter often default to on with the blinds down. So is the effort towards passive design really worthwhile?

The passive design task group recognised that in many cases the problems start at the appointment stage, where the fees may not allow the services designers to have proper input early in the design process.

Ancillary problems were identified as a lack of definitive guidance on the optimum thickness of thermal mass. 75 mm seems to be the norm, said the chief engineer at De Montfort University, Ian Wilson, but how do we know? Furthermore, the lack of thermal mass on top floor locations has proved to be a problem, particularly where pitched roofs prevent the use of a heavyweight ceiling. Problems have been encountered at the Inland Revenue headquarters building, and also in the top floor studios at De Montfort's Queens Building.

Wilson explained that the m&e fees for the naturally ventilated Queens Building were set as though it were fully air conditioned. Max Fordham & Partners was then appointed to design a passive building.

"That way," said Wilson, "Fordham's had the right incentive, even though the services were not of a large capital value."

Fighting the cuts

Many of the problems faced by building occupiers can be traced back to a cost cutting decision at the scheme design stage. Passive design details like external solar shading are particularly prone to budget cuts, ditto lighting controls and bems "front ends".

An item that is regularly the target for exclusion at the latter stages of design is the submeter. Since it is not essential to the operation of the building it is assumed to be dispensable. The £100 or so saved could potentially be saved many times over by virtue of the invaluable information it can render once the building is operating. Building managers need this type of information for space charging.

At the APU Learning Resource Centre, the design & build contractor replaced triple-glazing with double-glazing on a north elevation, which subsequently left the space heating system with a greater heating load to satisfy.

The answers seem to lie at the design stage, where designers should defend essential items

action plan

Fighting the cuts

- The professional fees for passive solar buildings should be benchmarked at the cost of a fully air conditioned building, which would become a lump sum cost and not a percentage of the actual building cost.
- Services designers should prepare a building outline environmental specification, produced at the same time as the outline scheme design. The former should act as a reference for the latter.
- Services engineers should champion the use of energy submetering and defend any attempts to cut them on cost grounds.
- Designers should project greater faith in the building physics, and defend the less complex, lower cost approach wherever possible.
- Building services consultants need to retake control of the bems narrative, and not leave it to systems integrators who do not necessarily understand the needs of building services from the occupiers' perspective.

like controls systems which are particularly prone to falling off clients' priority lists. "It's difficult to cut windows or foundations," observed Paul Ruyssevelt, "so it's no wonder controls are often the first overboard."

Designers also need to account for the effects of cost-cutting, said Ruyssevelt, which might require a change to the design. "This often doesn't happen because the designer does not appreciate the downstream effects of such cuts on occupant satisfaction."

Chris Twinn pointed out a major problem: a growing lack of financial accountability. "Designers are no longer responsible for costs, and consequently no longer have a feel for costs," he said. "Cost control is handled by a new profession, allegedly totally responsible for what it does. Yet too often cost consultants say that your design is too expensive and then disappear out of the frame.

"If you work at designing simple, cost-effective systems, you may be able to spend some more money where it is needed," added Twinn. "Then at least people think that you are on the good side because you have already demonstrated that savings are already being made, and if your services percentage is a lot less than for a conventional building, you have a very good foundation for defending your investment elsewhere."

Facilities management contractor John Barnes agreed. "If services designers want to prevent wanton cost-cutting, they must have faith in the physics, and adhere to the less complex, lower cost approach to design."

The task group concluded that a range of initiatives should be taken to arm the building services engineer with arguments to prevent ill-informed cost-cutting. For example, client's need to appoint someone who will take ownership of some of the problems, although this has become more difficult as organisations restructure and concentrate on running businesses rather than buildings.

Second, services designers should produce a building outline environmental specification, explaining the respective roles of solar shading and controls, for example, which is produced at the same time as the outline scheme design and effectively acts as a reference point for it.

Tail wagging the dog scenarios

This is a common problem in buildings with large central systems, distributed loads and extended hours of operation. Extended hours of occupancy in specific parts of a building – the communications rooms especially – often lead to situations where main plant is working just to satisfy a relatively small load. Again, this leads to poor part-load efficiency, higher energy consumption and increased component wear.

In a naturally ventilated building, extended hours of occupation can seriously compromise a designer's carefully worked out night cooling strategy, preventing the building from discharging its heat. Unless there is mechani-

"If 0·1% of the budget is retained for some after-sales service, it would ensure that anything which is a bit flaky would get sorted. Let's not fight about whose fault it is"

Bill Bordass

cal means of cooling the building during the day, overheating problems can result.

The widespread absence of energy metering and extreme prevalence of complex building energy management systems (bems) are seen to be at the centre of this problem: if you can't measure it, says the old adage, you can't manage it.

"Buildings do not go into the world using the same amount of energy that the computer predicted," said Bill Bordass, "it all depends on how they are driven. Without energy meters or a bems front-end, a building won't have a speedometer or even a steering wheel, so it should be no surprise if it ends up in a different place than everyone expected."

Strong views were expressed about over-sophisticated bems. "The problem with bems," said Chris Twinn, "is that consultants have come to regard them as black-box technology. If consulting engineers took back the responsibility for writing bems narratives, the controls system may end up being much simpler than the specialist who knows all the software routines that can be thrown at a problem. Many bems suppliers claim they are refining the quality of control when in reality the users can never get them all to work."

Fragile design

Ill-informed design decisions can often result in rather fragile building services systems, particularly when it comes to things like openable windows, radiator valves and lighting controls. Designers often worry about the level of occupancy without thinking of the occupants' profile and their willingness (or aptitude) to manually operate the services.

"Thermostats are the worst examples," said Bill Bordass. "Often people think they are volume controls, which suggests that the occupants' view of their function does not properly map onto the thermostat's function, which is to maintain a set-point."

Risk assessments are crucial to the design process, said the delegates, and any discussion of options must be done with the client's involvement. Time and again, the issue was raised that the users' expectations must positively correlate with the designers' intentions, otherwise the building will be difficult to manage and users will lose faith in the controls they have been given. "We all want less complication in buildings, and buildings which are more robust and with better usability," said Matthew Hall's George Adams.

The BRE's Colin Ashford identified reduced professional fees as being a major issue. "Clients have driven down fees to a level which cannot sustain anything more than a very simple design process," he said. "Clients must be told that they have reduced fees down to a level at which designs are not as competent as we all wish them to be."

Bill Bordass called for a more grown-up approach to risk management, arguing that designers should be prepared to tweak services before they settle down. "It's not something to be ashamed of," said Bordass, "but something to share and learn from, provided that the risk management is set up in a frame understood by the client.

action plan

Fragile design

- Consultants must carry out option analyses with the client's full involvement.
- Commissioning time should be defended, as it is crucial to long-term building performance.
- Controls are becoming too sophisticated. Consultants should take back responsibility for controls narratives, currently handled by systems integrators.
- Risk assessment is a crucial factor in the design process.

"If 0·1% of the budget is retained foı after-sales service, it would ensure th: thing which is a bit flaky would get s Let's not fight about whose fault it is."

Effective controls

This raised the issue of suitable controls egies to suit the occupant. The del agreed that they should be obvious to u intuitive and follow a set convention, a close to whatever they were controllin

"Any control that is going to work well must give instantaneous feedba whether it is working," said the BRE's Godwin. "It must tell you when it is on and should ideally give you some ki noise that informs you that something is pening."

