Building intelligence in use: lessons from the Probe project

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The Probe project undertakes post-occupancy surveys of technically interesting non-domestic buildings and provides feedback on how they are performing. This paper outlines how the buildings surveyed to date are coping with emerging building intelligence technologies and the degree to which these improve energy performance and occupant satisfaction. It reveals that intelligent controls are only as good as the strategy, design, specification, installation, commissioning, handover and facilities management which establish, nurture, fine-tune and maintain them and the associated services in good operational condition. At present the industry does not find it easy to turn design intentions into reality. Improvements are also required in fundamental understanding; in closing the gaps between design aspirations and occupant and management perceptions and requirements; and in controls ergonomics.

Introduction

The Probe research project undertakes and publishes post-occupancy surveys of technically interesting non-domestic buildings completed in the last 2 to 5 years. Its intention is to provide feedback to designers, their clients, government and the industry feedback on how recent buildings are performing; the extent to which innovation (and indeed established practice) has been successful; and where improvements might be made. So far thirteen buildings of all sizes have been investigated, ranging from advanced naturally-ventilated designs to fully air-conditioned office headquarters. The surveys focus on occupant satisfaction, energy efficiency and technical performance of environmental control systems; and provide valuable insights into the opportunities and pitfalls of increasing building intelligence. This paper reviews how these 1990s buildings and their occupants are coping with the emerging building intelligence technologies. It suggests how the industry, and in particular designers, facilities managers and clients can learn from their experiences.

Effective building controls, whether local or central, manual or automatic, have been found to be key to achieving good energy performance and occupant satisfaction. While the Probe studies identified some important successes in this area, they also revealed widespread scope for further improvement, including:

- better understanding of occupant requirements and behaviour;
- more effective transformation of design intentions into built reality;
- a commissioning process which recognises the need for support beyond practical completion – with programmed involvement of management and the design team;
- better understanding of designs by management – and management by designers;
- better provision, functionality and usability of control interfaces: frequently items that would have been desirable were either absent, inappropriate, or out of reach.

Aspects of intelligence considered

This paper deals with those elements of building intelligence which affect energy performance and occupant comfort (thermal, air quality, visual and sometimes aural). These in turn relate to issues which are coming under increasing scrutiny:

- Productivity: perceived productivity is closely related to comfort - or more properly avoidance of discomfort ([i]);
- Greenhouse gas emissions, when the government's commitments at Kyoto ([ii]) are translated into regulatory and fiscal instruments.

Building intelligence intended to maximise occupant comfort may or may not reduce energy use, but well-designed and managed buildings can be both comfortable and energy efficient ([iii]). Sometimes the two objectives are in conflict, e.g. when heating is required in cold weather. Sometimes they can be in harmony, as when unnecessary electric lighting is causing overheating. Often they are totally decoupled, as when lighting, ventilation or plant is running needlessly or inefficiently, but is not actually bothering the occupants.

Commonly, requirements to satisfy one form of comfort conflict with those required for another, e.g. an open window providing a cooling breeze but letting in noise or pollution from outside. Building intelligence has to cope with all these conflicts, plus the differences in perceived ideal conditions between occupants owing to age, sex, location, activity or plain personal preference. In addition, building intelligence which aims to reduce energy consumption usually has to compensate for a lack of interest from occupants - for example, people commonly fail to switch off unnecessary lighting.

Building intelligence can also help to improve performance, or compensate for the lack of features which building occupants hold dear, like openable windows, control over noise and privacy, views out and natural light. However, Probe and other studies suggest that much progress is still to be made, especially in improving perceptions of effective control by building occupants. In a cellular office, the level of control an occupant should have may be reasonably clear: in open-plan areas, the problem becomes much more difficult, owing to the wide range of individual and group requirements and potential conflicts.

In practice, what initially seems a simple, common sense task for building intelligence - to ensure comfort whilst avoiding unnecessary energy use - is seldom straightforward. As advances in technology make yet more options available, the problem continues to tax the ability of design teams, facilities managers and clients; and often the patience and tolerance of occupants.

Notwithstanding all the implications of supposedly advanced automation, our experience is that the best intelligence in most buildings lies in the occupants themselves. The challenge for designers and manufacturers is then to support them with appropriate and understandable systems with readily-usable control interfaces, which give relevant and immediate feedback on performance.

