PROBE STRATEGIC REVIEW 1999

FINAL REPORT 2: Technical Review

A confidential report to DETR

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August 1999

PROBE STRATEGIC REVIEW 1999:
FINAL REPORT 2: TECHNICAL REVIEW

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Executive Summary

From 1995 to 1998, the Probe project (Post-occupancy Review Of Buildings and their Engineering) undertook and individually published surveys of sixteen recently-completed buildings (seven office buildings, five educational buildings, and four other buildings), together with a range of introductory and overview reports. The procedures used are reviewed in Report 1 of this series.

Probe was jointly funded by Building Services Journal (BSJ) and DETR, in two projects - Probe and Probe 2 - under DETR's Partners in Technology programme. This report, No 2 in the series[1] compares and contrasts the technical features of the buildings, together with the findings, particularly for technical and energy performance. Such feedback has become particularly important with the Egan initiative to improve the performance of the building industry and its products; the Kyoto protocol to reduce greenhouse gas emissions; and other drivers to improve technical, economic and environmental performance, together with occupant satisfaction and productivity.

The studies revealed progress on a number of fronts, for example:

- Good occupant satisfaction in some deep-plan air-conditioned buildings, owing to improvements in design and particularly management.
- Mixed mode buildings (which combine natural with mechanical ventilation and cooling), with significantly lower energy use than their air-conditioned counterparts.
- Innovative naturally-ventilated buildings with low electricity consumption.

Probe also confirmed the pervasiveness of some persistent problems, including:

- Unnecessarily high energy consumption, particularly in the air conditioned buildings and areas; exacerbated by excessive levels of ventilation, humidification and plant operation. Intrinsically efficient solutions should be seen as essential features, not added costs. Clearer benchmarking in design and use is also needed; taking into account the full range of end-uses.
- High levels of air infiltration. Pressure tests showed that only two of the eight buildings in Probe 2 met reasonable standards (and motorised openings for automated natural ventilation could themselves be very leaky). A lack of controlled airtightness not only wastes energy directly but causes poor comfort and additional plant running hours. It also undermines the benefits of good insulation and requires plant to be routinely oversized.
- Little energy management activity, even in otherwise well-managed buildings and in those for which energy efficiency had figured prominently in the brief.
- Often too much complication, leading to technical problems, unintended consequences, and difficulties for management. "Keep it simple and do it well" is a strong message.
- Poor functionality, usability and manageability of controls, both manual (e.g. windows) and automatic. This often increased energy use, particularly by systems defaulting to ON. It also reduced comfort - particularly in buildings with automated control of natural ventilation: these buildings are innovative, and need care. But in these and other buildings there was usually:
- little or no provision for monitoring and fine-tuning systems after occupancy; where indeed effective action could also be contractually constrained during the Defects Liability Period.
- Outsourced contractors (and presumably the contracts they were working to) also seemed to be more likely to maintain the status quo than to question and improve it.

Section 4 contains a more complete list of conclusions and suggested actions.

The best results tended to come from combinations of technical and management measures. The best example of combining comfort and energy efficiency was the Elizabeth Fry Building, where a committed client and a design ream which had worked with them before were able to make thoughtful and responsible innovations, to take advice where necessary, and to deliver - via a committed contractor - an attractive, comfortable and energy-efficient building at normal cost levels. However, even this building needed careful monitoring and fine-tuning before all the performance benefits could be delivered[2]. With this knowledge, the designers considered that they could reduce energy consumption still further next time, particularly for lighting & mechanical ventilation.

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[1] Report 1 is on the survey process. Results of the occupant surveys are discussed in Report 3. The strategic findings are in Report 4: this should be read first for those wanting an overview of the project and its findings.

[2] This building also had features - in particular cellular offices - which are also generally associated with higher perceived comfort and lower energy consumption levels.

#1 TAN Tanfield House

#2 ALD 1 Aldermanbury Square

#3 C&G Cheltenham and Gloucester

Probe 1 and 2 buildings with article sequence numbers

#4 DMQ De Montfort Queen's Building

#5 C&W Cable and Wireless

#6 WMC Woodhouse Medical Centre

#7 HFS Homeowner's Friendly Society

#8 APU Anglia Polytechnic University Queen's Building

#11 CAB John Cabot CTC

#12 RMC Rotherham Magistrates' Courts

#13 CAF Charities Aid Foundation

#14 FRY The Elizabeth Fry Building

#16 MBO Marston Books Office

#16 MBW Marston Books Warehouse

#17 CRS Co-operative Retail Society

#18 POR The Portland Building

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1 BACKGROUND

1.1 THE SURVEYS UNDERTAKEN

1.1.1 Probe 1 in 1995-96 and Probe 2 in 1997-98 undertook post-occupancy studies of a total of fifteen buildings and published them individually in BSJ - the *Building Services Journal.* One of these - Marston Book Services - was a small office attached to a large warehouse; and was analysed as two separate buildings, making a total of sixteen building analyses in all.

1.1.2 The Probe process is described in Report 1. Probe was unusual in looking at buildings, and particularly their environmental services, from five main standpoints:

1 The experience of the occupier, by informal and structured discussions.
2 The perceptions of the individual occupants, by questionnaire, developed from longer questionnaires previously used by team members Building Use Studies Ltd..
3 Energy performance, using the EARM™ Office Assessment Method procedure or precursor methods developed by team members William Bordass Associates.
4 Technical performance, from discussion, survey results, observations & spot measurements.
5 In Probe 2, all buildings except CAF were pressure-tested for air leakage by BRE or BSRIA.

1.1.3 The buildings studied date from the early to mid-1990s. When first completed, the editor of BSJ had regarded them as being of special interest to readers, and made them the subject of building studies typically five pages long. Most Probe surveys were undertaken 2-3 years later, to allow the building, its occupants, and its pattern of energy consumption to have the time to settle down. Table 1.1 gives basic details of these buildings, in order of publication of the studies[3]. It also gives three letter codes, used to refer to the buildings throughout this report.

1.1.4 This report looks at the technical findings. It should be read together with its companion reports:

1 Review of the Probe Process.
3 Review of the Probe Occupant Surveys.
4 Strategic Findings, which summarises and builds upon the three other reports; and which should normally be read first.

1.2 STRUCTURE OF THIS REPORT

1.2.1 The surveys of the sixteen buildings include a large and somewhat unmanageable amount of material. They are therefore considered in three main groups:

- Seven office buildings: three sealed and air-conditioned (ALD, C&G, HFS); two nominally mixed mode (TAN, CRS), with openable windows but functioning essentially as air-conditioned; one genuinely mixed-mode (CAF) and one naturally-ventilated (MBO).
- Five educational buildings, including “advanced” natural ventilation (ANV) systems at DMQ, APU, CAB and POR and mixed mode at FRY.
- Four other buildings: C&W, a management training centre with some ANV; WMC, a small, naturally-ventilated medical centre with supplementary cooling in places; RMC, a mixed-mode magistrates’ courts; and MBW, a naturally-ventilated book distribution warehouse.

1.2.2 Sections 2 to 4 of this report cover the following material:

2 Outlines the general features of the buildings group by group, picking up important common themes and throwing some light on their similarities and differences[4].
3 Introduces the energy consumption and carbon dioxide emissions statistics for all the buildings, and particularly the characteristics of the high and low energy consumers.
4 Draws general conclusions of a technical nature.

Appendix A contains a lengthier description and comparison of technical, management and energy issues for the three groups of buildings, identifying common features and particular areas of success and difficulty. It also contains comparison tables for each of the three groups.

1.2.3 Report 4 unifies the issues issues raised in the process, technical and occupant satisfaction reports, and draws conclusions, both on the buildings surveyed and on the ways in which the findings might be used to improve the performance of buildings in the future.

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[3] A full list of the Probe publications in BSJ and at the Probe conference 1997 is at the back of this report.

[4] This section will also be issued in illustrated form as a supplementary free-standing Report 5.

TABLE 1.1: THE BUILDINGS INVESTIGATED IN PROBE

PROBE 1 Buildings Investigated

Seq	**Full name**	**Location**	**Site**	**Short name**	**3-letter**	**Type**	**Gp**	**HVAC**	**Article**	No
1	Tanfield House	Edinburgh	IC	Tanfield	TAN	Large administrative centre	O	AC/(MM)	Sep-95	1
2	1 Aldermanbury Square	London	CC	Aldermanbury	ALD	UK head office (speculative)	O	AC	Dec-95	2
3	Cheltenham & Gloucester	Gloucester	BP	C&G	C&G	Large head office	O	AC	Feb-96	3
4	de Montfort Queens Building	Leicester	IC	de Montfort	DMQ	University teaching	E	ANV	Apr-96	4
5	Cable & Wireless	Coventry	BP	C&W	C&W	Company training college	M	ANV/NV	Jun-96	5
6	Woodhouse Medical Centre	Sheffield	IC	Woodhouse	WMC	Medical surgeries	M	NV/(MM)	Aug-96	6
7	HFS Gardner House	Harrogate	BP	HFS	HFS	Principal office	O	AC	Oct-96	7
8	APU Queens Building	Chelmsford	IC	APU	APU	Learning Resource Centre	E	ANV	Dec-96	8

PROBE 2 Buildings Investigated

Seq	**Full name**	**Location**		**Short name**	**3-letter**	**Type**		**HVAC**	**Article**	No
9	John Cabot CTC	Bristol	IC	Cabot	CAB	Secondary education	E	NV/ANV	Oct-97	11
10	Rotherham Magistrates Courts	Rotherham	IC	RMC	RMC	Courtrooms and offices	M	MM	Dec-97	12
11	Charities Aid Foundation	Kent	BP	CAF	CAF	Principal office (pre-let)	O	MM	Feb-98	13
12	Elizabeth Fry Building	Norwich	UC	Elizabeth Fry	FRY	University teaching	E	MM	Apr-98	14
13	Marston Books Office	Abingdon	BP	MB Office	MBO	Principal office (pre-let)	O	NV/(ANV)	Aug-98	16
14	Marston Books Warehouse	Abingdon	BP	MB Warehouse	MBW	Warehouse (pre-let)	M	NV	Aug-98	16
15	Co-operative Retail Services	Rochdale	BP	CRS	CRS	Large head office	O	AC/(MM)	Oct-98	17
16	The Portland Building	Portsmouth	IC	Portland	POR	University teaching	E	ANV/MM	Jan-99	18

Site: *BP=Business Park or similar; CC=City Centre; IC=Inner City; UC=University Campus*

Group: *E= Educational; M=Miscellaneous; O=Office*

HVAC: *AC=Air Conditioned; NV=Naturally ventilated; ANV=Advanced NV; MM=Mixed Mode (bracketed if minor influence)*

2 OVERVIEW OF THE BUILDINGS

2.1 The office buildings

2.1.1 TANFIELD HOUSE (TAN)

The 24,000 m^2 (gross, not including the underground car park) administrative headquarters of Standard Life was the first Probe and the largest building studied to date. Completed in 1990, this owner-occupied groundscraper on the edge of Edinburgh New Town houses 1300 largely clerical staff. It has two very deep open-plan floors, up to 120 m across, punctured by three atria. The office floors have underfloor VAV[5] air conditioning, uplighting, and tall (3.6 m) exposed concrete ceilings with no services other than sprinklers. The twin-walled facade is of an irregular shape with outer fixed glazing, a ventilated walk-though interspace, and inner sash windows which can be opened manually, or dropped automatically in a fire. Lengths of fully-glazed curtain walling span between stone stair/service towers which give a sense of solidity and help to unite the building with the Edinburgh New Town vernacular and the retained facade of the former Woolstore at the NE corner. Below the two office floors are two levels of car parking for a total of 306 cars (24% of staff).