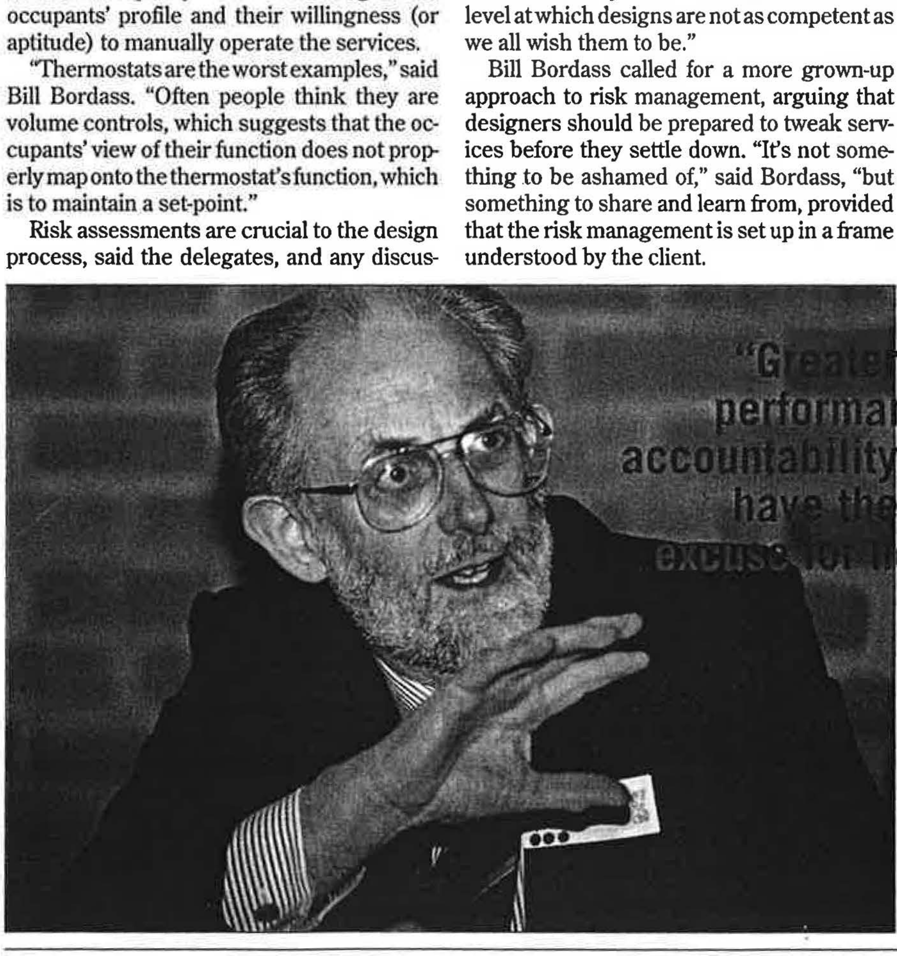
As the PROBE surveys have shown, trols systems are often too responsive faulting to on when they should default t This seems to be true of automatic lig controls, in particular complex systems w are daylight-linked or controlled by pres detectors. Often, simple on switches and t off routines would suffice.

For advanced natural ventilation, it regarded as absolutely vital that occupan given full control of the ventilation sys whether it be manually controlled or a m ised system.

According to Bill Bordass, the install of such controls has become a relay race it surprising that these things end up bei mess when the engineer designs some passes it to the controls contractor who t passes it on to a systems house who then no view of whatever anybody wanted fur up the chain, nor any appreciation of who end user might actually be?"

Minimising downside risks

"Facilities management is not my fault, b is my problem," said De Montfort's P Warm. Which is why post-occupancy stu represent a good opportunity to identify



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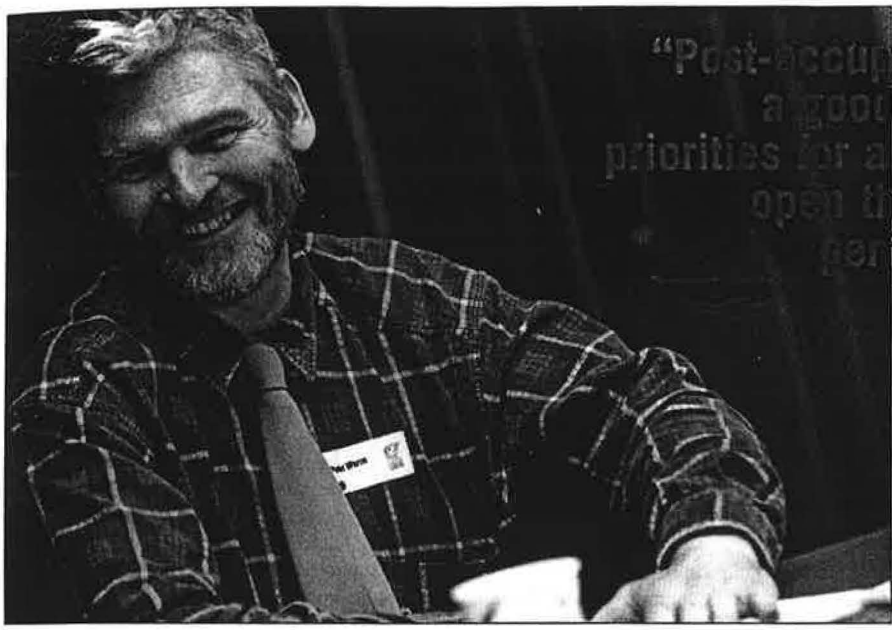


> **"Post-occupancy studies represent a good opportunity to identify priorities for a building manager, and open the door for user-related performance benchmarks"**
>
> **Peter Warm**

orities for a building manager, he added, and open the door for user-related performance benchmarks.

Minimising the downside risks of building operation often involves reining back on such technology which is not understood by building occupants. The degree to which building designers should be allowed to innovate is always controversial, but there is a strong argument that most buildings should use tried and tested ideas, with innovation only used in small areas. "If we rein back on innovation," said Paul Ruyssevelt, "we would have a much better chance of minimising the downside risks because the elements we need to focus on are more constrained."

Design reviews and performance verification were regarded by the task group on minimising downside risks as being crucial to a successful project. "A comprehensive design review should take into account the various disciplines involved in the design process," said Paul Ruyssevelt. "Admittedly that is difficult in practice as things happen at different times and it is difficult to co-ordinate properly, but if clients can be encouraged to make the process more formal then perhaps we can begin to address some of our problems."

Occupant satisfaction and productivity

Not before time, the value of behavioural studies to the design and management of buildings is achieving greater currency among designers and client organisations, who are beginning to recognise that buildings must be geared more to the needs and aspirations of occupants.

This means that the mental map that engineers and architects use as the basis of their designs must be the same as that expected by the occupants. But who decides what the map should be?

Occupant surveys could be the key to obtaining useful information on how users relate to their workplace, and how their perceived productivity is enhanced or compromised by the working environment.

But, as behavioural scientist Adrian Leaman pointed out, buildings are extremely complex entities to study, and over-complicated questionnaires can present "a mass of spurious correlations. The questions posed to occupants must be very straightforward and not beg too many other questions," he said.

So is productivity really affected by comfort conditions? "Research is revealing that, depending on the task, there is a borderline between 'comfortable and stimulating' and 'uncomfortable and hacked-off'" said Bill Bordass. "When comfort parameters begin to go off-beam, it might be stimulating for some people, but when you gather many people in one space the variability that you can allow in the conditions begins to reduce.

"One's options for playing tunes with the building services, without bashing through certain people's thresholds of discomfort, are extremely small," he explained. "If, when trying to make things reasonable for everyone, you push systems closer to the edge, you will push people over their threshold of comfort and get severe complaints."

The delegates agreed that occupant surveys of the kind carried out under the PROBE survey were proving useful, but that strategies need to be developed so the results can be applied.

"It seems to me," said ECD's John Doggart, "that even if corporate customers want to specify a good building, they don't have the wherewithal to do so in the brief. They simply don't yet have access to the sort of information that Adrian Leaman's occupancy surveys are beginning to provide."

Foggo Associates' Mike Jeffery agreed that getting the views of the users back to the design team was becoming vital to the design process. "If the client will not allow the designers to interview or even talk to the users," he said, "then the designers cannot take responsibility for any problem that might result from the users' relationship with the building."

