TEST of TIME

Too many new public and commercial buildings fail to live up to their expectations for energy savings and user comfort, but can the good ones maintain their performance? With support from CIBSE, a team of experts returns to a university building that was found to perform exceptionally well in the late 1990s. **Bill Bordass** and **Adrian Leaman** report on their findings. A separate article on the performance of school buildings generally starts on page 39

A 'PROBE' investigation into the Elizabeth Fry Building at the the University of East Anglia in the 1990s found that it had exceptionally good performance in many respects. A recent follow-up visit found that, despite some inevitable 'drift' in its operations, it is still performing better than many brand-new buildings. In the background is the Queen's Building, an earlier building by the same design team

In the early 1990s, the editorial advisory board of *Building Services Journal* (the forerunner of *CIBSE Journal*) had wondered how well the buildings it featured actually performed in practice. In 1994 the *Journal* made a successful bid under the government's Partners in Technology programme to undertake and publish the 'PROBE' (Post-occupancy Review Of Buildings and their Engineering) studies.

Between 1995 and 2002, a total of 20 non-domestic buildings were surveyed, typically two to four years after handover. The process, results and general findings are described in 29 articles in the *Journal*, and in reviews elsewhere.

PROBE number 14 investigated the Elizabeth Fry Building at the University of

Bill Bordass

Administration office for the Hub: This was occupied in September 2011, replacing the popular ground floor seminar rooms. Note the lowered blackout blinds (inherited from the former seminar rooms) to counter solar glare through the side windows

Roderick Bunn

East Anglia (UEA). It revealed a modest but refined building that had exceptionally good performance in many respects. Annual gas consumption for heating and hot water was 35 kWh/sq m of treated floor area (TFA), while other buildings surveyed by PROBE tended to use 100 kWh/sq m or more.

Overall levels of occupant satisfaction were the best in the PROBE dataset, particularly in summer. The cover of the April 1998 edition of the *Journal* therefore asked the question, 'The Best Building Ever?'. In 2011, PROBE team members returned to review how well the building had fared since then.

Fine-tuning

The Elizabeth Fry Building benefited from a client representative, Peter Yorke, who was seeking good-quality, robust, low-energy buildings at normal cost levels and had gained considerable experience from previous UEA projects. The design team was keen to oblige and had worked together before on the adjacent Queen's Building. The result was a 'keep-it-simple-and-do-it-well' design. During construction, critical details affecting insulation and airtightness were followed through by the team with Elizabeth Fry's builder Willmott Dixon and the university's clerk of works, who visited the site daily.

In 1995, the first year of operation, gas use for heating was 65 kWh/sq m, good for the UK but disappointing in relation to some Swedish Termodeck buildings. Fortunately, with the encouragement of Termodeck's UK representative Derrick Braham, the building was being monitored for the government's *Energy Efficiency Best Practice programme*. This showed that the boilers sometimes put too much heat into the fabric via the supply air, only for it to be removed by extra outside air ventilation some time later.

A strategy based largely on mass sensing was therefore proposed, but could not be implemented using the original standalone controllers. In 1996 the university therefore extended its new Trend building management system to Elizabeth Fry – ahead of schedule. The results were dramatic, with gas consumption halved in 1997, the year analysed in the PROBE survey.

> In 1998 the Elizabeth Fry Building set new highs for overall comfort, summer temperature, and air quality, in terms of average responses to the Building Use Studies occupant survey

Roderic Bunn

Gradual changes were made to Elizabeth Fry over a 15-year period, resulting in increasing occupancy levels and a proliferation of computer equipment. This is north façade of the building, facing on to Chancellor's Drive, a bus route

Building features Elizabeth Fry in the 1990s

Elizabeth Fry is a four-storey rectangular building with a gross internal area of 3,250 sq m and treated floor area (TFA) 3,130 sq m. Its principal elevations face almost north, on to the main distributor road, Chancellor's Drive; and south, on to a courtyard.

In the 1990s it had lecture rooms on the lower ground floor, and seminar rooms and offices on the upper ground floor.

On the first and second floors were one-, two- and four-person teaching and administrative offices at the west end, seminar rooms and common rooms at the east end, and a catering kitchen.

It was the second building in the UK to use the Swedish Termodeck system of mechanically ventilated hollow core concrete floor and roof slabs with exposed soffits.