Surveys in the 1980s suggested that very deep, open-plan air-conditioned building with largely clerical occupancy had all the danger signals for high levels of building-related sickness symptoms. However, initial impressions were good and the occupant survey revealed that TAN performed very well. Why? Essentially the answer was:

- A committed and experienced client representative throughout the project, and who then became responsible for managing the building.
- Good procurement, by a traditional route over a seven-year period of site assembly, needs assessment, briefing, design, review and ultimately construction.
- Good, imaginative, careful design.
- Excellent, responsive facilities and engineering management, applying the firm’s policy of customer service and continuous improvement to their own customers, the occupants.

Energy consumption, however, was high - even for a prestige air-conditioned office, as discussed in Section 3. Some of this resulted from the high occupancy and equipment levels, but much was also related to systems being too powerful (at least in hindsight) and/or on too much owing to control problems. For example, for lighting:

- All the circulation and toilet lighting came on together whenever the building was occupied.
- The meeting rooms were also initially on these circuits, but were given independent switches when it proved impossible to show slides! Surprisingly, this oversight is not uncommon.
- The extended restrike times of the high-intensity discharge uplighting meant that it could not be turned off if there was a chance it would be needed again. In any event, individual occupants could only select high/low.
- The large open-plan nature of the spaces - together with cleaning right through the night by a small and effective team - meant that the office lighting tended to default to ON.

Such over-usage problems proved to be widespread in Probe, particularly in the more highly-serviced buildings. Following their continuous improvement philosophy, the results of Probe caused the FM team to increase their responsiveness to occupant comments still further, and to accelerate the implementation of the energy-saving measures identified; in particular replacing the eddy-current drives for the main VAV fans with more energy-efficient inverter drives.

The long gestation time of TAN and the bespoke solution which emerged for an established owner-occupier are unlikely to be repeated for many office buildings in the UK today. TAN was built by a firm with a long history in Edinburgh, and which planned to occupy its new building indefinitely - as it most probably will. However, in the fifteen years since the need for TAN was identified, the world has changed. Markets are changing fast and even the most well-established company may find itself facing competitive threats; mergers and acquisitions; and periods of rapid change with the need to move quickly. They are therefore forced into the rental market, or at least to build offices which are more subdivisible and closer to established market standards, so that they can be valued and traded. Standard Life’s recently-completed new head office in Edinburgh is of this kind, and was a pre-let in collaboration with a developer.

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[5] Variable air volume. Air is introduced into a zone at constant temperature (at Tanfield with slight variations between seasons) and in quantities which increase with the cooling requirement.

2.1.2 1 ALDERMANBURY SQUARE (ALD)

ALD, a seven-storey (plus two basements) 8000 m^2 A/C office in the City of London was the only truly speculative building in the whole Probe data set (CAF and Marston Books were pre-lets). The rectangular building occupies a corner site, and was the only Probe building not free-standing - one flank wall and part of the back wall adjoin other buildings. It was nearly two years between its completion and its occupancy by a single tenant (Standard Chartered Bank), in which some continuity was lost, so understanding and design and record information was not nearly as good as first encountered at TAN.

ALD's A/C boasted a number of relatively novel features, particularly for a speculative building:

- An ice storage system[6].
- Low temperature air distribution.
- Fan-assisted variable-volume and temperature (VVT) units to blend the low-temperature primary air with room air.
- Local optimising controls for the VVT control zones plus more conventional central controls for the boiler, chiller and ice storage equipment, but no BMS[7].

Low temperature air can potentially save energy by reducing the fan power required for air handling. On the other hand, the refrigeration will be less efficient (see below) and more humidification may be required. Ice storage tends to increase energy use: chillers become less efficient at the lower temperature and heat has to be double-handled in and out of the store. There are also additional standing losses from the extra surface areas of the pipes and storage vessels; the larger temperature differentials; and some condensation at ALD. However, there can be savings in fuel cost (night electricity can be very much cheaper), and possibly carbon dioxide (since a higher proportion of baseload electricity is generated by renewable, nuclear and the more efficient fossil-fuelled stations). At ALD there were also some important site-specific reasons:

- The ice storage reduced peak electricity demands: at the time of design, over-estimated electrical requirements for office equipment and air-conditioning had been causing fears of electricity shortages and demand restrictions in the City.
- Ice storage also reduced the space required for chillers and heat rejection equipment on this restricted site.
- The low-temperature air permitted air volumes and duct sizes to be smaller, which here allowed ALD to have an additional floor within the planners' prescribed sight lines; but at some cost in increased fan power.

Probe however indicated that ALD's energy consumption was relatively high owing particularly to fans at high pressure, pumps transferring chilled water in and out of store, and reduced chiller efficiency when making ice. In addition, with the electricity supply contract applicable, the off-peak chiller use for ice making did not translate into lower overall bills. The contracts available which offered cheaper electricity at night also charged more for it during the day; and the overall balance of ALD's consumption profile produced no savings. When considering potential benefits of night electricity use, it is necessary to consider the load profile of the building as a whole - and not just the off-peak system - in relation to the contracts available. However, such information is subject to changing commercial factors, and may not be known to the designers. ALD's energy costs could probably have been lower (and occupant satisfaction higher) if the occupier had devoted more time to fine-tuning the system. The occupier agreed, but said that the building was more demanding than they were accustomed to, and they had achieved what they thought was the most appropriate balance between effort, cost, performance and occupant satisfaction.

This study illustrated some recurring points in Probe about design for manageability, particularly in speculative buildings where a tenant (or a contractor) will tend to be less likely than an owner-occupier to buy into an unfamiliar concept. Having said that, some later Probes indicate that it is one thing to be prepared to pay for energy-saving features and quite another to be prepared to devote the necessary effort to looking after them. Although there is scope for better management, "keep it simple and do it well" is a strong message.

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[6] Here the chiller makes ice, usually overnight, which is then melted the next day to provide cooling, either instead of or as well as the chiller. This both permits use of - often much cheaper - night time electricity (usually between midnight and 7 AM) and also provides additional cooling capacity to meet peak daytime demands.

[7] A BMS - Building Management System - is a computer system used for control and monitoring of building services plant. It permits more flexible control, management, and reporting than traditional stand-alone controls, and is often supervised from a PC at a central point - often the facilities manager's office. Most Probe buildings have BMSs - for the offices all except ALD (though the VVT zone controllers have some BMS characteristics) and MBO. FRY's was retrofitted.

2.1.3 CHELTENHAM AND GLOUCESTER (C&G)

C&G was Probe's first out-of-town office, on a suburban site set back from a roundabout at Barnwood, on Gloucester's by-pass road. As commonly happens, the move to this type of office increased the staff's car use. In the Probe survey, 89% of staff travelled to work in their own car. None in the sample shared cars - the others either walked or used a bus. Average journey-to-work mileage had increased from 15 to 19; but 45% had a journey of less than 5 miles, which potentially might be cycled. Since the number of staff in the building had also risen to 930 from an intended 700, the original 450 car parking spaces were not enough and were increased to 600 (65% of staff): these were also under pressure and unfortunates sometimes had to park nearby.

The estimated car fuel consumption for commuting was 324 kWh/m^2 of building area per year: 2.5 times the building's normalised gas consumption and of a similar magnitude to Davis Langdon Consultancy's survey of travel to the British Council's offices on the edge of Manchester [1]. However, the extra car use stimulated by out-of-town location does not stop there: once the car habit is reinforced by commuting requirements - perhaps requiring the purchase of a first or second car - studies indicate that cars become used more for other purposes too.

At 20,000 m^2 and also completed in 1990, C&G was almost as large as TAN, and for a similar financial services organisation. However, it had many significant differences, including :

- A head office, with a more diverse range of functions, more cellular offices, lower occupancy densities, and a computer suite (Standard Life's main computers were not in TAN, but a dedicated building nearby).
- Owing to rapid organisational growth and change, the building had been required urgently and was briefed and built rapidly, taking only two years from decision to occupation.
- Perhaps for this reason, it had no basement and was a simple rectangular shape around a central atrium, and divided into four similar quadrants as far as plant was concerned.
- Systems were relatively conventional for the time, for example VAV A/C from the ceiling.

In spite of the speed, standardisation and relative conventionality, the building is of high quality. The occupants however regretted the lack of storage space, which might have been available in the basement of a less rapidly-constructed building; and off-site storage had to be obtained. In places more time might have allowed the building's planning to be improved, for example in the relationship between entrance and atrium and the space planning on the top floor; where the two occupied ends are separated by plant and long corridors.

C&G's urgent requirement also coincided with an overheated building industry at the time of construction and completion. C&G's management felt that the building had been completed in too much of a hurry and then rapidly abandoned by the building team. They thought this had, for example, led to problems with airtightness - but sadly this was not unusual in Probe, nor indeed in recent UK buildings generally - as work by BRE, BSRIA and others has shown. Widespread problems with solar gains and glare had resulted from a client decision not to install the external shading the designers had recommended: they had felt that it would mar the building's clean appearance. Hence the translucent curtains had had to be doubled-up and were often kept shut.

Its relatively conventional services would generally have been regarded as less energy-efficient than those in the other four Probe A/C offices. In fact, C&G was the lowest-energy user, though for most end-uses still above the ECON 19 [9] Good Practice benchmark for a "Type 4" prestige head office. It had some nice touches, including differently-coloured light switches for lobby, circulation and office space and a common glycol[8] heat rejection and free cooling system for the water-cooled 700 m^2 computer suite. The Probe team had some doubts whether the free cooling was saving much energy in practice - but this would have required a more detailed study over a longer period. Apart from FRY, C&G was the only Probe building to be seriously practising energy management at the time of the Probe survey. Even here, the energy manger said that the potential had been restricted by general management - who were not prepared to support measures which might carry any risk to service, comfort and reliability in their chief office. This is a common message from UK offices in the 1990s, as has been confirmed, for example, in the recent PiT RESET project [2].

