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.

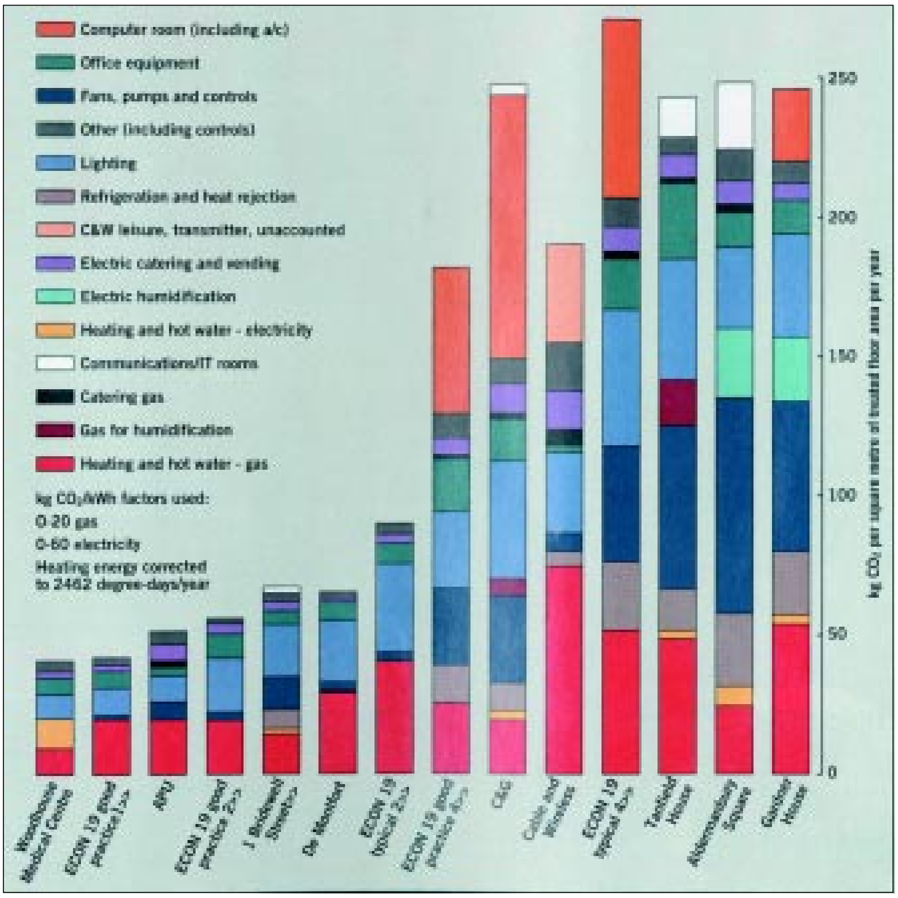

FIGURE 1: Annual CO_2 emissions for the PROBE buildings measured against *ECON 19* benchmarks.

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 / m^2 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 / m^2, 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 C&W is almost totally down to non-hvac uses, and CO_2 emissions are 20% higher than typical. Attempts are being made to rectify the building's high energy consumption, and it is probable that the building's energy performance will be better by the end of 1997.

In terms of electrical lighting consumption, APU and the Woodhouse Medical Centre have very low consumption, although improvements could be made. The lighting consumption at the Queens Building is over double that at APU, but still comparable with a good practice type 2 office.

THE OFFICE BUILDINGS

Curiously, the four commercial buildings studied under the PROBE series of post-occupancy surveys were air conditioned offices for financial services companies[1,2,3,7].

Three of the buildings were occupied in 1990. They are Cheltenham & Gloucester (C&G) Building Society's 20 000 m^2 headquarters, Tanfield House, the 24 000 m^2 chief administrative centre for Standard Life, 1 Aldermanbury Square, the 8000 m^2 central London hq for Standard Chartered Bank. Gardner House, the hq for the Homeowners Friendly Society, was occupied in 1994.

All the buildings are of a high quality: Tanfield House won the 1992 Office of the Year award, C&G won a National Lighting Award in 1990, Aldermanbury Square a Beta energy award and Gardner House an architectural award.

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 CO^2 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/m^2	●	17 W/m^2	●●●	8 W/m^2	●●	13 W/m^2
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/m^2	●●●	1·5 W/m^2	●●●	4 W/m^2	●●●	3 W/m^2 current
Occupant density	●	5 m^2/person	●	5 m^2/person	●●	10 m^2/person	●●●	23 m^2/person
Clothing choice	●●●	Casual	●●●	Casual dress	●●●	Casual	●●●	Casual
Total internal heat gains	–	42 W/m^2	–	38 W/m^2	–	22 W/m^2	–	20 W/m^2
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 caused glare, particularly on computer screens. More curtains were installed, many of which are now frequently closed.

The atrium rooflight at C&G produced an attractive daylit coffee/meeting area alongside the top floor corridor, but dark finishes at lower levels tended to require the main lighting to remain on. As this was manually switched from reception the lights tended to remain on.

Other lighting features at C&G scored better, such as colour-coded light switch rockers: red for circulation, white for lobbies and silver for general areas. This was a helpful touch which avoids the lights being used unnecessarily, particularly once the silver switches had been rewired after completion to correspond with lighting layouts.

Lighting energy use in all the buildings is below typical, and at Aldermanbury Square it is near good practice, with the lowest density at 12 W/m^2 and the most efficient at 2·8 W/m^2/100 lux. When *ECON 19* was written, 10 W/m^2 was regarded as very good. Today many installations lie within 12-18 W/m^2.

In general, the automatic lighting controls delivered less in energy savings than might have been expected. Daylighting was not particularly good in any of the study buildings, and in open-plan areas the tendency to default to "on" was widespread. Given its low density of occupation, it is surprising that Gardner House was not closer to the good practice level. Partly this resulted from a relatively high illuminance standard of 600 lux and the use of compact fluorescent lamps which are less efficient than full-sized ones.

Additional energy consumption was due to unintended consequences of the automatic controls, in particular occupancy sensors bringing on lights whether or not they were required, for example when popping into a room or passing through an open-plan area.

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

The daylight-linked dimming could not be set quite as precisely as one might have thought. This was largely due to the fact that people wanted the illuminance inside to respond to that outside, as well as the sensors being affected by light reflected upwards from venetian blinds or from white paper on tables. This has led to a widening of the control band and more lighting than was strictly necessary.

At C&G, energy consumption by office equipment is typical, and at Tanfield House 50% more, while the other two offices with their low occupancy densities use less.

In all the offices, a relatively high proportion of people undertook routine screen-based work and were quite diligent at turning off equipment when they left the office, typically leaving about 10% of the equipment on overnight.

Equipment with "slumber" modes is not always very energy-efficient, and it also encourages people to develop the habit of leaving things on. Over a year a single Watt of unnecessary power chalks up an extra 1 kWh/m^2 for one 9 m^2 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


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

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.


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.


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.

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.

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.