It was very well insulated: block walls with 200 mm mineral fibre cavity fill; triple-glazed (2+1) aluminium-clad timber windows with blinds between the inner and outer panes; a roof with 300 mm of insulation and a profiled metal sheet covering; and an insulated floor.

The U-values of all these elements remain better than the limiting requirements in the 2010 edition of Approved Document L2A.

Thermal inertia was further enhanced by blockwork internal and external walls and good airtightness. With a design heat loss of only 15 W/sq m, two 24 kW domestic wall-hung condensing boilers could provide all the heat required, with a third in reserve.

Heating and cooling is entirely through the air. The four air-handling units incorporate heat recovery: the two AHUs serving the lecture rooms having conventional cross-flow systems; and the offices and seminar rooms the more efficient (nominally 85%) flow-reversing regenerators.

Following initial monitoring, six small (200W) electric heaters were added in six rooms to counter additional heat loss through overhangs and exposed corners.

The new control strategy was simple: during occupancy hours, the AHUs endeavoured to maintain a supply air temperature of approx 21C by varying the amount of heat recovery. If slab temperatures in locations towards the room ceiling outlets fell below 20C, the heating was boosted to maximum, with recirculation at night. If the slab temperatures rose above 22C, the heat exchangers were bypassed and outside air cooling was extended overnight.

Monitoring showed that the thermal inertia of the hollow core slabs made finer control unnecessary: it simply increased energy use. The lecture room systems also included air quality control to boost air volumes for short periods if needed, bypassing the Termodeck.