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[8] The refrigeration compressors in the room units at C&G reject their heat into a cooling water which is then pumped through air-blast coolers (like large car radiators) on the roof. In chilly weather (typically below about 8°C) the return water can cool the computer room directly. It is therefore passed through cooling coils in the room air conditioning units first, to reduce or eliminate the use of the compressors. The name "glycol cooling" is used because ethylene glycol has to be added to the circulating water to stop it freezing in cold weather.

2.1.4 HFS GARDNER HOUSE (HFS)

Gardner House, Harrogate is the headquarters of Homeowners Friendly Society (HFS) and was the smallest (4100 m^2) of the A/C offices in Probe. It was the result of an architectural competition for a rural site just outside the city and at the far edge of a former industrial complex (now a business park) with a railway station on the opposite edge, about ten minutes' walk away. The site has a spectacular outlook to the south into the Crimple Valley and its Victorian railway viaduct.

In spite of the open site, the building is air-conditioned. HFS's former premises in central Harrogate had suffered high temperatures and poor air quality owing to poor environmental design of this early post-war building, plus overcrowding as the company grew rapidly in the late 1980s. HFS therefore wanted to do their best for their staff, and were also advised that a building with A/C would be more marketable if they ever wanted to move on or to sublet. They had already been impressed by buildings with static cooling[9], and finally chose a system with displacement ventilation[10], chilled beams and 100% fresh air.

The three-storey building is cut into the hillside and is square, with two stubby wings at the SE and SW corners. Its architecture juxtaposes heavy stone elements for the ground floor, gable ends etc.; with inserts of lightweight curtain walling under a pitched slate roof. The principal open office floor has some 1500 m^2 of open plan area and a suite of meeting rooms and cellular offices on the south side. Above it is a square doughnut of management offices facing outwards with an internal glazed corridor around a central courtyard. Below this is a lower ground floor on the east side only, with offices facing onto a lawn to the east and storage and plant rooms behind them against a retaining wall to the west.

In spite of the care taken in seeking a good building, HFS were unhappy about site management in the later stages of construction, when the original manager left and a promised M&E coordinator never appeared. They therefore felt that the building was not properly finished when they moved in; and then found difficulties in achieving the anticipated comfort levels. An important reason for this proved - yet again - to be a lack of airtightness: at the eaves, at the junctions between the curtain walling and the windows with the stonework, and through the mullions and transoms of the curtain walling system itself. At the time of the Probe survey, remedial measures had been taken but with less than 10% improvement in the pressure test results. Comfort was particularly affected because the air turnover rate of 3 ac/h was relatively low for an air-conditioning system, so there was less power to spare than for the VAV systems in the previous three buildings. Consequently, the A/C plant had to be run for extended hours, increasing its energy use and running costs, and still leading to occupant comfort levels little better than average at the time of the occupant survey.

HFS's lighting also made widespread use of luminaires with automatic occupancy-sensing and dimming. Unfortunately the anticipated energy-savings had not materialised and lighting energy consumption was slightly above Typical levels. There were four main reasons for this:

- A relatively high design illuminance level of 600 lux in the offices, contributing to an installed power density (IPD) [11] (18 W/m^2) 50% higher than the ECON 19 good practice level of 12.
- Difficulties in commissioning the controls satisfactorily, owing, for example, to upward reflection of daylight from the slats of the venetian blind onto the photocells, requiring settings to be increased.
- Automatic switching-on of lights to achieve the 600 lux or more, even when the occupant regarded the daylight as adequate; leading to excessive use - particularly in the cellular offices.
- Occupant disturbance by lights triggering in the open plan area, leading to all lights being switched on and left on for all the core time.
- Little effective control of lights in circulation areas, which tended to be left on all day.

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[9] Static cooling has no moving parts in the spaces cooled, for example using embedded coils in the fabric of the building, cooled radiant panels (e.g. chilled ceilings), or natural convection to extract heat. So-called chilled beams consist of finned pipes fixed to the ceiling in a boxed enclosure to assist the natural convective flow and improve appearance. These linear boxes projecting down from the ceiling look a bit like downstand beams, hence their name. The chilled beams at HFS are partially recessed into a suspended ceiling. Those at CRS (see below) are fixed directly to an exposed soffit.

[10] Displacement ventilation introduces air slightly below room temperature at floor level in a controlled manner, often from under the floor (although large-area wall diffusers or free-standing turrets can also be used). The air then rises over occupants and equipment and is extracted at high level. Advantages claimed are simpler control (within design limits, the occupied zone stays at a similar temperature whatever the cooling load) lower cooling demands (because the rising warm air is extracted directly) and higher air quality, because the pollution rises with it, and is mixed less with air in the breathing zone.

[11] The installed power density (IPD) of a service, in Watts per square metre, is the total electrical load in the area concerned, divided by the floor area. It can be a useful guide, and can be applied to end-uses other than lighting. For instance the electrical demands (and heat output) from office equipment is usually stated this way.

2.1.5 CHARITIES AID FOUNDATION (CAF)

CAF - at Kings Hill Business Park on the former West Malling aerodrome near Tonbridge, Kent - was the first office building in Probe 2. It had several other Probe firsts:

- Pre-let: constructed by the site developer (Rouse Kent: a partnership between Rouse - a commercial developer - and Kent County Council) for letting to CAF.
- Construction under a management contract, not a traditional one, with a clear focus on speed and buildability. The work was split into 35 self-contained subcontract packages, tendered separately; and including items such as packaged and largely pre-commissioned ventilation plant and a prefabricated boiler plant room, craned onto the roof. This process allowed (for example) work to start on the frame before decisions had been made about other aspects of the design; and for the designer to concentrate on resolving design details and interfaces with the trade contractors while the manager did the administration [3].
- The first truly mixed-mode[12] office building in Probe: a *concurrent* design [4] with full fresh-air mechanical ventilation from the floor and top-hung projecting openable windows, with similar but smaller openable fanlights above. TAN had MM aspirations (the lower sashes of its windows were openable), but these had little real meaning or utility (except perhaps in an emergency) in such a deep office. Indeed, following practical experience, the use of TAN's windows was discouraged by its management.
- Ventilation plant with indirect adiabatic cooling[13].
- Telephone-controlled lighting in the office areas. Unfortunately this was performing less well than had been hoped owing to zoning too coarse for individual control, an unwieldy PIN number system, and no local light switches for visitors and cleaners.

The 3-storey U-shaped building has exposed concrete ceilings to help stabilise internal temperatures. These were elegantly modelled with slots for partitions and shallow dished coffers surrounding light fittings (some with air extract points), but no acoustic treatment, which added to occupant perceptions of the building being noisy. On the top floor, the concrete ceilings had insulation on top and a shallow-pitched metal roof over much of their area to protect high level ductwork and electrical services to the second floor offices. CAF were keen on daylight, so the architect added rooflights to two wings of the top floor, with punched holes in the roofslab, in place of some of the coffers. In practice, however, solar gain and glare was a problem; and in 1998 blinds were under investigation. Motorised blinds had also been retrofitted to the double-height planar-glazed wall of the SW-facing reception area. In common with many buildings, the windows did not provide optimal control of ventilation, closing themselves too easily either by gravity or with a puff of wind; and with the fanlight handles not easy to reach, particularly when open.

In a previous study [6], higher levels of occupant satisfaction and energy performance had been found in pre-let buildings than in either owner-occupied or speculative ones. Although possibly a quirk of a small sample, a possible reason was that owner-occupiers could be self-indulgent in their requirements and - if not procuring buildings regularly - might also lack the experience as a client to ask questions and exercise effective control. Conversely, developers might not understand certain occupier needs; and be unable to fund features which - however good - were not reflected in market valuations and rental levels. Putting the two parties together might achieve better user value within the discipline of the market. However, at CAF occupant responses were no better than average, perhaps because here the landlord (via maintenance contractors) looked after the fabric and ran the services (CAF had no access to the plant room or to the system controls), while the pre-let buildings studied before had strong in-house technical management with full responsibility for running them. The landlord/tenant split also complicated the Probe study: the landlords were helpful on the first visit, but not prepared to give any more of their or their maintenance contractor's time after that.

At 3900 m^2, CAF is a very similar size to HFS, and on a similar parkland site. Both organisations outgrew their former town centre accommodation at much the same time. Although very different in origins, both now undertake similar work, providing advice and financial services to individuals and organisations. This permits an interesting comparison between the MM and A/C approaches to these two buildings. Although neither is a particularly efficient example of its type (and both have airtightness problems), CAF's energy consumption was less than half HFS's. Some of the reasons and consequences are discussed in Section 3 and Appendix A.

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[12] Mixed mode ventilation and cooling is deliberately designed to combine the benefits of openable windows and mechanical systems. In concurrent designs, the mechanical systems run constantly (at least during the occupied period), and the windows can be opened as well.

[13] A water spray cools the outgoing exhaust air, which then cools the intake air via a plate heat exchanger.

2.1.6 MARSTON BOOK SERVICES OFFICE (MBO)

The 1000 m^2 MBO is a relatively shallow-plan (13.5 m glass-to-glass) brick-clad building with a metal pitched roof. Largely open-plan, with a few cellular offices, it was the smallest office studied in Probe and the only naturally-ventilated (NV) one. It was also a pre-let to a tight budget, procured by a construction management route as part of a larger development with the attached warehouse MBW (outlined later).

The office aimed to provide good comfort with low energy use and includes some advanced (ANV) features[14]: motorised rooflights and fanlights (though with manual local and central control only) and ventilation grilles in the suspended ceiling on the ground floor to improve access of the air to the floorslab mass, following Dutch research [7]. In previous projects, the site developers had had difficulty in procuring suitable windows for naturally-ventilated low-energy buildings rapidly and reliably. They were looking for a kit system which could receive - as required - items such as operating motors, acoustic shields, and light shelves; and with sufficient mechanical strength in the transom below the fanlights to support projecting external sunlouvres. Requirements and solutions were first developed [8] in the Lansdown Window System study jointly sponsored by BRECSU and the developer. The ideas were subsequently engineered and marketed by Colt as the Interactive Window System, of which Marston Books was the first full-scale application.

The design also aimed for good use of daylight, using window design, rooflights, tiltable lightweight light shelves, and automatic lighting controls. Sadly - but again as in many buildings - the results were disappointing, owing to problems with glare control at the windows and the functionality, usability and occupant acceptance of the lighting control system.

MBO and the much larger MBW (five times the floor area, fifteen times the volume) shared the same electricity and gas meters. Although the average energy consumption was low, it was difficult to resolve the contribution of the office to this. In addition, the availability of meter readings from the gas bills was abysmal - with nearly all the bills estimated (again as in many Probes) so it was impossible to discern degree-day variations.