"There is a limit to what designers can do," warned Eamonn Cronnolly of the Energy Design Advice Scheme. "If clients want a deep-plan office and executive offices around the perimeter, inevitably they will procure that type of building and adapt it accordingly."

"We still need to know something about users' activities and how they are likely to use the space before the building is designed," responded Mike Jeffery. "That should not only come from the initial client briefing session, but through ongoing dialogue between client and designer."

AMEC's Tim Kempster warned that polling end users' views and then ignoring them is probably worse than not asking their opinions at all. "This is because they end up comparing what they have been given with what they asked for, and finding that they have not got it. Nevertheless, occupancy surveys could be very beneficial to the design process," he added.

Designing by consensus is fraught with all sorts of problems, agreed the delegates, and

action plan

Minimising downside risks

- Limit innovation to small areas, and use tried and tested methods elsewhere.
- Introduce formal design reviews in co-operation with the project design team, and introduce quality assurance verification based on original design specifications.
- Warranty periods should be introduced for both designers and contractors, perhaps linked to a professional indemnity scheme backed up by a defects database.
- Clients and designers should aim to promote open exchanges during the entire design process in a way which does not adversely affect professional liability.

action plan

Occupant satisfaction

- Corporate managers should be targeted to get comfort, energy and productivity benchmarks on to the design agenda.
- Designers and clients should champion the use of occupancy surveys to produce a set of performance benchmarks. These benchmarks should be promoted to both corporate and speculative building clients, and pension funds.
- Hot-desking may require more extensive local environmental control to satisfy a wider range of user expectations, and the controls must be very simple to use.
- Good views, whether external or internal through visual delight like planting or sculpture, are beneficial to occupant satisfaction.

clients can become very nervous if the eventual users of the building get too closely involved, as it could lead to a loss of control over the design and budget. But it nevertheless seems essential to get users involved, as they have the biggest handle on what their requirements actually are.

The key, as Adrian Leaman explained, is not to ask users what they want, "but to study what they need."

A task group looking specifically at the role of senior management concluded that the results of occupancy studies will need to be transformed into benchmarks applicable to the speculative market. "But if buildings are to be designed to occupancy benchmarks," said John Doggart, "then there must be a payback element."

Doggart predicted that occupancy performance benchmarks may have wider currency than existing (but oft-ignored) energy benchmarks, as energy overheads only equate to around £20/m^2/y as opposed to staff salaries which are upwards of £2000/m^2/y.

"In the short term, PROBE-type information should be used to develop a list of building features that will help us avoid the worst problems," said John Doggart.

"That list could then be used within our design briefs, and if cost-benefits could be attached to them they could even help to change speculative design briefs.

"Such a checklist should be promoted to the corporate managers and to the pension funds who are largely the drivers behind the speculative market," added Doggart.

"Ultimately," said Peter Warm, "we facilities managers are trying to identify how much certain changes to the internal environment will cost, and justify expenditure in terms of increased productivity.

"That requires not just a PROBE-type survey, but a set of predetermined strategies and solutions, and some idea of how much they will cost."

benchmarks for better buildin

Finding fault

The vast number of mechanical components in building services means that system faults are unavoidable. Valve leaks sensor drift and fouled heat exchangers lead to higher energy consumption, lower system performance and inevitably the degradation of comfort conditions. How can such faults be predicted and eradicated?

BY RICHARD FARGı

Faults abound in many building services installations. Often problems such as actuator failure, plant tripping and out-of-range sensors can lead to the critical failure of an important item of plant. While these faults are usually easy to spot, far more challenging are the wider set of non-critical faults that are difficult to detect and diagnose.

In a typical building energy management system (bems) there are very few sensors available to observe the operation of subsystems such as coils, and generally the plant operator has very little time available to observe their behaviour and identify any changes. In large buildings, with several hundred components, monitoring all of the systems manually in sufficient detail to detect such changes is not feasible.

When degradation occurs, the performance of the system changes very slowly over time and this makes it exceedingly difficult for operators to spot the faults before significant changes have occurred – the cumulative effect being large increases in energy use and degradation of comfort over long periods.

Even with abrupt failures, such as damper sticking, the limited number of sensors available makes it difficult to trace the source of the observed problems without laborious plant inspection.

The rise in contract maintenance and remote monitoring means that it is highly attractive to both spot faults as quickly as possible and minimise the time spent on site diagnosis and repairing them. The rise in low cost/high performance computing enables the application of advanced automated techniques to perform fault detection and diagnosis (fdd).

Automated fdd involves observing plant operation using installed sensors, and then comparing the operation with that predicted by a mathematical model of the system. Differences between expected and actual operation can be used to diagnose faults. Building services plant differs from the process plant in other industries such as the chemical and aerospace industries because there are generally only a very limited number of sensors available to monitor the plant. In addition, the design specification for hvac plant is general idealistic and insufficiently detailed to pr duce good models of normal operation. Tl tight cost constraints related to plant speci cation, design and installation precludes tl addition of extra sensors and the generati of more accurate design data.

Recognising the potential benefits of tl development of automated fdd routines, tl DoE's Construction Sponsorship Directora funded a three-year BRE project under tl EnREI programme to examine these issu and develop working prototypes[1].

Research was undertaken by the BRE ı gether with the Universities of Oxford aı Loughborough. The work formed the l contribution to the International Energy Age cy's (IEA) Annex 25, an international collab ration concerned with fdd in buildings[2].

The result of the UK work was the develc ment of several generic techniques that ; count for many practical challenges found real systems. These routines were validat on the air conditioning test rig at the BF where real-time fdd operation was demc strated. The routines were shown to be robı and simple to implement in limited computi environments.

The resultant techniques were sufficien 'near-market' to stimulate industrial intere from both controls manufacturers and bui ing owners. At the completion of the EnR project a successful application was ma under the Partners in Technology (PiT) pı gramme to take the work forward and demc strate its application in several existing occ pied buildings.

This work will form the UK contribution the new IEA Annex 34 project "Comput aided evaluation of hvac system performan the practical application of fault detection, a detection and diagnosis in real buildings".

Practical issues

The PiT project is chiefly concerned with t practical issues concerned with using f routines in buildings with different systeı and levels of sophistication. The result of t project will be a set of prototype fdd modu that can be integrated with a bems, anc methodology for the commissioning and operation of the routines.

To apply fdd to a particular system it is necessary to know the behaviour of the system under fault-free conditions. Even if design information were available, expecting a commissioning engineer to configure the fdd algorithm would be unrealistic because it may be necessary to define about 20 to 30 parameters for a system such as a cooling coil.

To overcome this problem an automated performance validation tool is being developed which can inject test signals into a newly (re)commissioned system and validate its performance using very simple design data.

The purposes of the tool are twofold: to validate the system by comparing the performance of the system with simplified models that are highly generic and to collect performance data by injecting test signals into the system. At this stage only crude levels of fault detection are possible, however the validation can measure how close the system is to "typical" performance. The result of applying the tool is a system that is initially fault-free, hence the performance validation tool is a valuable one in its own right.

Once a validated data set has been collected, this is used as the basis for configuring a more sophisticated fdd algorithm that requires more design information. Rather than entering the design information by hand, the validated data is used to calibrate the fdd model parameters until the model closely replicates the plant characteristics. The result of this phase is a performance monitoring tool which is used to continuously monitor the plant and identify changes in the plant due to non-critical faults.

Within the project both tools will be tested in several occupied buildings. This raises a number of issues because the building operators and owners need strong assurance that the tests will not affect the occupants. This is particularly important in multi-tenanted buildings with diverse occupant requirements.

The Eastern Group's Rayleigh office, refurbished by WSP in 1994-95 to include state-of-the-art controls systems.