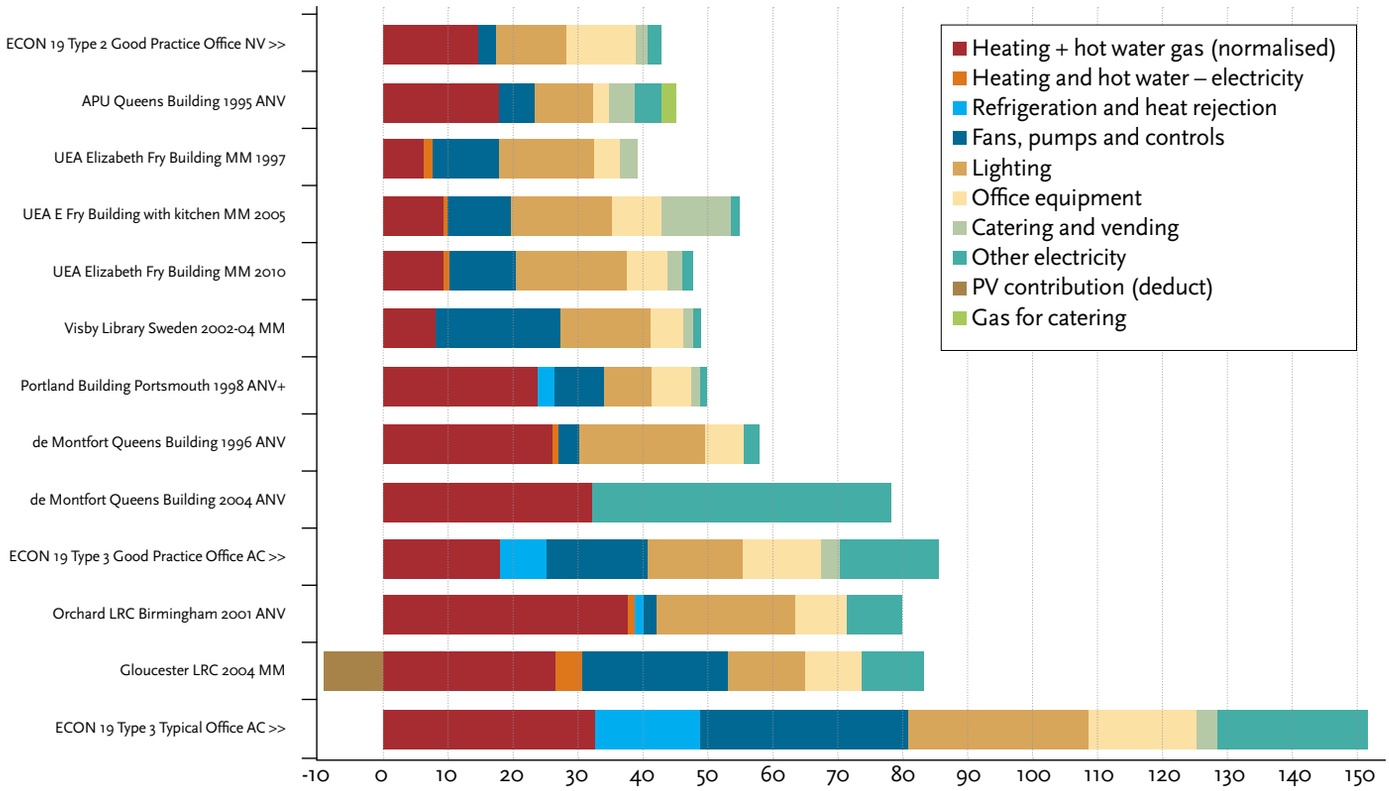
1995 to 2011

During this 15-year period, changes to the building were gradual. PCs inevitably appeared on everyone's desk, with computer projectors and audio-visual systems in the lecture rooms and some seminar rooms. Room occupancy increased generally, while staff and student common rooms on the first and second floors were converted into offices and meeting rooms. In 1997 the building contained 70 office workstations. In 2010 there were 120.

Changes in operation of the catering kitchen on the top floor significantly affected overall energy use. In the 1990s the kitchen was used for special events, typically one a week; and usually just for serving, not cooking.

During 2004-06 the kitchen was in regular daily use while the Sainsbury Centre was being refurbished. In 2008 the kitchen and dining area were converted into a densely-occupied, open-plan postgraduate administrative office with 25 workstations: a purpose to which it is not very well suited, because the kitchen only had three small windows and no views.

Bigger changes happened in summer 2011. However, these alterations are too new to be evaluated reliably for energy use and occupant satisfaction, so this



Annual CO2 emissions from university buildings (kg/m² Treated Floor Area at UK CO_2 factors of 0.184 for gas and 0.525 for elecricity)

AC = air conditioned, **ANV** = advanced natural ventilation, **MM** = mixed mode, **NV** = naturally ventilated

The diagram shows the estimated breakdown of energy use in 1997, 2005 (when the catering kitchen was in full operation) and 2010, in relation to office benchmarks from the Carbon Trust's Energy Consumption Guide 19 (marked with chevrons) and to other university buildings reviewed in PROBE and related studies. The graphs are expressed as annual CO2 emissions at Defra 2011 UK factors. The data are sorted by CO2 emissions for heating, hot water, cooling, ventilation and lighting.

At all three dates, Elizabeth Fry still maintains its place towards the low-carbon end of the range. The biggest changes between 1997 and 2010 are in heating and hot water, largely due to the change to 24/7 hot water and the appearance of some additional electric heaters. Lighting and office equipment energy use have also gone up owing to increased occupancy and equipment levels.

In relation to other buildings and benchmarks, energy use for heating and hot water is still good, while lighting has deteriorated owing to the low efficiency of the original pelmet system and greater hours of use now. CO2 emissions from fans, pumps and controls (mostly fans) are reasonable in relation to the other mixed-mode buildings and to air-conditioned benchmarks, but nevertheless of a similar magnitude to those from heating and hot water.

article does not change them. The changes included stripping-out the popular ground-floor seminar rooms and their heavy blockwork walls and providing a student hub and administration centre for a large number of faculties.

The Hub includes pigeon holes and deposit boxes for coursework and a four-position enquiries counter behind the entrance hall.

To the east, it has a drop-in area for students and staff, with soft chairs, a kitchenette and vending machines. To the west, there are open-plan offices for 45 administrative staff and a hub room for the computer system (the servers are elsewhere).