Following a request from the Probe team, office submeters were kindly installed by the developer. These revealed that the office's energy performance was reasonable, but only a little below ECON 19's [9] "typical" benchmark for a "Type 2" open-plan naturally-ventilated office. Reasons included a relatively high use of artificial lighting; disappointing air infiltration levels; and a surprisingly high heat requirement by the toilet supply ventilation unit - which also meant that the boiler had to be on nearly all the year, incurring standing losses. Heat recovery or extract-only ventilation would have been considerably more economical.

2.1.7 CO-OPERATIVE RETAIL SERVICES (CRS)

CRS's 18,400 m^2 5-storey building outside Rochdale was the only AC office in Probe 2, and although for a retail organisation was similar in many ways to Probe 1's TAN and particularly C&G. In addition to some 8000 m^2 nett of largely open-plan office area arranged around a series of atria, it included other facilities such as large restaurant with separate (and unusually and commendably separately-metered) services. Like HFS, the building was cut into a hillside. It has a large (1300 m^2) suite of computer rooms in the internal areas, cooled by close-control downblow room units connected to a central chilled water system with glycol free cooling. Some of the computer rooms were under-occupied and unusually (but creditably) the reserve AC units - about one-third of the total - had been switched off. Nevertheless - and as often happens - estimated energy use for the computer suite AC was higher than that of the equipment in the rooms.

Like HFS, CRS has chilled beams and displacement ventilation. Like TAN, it has HID uplighting (and control problems leading to over-use), an exposed ceiling (here with a sprayed acoustic finish), and air exhaust through the atria. Unlike C&G and TAN, it did not have its own on-site engineering staff. Instead this work was outsourced to a maintenance contractor who had an on-site supervisor and staff. Like nearly all the buildings in Probe, there was little or no energy management - exceptions in the offices were C&G and FRY (see below) - but CRS was beginning to become interested in the potential.

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[14] Probe distinguishes between natural ventilation (NV) with openable windows for single-sided or cross-ventilation as in traditional buildings; and the more highly-engineered advanced natural ventilation (ANV), using techniques such as openings other than windows, natural buoyancy effects through stacks and atria. ANV is often combined with motorised and automated controls, and designed with the benefit of computer simulation.

As on many sites where contractors are employed, contract conditions often do not have explicit requirements for plant operation and energy efficiency, which therefore fall through the gap. One consequence at CRS is that the systems did not seem to be working optimally. For example:

- There seemed to be a lack of cooling capacity, but the chillers were not working hard.
- Humidification seemed to be being over-used (a common problem in Probe, and in other humidified offices visited by team members).
- Plant was running to the original time schedule, even though the office got hot overnight (owing to the high insulation levels and direct and stored heat gains from office equipment and lighting). An earlier start or some overnight running could well have improved matters.

Like ALD, CRS's office air conditioning included ice storage. Also like ALD, the system had created difficulties for the occupier: here from low reliability owing to repeated bursting of the plastic pipes which transfer heat between the circulating glycol and the ice; each time also losing the whole glycol charge. The reason for the bursts was not entirely clear: maintenance thought that they could well have arisen from limited headroom over the tanks, causing the last batteries of pipes inserted into a congested tank to be kinked and scratched in the process. With the chillers at roof level and the tanks in the basement, the pressures involved may also have exploited any points of weaknesses.

CRS was unusually well insulated (though the walls and floors at FRY were better). Gas consumption, although lower than the ECON 19 Typical benchmark for a head office and at ALD, HFS and TAN, was higher than the older and less well-insulated C&G. Reasons included:

- The need to preheat air in a displacement ventilation system, even often in summer.
- Air infiltration: while measured leakage at CRS was at a normal UK level, it was over three times BSRIA's recommended standard for an air-conditioned building.
- Energy management at C&G, which for example had installed a small summer boiler for kitchen hot water in summer and turned its main boilers off.

Like C&G and CAF, CRS's move out of town had increased car use and taxed the car parking capacity initially regarded as adequate. The surrounding roads were congested with the overflow of CRS's parked cars.

2.1.8 OFFICES IN THE ELIZABETH FRY BUILDING (FRY)

Although part of an educational building (see section 2.2.4 for details), the offices at FRY make an interesting comparison with the buildings above. A well-insulated and airtight envelope permitted perimeter heating to be dispensed with, save in four offices in exposed corner positions, which required additional electric panel heaters - each with a low rating of 200 Watts. Nearly all heating and cooling in this mixed-mode building was provided through mechanically-ventilated hollow core floor/ceiling slabs with heating, free cooling and highly-efficient regenerative heat recovery.

Occupants can open windows in this concurrent mixed-mode design, but - and as intended - windows are little used because the mechanical system maintains cool, fresh conditions in summer, as confirmed by the occupant survey; though occupants would also have welcomed more options for window adjustment. In spite of the energy used by the mechanical ventilation, the services in this building used less energy than any other Probe offices, even the naturally-ventilated MBO. However, with a cellular office plan and lower hours of use, this is not an entirely fair comparison; which is why the ECON 19 benchmark for naturally-ventilated cellular offices is lower than for open-plan ones. After fine-tuning, FRY's CO_2 emissions were very close to the Good Practice benchmark for naturally-ventilated cellular offices..

2.2 The educational buildings

2.2.1 DE MONTFORT QUEEN'S BUILDING (DMQ)

DMQ has academic facilities for about 100 staff and 1500 students in the School of Engineering and Manufacture at de Montfort University, Leicester. Occupied in 1993, it is of particular interest for its daylighting strategy and its innovative use of natural ventilation, with its distinctive ventilation stacks. It also has a small CHP unit. The 9850 m^2 (gross) building has three distinct areas: the central building, the mechanical laboratories and the electrical laboratories. A full height concourse in the central building acts as lightwell and thermal buffer zone for adjoining spaces, including ground floor main auditoria and classrooms ventilated by the stacks. The mechanical laboratories are mainly a naturally-ventilated machine hall, flanked by small specialised mechanically-ventilated labs which also form an acoustic buffer. The electrical laboratories are housed in two shallow plan, four storey wings either side of a narrow courtyard which facilitates simple cross ventilation and well-distributed daylighting; though with somewhat unusually placed windows.

The design team's concept for DMQ was a highly insulated (e.g. wall U-value is 0.3 W/m^2 K), thermally massive envelope with generous ceiling heights (3 to 3.3 m) to facilitate natural ventilation and daylighting; and greater heights in main circulation and the mechanical laboratories. The ANV building uses innovative ventilation stacks and passive design features for summer comfort. Control of internal conditions relies extensively upon a BMS to control roof vents and motorised dampers. The complexity of the passive control requirements led to the use of BMS algorithms written in plain English, which could also support student usage. The client and the design team knew that extended monitoring and fine tuning would be necessary over the first year in relation to changing internal and ambient conditions. Unfortunately, however, various problems and disputes during the defects liability period made intervention difficult and meant that the system was not fully commissioned, even by the time of the PROBE survey. This led to some initial occupant dissatisfaction, particularly with comfort on the third floor due to non-functioning rooflight opening mechanisms (since resolved) and uncontrolled heating circulation.

BRECSU commissioned extensive monitoring of this innovative building, particularly of the auditoria with their 13 m high stacks. The results confirmed the outcome of short-term heat load tests, as recorded air temperatures tended to remain stable between 20 and 22°C. In winter there were some initial problems with thermosyphoning in the stacks, now reportedly resolved. The stacks, although highly distinctive, are questionable from the point of view of cost-effectiveness and maintenance. Although potentially the quest to avoid fans is praiseworthy, potentially low-powered extract fans at high level could have done a very similar job using very little electricity.

In energy terms, DMQ performed well with overall CO_2 emissions nearly 30 % below EEO low figures. However, heating and lighting energy consumption were relatively high in relation to other Probe educational buildings. A lead condensing gas boiler meets nearly half the annual heating requirement. The CHP unit provides about 15% of heat demand and runs for about 60% of boiler run hours - the expected kitchen HWS base load never materialised.

On the occupancy side, staff strongly disliked the move to open plan accommodation, which was on the top (third) floor of the building, where their dissatisfaction was compounded by high temperatures. Historic BMS data shows high average temperatures in third floor staff areas, with daily summer peaks reaching 30°C (the outside temperature peaked at 32°C). However, the systems were not working properly. The remainder of the building reportedly maintained satisfactory internal conditions even during the heatwave in the summer before the Probe survey.

2.2.2 APU QUEENS BUILDING (APU)[15]

Anglia Polytechnic University obtained university status in 1992 and needed to consolidate its activities in Chelmsford on a single site. It acquired a 9 hectare former industrial site in central Chelmsford. The Queen's Building, occupied in August 1994, was its first building there; and a flagship building for the University. Its mix of library, IT and café-bar functions in a Learning Resource Centre (LRC) was innovative for the time; and many LRCs of a similar date were mechanically-ventilated and often air-conditioned.

The University determined the main spatial and low energy requirements. At an intensive design workshop in March 1993, the design team resolved the preliminary design strategies, including side lighting with light shelves[16], two atria, a highly insulated, thermally massive structure, passive solar gain, winter trickle ventilation and stack driven natural ventilation with night cooling[17] for summer. The construction contract was tendered using a performance specification written by the design team, who were then novated to the successful tenderer. An EC Thermie grant was used to help demonstrate low energy design, the results being disseminated under the EC2000 programme.

The completed building (6000 m^2 gross, 5600 m^2 treated floor area) runs roughly north-south with two separate atria lying on the main axis. Three and four storeys surround the north and south atria respectively. APU was designed to provide facilities for 750 students, but was operating at a small fraction of this capacity at the time of the Probe 1 survey in summer 1996. To make use of spare space, the University had temporarily housed the accounts department and the Vice Chancellor's secretariat in perimeter cellular offices around the north atrium on the first floor; the third floor of the library was used as open plan offices. Unfortunately the third floor, although easiest to separate, was the least able to cope with such a change of use - being south facing; receiving warm air rising in the atrium; and lacking the thermal mass of coffered ceiling slabs of the lower floors. Consequently, staff working there reported significant summertime discomfort. It seemed that here (as frequently occurs with fit-outs) the occupants or their advisers made changes without proper reference to the design strategy for the building.

APU's innovative natural ventilation and daylighting features lead to classification as an ANV. Its low energy credentials are enhanced by the use of condensing boilers, evaporative cooling in the mechanical ventilation serving the kitchen, and pre-heat of HWS using waste heat from the bar cellar chiller condensers - an energy saving technology developed for pubs in the 1980s. Fabric insulation levels are also good with wall, roof and floor U-values of less than 0.3 W/m^2 K, and triple glazing (using cost-competitive Scandinavian 2+1 aluminium-clad timber windows) specified throughout. Unfortunately contractor cost saving meant triple glazing was omitted from the north facing conference room (where the details were different); but there was no corresponding increase in radiator sizing, leading to underheating.