Performance validation involves the automated injection of test-signals into plant to drive it through different operating conditions, this can affect space temperatures and must therefore be performed outside of occupancy. The tests must be designed so that on resuming occupancy no ill-effects are observed. With performance monitoring it is necessary to gather about 15 points every minute from every air handler being monitored. With the current state-of-the-art in bems outstations and communications this can place a significant overhead on network traffic – with the help of the controls manufacturers it has been possible to design the experiments so that they do not overload the systems.

The first phase of the experiments involves setting up monitoring in buildings owned by two of the project sponsors, in this phase fdd will be performed remotely by gathering data in the bems and accessing it via the modem. During this phase practical testing methodologies will be developed.

The first building is the Eastern Group's Rayleigh office. The building is a typical 1970s design. The building was refurbished by WSP consultants in 1994 and 1995, during which time the controls were upgraded to current state-of-the-art systems and the mechanical plant was replaced. The experiments will concentrate on the plant supplying one large open-plan floor with 330 occupants.

The plant consists of eight CAV air-handlers with heating, cooling and humidification. The plant has a large number of sensors which simplifies the fdd problem, in addition

ENERGY CONSUMPTION GUIDE FOR OFFICES

This forthcoming publication is intended to expand and update the current version of the Energy Efficiency Best Practice Programme *Energy Consumption Guide 19*, the well-respected summary of data on energy consumption in office buildings, *writes Tony Johnson*.

The new guide will draw on a wide variety of more recent source data on monitored office buildings, including work on the PROBE project, to bring *ECON 19* up to date with current good practice. It is also apparent that some types of office building do not fit readily into the categories used by the existing guide, so the descriptions will be broadened to accommodate them.

The new guide will enable surveyors, designers and facilities managers to assess a building's energy consumption, energy costs and environmental performance. By comparing a building with published benchmarks, the scope for improving its performance can be identified.

Essentially the new version of *ECON 19* will:

- ☐ provide information on the energy consumption of various services in office buildings, and provide a means of working out its cost;
- ☐ raise awareness of the environmental implications of energy use in terms of CO_2 emissions;
- ☐ enable the comparison of actual or predicted consumption and/or installed loads with benchmarks, thus encouraging buildings to match or surpass good practice standards;
- ☐ assist in the identification of opportunities to reduce energy consumption while maintaining comfort standards;
- ☐ indicate where more detailed information can be obtained.

The most important reason for revising *ECON 19* is to make the document easier to use for a wider variety of target audiences, many of which were not envisaged for the earlier version. The target audience now includes facilities managers, energy managers and consultants and the whole gamut of disciplines present in building design teams.

The revised version of *ECON 19* will start with the broader issues and move progressively into increasing detail. Thus non-technical readers will be able to learn whether or not they have a problem, and what issues to focus upon to make improvements. Energy managers will be able to compare the performance of individual services with appropriate benchmarks, while readers who are technically aware will be equipped to adapt the benchmarks to special circumstances such as higher business machine use or mixed-mode building operation.

Ultimately, each target audience will have a checklist of actions which they should take on board.

The revised *Energy Consumption Guide 19* will be available in November 1997. Copies can be obtained from the BRECSU Enquiries Office on 01923 664258.

Tony Johnson CEng MCIBSE is a project manager with the BRECSU.

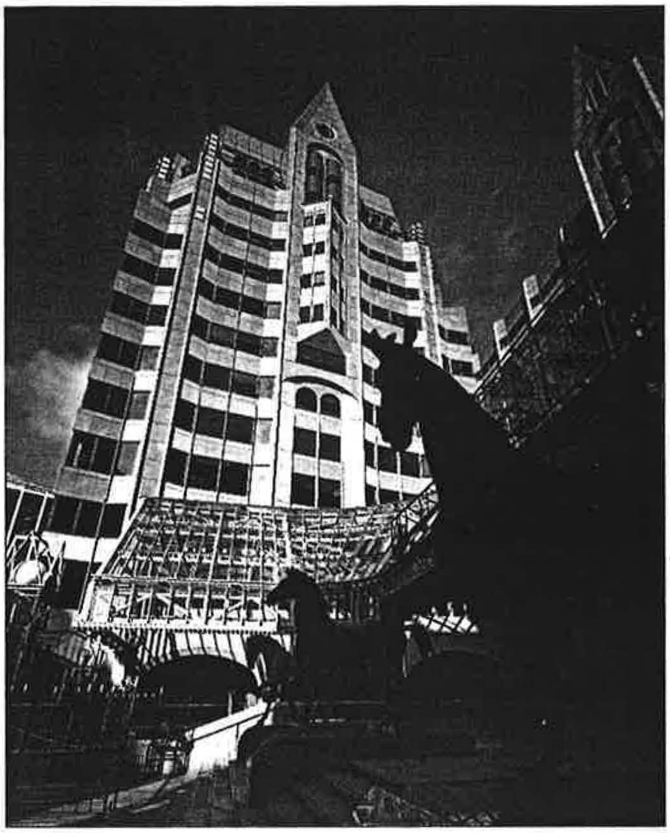
the simplicity of the plant and the availability of design specifications makes this building suitable for the first phase of experiments in which the testing methodologies will be established.

The second building is Minster Court, owned by Prudential Portfolio Managers. This is a group of three large multi-tenanted buildings with mechanical services designed by Ove Arup & Partners. The plant consists of multiple vav terminals on each floor supplied by local packaged air handling units (ahus). The system is more complex than that at the Rayleigh office. Also, the multi-tenanted occupancy makes experiments far more difficult.

About ten out of the 40 ahus will be monitored with two receiving special attention. Practical difficulties in validating the performance and the less extensive number of sensors make this building suitable for demonstrating the degree to which fdd can be applied to existing buildings without requiring significant recommissioning periods.

The second phase of experiments involves testing in buildings owned by other partners in the project, as well as the two described above. This phase will be used to demonstrate how the fdd tools would be set up and operated in practice.

In this phase the fdd will be performed on site, with pcs attached to the bems network. If time allows, a further step will be made by implementing one or both of the tools within a bems Supervisor environment.



Minster Court, owned by Prudential Portfolio Managers, is a group of three large multi-tenanted buildings with mechanical services designed by Ove Arup & Partners. The plant consists of multiple vav terminals on each floor supplied by local packaged ahus.

The Man-Machine Interface

Once fdd algorithms are integrated within the bems, there is a potential for a large increase in the volume of information that the plant operator is expected to deal with. Even at present the volume of alarm information presented by a bems supervisor is difficult to deal with, and often gets ignored.

Supervisors have the capability to present information on significant deviations and out-of-limit alarms that are often the first symptoms of abnormal operation. Often the manpower is not available to monitor these alarms, let alone perform site inspections to determine their causes. Adding raw fdd information to this load would be impractical, and it is very likely that such information would not even be used.

To overcome the problem of information overload the only practical solution is to use an intelligent software-based fault information manager (fim) within the bems. The fim acts as a filter between the operator and the system by condensing information and prioritising it. By combining fault information with data concerning cost-effective maintenance it is possible to present fault information only when repairing the fault is practical and cost-effective.

The fim can also use information concerning non-critical faults to modify control strategies and overcome problems before it is practical to repair them. For example, leakage of only 15% of refrigerant charge in a chiller can lead to a reduction of around 40% in the peak capacity of the chiller. If such a leak can be detected by fdd modules then a fault-tolerant control strategy could temporarily change the sequencing of the chillers to minimise the use of the faulty chiller, thus avoiding inefficient operation.

The fim could use such fault information to automatically contact the chiller maintenance contractor and inform them of the problem. Further problems with chiller tripping are therefore avoided, and the maintenance can be efficiently scheduled to minimise costs before the problem becomes critical.

The future of fault detection

The potential for both cost savings and improvements in overall reliability and therefore occupant satisfaction makes it financially justifiable to apply far greater computing power than is normally available within plantrooms. Typically, the algorithms discussed can run very efficiently with a typical desktop pc.