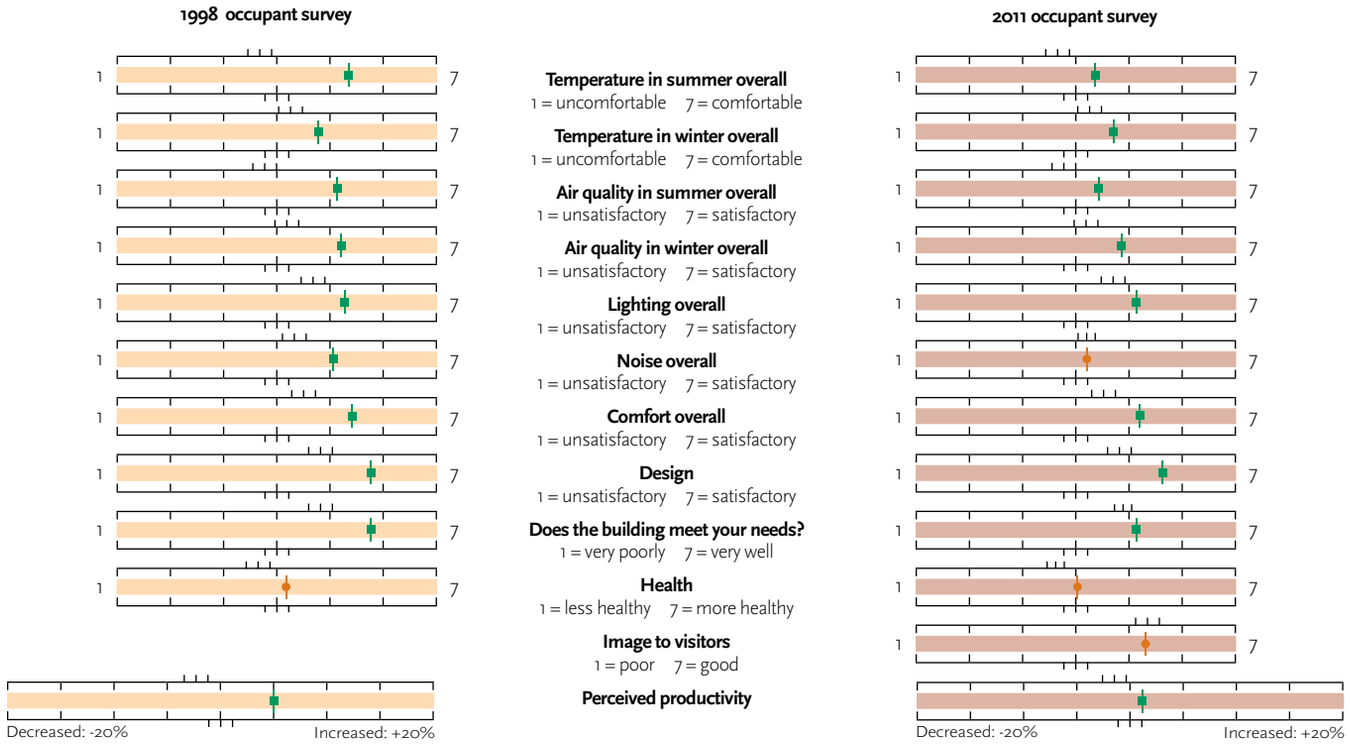
Energy use

Annual energy use in calendar year 1997 was 61 kWh/sq m treated floor area (TFA) of electricity, 31 kWh/sq m of gas for heating, and 4.2 kWh/sq m for domestic hot water.

In the ensuing years, annual electricity use rose inexorably by some 2 kWh/sq m every year, to a total of 75 kWh/sq m in mid-2004. In 2004-06, with the all-electric catering kitchen in daily use, annual consumption climbed to 90 kWh/sq m. It then fell to 72 kWh/sq m in the year to June 2008. Data after that is unreliable owing to metering faults.

In addition, annual gas consumption for heating fluctuated within a narrow range of 27-33 kWh/sq m. The total in the year to July 2007 was 28.5 kWh/sq m, after which there was a meter fault. Resumed measurements revealed higher figures of 35-36 kWh/sq m for the years to July 2009, 2010 and 2011. The reasons include

> Fifteen years on, Elizabeth Fry remains a comfortable, low-energy building in relation to most of its peers, although some things have drifted a little



Building Use Studies (BUS) occupant survey results for 1998 and 2011

The diagrams above show average responses by staff to 12 key questions in the BUS surveys in 1998 (on the left) and 2011 (on the right), just before the recent changes. For comparability, the 2011 survey excludes occupants in the converted kitchen and dining area. The satisfaction scales run from 1 (poor, on the left) to 7 (good), apart from the final question – the effect of environment in the building on perceived productivity – which goes from –20% to +20%. Green squares show where average scores are significantly better than benchmark values at the 95% confidence level. Orange circles indicate averages that are similar. For most occupant satisfaction variables, The Elizabeth Fry Building remains significantly above average. There are no red triangles, which would indicate scores significantly worse than average. The question about image (to visitors) was not asked in 1998.