Good performance of the ANV features has been hamstrung by the widespread industry problem of poor controls performance and commissioning, which can be more serious for ANV owing to their high dependence on effective operation: with mechanical systems, comfort can often be salvaged at the expense of increased energy consumption - as the Probe AC and MM buildings have often confirmed. The lack of local over-ride facilities for the occupants could make this worse; for example on occasions when the windows opened automatically when building work outside was creating noise and fumes. In particular, night venting was not working two years after initial occupation (and this might not have been properly diagnosed if it had not been for the investigations of the building physics researcher under the EC 2000 programme). The lighting controls also did not function well and the heating flow temperatures were set too high to ensure boiler operation in condensing mode. Nevertheless, energy performance was good, though partly related to the low occupancy levels at the time.

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[15] http://www.be.anglia.ac.uk/bpru/LearningRes.html

[16] Light shelves are designed to reflect incoming skylight from upper window elements onto light-coloured ceilings to improve daylight uniformity. The APU light shelves are made from semi-mirrored but transparent glass and reflect light onto a white painted coffered slab ceiling.

[17] APU is designed to discharge accumulated daytime heat by naturally ventilating the structure at night using cool outside air via automatically opening window toplights.

However from the client's perspective (and the contractors to which they have outsourced their operation and maintenance), a new building like a new car shouldn't require much attention, particularly when compared to the University's older properties. The fact that innovations will always need care and fine tuning to bring them into life seems to be lost on the building industry and its clients; under-rated by designers; and often suppressed by procurement and contractual mechanisms. While standardisation and best practice can potentially make many more things "right first time", it must be better recognised that innovative, unpredictable and non-repetitive aspects of buildings are always likely to require a development period of "sea trials" and fine tuning.

2.2.3 JOHN CABOT CITY TECHNOLOGY COLLEGE (CAB)[18]

CAB, in Kingswood, Bristol was the last of fifteen City Technology Colleges established between 1986 and 1993 as centrally funded, independently managed secondary schools providing an emphasis on technology and business education within large urban catchment areas. CAB opened in August 1993 and has been filling up by a 150 strong intake of pupils each August. It will reach its full complement of 900 pupils in August 1999, and is already planning for expansion to cater for a staying-on rate to sixth form of 85%, not the 50% anticipated in the brief. Academically the college is doing well, with glowing OFSTED reports.

The classrooms are in three two-storey wings arranged as radial fingers projecting south from a central street running east-west with the main assembly hall and dining room at the eastern end and the sports hall at the western end. Staff room, administrative offices and library are in a two storey crescent to the north of the street. Gross area is 8900 m^2, treated area 8800 m^2.

The design team aimed to provide a stimulating internal environment for multiple educational activities using daylight, sunlight and high-ceilinged naturally ventilated spaces. Good energy performance was a secondary objective. The strategy was also to give occupants local control of ventilation and solar control blinds to mitigate any overheating risks. Local manual lighting controls were also favoured for this reason, but the heating plant is linked to a 200-point BMS to provide central control and monitoring functions. Throughout there was a desire to express the technology, including the building structure and services, as part of the learning environment. For example structure is often exposed; view windows were provided into the boiler plant room; and a BMS repeater panel displaying key parameters such as weather conditions, internal temperatures and energy consumption was located in the main street. Unfortunately, as at APU, insufficient attention to detail in the implementation, commissioning and usability of services and the BMS mean that maintenance staff have little confidence in the BMS; and the repeater panel has never functioned reliably.

CAB was the first Probe building to have a pressure test, by BRE. This confirmed high leakage rates through ridge ventilation dampers; even those which the school had plated-over with cover panels during the first winter, in an attempt to reduce cold draughts. The lesson - sadly not a new one - was that conventional HVAC dampers - even low-leakage ones - when used to control natural ventilation rarely close tightly, and that sizing free areas for the summer condition can lead to uncontrollable winter situations. In fact, and as often happens with windows, leakage occurred not only via the damper mechanisms but also around the outside of the assembly, where it was built into the structure. Neighbouring residents also objected to noise breakout through the dampers in the main hall, particularly for evening events, and they too had to be sealed.

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[18] Website: http:/www.cabot.ac.uk

2.2.4 THE ELIZABETH FRY BUILDING (FRY)

FRY is the most recent low energy building commissioned by the University of East Anglia at Norwich. Occupied in January 1995 the four-storey building contains academic accommodation, with two 120 seat lecture theatres, two smaller lecture theatres and numerous seminar rooms on the lower ground and ground floors and some 50 cellular offices for about 70 staff in the schools of Social Work and Health Policy and Practice on the first and second floors. The building was designed to accommodate up to 1000 students, although a typical maximum is closer to 600. Gross floor area is 3250 m^2 , treated area 3130 m^2.

The building has a very clear environmental control strategy, with a well insulated, thermally massive and airtight envelope to minimise external heat losses and gains, low-e argon-filled triple glazing, ventilated hollow-core floor slabs with exposed soffits to provide better radiant conditions in the spaces and more effective heat transfer with ventilating air, and 'trickle-charge' mechanical ventilation via the cores to achieve stable year-round internal conditions (with added heat if needed in winter and night cooling in summer). Occupants can also use opening window elements for local ventilation as needed, making this a mixed-mode building.

With high efficiency heat recovery in the AHUs, the design heat loss fell to just 15 W/m^2, met by three domestic gas fired condensing boilers with an installed capacity of just 23 W/m^2 including 50% reserve (most other Probe buildings have between 100 and 200 W/m^2). The high insulation and thermal capacity also made it possible to simplify the systems by avoiding perimeter heating[19]. There is a separate direct gas fired storage heater for the kitchens and main toilets.

The energy and comfort performance has been well documented by monitoring for BRECSU, upon which the PROBE study has drawn, while also making independent checks. The monitoring identified control problems, and after attention by the occupier, the controls specialist and the design team, normalised heating gas consumption was reduced to just 33 kWh/m^2 in 1997. Total CO_2 emissions (including HWS gas and all electricity use) were 44 kg/m^2/yr - just over half a low to medium academic benchmark and comparable to an ECON 19 good practice naturally ventilated office. Low HVAC electricity usage is ensured by good specific fan powers of around 2 W/l/s (higher than the desirable target of 1 W/l/s, but well below typical 3 W/l/s), low supply volumes determined by minimum fresh air requirements only, and variable volume supply with automatic air quality control to the intermittently occupied lecture theatres.

Exceptionally high occupant satisfaction with comfort in the offices arises from a combination of good stable background levels of services (especially fresh air and modest artificial light levels) and provision of sufficient adaptive opportunity for users to fine tune local conditions (via opening windows, blinds and manual light switching) which means that users are rarely exposed to discomfort. Cellular office accommodation (usually preferred to open plan) and good building management by the Estate's team are also important contributing factors. Students regarded comfort levels in the lecture rooms as similar to others in the university.

Overall FRY presents the best example yet of virtuous processes with careful briefing, team selection, design, construction, commissioning, monitoring and operation leading to unusually high levels of satisfaction, together with low energy consumption. Nevertheless, even here, there was considerable scope for yet more reductions in electricity use and carbon dioxide emissions, particularly for lighting installed capacity and control, and specific fan power.

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[19] Electric perimeter heaters are often fitted as contingency in Termodeck buildings. Design calculations indicated that these would seldom be required, so the design team agreed with the client that they would omit them generally, but that it might be necessary to add a few is any rooms proved to be cold. At the time of the Probe study, five 200 Watt heaters had been added, mostly in corner rooms with their extra perimeter heat loss.

2.2.5 THE PORTLAND BUILDING (POR)[20]

The Portland Building was commissioned by the University of Portsmouth to house the School of Architecture and the Department of Land and Construction Management in a single building which also includes shared learning and teaching resources for the whole Faculty of Environment. The building is on a former car park next to existing faculty buildings in central Portsmouth. Occupied in July 1996, it houses 60 staff and serves 870 students from the two departments. Including those from other departments, some 1200-1300 students use the lecture theatres each day.

POR has 6230 m^2 gross floor area in an E-shape plan form with north and south wings housing four storeys of classrooms, design studios and staff offices, a west facing spine housing a three-storey resource centre with two 80 seat lecture theatres, four large seminar rooms above them, and a galleried library in between. The central wing of the building houses a 200 seat displacement-ventilated comfort-cooled lecture theatre, above a ground floor café. In the centre of the E between the wings is a full height galleried atrium which creates an enclosed but light and spacious forum.

The building is predominantly naturally ventilated, as signalled by distinctive glazed plantroom turrets at the top of massively-constructed stairwells which double as stack ventilation towers. However, the designers used a variety of environmental systems and experiences both to deliver acceptable comfort and to be of value didactically to the students. These run from wind protection only in the courtyard to the fully mechanically ventilated comfort cooled main lecture theatre, so the building is very much a mixed mode one.

Insulation levels are reasonable with wall U-values of 0.33 W/m^2 K, air tightness was tested and found to be about average; and total boiler output of 123 W/m^2 confirms the average performance levels. Unusually the building has solar panels in four of the five ventilation towers which pre-heat the hot water. Surprisingly, however (and despite extensive underfloor heating) none of the twelve boilers (distributed amongst plantrooms at the top of each of the five ventilation towers) is condensing; although condensing boilers would have been likely to save more gas at less cost than the solar panels. Is it not time that condensing boilers are simply accepted as standard?

The daylight is good. The design strategy was to give occupants as much control as possible over their comfort conditions, so in many spaces local wall switches are combined with effective occupancy sensing controls. Although somewhat haphazard in operation, these worked quite well to reduce lighting energy use. Ventilation and solar shading is also locally-controllable.

Originally most controls were local: only the main boiler plant and associated toilet extract fans and make-up units were on the central campus BMS system initially. Progressively the estates team has been installing further outstations to improve control of the advanced passive design features such as atrium vents, atrium solar shading and external solar shading, for which the local controls had proved inadequate. Sometimes, however, the local controls have been sealed-off, owing to the Estates Department's desire to have responsibility for the building's security and protection. This raises interesting issues about central and local occupant control - which cropped up frequently in Probe. The Probe team’s view is that there are major benefits in combining central and local controls appropriately, but that doing this requires much more attention to strategy and detail than the industry can normally afford to provide.

As at APU, the already overstretched Estates Department had assumed that this new building would need little attention and did not allocate much time to fine tune and fully understand the building's performance. For this building, they had also been little involved in briefing and procurement, which owing to the former polytechnic status, had largely occurred between the Faculty and the designers, Hampshire County Council. Further evidence of insufficient commissioning was given by the non-operational electricity submetering; the poorly-understood automatic control of lighting, solar shading and library ventilation; and user over-rides which sometimes proved to be ineffective in operation.