Currently, pcs can provide 100 to 1000 times the computing power available from a typical high-end outstation. It is therefore likely that in the near future the commercial exploitation of the fdd techniques discussed here will tend towards the use of fault detection servers attached to the bems network.

One present limitation with the application of fdd in hvac is that the limited sensor information available can place limits on the degree to which faults can be detected. In some cases it is only possible to narrow down the location of a fault to a particular subsystem, eg a cooling coil, but it is not possible to diagnose the exact cause of the fault, only to give a list of the most probably causes.

The addition of extra sensors is the only solution to this problem. Given their cost this is unlikely to occur quickly. It is expected that the successful application of such fdd techniques will be one of the major driving forces in justifying the addition of extra sensors (eg air and water temperature and flow sensors), as well as providing the impetus for the use of more powerful outstations with faster processors and greater memory.

FDD routines can be embedded in hvac plant in a variety of ways. The increasing integration of building services systems means that fault information will be available from components ranging from lighting to lifts. Packaged components will generally contain dedicated fdd routines that can provide fault information to the fim, provided that suitable integration is achieved.

The increasing use of microprocessor controllers within the plant components and the standardisation of communication and information transfer protocols will allow such an integrated approach to be taken in the near future.

It is expected that automated fdd technology will start to become commercially available within the next couple of years.

Richard Fargus BEng is a senior researcher at the Building Research Establishment.

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[2]"Identifying faults in hvac systems", *BSER&T*, Vol 17(3), pp B13-B34, 1996.

The Partners in Technology (PiT) partners were the BRE, the University of Oxford, Loughborough University, Caradon Trend, Prudential Portfolio Managers, the Eastern Group, Serck Controls, Ove Arup & Partners and S G Warburg.

PROBE 9

benchmarks for better buildings

Eight buildings were studied under the PROBE research project – four offices and four non-commercial buildings. In the penultimate article in this PROBE series, we focus on the engineering and energy issues of all the study buildings to draw some conclusions on building performance. How well do lighting controls work? Are energy efficiency targets being met, and how important is the quality of construction to delivering good comfort conditions?

BY BILL BORDASS, ROBERT COHEN AND MARK STANDEVEN

THE NON-OFFICE BUILDINGS

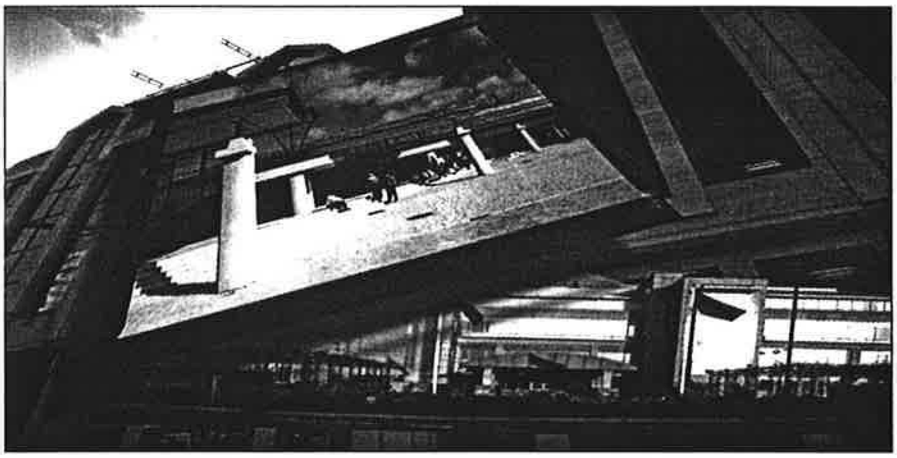
Three of the non-commercial buildings in the PROBE survey can loosely be defined as educational buildings, although they differ markedly in many respects[4,5,8]. The fourth building is a small medical centre[6].

The award-winning School of Engineering and Manufacture at De Montfort University in Leicester was completed in 1993. Named the Queens Building, the thermally massive building is mostly naturally ventilated.

The Cable & Wireless (C&W) Training College was completed in 1993 on the outskirts of Coventry, and won a Building of the Year Award in 1994. Three separate low-rise buildings provide high-quality teaching and residential accommodation for long and short-term courses in technology, management, sales and account management.

Woodhouse Medical Centre was built in 1989 by the 'green' architects Brenda and Robert Vale. It is occupied by two general practices and one dentist. Anglia Polytechnic University's Learning Resource Centre (also called the Queens Building, but hereafter referred to as APU) is a low energy, naturally ventilated building.

Hours of occupancy vary markedly for each building, although they all have longer hours of occupancy than most office buildings. C&W, for example, operates an intensive eight-hour day, while the dentist at Woodhouse Medical Centre provides evening surgeries.



Services performance: heating

All the buildings are heated by gas-fired boilers, although De Montfort has a sequence of combined heat and power, a condensing boiler and a high efficiency boiler. C&W has high efficiency boilers, while APU and Woodhouse both have condensing boilers.

The comparatively low installed boiler power for APU and Woodhouse (66 W/m^2 and 42 W/m^2 respectively) reflects the low heat losses from two very well insulated buildings. However, APU has experienced underheating in the north zone owing to insufficiently sized perimeter heating which was not resized following a cost-saving change from triple to double-glazing in that zone. This was exacerbated by the external temperature sensor being located on a west-facing wall.

The medical centre avoids hws pipework by using point-of-use electric undersink storage heaters. Standing losses from these units are high, accounting for perhaps half the building's 50 kWh/m^2/y electricity consumption.

Services performance: ventilation

All four buildings have a range of ventilation control strategies, from Woodhouse Medical Centre's very simple manual window opening to the mixture of manual and automatic systems at De Montfort and APU.

At APU, the atrium vents and window toplights in open-plan areas open automatically according to zone CO_2 and temperature sensors. There is no manual override, which has proven to be an occasional irritation owing to cold draughts on very sunny but cold winter days, outside noise and traffic fumes.

There is a self-learning night cooling algorithm, but this has suffered a few commissioning difficulties and at the time of the survey had not operated as intended.

The medical centre has a mechanical ventilation and heat recovery system (mvhr), intended to reduce heat loss during the heating season. The system has no time control and relies on manual switching. Its fan energy would be significantly reduced if it were switched off outside occupancy.

The mvhr system cannot be used for overnight cooling in summer because the heat recovery element cannot be bypassed. In practice, the system was not understood and has been out of use for several years. Indeed, one doctor's practice has installed split dx room air conditioners.

The medical centre's trickle vents have been varnished over. Ventilation now relies almost totally on manual window opening, as the roof Velux windows are not accessible.

Services performance: lighting

Each of the four buildings incorporate reasonably efficient lamps, apart from some retrofitting of 300 W halogen uplighters at the medical centre due to perceived inadequate light levels. However, in all the buildings the interaction between daylighting and artificial lighting reveals the ease with which control instabilities can occur.

APU has suffered commissioning problems with the photo-responsive controls and a significant minority of lights are on permanently as emergency lighting. In the machine hall at the De Montfort building, the striking characteristics of the high-bay SON lamps do not encourage frequent manual switching, so they stay on all day regardless of available daylight or whether heavy machinery is operating.

The occupancy sensing system at De Montfort has also not been wholly successful. Economy was sought by doubling up the passive infra-red detection lighting control elements as intruder sensors for the bems-based security system. This sensing system has proved insufficiently sensitive both in terms of coverage and response time, leading to them being overridden as lighting controllers. They may be improved in the future.

At C&W, manual switching is effective in classrooms but not in communal areas like corridors. Here, the tungsten lamps are on most of the day independent of occupancy. In the C&W leisure centre, a lighting controller is so user-unfriendly that it is not used, resulting in all the lights being on at least 18 h/day.