The score for overall comfort in 2011 is at the 79th percentile of the reference data set, while in 1998 it was at the very top. Two things have happened since then: perceived conditions in the building are not quite as good (e.g. the overall comfort score has fallen from 5.41 to 5.20), whilst buildings with better comfort levels have subsequently been surveyed. The 1998 result for Elizabeth Fry now falls at the 90th percentile of the 2011 reference dataset.

The main influence on comfort is likely to be the higher occupation density. The variable most affected is summertime temperature, where the average score has fallen from what was a very good 5.30 (the most comfortable in the 1998 dataset) to 4.24. The effect is exacerbated by a loss of perceived control in the open plan areas. Perceived air quality in summer has also fallen, but remains significantly above average. The average score for noise has dropped from 5.05 to 4.24, and is now indistinguishable from the average. The main causes are probably the creation of open plan offices and the growth in traffic on Chancellor's Drive – particularly regular buses, which did not go past the building in 1998. Some people also mentioned noise from the ventilation plant.

Air leakage Pressure tests reveal change

Envelope pressure tests have been carried out three times by building services research body BSRIA:

- In December 1994, before the building was handed over. The result was 0.97 air changes per hour at 50 Pascals pressure, equivalent to an air leakage index of 4.2 m/h (cu m per hour per sq m of exposed envelope area) and an air permeability of about 3 m/h, 30% of the current limiting requirement in Part L.
- In February 1998, as part of the PROBE survey, giving an air leakage index of 6.5 m/h, equivalent to a permeability of 4.7 m/h. With the front doors sealed, the air leakage index fell to 6.2 m/h.
- The test in September 2011 gave the surprising result of a 5.3 m/h air leakage index (air permeability 3.8 m/h), better than in 1998. The main reason is thought to be the removal of the catering kitchen and its ventilation plant. BSRIA also thinks the lecture room ventilation plants may not have been sealed off as well in 1998.

Smoke tests in 2011 confirmed similar leakage routes to earlier tests, including the entrance doors, particularly the main revolving door which needed new seals; the perimeters of the rooflights over the main and escape stairs; and through the windows themselves, though their seals remain in good condition.

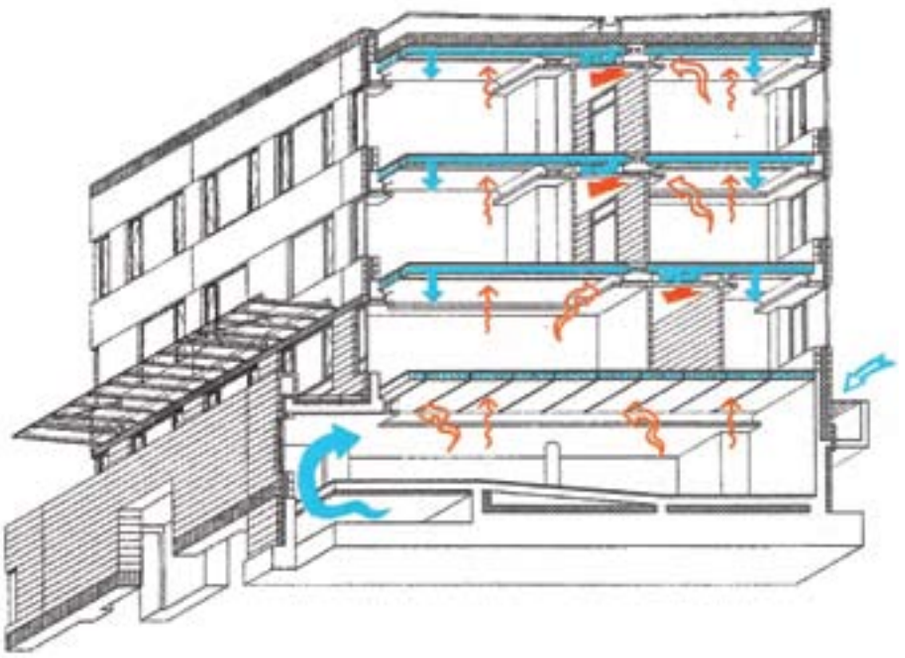
A new leakage route had also appeared under the cills of the windows, where the compressible foam plastic seals had begun to deteriorate and fall out. The mastic seals around the window and door frames were also cracking, but little air leakage was detected here.

More about the pressure test results can be found in: R Bunn, Elizabeth Fry, Ageing gracefully? DeltaT magazine 6-8, February 2012, published by BSRIA ***www.bsria.org.uk***

a period when the main regenerative heat exchanger failed and the cold 2010-11 winter.