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[20] Website: http://www.port.ac.uk/estates/portland.htm

2.3 The other buildings

2.3.1 CABLE & WIRELESS (C&W)[21]

The Cable & Wireless residential training college on a business park outside Coventry was commissioned to replace their original training centre at Porthcurno, Cornwall. The site was selected from over 100 alternatives, primarily for easy communications. The building provides high quality facilities for courses in technology, management and marketing for all parts of the Group. Occupied since December 1993, the building has been widely acclaimed and won the Sunday Times Building of the Year award in 1994. The designers used an innovative wave roof form to provide natural ventilation of the main teaching spaces, responding to the client's brief for a low tech but distinctive building. For this reason it is classified as ANV. The NV residential building and the mechanically-ventilated sports centre were also included in the energy analysis (sadly - but normally - they were not sub-metered) but not the occupant survey.

The 12,000 m^2 (gross, 11400 m^2 treated area) college has three distinct blocks:

- a 7,000 m^2 single storey teaching block to the south of the site, with 2 lecture theatres, 20 classrooms, 22 laboratories, tutor offices and library;
- a three-storey 3,600 m^2 residential block, with 168 study bedrooms, plus restaurant and administrative offices;
- a 1,400 m^2 leisure pavilion with 25 m swimming pool, sports hall, squash court, gym and café-bar.

The college achieves a high level of architectural delight and is finished to very high standards. The ANV classrooms are a success in terms of the design ambition - supported by physical and computer modelling - of providing summer comfort in a deep single-storey space with openings at high level only. However, underheating and cold draughts from open windows have occasionally been a problem in winter. High areas of south facing glazing in the restaurant and mezzanine offices have led to summer overheating, which would typically be solved by air conditioning. Staff dissatisfaction with comfort in this area is exacerbated by conflicting environmental demands of the restaurant and the administrative spaces, which share the same space, noise, heat and means of control - manually operated opening windows and blinds.

Mechanical ventilation and cooling were largely avoided for areas with expected internal heat gains of up to 50 W/m^2 . For classrooms in which gains were expected to be higher, a single 47 kW packaged air cooled water chiller provides chilled water for downflow fan coil units. In practice, these high heat gains have seldom occurred, owing to a change in emphasis of the college from technical to management and professional training. LTHW is from modular high efficiency boilers, seemingly missing an ideal opportunity for condensing boilers or even CHP[22] given the steady base load heat demand of swimming pool, catering kitchen and residence HWS.

The 'low tech' philosophy extends to all aspects of services controls. Except in the leisure pavilion, control is left to occupants via local wall switches for vent opening, blind operation and light switching and TRVs for perimeter radiators. So far, unfortunately the lack of "ownership" by short-stay students of the local control and the absence (as in most buildings surveyed) of any energy management policy has led many systems, and in particular lighting, to default to on. In the pavilion, the automated lighting controls were not understood by occupants and so were overridden to the default state of all on for 18 hours every day despite highly variable occupancy. As is normal in swimming pools, the pool hall ventilation ran 24 hours to avoid condensation: however, it could have been variable in capacity. The chilled water to the classrooms also circulated constantly.

Both gas and electricity consumption were far higher than expected: partly because only the classrooms were attempting to improve on normal practice in servicing terms. This situation was exacerbated by the high running hours, default to ON, lack of basic sub-metering and no energy management.

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[21] Website: http://www.cwplc.com, http://www.cwcollege.com/

[22] CHP (Combined Heat and Power) uses an on-site engine (usually gas-fired) to drive an electrical generator, while the engine's waste heat is recovered and used for heating, sometimes hot water, and occasionally absorption chilling. Overall conversion efficiencies are high, but economic use depends on the availability of a year-round heating demand which is rarely found. To meet normal economic criteria, useful heat typically needs to be required at the full capacity of the CHP unit for 4000 hours a year or more; and preferably between 7 AM and midnight.

2.3.2 WOODHOUSE MEDICAL CENTRE (WMC)

WMC (640 m^2 gross) is the smallest building studied in Probe. The single-storey medical centre on the outskirts of Sheffield is domestic in scale and construction. It is divided into three individual units occupied by two separate GP surgeries and a dental practice. Opened in 1989, it was built to very high standards of insulation (Wall U-value 0.2 W/m^2 K, Roof U-value 0.1 W/m^2 K) and includes several other low energy features such as mechanical ventilation and heat recovery (MVHR), gas condensing boilers and low energy lighting. It was also completed within the strict financial and spatial constraints of the local Health Commission, with no additional funding for the low energy features.

WMC has the lowest CO_2 emissions per square metre of any of the Probe buildings. It is well liked by occupants despite several gaps in their understanding of the design intent - which appeared to stem from little contact between the designers and the building's end users during and after handover. For example, the domestic-style mechanical ventilation heat recovery systems were generally assumed by users to provide a form of year round air-conditioning, and hence to provide improve summer comfort. In fact, they had no bypass, so would actually tend to increase air temperatures. These units had fallen into disuse by the time of the Probe survey.

Similarly, the natural ventilation strategy was to use casement windows (sometimes now with their movement restricted by added external security bars) and if necessary to cross-ventilate with outlets via openable roof windows near the ridge in corridors and public areas. However, the roof windows were not used because they are high up and impossible to reach. Although operating poles or motors could quite easily have been added, after completion nobody had got round to doing it, and consequently summertime temperatures could be high. In addition, the intended cross-ventilation of doctor’s surgeries via high-level windows to the corridors was not possible owing to the need for acoustic privacy. One practice decided to retrofit split DX room units in two spaces: but since these were only used in times of need, their contribution to annual energy consumption was low. The generally high satisfaction levels, despite the summer discomfort, is probably due to the general domestic style of WMC and its consequent familiarity, as discussed in Reports 3 and 4.

Several other services issues are noteworthy:

- High electricity use by the 27 local electric water heaters, each with standing losses of 0.5 kWh each per day, amount alone to 15% of total electricity usage. Time controls would have been beneficial. Using the domestic gas boilers to provide the hot water would probably have been better.
- Artificial lighting levels were low. Since most rooms also require the use of internal blinds for privacy, each practice quickly installed additional lighting including very inefficient 300 W halogen uplighters in one practice.

The cellular and domestic nature of the building, with local control in each room, tended to lead to less wasteful operation than in open-planned areas, where everything is more likely to default to ON.

2.3.3 ROTHERHAM MAGISTRATES COURTS (RMC)

RMC was occupied in March 1994. It houses ten courtrooms to meet anticipated needs over the next fifty years. The brief - set by a committee of Magistrates - sought a building which avoided air conditioning (it was at a time when concerns about sick building syndrome had a high profile) and provided some daylighting to all court rooms. The designers used EC programme funding to obtain specialist thermal and daylighting analysis to inform decisions about the built form, natural lighting, and sunspaces for both passive heat gains and ventilation air preheating.

Of the building's gross floor area of 5450 m^2, 1200 m^2 is circulation space, reflecting the need for three separate circulation zones for the magistrates, defendants and members of the public. These are elegantly resolved: the building has a courtyard at its centre; the south-facing double-height glazed sunspaces with galleries are used for public circulation and waiting areas and demonstrating the passive design concepts; and the magistrates rooms and circulation systems have views on the north side. However, the ushers did comment that the courtyard plan had made people more difficult to find than in a more compact arrangement with a central core of waiting areas.

Following initial tendering, a budget cut of £ 1 million was imposed, which led to changes in the solar and low-energy strategy, with some compromises:

- The sunspaces were reviewed and it was found that their glazed roofs were not necessary. Without them, overheating risk was reduced, daylight to the public areas was still good and ventilation and solar shading could be reduced. This was probably an improvement.
- The separate mechanical ventilation systems for waiting and courtroom areas - with heat exchange from outgoing sunspace air to incoming courtroom air - were combined.
- Roof windows were omitted from the offices with high ceilings rising into the roofspaces. This proved a false economy, and after the building had been through its second summer fifteen wall-mounted split system air conditioners were fitted.

Mechanical ventilation to the courtrooms and public areas is largely via floor-mounted displacement ventilation terminals using 100% fresh-air with heat recovery from exhaust. A chilled water system also provides cooling to the AHUs in hot weather, but is quite sparingly used. The cost-cutting and associated changes compromised the original operating strategies which were originally intended to treat the sunspaces and the courtrooms separately. In winter it was intended to exploit the passive sunspaces by using solar and exhaust air heat recovery to pre-heat fresh air, whilst in summer sunspaces would be entirely naturally ventilated and the courtrooms would be supplied with chilled fresh air and extracted to ambient via a by-pass to the heat exchanger. However the systems as finally installed are unable to serve separate zones or to bypass the heat exchanger. They also supply a very generous average 4.5 l/s per square metre of the total area despite low occupancies. Hence there is high fan energy consumption and associated air tempering loads, particularly heating. This is exacerbated because even though the system is zoned to some extent, if any one courtroom is used, it typically requires the ventilation systems for two or three others and their associated waiting areas to run.

Generally daylight availability is good, although the requirement for daylight in each courtroom leads to some complex internal arrangements particularly with respect to fire compartments. The use of nearly sixty different lamp types is also troublesome for the building managers. Average IPDs are reasonable at 11 W/m^2. Lighting control is manual and fairly high numbers of lights were unnecessarily on during Probe visits: inconsistent switch layouts between otherwise identical rooms leads to confusion in use. Nevertheless, lighting energy use was relatively low owing to the intermittent occupancy of many of the spaces, the good daylight in the public areas, and the availability of local switching.

Occupant comfort in the courts, public areas, and magistrates' areas is high. Comfort in the offices is now high too - though at some cost in terms of energy consumption - following the fitting of local air conditioning which is available on-demand via local controls for each unit.

It was disappointing that the gas consumption in this low-energy design was only just below the "high" benchmark level in the Yellow Book for Crown and County Courts, and electricity somewhat above the "high" benchmark. The main reason for this was the mechanical ventilation: the high air change rates having high air tempering requirements, in spite of the cross-flow heat recovery. The electricity used by the fans was also very high, owing to:

- The high air change rates.
- The relatively high specific fan power (3.8 W/l/s)
- Relatively long hours of use (averaging 11 hours/day, even though courtrooms are only required for a maximum of six hours and typically only half are in use at any one time.

At RMC - as in many buildings - it seems that designers and their advisers frequently fail to consider the energy - and in particular the CO_2 - costs of air handling in sufficient detail. This sometimes leads to fan anathema - as in some of the ANV buildings - although efficient slow-speed extract fans at high level could often perform a very similar function using little energy without the capital and maintenance costs of stacks. On the other hand - as at RMC - fan energy can slip through the net. For example, one of the main reasons for RMC’s ventilation system design was to recover heat from the sunspaces and save 5 kWh/m^2 of gas (1 kg CO_2/m^2) per year. However, in the completed building the fans was used nearly 40 kWh/m^2 (20 kg CO_2/m^2), so the benefit of the solar preheat to the environmental bottom-line was equivalent to a 5% reduction in annual fan energy, whereas a good practice air handling system would have produced at the very least a 50% saving; and operating hours could probably been halved as well if control could have been more demand-responsive.