Daylight and glare problems have affected all the non-office buildings, an important finding given that daylight is an intrinsic element of passive design, the fundamental basis of all four buildings.

APU has suffered from glare problems in the top floor areas designated as office space. Despite tinted film having been applied to the top lights of the south-facing windows, vdu users are still bothered by glare from low winter sun penetrating the perforated mid-pane blinds in the main view windows.

Although the use of this space as offices is temporary and will revert to library area in the future, it does highlight the delicate balance between the success and failure of a daylit space in respect of occupant satisfaction.

On lower floors, twin internal light shelves of semi-transparent reflective glass protect the perimeter areas for high altitude sun and sky glare, but have proved ineffective in enhancing light levels deep into the space because the light is reflected into the coffers of the waffle slab ceiling.

All the buildings save substantial amounts of electricity by not using mechanical ventilation or cooling to maintain comfort during summertime. They rely on a combination of measures to avoid overheating, such as natural ventilation, daylighting, exposed thermal mass, solar shading and night ventilation.

To compare the risk of summertime overheating in the buildings a simple (and provisional) scoring system has been used which accumulates credits for relevant features (table 1). While some features are more important than others, and their effect is not neatly cumulative, the exercise is a useful checklist.

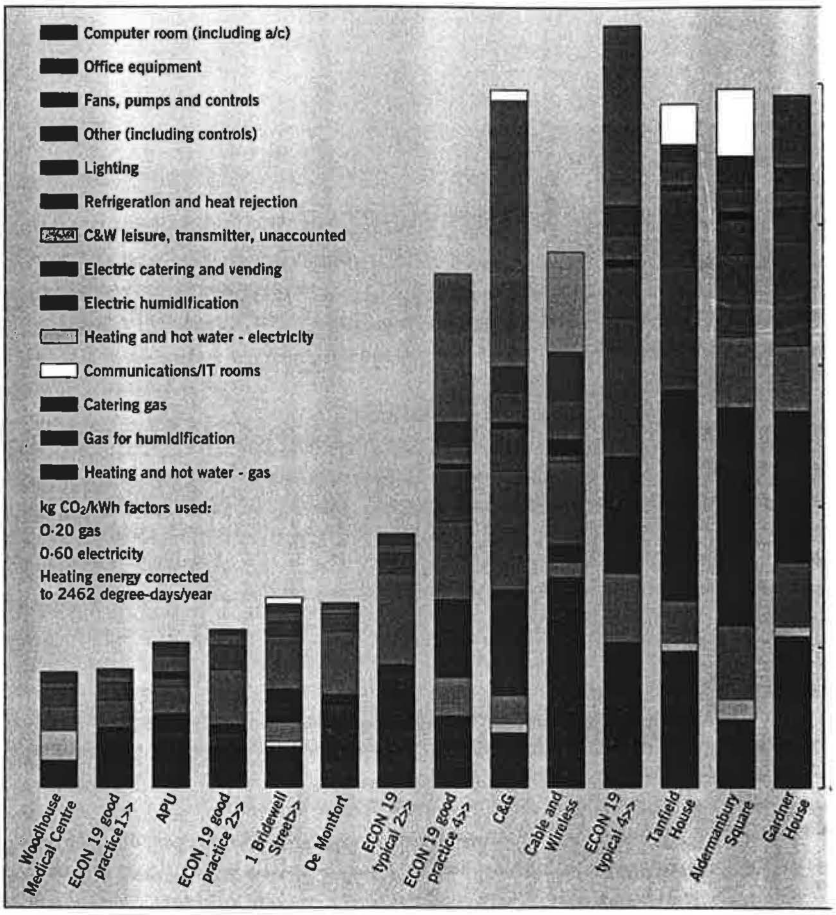


FIGURE 1: Annual CO_2 emissions for the PROBE buildings measured against *ECON 19* benchmarks.

There is a close correlation between ranking of the buildings according to overheating risk and ranking according to acceptability of summer temperature in the occupancy surveys, suggesting that all the buildings have only been partially successful in providing acceptable conditions during the summer. In mitigation, occupants of all the buildings were questioned after they had experienced one of the hottest summers (1995) on record.

Energy consumption

Accurate measurements of end-use energy consumption were not possible due to the lack of sub-metering in the study buildings. The general adage of "what you can't measure you can't manage" also seemed to apply.

At 45 kWh/m² for gas, the medical centre came out substantially less than the *ECON 19* good practice benchmarks (figure 1). Adding the electrical consumption for hws at 17 kWh/m², the building was very similar to the good practice benchmark for CO_2.

The absence of extensive fans, pumps and chillers in what are predominantly naturally ventilated buildings ensures that hvac electricity consumption is a small proportion of total electricity consumption for each building. However, hvac consumption is higher in all the PROBE buildings than the type 1 and type 2 typical office benchmarks. This is largely due to the fact that there are longer hours of occupancy.

The relatively high electricity use at is almost totally down to non-hvac use: CO_2 emissions are 20% higher than ty Attempts are being made to rectify the ing's high energy consumption, and it is able that the building's energy perforn will be better by the end of 1997.

In terms of electrical lighting consum APU and the Woodhouse Medical Centre very low consumption, although improve could be made. The lighting consumpt the Queens Building is over double tl APU, but still comparable with a good pr type 2 office.

THE OFFICE BUILDINGS

Curiously, the four commercial buildings ied under the PROBE series of post- pancy surveys were air conditioned offic financial services companies[1,2,3,7].

Three of the buildings were occupi 1990. They are Cheltenham & Glouc (C&G) Building Society's 20 000 m² head ters, Tanfield House, the 24 000 m² administrative centre for Standard Li Aldermanbury Square, the 8000 m² ce London hq for Standard Chartered I Gardner House, the hq for the Homeow Friendly Society, was occupied in 1994.

All the buildings are of a high quality: Ta House won the 1992 Office of the Year av C&G won a National Lighting Award in Aldermanbury Square a Beta energy a and Gardner House an architectural aw

Tanfield House has two very deep-plan office floors, 120 m across in some directions, penetrated by three circular atriums. C&G is a rectangular, four-storey symmetrical building with a central atrium.

1 Aldermanbury Square is a street corner block with six floors above ground and three basement floors, while Gardner House is a two-storey, largely open-plan office building with three short wings projecting from three corners. The smaller, lower ground floor is partially cut into the hillside of the rural site.

All the buildings possess varying amounts of stone cladding with infills of aluminium curtain wall/window units. All are concrete framed except 1 Aldermanbury Square. Envelopes are conventional in design, construction and insulation, except for Tanfield House which has double-skin window walls.

All the office buildings exhibited the 1990s trend towards increased hours of occupancy, requiring plant to run from 07.00 to 21.00 h on weekdays. Three of the buildings also have their hvac systems running for at least half a day on Saturday. There is occasional (and increasing) operation on Sundays, particularly at Tanfield House.

Ventilation and space cooling

The C&G and Gardner House buildings have both suffered major problems with excessive air infiltration. C&G has been partially cured, but parts of the building are still cold and require boosted compensation and additional electric heaters. Problems at Gardner House persist, requiring extended hours of operation and raised flow temperatures, in addition to some local electric heaters.

C&G, Tanfield House and Aldermanbury Square all had initial problems with chilly reception areas, which required additional enclosures and/or heating. Two small communications rooms at C&G were initially connected to the office vav system, but as they required cooling at night, one of the four central vav plants had to be left running. Self-contained dx units were fitted to overcome this problem.

All the buildings use chilled water systems, and are all air cooled except for Aldermanbury Square which has cooling towers and an ice storage system.

At Tanfield House the heat is rejected into office exhaust air handling units (ahus), avoiding the need for separate condenser units. However, the resultant coupling between office ventilation and heat rejection has led to problems with the full fresh air system, such as the need to operate the office exhaust fans whenever heat needs rejecting, for example outside normal occupancy hours.