In 1998 and 1999, the self-contained water heater used as little as 3 kWh/sq m of gas, even less than in 1997. Consumption then rose to 4.4 kWh/sq m in 2000 and 5.5 in 2001, perhaps owing to temperature adjustments. In 2003-08, consumption nearly tripled to 12-14 kWh/sq m, owing to a change to 24/7 operation at 55C (65C on Sundays), resulting from concerns about legionella. In 2009 a new condensing water heater was fitted and its gas use fell to 11 kWh/sq m. Although the building is more heavily used, most of the extra consumption in relation to the PROBE survey data is thought to be from standing losses from lightly-insulated and uninsulated pipework.

The box on the previous page shows an estimated breakdown of annual energy use



KEY **SUMMER MODE**

- Structure cooled by air
- Return air
- Energy storage in fabric
- Night-time air intake

Section showing heat storage in the ventilated concrete slabs. In winter, if the fabric gets cold, additional heating is provided by the boilers at night with the relevant air handling units on full recirculation

in 1997, 2005, and 2010, in comparison with other buildings and various benchmarks.

Occupant satisfaction

In 1998, Elizabeth Fry set new highs for overall comfort, summer temperature, and air quality, in terms of average responses to the Building Use Studies (BUS) occupant survey questionnaire used in PROBE.

Four main reasons were identified for these high scores: the design and construction of the building; stable winter and summer temperatures; a predominance of cellular offices (in which comfort tends to be higher owing to better perceived control); and only half the staff spending all the week in the building (permanent occupants tend to be more critical of the indoor environment).

Reported problems included glare through the perforated blinds and unshaded side windows on the south side, still air, dark ceilings when the pelmet lights were off, and reflections in computer screens. There were also some complaints of cold.

The 2011 survey shows that occupant satisfaction has fallen back a little, both absolutely and relatively, because the reference dataset now includes more buildings with good performance levels. However, average comfort levels are still good (see previous page) and are typically within the second decile of the dataset. Occupants also rate the quality of cleaning very highly.

Conclusions

During briefing, design and construction, and in the two years after handover, the building received an unusual level of attention. However, time and again we find that few buildings work well without such attention to detail and some support after handover – which is why we have been striving to develop and promote the UK *Soft Landings* approach (see **www.softlandings.org.uk**).

Fifteen years on, Elizabeth Fry remains a comfortable, low-energy building in relation to most of its peers, although some things have drifted a little. For example, after common rooms were converted to offices, some local complaints of cold were dealt with by adding standard 2 kW electric heaters, not the original 200W ones. Replacement light fittings in the student hub are also more powerful than necessary, typically with twin tubes where single tubes would have been sufficient – thereby missing the opportunity to tackle the originally high installed power density of 22 W/sq m.

Where spaces have been converted to open-plan offices, comfort has been affected, particularly acoustics, owing to high occupancy densities and reflective exposed concrete ceilings. More overheating is also reported, though some complaints of cold persist. Solar glare from the south-facing slit windows (which do not have blinds) is more of a problem in the open-plan than in cellular offices and seminar rooms, where the furniture could be arranged to suit.

In hindsight, with changes of kitchen, stores, and so on, to offices, the question arises as to whether the building should have had a more uniform pattern of windows to facilitate changes. On the other hand, does management really need to alter buildings so much? Several occupants expressed regret at losing prime teaching and meeting space to administration facilities.

Now that UEA has many more buildings to look after, it is a credit to the robustness of Elizabeth Fry's design and fine-tuning and to UEA's maintenance and cleaning that its performance remains good. Twenty years after it was designed, why have so few newer buildings caught up? We hope to explore the broader issues in a future article. **CJ**

● **BILL BORDASS** and **ADRIAN LEAMAN** are independent consultants who also work with the Usable Buildings Trust charity. The PROBE articles and other related papers can be downloaded from the PROBE section of **www.usablebuildings.co.uk** The authors wish to thanks those organisations who supported their work: CIBSE, UEA and Build with CaRe (**www.buildwithcare.eu**). In addition, BSRIA and Willmott Dixon sponsored a new pressure test by BSRIA: its results are summarised on the previous page

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M&E installation contractor: Matthew Hall

Energy adviser (fabric): Energy Advisory Associates (David Olivier)

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