2.3.3 MARSTON BOOK SERVICES WAREHOUSE (MBW)

The offices at Marston Book Services (MBO) are attached to the corner of a large warehouse (MBW) of fifteen times the office building's volume. The warehouse provides goods inwards, pallet racking, retrieval, packaging and despatch of books to customers. Importantly MBS felt that the warehouse should be built to similar standards of fabric insulation to the offices, which has resulted in good performance. Heating consumption is around half the benchmark level for a new warehouse: though this is partly the consequence of the relatively low internal temperatures set (10-12°C), with boosting under occupant control and regularly checked by the supervisor. Measured air leakage, although higher than best practice standards (achieved, for example, by some supermarket chains) was also very good for a UK industrial building.

Summer conditions in the warehouse can become uncomfortably warm for the staff who work there, particularly the 25 or so on the daytime shift; and the fork lift operators who rise to the top of the racking with their cargoes. Natural ventilation through windows and loading doors is concentrated at the north-west corner of the building. Motorised roof ventilators would have been helpful, but MBS wanted to protect their stock from the risk of rainwater ingress. The destratification fans provided with the warm air heating have also not been entirely successful, owing to obstruction of downflow by the mezzanines.

In common with many warehouses, the lighting has relatively low illuminance levels (150-200 lux) and installed power densities (5 W/m^2), but is all on just two switches and so has long hours of use even though much of it, particularly above the racking, is only occasionally required. More demand responsive controls would have been beneficial.

Owing to the slow run-up time, the SON lighting is also switched on automatically each day on a 24-hour timeclock. There is no Saturday morning shift, so the supervisor has to call in then to switch the lights off. This no doubt also has other advantages for security, checking the work of the previous night shift, and setting things up for the Sunday night’s work. This again illustrates how easily minor problems in buildings can persist, with occupants finding practical but non-optimal ways of living with them rather than considering simple alterations, for example a 7-day time clock here (or window poles at WMC).

3 OVERVIEW OF ENERGY PERFORMANCE

3.1 Introduction

BACKGROUND

Probe has sought to provide feedback from buildings in use, with the intention of helping the building industry, its clients, and government to find ways of improving technical performance and occupant satisfaction with less impact on the environment. Details have been given in the individual published studies. The current review seeks to identify some of the more strategic implication for briefing, design, construction, management and regulation; and to avoid common pitfalls

CARBON DIOXIDE EMISSIONS

Energy performance and greenhouse gas emissions are key concerns at present, with the government seeking measures which will help the UK to meet commitments made in its election manifesto and at Kyoto. Buildings account for about half the UK's CO_2 emissions; for the most part from operational rather than embodied energy. Emissions related to the service sector - including non-domestic buildings - have also been growing, both absolutely and proportionally; and are now overtaking those from manufacturing industry. Energy however tends to cost less in relation to turnover than in manufacturing; and is also less visible, being more diffusely spread around organisations and their buildings.

THE RELEVANCE OF NEW BUILDINGS

It is often claimed that new buildings are but a drop in the ocean, with annual output representing no more than 1% of the total stock. However, it is clear that in the next century major improvements in energy performance will be essential; and if our new buildings are part of the problem and not the solution, this will be a massive lost opportunity. Many issues exposed in Probe are also equally applicable to the alteration, refurbishment and management of existing buildings; and to the equipment used in them. It is also timely to link such issues to the Egan focus on improving the building industry's performance and cost-effectiveness.

PROBE ENERGY DATA COLLECTION METHODS

The methods used have been described elsewhere [10 and PC1]. The Probe survey process and its effectiveness are reviewed in Report 1 of the current project.

3.2 Gas consumption

HEATING SYSTEMS

All Probe buildings to date have been gas-heated, mostly with perimeter LPHW radiators or convectors, except for the highly-insulated FRY (which is kept at a stable temperature by its embedded ventilation system - with a very few electric perimeter radiators); the warehouse MBW (with suspended gas-fired warm air heater units); and the speculative ALD (via the AC system).

DOMESTIC HOT WATER

Domestic hot water services (HWS) for WCs and tea points in the office and "other" buildings was usually local electric, with LPHW calorifiers at C&W, HFS, and CRS. Where offices had catering kitchens, however, these had LPHW calorifiers, except at the speculative ALD. All the educational buildings had LPHW calorifiers, plus electric water heaters in remote locations at CAB and FRY. POR used solar collectors and APU condenser heat from the bar cellar cooler to preheat their HWS.

OVERVIEW OF GAS CONSUMPTION

Figure 3.1 shows the annual gas consumption of all the Probe buildings, sorted in order of increasing use in kWh/m^2 of treated floor area, and split into:

- Heating and hot water. With the time and information available, it was not possible to apportion gas use to HWS with any precision. Instead differently-patterned bars are used to identify the various systems installed.
- Catering, for the six buildings with catering kitchens including gas equipment.
- Gas-fired steam humidification: this was used in TAN and C&G only.

Further details on energy consumption are available in Appendix B. For clearer comparison, the heating consumption has been normalised to a standardised year of 2462 degree-days. For many of the buildings the normalisation could only be crude, owing to inadequate monthly gas bill data. At MBW and C&W there was not enough information to justify any normalisation.

BENCHMARK COMPARISONS
Figure 3.1 also shows (marked >>) some relevant benchmarks for offices from the 1998 edition of Energy Consumption Guide 19, ECON 19 [9] (1998)[23]; plus a reference good practice AC office building, One Bridewell Street [11], a case study in the Energy Efficiency Best Practice programme. Benchmarks for the educational buildings have been discussed in the articles and reference [PC3].

A WIDE RANGE
The data reveals a wide range in gas consumption, from under 40 kWh/m^2 at FRY to 400 at C&W, which however has special features including 24-hour residential use and a sports centre with swimming pool. The majority of the Probe buildings used between 100 and 150 kWh/m^2 - most of it for heating; and also tended to fall between ECON 19 “typical” and “good practice” levels. Since nearly all the buildings claimed to be low-energy, this performance was somewhat disappointing. Buildings in the UK which consume much less than 100 kWh/m^2 of heating fuel appear to be rare; although design estimates frequently produce figures of around 50 kWh/m^2, and sometimes less.

THE HIGHER GAS CONSUMERS
Apart from the anomalous C&W, the high gas consumers TAN and HFS had two things in common, they were air-conditioned head offices with full fresh-air ventilation and no heat recovery. Both also had long running hours: TAN owing to extended occupancy and the difficulty of zoning an office with very large open floorplates; and HFS because of the extended pre-conditioning times required to overcome a major air leakage problem. If full fresh air is used - and it is increasingly advocated for health reasons - then heat recovery should form part of the package. This is particularly important with displacement ventilation or floor supply, as in these two buildings; where incoming air does not mix with warmer room air before entering the occupied zone. TAN also had high gas consumption for its central steam humidification; again partly owing to full fresh-air ventilation: this is discussed further in Section 3 and Appendix A.

The other buildings with displacement ventilation - CRS, RMC and CAF - all had heat recovery with cross-flow heat exchangers; and lower - though only average - levels of gas consumption. Here further savings could have resulted from better airtightness and better system control in all the buildings; and in particular better zoning at RMC, where the ventilation often had to run (and at constant volume), even when most of the courtrooms and waiting areas served were empty.

THE LOWER GAS CONSUMERS
Of the AC buildings, C&G consumed less than the Type 4 GP benchmark (which does not include gas humidification). FRY, the lowest gas consumer, stands out as an example of what can be done in a massive, well-insulated, airtight building with fabric thermal storage ... provided sufficient attention is devoted to detail in briefing, team selection, design, construction, handover, monitoring and management. However, FRY’s gas consumption was considerably higher until monitoring for BRECSU [12, 13] revealed control problems which the university took seriously, adding new BMS outstations. FRY’s ventilation plant also had highly-efficient heat recovery and the boilers were small and all condensing. Condensing boilers were surprisingly rare in Probe; otherwise being fitted only at APU and for the lead boilers at DMQ and CAB; and in none of the office buildings.

The highly-insulated WMC - again with domestic wall-hung condensing boilers - also had very low heating energy consumption. However, this building had been designed primarily with winter in mind and tended to overheat in summer - partly as the intended ventilation strategy could not be operated by users, e.g. with inaccessible roof windows. Nevertheless, in the quasi-domestic environment of WMC, the occupants forgave such deficiencies - as is discussed in Reports 3 and 4. FRY had mechanical night cooling, which helped to make it exceptionally comfortable in summer.

MBW’s gas consumption was also low, but it was only heated to a minimum of 10°C at low level, seemingly more like 12°C in practice, with rather higher temperatures (typically perhaps 15°C) on the mezzanine. The five small offices inside it were dotted-about and heated to normal by internal gains, plus local electric panel heaters, used on-demand. The metering undertaken for Probe allowed MBO’s degree-day behaviour to be well established, but warehouse use could only be calculated by annual difference as there was not enough of a cold spell during the monitored period. With degree-day correction, MBW’s gas consumption might have risen to some 75 kWh/m^2.

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[23] Some designers say that the ECON 19 1998 benchmarks were not available at the time of the design. However, they apply to occupied buildings, and its good ones to proven good practice examples. They are not design targets, although sadly they are often used as such! Appendix B, tables B1 to B3 include ECON 19 (1991) benchmark comparison tables and graphs.