Increased pressure drops and higher exhaust fan energy consumption has also resulted. Averaged over annual operating hours only about 7% of the design cooling load is being rejected whereas the coil resistance exists for 100% of the time.

In addition the exhaust strategy also means that there can be a lack of heat rejection on very hot days. As Tanfield House does not meet its peak airflow capacity, the heat rejection capacity drops more than pro-rata. Raising the exhaust airflow to improve matters creates a vicious circle by increasing the cooling requirement for air tempering. To achieve stability the office temperature set-point also has to be raised, leading to lower chiller efficiency and reliability owing to increased condensing temperatures.

Aldermanbury Square's ice storage system was the first of its kind, installed predominantly for space rather than for energy saving reasons. Unfortunately, on this site and with the existing supplier at the time of the PROBE survey, a day/night tariff gave no savings as not enough electricity was used at night to counteract the higher cost of day units. The lesson for other ice storage systems is to make sure the appropriate tariff is negotiated.

It appears that the operational problems experienced with the ice storage system were a result of the technology being too complex for what was, after all, a speculative building.

System performance and reliability

Although the services in the commercial buildings have performed well, some general lessons have emerged.

Eddy-current drives, as used on the vav plants at Tanfield, are not ideally suited to building services fan and pump loads where power requirements decrease rapidly with speed. The resulting low efficiency has not only reduced energy cost savings, but the associated low power factors and high reactive power have caused switchgear to overheat. Inverter drives, as used at C&G, are now being retrofitted. Concerns about electrical interference from the inverters appear to be unfounded.

Office equipment and some discharge lighting units and ballasts (particularly compact fluorescent) often have poor power factors and waveforms. As the use of these products increases, some buildings appear to be suffering problems with electrical interference and, sometimes, overheating problems.

Primary air temperatures were raised in all the study buildings to improve comfort and to compensate for over-estimated internal gains. This has sometimes reduced energy consumption for cooling and heating, but has increased vav fan power and, particularly at Gardner House, has also raised the heating load.

TABLE 1: ASSESSMENT OF FACTORS AFFECTING SUMMERTIME PERFORMANCE

	Queens Building, De Montfort		Cable & Wireless (classrooms)		Woodhouse Medical Centre		APU Learning Resource Centre	
Feature	Assessment	Notes	Assessment	Notes	Assessment	Notes	Assessment	Notes
Exposed mass	•••	Exposed soffits, fairfaced brickwork	•	Raised floor and lightweight clad ceiling	••	Exposed floor and walls	•••	Coffer ceiling
Ceiling height	••	>2·5 m	•••	3·6-5·1 m	••	2·5-4·5 m	•••	>2·5 m
Plan depth	•	30 m	••	9 m	••	12 m	•	30 m
Night purge	•••	Yes, bems controlled	•	None	•	None	•••	Not fully operational
Ventilation capacity	•••	Crossflow and atria or stacks	••	Cross flow via opening toplights	•	Rooms have single-sided vent	•••	Crossflow with two atria
Ventilation control	•••	Automatic and manual, some CO² sensing	••	Manual control powered action	•	Manual opening windows and rooflights	••	Mostly automatic only
Lighting control	•••	Timed with local manual, photo and PIR not fully functional	•	Manual only	•	Room switches	••	Not fully operational
Lighting gain	••	13 W/m²	•	17 W/m²	•••	8 W/m²	••	13 W/m²
Daylighting	•••	Sidelights, rooflights, northlights	••	Reasonable	•	Privacy blinds	•••	Atria and lightshelves
Solar gain	••	Good shading, deep reveals	••	Overshading and few south	•••	No direct sun	•	Small windows and shades
Equipment gain	•••	9 W/m²	•••	1·5 W/m²	•••	4 W/m²	•••	3 W/m² current
Occupant density	•	5 m²/person	•	5 m²/person	••	10 m²/person	•••	23 m²/person
Clothing choice	•••	Casual	•••	Casual dress	•••	Casual	•••	Casual
Total internal heat gains	–	42 W/m²	–	38 W/m²	–	22 W/m²	–	20 W/m²
Overheating performance	•••	31 points	••	24 points	••	25 points	•••	27 points

Key: • Poor •• Average ••• Good • Feature included as part of the building design, but not yet fully operational

A key lesson to be learned is that extended hours of operation and diversity of use make it very important that engineering systems are designed to respond in a graduated manner to varying and sometimes small loads.

Energy consumption

Figure 1 shows annual CO_2 emissions for all the buildings, using conversion factors of 0·20 kg/kWh for gas, and 0·60 for electricity. The data is bracketed between *ECON 19* "good practice" and "typical", and includes one of the best air conditioned offices surveyed under the EEO's Best Practice programme: 1 Bridewell Street. The electricity factor represents a typical level for the years in which the consumption data was collected – the current industry value is lower.

C&G is near the good practice level, while the others are just above typical. Energy consumption at Gardner House is anomalously high (by at least 20%) due to the extended plant run times, necessary until airtightness problems are sorted out. Gas/electricity consumption is currently 20% higher.

Although the *ECON 19* benchmarks were established in 1991, they are based on updated data from energy surveys in the late 1980s. Several things have changed in the meantime: an increase in electronic equipment, an increase in communications equipment (justifying a new category for communications rooms) and the introduction of steam humidification (many owners of 1980s buildings disconnected their evaporative systems owing to concerns about airborne diseases).

Although the installed loads in communications rooms are often modest, annual energy consumption tends to mount up owing to their 24 h operation. Standby air conditioning units are often kept running to improve security, not only adding to fan energy consumption but, if the plant is not well supervised, there can be simultaneous heating and cooling or humidification and dehumidification.

Hours of occupancy have also been increasing, as these buildings confirm. Making allowances for this – and for added humidification – building services consumption is generally just below a modified "typical" level.

In terms of heating and hot water, C&G and Aldermanbury Square are similar to good practice levels, while the other two are at, or above, typical. The high energy consumers have full fresh air systems with no recirculation or heat recovery, exacerbated by high ventilation running hours in both buildings: an estimated 4500 h at Tanfield and 4200 h at Gardner House, against 3500 h in the other buildings.

Although representing only a 10% increase in overall CO_2 emissions, is this too high a price to pay in the quest for better air quality?

One issue which does not seem to be widely appreciated is the extension of heating seasons because cold air needs preheating to avoid discomfort, even sometimes during the morning of a hot summer day. The problem is worse where recirculation is not possible and for displacement systems where supply air tempering through room air mixing is inherently restricted.

The cooling energy saved by a displacement system also translates into some increase in heating load.

The high energy consumption at Gardner House appears to be related primarily to control and energy management. Air infiltration has made it difficult to maintain a stable environment and caused all hvac systems to default to "on".

With the low occupancy densities at Gardner House, the 4000 h/y run times of the chillers seems high bearing in mind that spot measurements on a hot afternoon indicated that one chiller could carry the peak load.

Unfortunately, much of the cooling energy appears to have been devoted to removing heat put in by the boilers, either through the perimeter heating or in plant which tended to hunt (at least during the survey). If the uncontrolled infiltration can be improved, energy consumption at Gardner House could be substantially improved.

As always, fans tend to account for the largest portion of electricity consumption in central air conditioning systems. In spite of its low air change rate (3 ac/h) Gardner House is also above typical owing to relatively high running hours and specific fan power.

C&G performs between typical and good practice, while Tanfield is above typical, partly owing to its longer occupancy periods and operating hours. Both, however, consume rather more than might have been anticipated owing to the increase in supply air temperatures and, consequently, volumes.

Surprisingly, the highest fan energy consumption occurs at Aldermanbury, despite a low temperature air supply system which might have led to lower fan energy consumption. Not only do the smaller duct sizes have increased pressure drops for a given flow rate, but the management has raised supply temperatures (and hence flow rates) to improve comfort and refrigeration plant performance. The energy consumption of the fan-assisted terminals is also not trivial.