A key design issue is what aspects of building control should be implemented automatically, and the extent to which they should be pre-programmed by the designer and controls specialist, or accessible to by the manager or the individual occupant. Some of the issues were explored by two of the writers in a scoping study five years ago ([iv]): the current work has identified the need for further effort on integration of user and automated controls if the true potential of building intelligence is to be realised effectively.

Building intelligence in the Probe buildings

Introduction

The thirteen buildings studied so far had the following characteristics:

Fully air-conditioned head office or administrative centre	4
Principally naturally-ventilated academic building	4
Mixed mode courthouse, including offices	1
Mixed mode office (one pre-let, one academic)	2
Naturally-ventilated office	1
Naturally-ventilated medical centre (with added mechanical systems)	1

Nine buildings had electronic building management (BMS) systems at the outset. Another (Elizabeth Fry[v]), had BMS rapidly added once independent monitoring convinced the management that it could not run the building effectively without the information a BMS could provide. Ironically but not unusually, the management then found that they could run the building very efficiently more simply than the designers had anticipated. However, they needed the management information and authority that a well-configured BMS afforded to give them the knowledge and confidence to do so.

In only three buildings (including Elizabeth Fry) could the management be said to have had a thorough understanding of the engineering systems and to be making really effective use of the controls. Even in these, technical and operational shortcomings did not always permit systems to be operated in accordance with design intent. Ten buildings had shortcomings which inhibited economical operation, commonly with systems defaulting to “on”. This frequently applied to boiler and chiller plant – which tended to operate year-round whether really needed or not.

HVAC

In all four AC buildings (3 VAV and one displacement ventilation with chilled beams), BMSs provided automatically controlled environments for the occupants. The four also had professional facilities management teams, three with in-house M&E maintenance staff. The other used visiting contractors, who inevitably had less understanding of organisational needs and were less able to operate the systems accordingly: this led to a particularly liberal control regime.

Other key characteristics included:

- All had a culture of “service before economy”, so energy management did not have a high priority.
- The two smaller buildings (4000 and 8000 sq m gross) had nominally the more innovative HVAC systems. However, in spite of also being much less densely occupied, they had the higher levels of HVAC energy consumption per sq m (well above “typical” in ECON 19([vi]) and carbon dioxide emissions a staggering five or six times higher than the lowest-energy Probe buildings. They also had only average levels of occupant comfort. Essentially their engineering and control systems were too unfamiliar and complicated for the management available in such relatively small buildings. They also had tricky technical problems, which the management found difficult to surmount.

- The two larger buildings (20,000 sq m gross and more) were much more densely and intensively occupied, but had lower levels of energy consumption and unusually high occupant satisfaction, reflecting both on their design and on the high standards of facilities and engineering management. Interestingly, the lower-energy of the two was also the most conventional in its design; and following the Probe survey the management of the other has significantly reduced its energy consumption too.

The lessons from the above are that:
- Sophisticated services and controls require excellence in their management.
- The necessary level of management is more likely to be found in the larger buildings.
- At present, management generally is likely to be much more concerned with occupant satisfaction than energy performance.
- Achieving tight and efficient operation usually seems to require too much management input. This is often exacerbated by poor user interfaces: as was clear in the two smaller buildings. Even in the larger ones, with staff in good command, operators felt that interfaces to BMS and controls systems could have been more user friendly.
- Once energy performance does become a priority in this type of building, major savings could made; and building intelligence will then have very significant potential in helping management to achieve its objectives.

The MM and NV buildings were generally more pioneering than the AC examples. Of these, six had a central BMS, but a far smaller facilities management resource and more (but not always sufficient) opportunity for the occupants to control their own environment. The two smallest buildings (at 1000 sq m or less) had no BMS. One intermediate size building (a 4000 sq m office) had a BMS outstation but no installed central supervisor: its controls had been regarded as “fit and forget” but - as at Elizabeth Fry – would have benefited from fine-tuning.

Amongst the most intriguing applications of building intelligence were attempts to automate natural ventilation. This came about because designers have sought to overcome the limitations of manual control in open-plan environments by using more sophisticated control technology. However, controls in open-plan areas are proving difficult to perfect - the disadvantages of automatic control apply, while the use of complementary manual controls including manual override is constrained. For instance:
- it can be awkward to reach consensus on window opening, blind position, lights etc.;
- to minimise the need for change, systems lapse into “default” states which minimise conflict and inconvenience but are not optimal, e.g a bit hot, or blinds-closed-lights-on;
- people then only make changes when personal “crises of discomfort” are reached[vii];
- when such a situation arises, people want rapid response; but then
- the scope for dissatisfaction is made greater by the conflicting requirements and often inherently limited adaptive opportunity available for open-plan occupants.