Pump energy consumption is below good practice in C&G, but three times typical in the other three buildings. This difference is largely explained by the tight energy management of the heating and chilled water pumps at C&G, and very liberal operation elsewhere.

Steam humidification is a substantial user of energy, with high CO_2 emissions, particularly for the electric systems. Apart from C&G, there appeared to be scope for considerable savings by tighter energy management in the survey buildings.

Lighting

Three of the buildings possess tinted glazing which typically transmitted 30% or less of the available daylight. Although perimeter lighting had automatic high/low switching controls at Tanfield and dimming at Gardner House, the reduced daylight made energy savings relatively small.

C&G was designed to use more daylight, with clear glass and external motorised awnings. These were omitted following client concerns about appearance and maintenance. Consequently, daylight and sunlight c
glare, particularly on computer screens
curtains were installed, many of whi
now frequently closed.

The atrium rooflight at C&G produ
attractive daylit coffee/meeting area
side the top floor corridor, but dark finis
lower levels tended to require the mair
ing to remain on. As this was manually sw
from reception the lights tended to rem

Other lighting features at C&G scor
ter, such as colour-coded light switch ro
red for circulation, white for lobbies and
for general areas. This was a helpful
which avoids the lights being used un
sarily, particularly once the silver sw
had been rewired after completion to
spond with lighting layouts.

Lighting energy use in all the buildi
below typical, and at Aldermanbury Sq
is near good practice, with the lowest d
at 12 W/m² and the most efficient at 2
m²/100 lux. When *ECON 19* was writt
W/m² was regarded as very good. Today
installations lie within 12-18 W/m².

In general, the automatic lighting co
delivered less in energy savings than
have been expected. Daylighting was n
ticularly good in any of the study buil
and in open-plan areas the tendency to c
to "on" was widespread. Given its low d
of occupation, it is surprising that Ga
House was not closer to the good pr
level. Partly this resulted from a rel
high illuminance standard of 600 lux a
use of compact fluorescent lamps whi
less efficient than full-sized ones.

Additional energy consumption was
unintended consequences of the aut
controls, in particular occupancy sensors
ing on lights whether or not they we
quired, for example when popping into a
or passing through an open-plan area.

Once activated, the lack of light sw
means that the lights stay on for 15 min
the cellular offices, and until the end of t
in the open-plan areas.

The daylight-linked dimming could
set quite as precisely as one might
thought. This was largely due to the fa
people wanted the illuminance inside
spond to that outside, as well as the s
being affected by light reflected upward
venetian blinds or from white paper on
This has led to a widening of the contro
and more lighting than was strictly nece

At C&G, energy consumption by office
ment is typical, and at Tanfield Hous
more, while the other two offices wit
low occupancy densities use less.

In all the offices, a relatively high prop
of people undertook routine screen-base
and were quite diligent at turning off
ment when they left the office, typicall
ing about 10% of the equipment on over

Equipment with "slumber" modes
always very energy-efficient, and it al
courages people to develop the habit o
ing things on. Over a year a single W
unnecessary power chalks up an extra 1
m² for one 9 m² workstation.

The effects of people on energy

All the buildings use some relatively advanced technologies, and interestingly all experienced some problems either with automatic controls not operating as intended, or with occupants not understanding the design intent and therefore inadvertently misusing or even not using the manual controls.

It is apparent from all of these buildings that occupants – particularly in buildings which can be described as advanced naturally ventilated structures – would benefit greatly from the dissemination of a short, non-technical, jargon-free manual explaining the building's design intent.

In some of the buildings occupants received inadequate training and either no user manuals or, at best, incomprehensible ones. In one building the occupants seemed unaware both of the design intent and of a contractual dispute which prevented the resolution of some teething problems.

When new technologies are introduced, post-occupancy teething problems will inevitably arise. Design teams should be honest with their clients, who should recognise problems as an inevitable consequence of exposing occupants to the unfamiliar. Clients should also be prepared to pay for quarterly site visits by the design team for at least a year after commissioning.

Automatic controls in naturally ventilated buildings came about because of a general dissatisfaction with manual controls in open-plan environments. People don't make changes until they are desperate, and when they do they offend those who desire the status quo. When it comes to energy-saving decisions, people forget to switch things off or, specifically, don't remember or can't be bothered to leave vents open for night venting.

Automatic controls have been introduced with far-from-perfect results. Of course, the industry and building users are still climbing the learning curve, and so many of the problems will be resolved in time. Other problems, though, result from false expectations that technology will get the building out of trouble. In practice, it is often difficult to solve one problem without creating several more.

PROBE 10 in next month's issue will cover the results of the PROBE occupant surveys.

PROBE References

[1]PROBE 1: Tanfield House, *BSJ*, 9/95.
[2]PROBE 2: 1 Aldermanbury Square, *BSJ*, 12/95.
[3]PROBE 3: C&G Chief Office, *BSJ*, 2/96.
[4]PROBE 4: Queens Building, De Montfort University, *BSJ*, 4/96.
[5]PROBE 5: Cable & Wireless Training College, *BSJ*, 6/96.
[6]PROBE 6: Woodhouse Medical Centre, *BSJ*, 8/96.
[7]PROBE 7: Gardner House, *BSJ*, 10/96.
[8]PROBE 8: APU Learning Resource Centre, *BSJ*, 12/96.

More detailed information on the PROBE buildings is contained in the conference papers for Buildings in Use '97. Proceedings of the conference are available on request from the CIBSE. Telephone 0181-675 5211 for details.

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Key design lessons

Airtightness Two of the commercial buildings suffered serious airtightness problems. Recent BRE and BSRIA research has shown that this is not unusual, ironic given they were ostensibly "sealed" buildings. Most of the problems arise at the junctions, so more attention to detail is needed in design, specification, workmanship and testing.

Gardner House: air leakage seriously affected fuel efficiency and comfort levels.

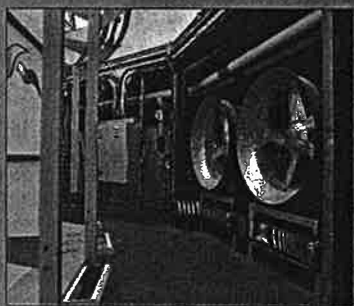
Woodhouse Medical Centre: good comfort levels, but occupants failed to understand the manual ventilation controls.

Internal gain assumptions from office equipment were uniformly much too high. This has led to higher plant costs, problems with comfort and operation, higher energy use and sometimes even the unnecessary installation of air conditioning.

Revenge effects arose with new technologies, particularly lighting controls, difficulties with managing ice storage systems and relatively unfriendly interfaces to bems and controls. Designers must make systems simple, efficient, robust and usable.

At APU, the twin internal light shelves of semi-transparent reflective glass have proved ineffective in enhancing light levels deep into the space, as the daylight is reflected into the coffers of the waffle slab ceiling.

Tail wagging the dog syndrome was apparent in many building services systems, specifically where pumps, fans, chillers and boilers were found to be operating for very much longer hours than the designers had anticipated. Services must be designed to avoid small requirements bringing on large systems, and for all systems to respond efficiently to varying demands over a wide range.



Heat recovery means constant system pressure drops at Tanfield House.

Lighting controls in all PROBE buildings delivered rather less than they promised, largely due to a lack of appreciation of occupants' real requirements. Occupant co-operation with automatic controls is critical – once faith in the system is lost it may be difficult to get it back again.

Building energy management systems are bedevilled by unfriendly user interfaces and complex narratives. Scrolling through umpteen application windows to get to the one you want is sometimes worse than memorising a DOS mnemonic. There is also an onus on designers and bems suppliers to ensure that software can generate outputs which clearly show whether or not a particular function (eg night ventilation) is actually working properly.

De Montfort: the striking characteristics of the high-bay SON lamps do not encourage frequent manual switching.