In addition, individuals are not good at making anticipatory responses, for example, leaving vents open for night cooling. To overcome such difficulties, it made sense to use automatic controls, but their implementation in practice has proved more difficult than had been anticipated. Natural ventilation is firmly associated with manual control. An openable window is a safety valve for the alleviation of discomfort; the very act of opening a window by its nature makes an important psychological contribution to the perceived effectiveness of the ventilation.

Automatic control where the occupant is not knowingly part of the control system can nullify the psychological benefit, and may even cause anger if there is no local manual override ([viii]). Typical problems found in the Probe buildings were:

- draughts from windows opened to remove heat on sunny but cool days;
- the inability to close windows which were letting in fumes, noise or insects;
- the denial to occupants of the opportunity to trade off discomfort (e.g. to choose between too hot or too noisy).

The points above help to explain why perceived occupant comfort tended to be higher in the smaller, simpler naturally-ventilated buildings than in those with the "intelligent" automated systems. Performance of the MM buildings was scattered. One (Elizabeth Fry) had excellent occupant satisfaction and good energy efficiency. One was good for occupant satisfaction but energy (particularly fan consumption) was relatively high – though much less than in most AC buildings. The other was middling for comfort and energy performance – but (like E Fry initially) it did not have a BMS, or anyone committed to fine-tuning the systems – other than in response to comfort complaints.

Some buildings aspired to achieve automatic night time cooling by natural ventilation, whilst others made provision for occupants to enable night ventilation by leaving open secure openings, sometimes with rain override. Both encountered problems: the former with correct programming and commissioning of the controls, the absence of staff to verify intended operation during the night, and sometimes with mechanically unreliable control devices. The latter fell foul of occupant uncertainty or indifference. Frequently motorised openings designed for summer cooling did not close tightly, causing excessive air infiltration at other times. Conflicts with security measures were also common.

The findings noted above can be partly explained by industry and occupants going up a learning curve; with care and commitment many of the problems could be resolved. However, one of the false promises of technology is that everything will be all right next time: in practice the challenge for building intelligence is to solve one problem without creating several more. A period of consolidation may be in order, in which time is devoted to improve understanding and develop more robust applications.

Lighting

In areas with predominantly manual light switching, switching in response to occupancy was reasonably effective in spaces that have some ownership, e.g. cellular offices and classrooms, but occupants were not always as diligent as they claimed in turning off unnecessary lighting. As found in other studies, the slow warm-up and restrike times of HID lighting inhibited frequent switching, leading to long hours of operation. Helpful labelling or colour coding of light switches and logical mapping onto occupied or daylit zones was rare, but it did help to encourage effective switching. More demand responsive controls, taking into account occupant requirements, presence detection (where appropriate) and daylight linking could potentially have given major reductions in consumption, particularly in "unowned" common areas ([ix]).

Unfortunately, however, in the eight buildings which did have sophisticated controls (typically a central system with timed and daylight responsive functions and sometimes occupancy detection), problems were widespread, including:

- Commissioning difficulties with photoelectric controls. External sensing could switch off lights in areas in which blinds were legitimately closed (for example to control glare): where lights could not be switched locally, this caused large areas to be controlled more generously). Internal sensing could be confused if blinds were down unnecessarily, and by reflections from their slats.

- Too many lights being switched on automatically and often permanently while the building was occupied, particularly in circulation areas, toilets, communal spaces, meeting rooms or as emergency lighting. Entrance lobbies are notorious in this respect, ironically advertising to visitors the occupier's wastefulness.
- Impenetrable programmable controls, causing wasteful operation.
- Inadequate user over-rides, for both the individual and for out-of-hours working.

One building used the telephones to control lighting. Occupants found this inconvenient:
- it switched lights for a zone and not for individual workstation
- access codes had to be remembered and varied with location (in other buildings, a standard code (e.g. 1234) from all telephones avoided this problem); consequently
- cleaners could not use it; so all the lights had to be switched-on automatically for the whole cleaning period.

Occupancy sensors were also problematic:
- In cellular offices, they often switched the lights on when the occupant would have been happy with daylight. Absence sensing would have been preferable, but so far no Probe buildings have had it, presumably owing to the extra cost of a light switch.
- In open plan areas, nuisance switching was common; which had led to times from last detection to switch-off being extended (typically to 15 minutes), or lights being programmed permanently on during core time.
- In meeting rooms, it was often impossible to switch lights off for presentations!
- Another problem resulted from doubling up the sensors for the security system. The difference in sensitivity and coverage requirements for the two purposes had led to them being overridden as lighting controllers.

In all eight buildings, control or usability problems led to higher energy consumption than had been hoped for. In four, occupants continued to be irritated by the lighting controls.

Building intelligence from the occupants' perspective

The myth of intelligence is that it is "fit and forget": buy it, and the electronics will do the rest. The actuality is that it is very much "fit and manage". Complex engineering and control systems tend to work best in an environment (such as the large air-conditioned head offices) in which the occupier can resource a high level of facilities and engineering management. Problems start to occur where sophisticated technology is applied in a management-poor environment, as in the academic buildings. Here simpler – or at least more robust – solutions might well have been more appropriate, even though their theoretical potential would have been further from the optimal.

As far as the individual user is concerned, they want either to be in control or to be so well looked after that they never become uncomfortable. The dangers come when they hit their crisis of discomfort in a space which is poor in individual control and management responsiveness – and they can do nothing to get out of it. Worse still, if unwanted operation of an automated control produced the discomfort problem in the first place.

Where automatic controls aim to combine energy efficiency with occupant satisfaction, they therefore take account of the following guiding principles:
- Controls should provide safe, healthy and stable background conditions automatically and economically for the times they are normally needed.
- Decisions to boost conditions or to extend operation should be made by the occupant where possible.

- After such boosting, reversion to low or off should be achievable both automatically and manually.
- Automatic control should if possible be imperceptible to the user in its operation. If perceptible, then user override is essential.
- User control actions should give an immediate and perceptible response.
- Appropriate, accessible user interfaces should be provided to suit the context of use.

Design intent should be obvious or intuitive ([x]). Where this is absolutely not possible, occupants will need the features explaining to them carefully and reminding regularly.

Improving building intelligence

The Brief

The brief is where general strategy is likely to be defined and attitudes set. It should start with lucid descriptions of design intent which can be translated into clear systems and controls descriptions. Ideally it should include:

- Targets against which progress can be subsequently assessed as the work proceeds and in post-occupancy studies.
- Specific requirements for user-friendly, adjustable control interfaces.
- Measures for monitoring energy consumption and alarm conditions to signal operation not in accordance with design intent.

Given the complexity of the issues, it is not surprising that problems often start here. Clients, many of whom are one-off procurers, may make (or be encouraged to make) inappropriate assumptions about occupants and about their own building management capabilities. The consequence can be poor control strategies. Some clients and designers insist on automatic control, ruling out manual override for fear that occupants will sabotage things. Automatic control and manual override can also be the victim of cost cutting at any stage, as the client's ambitions are reined in by the cost plan, by high tenders or by problems on site. Time and again the frustration this causes for occupants and facilities managers proves these cuts to have been false economies. Who would make cost savings on a car by removing steering wheel, speedometer and pedals?

Specification

How to specify building intelligence is difficult to generalise, with options ranging from a brief performance specification to a detailed definition of the complete system. Each has its shortcomings: a loose definition potentially allows unintended outcomes, whilst too tight a specification may close doors to effective competition and imaginative responses. A not uncommon fragmented supply chain and poor communications in a cut-throat market exacerbate the scope for problems. In general, the specification should:

- Require controls suppliers to provide the required functionality, with well-defined user interfaces and operator training;
- Require, for larger buildings and more complex or innovative systems, the early appointment of commissioning engineers to contribute to the design and programme;
- Promote better identification of an occupier's likely requirements and behaviour by the design team; where possible with occupiers themselves - or the developer if the occupier is not known;
- Include the specification of systems to facilitate commissioning;
- Require the design and assessment of control and monitoring systems for usability by different classes of occupier (permanent staff, visitors, maintenance staff, etc.).

Commissioning

Good commissioning is essential in achieving intelligent operation and occupant satisfaction, but one of the key messages from the Probe studies is that it does not by itself deliver buildings which operate as the designers intended. The solution goes far beyond successful commissioning and must be tackled throughout the design and procurement processes and continued post-occupancy.

All of the Probe buildings use some relatively advanced technologies, and all have experienced some problems either with automatic controls not operating as intended or with occupants not understanding the design intent and therefore inadvertently misusing or not using manual controls. Commissioning of night ventilation has been a particular problem, and emphasises the need for the design team to allow for commissioning certain systems during the appropriate season; and learning from occupant responses, both for the project concerned and for future ones. Another common problem is a failure to integrate design and control strategies of the landlord's base building with the tenant's fit-out. Building intelligence was also seldom configured to generate alarms when the automatic systems in the building failed to operate in accordance with design intent or when wasteful operation was occurring, e.g. simultaneous heating and cooling.

Handover

A successful building handover seems particularly difficult to achieve. Designers are under pressure to move on to the next project, and contractual arrangements can delay the resolution of teething problems during the defects liability period. The concept of a post occupancy review period of 12-24 months, built into the terms of appointment of the design team, still in its infancy. The Probe studies have revealed that the following measures can greatly facilitate the handover process:

- A “usability audit” where the client and designers are “walked through” the building and its controls agree how its systems will operate. This should include normal circumstances (e.g. weekday, weekend, night, holiday, cleaning) and exceptional ones (e.g. late working, sub-division into tenancies, contractors at weekends). For each scenario and relevant user (e.g. management, maintenance, tenant, visitor, individual, cleaner), one must agree who will make the operational decisions, and what user interfaces need to be provided to make this possible.
- Preparing the owner and/or the occupier to understand, obtain and motivate the skills required to operate the building and its services effectively, and to bring in appropriate staff or contractors sufficiently early in the process.
- Making an effective hand-over of systems to the owner and occupier, including an appropriate briefing, familiarisation, and "how it works" documentation.
- Appreciating that in the larger and more complex buildings there will necessarily be a learning period when the occupier learns to "drive" the building. Where systems have a variety of operational modes, a simple but robust "starter kit" can be a more effective way to build-up skill and confidence than if occupants are confronted initially with too much baffling complexity.
- A "sea trials" period during initial occupancy in which unexpected difficulties in systems behaviour and occupant requirements can be rapidly identified and accommodated with the help of the design team. This should not replace the handover and commissioning stages, but can effectively augment them, as was demonstrated at the Elizabeth Fry Building.

Facilities Management and Monitoring

Motivation, underpinned by monitoring which works on the basis of feedback and exception reporting is paramount. The Probe studies have reinforced its importance in ensuring intended and energy-efficient operation and the effectiveness of the associated commissioning or re-commissioning work. Where some sort of monitoring is in place, good things usually happen ; provided that the information gained is in manageable form. Too often motivation is absent owing to a lack of commitment at the top, and the lack of tools (for example appropriate contracts and job descriptions) by which any such commitment can be turned into individual motivation and action by those directly involved. Of course, some people achieve good results without such systems owing to their own personal commitment and professional pride.

Conclusions

Probe has highlighted how difficult it is to find recently constructed buildings operating in close accordance with the design intent. The consequences include occupant dissatisfaction, lower productivity, and higher energy consumption than necessary. The problems affect not only the building services and their controls: elements of the building fabric such as manual or automatic motorised windows and shading devices often had scope for improvement. Sometimes the design intent also needs to be more in tune with the potential of equipment and the requirements of occupants and management

The various problems commonly include:

- incorrect control (e.g. window gear inaccessible or with insufficient fine adjustment);
- failings of an automatic controls or their integration with occupant requirements;
- lack of understanding by the occupants of the design or vice versa;
- faults in the procurement chain affecting strategy, design, specification, installation, commissioning, handover and management.

Post-occupancy surveys are good at bringing such problems to light, and indicating where solutions may lie. However, achieving robust solutions will be difficult. The knee-jerk reaction is often to blame poor commissioning, but the problem goes far deeper and must be addressed throughout the design and procurement process from briefing through and beyond handover and sustained by operation and maintenance. Buildings and their occupiers are complex systems and for any intended outcome there can be many unintended ones. Careful study will be required, with much more time devoted to controls and usability than is normally possible within today's budgets. At present the industry often seems to regard occupant interaction as meddling, but appropriately designed interfaces can be an effective way of matching system operation to actual needs, and achieving the desired outcomes of occupant satisfaction (and productivity); energy efficiency (and lower emissions); and improved sustainability and cost-effectiveness.

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