FIGURE 3.1: Annual gas consumption

Benchmarks 1998 ECON19. Sorted by total gas consumption.
Heating normalised to 2462 degree days except C&W and Marston Warehouse

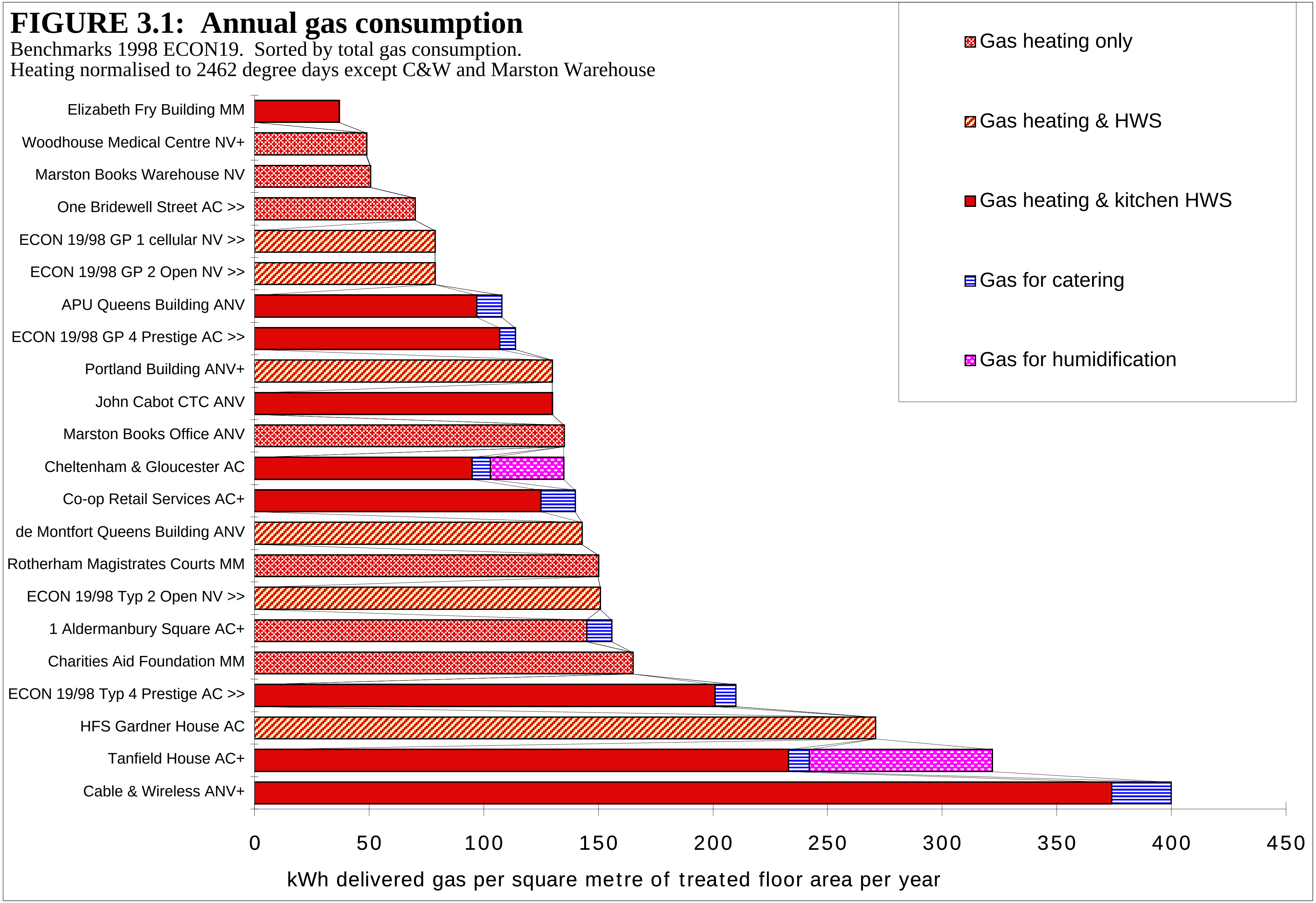


FIGURE 3.2: Annual electricity consumption

Benchmarks 1998 ECON 19

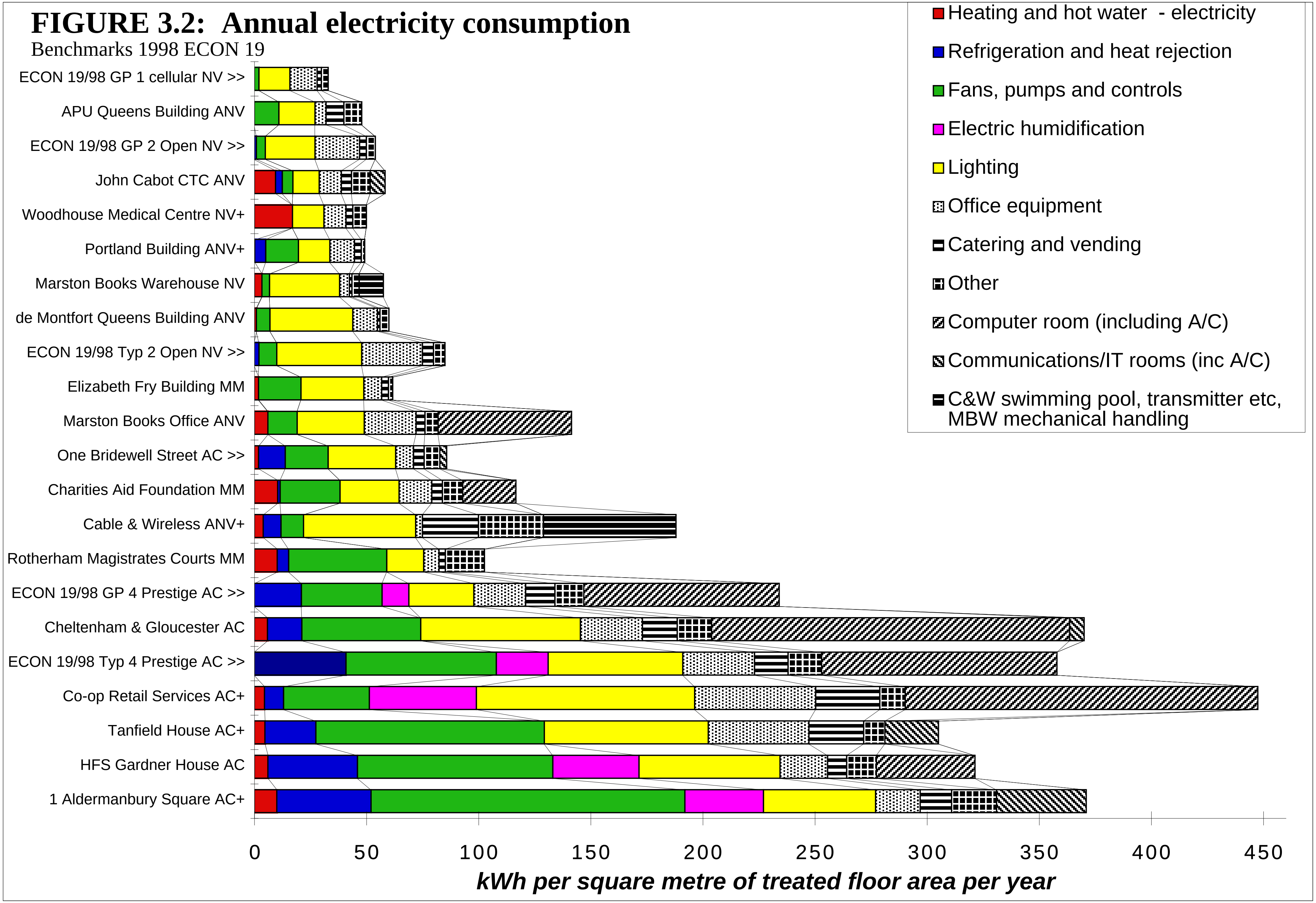


FIGURE 3.3: Annual CO_2 emissions

Benchmarks 1998 ECON 19. CO_2 factors kg/kWh: gas 0.20, electricity 0.52
Heating normalised to 2462 degree days except C&W and Marston warehouse

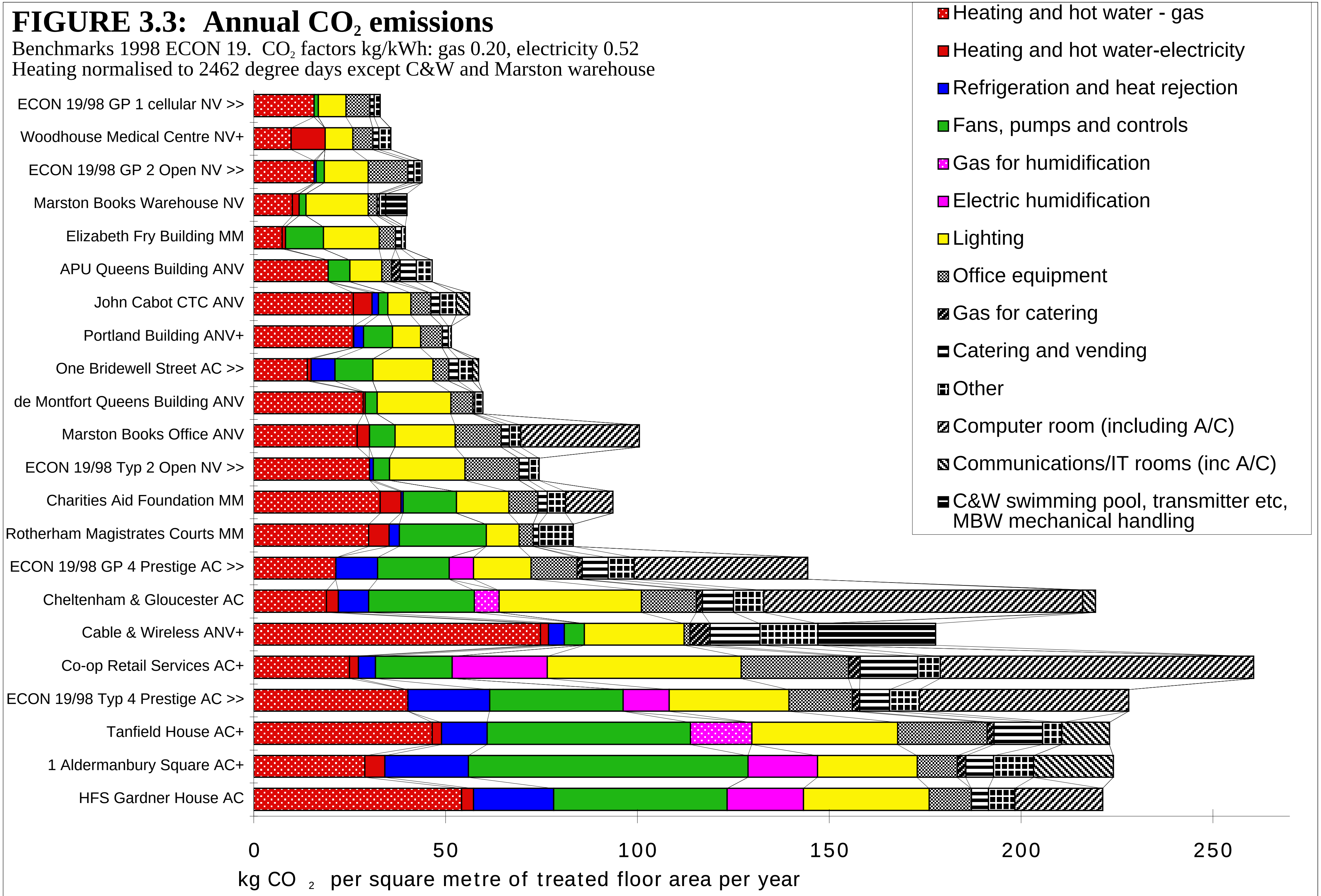
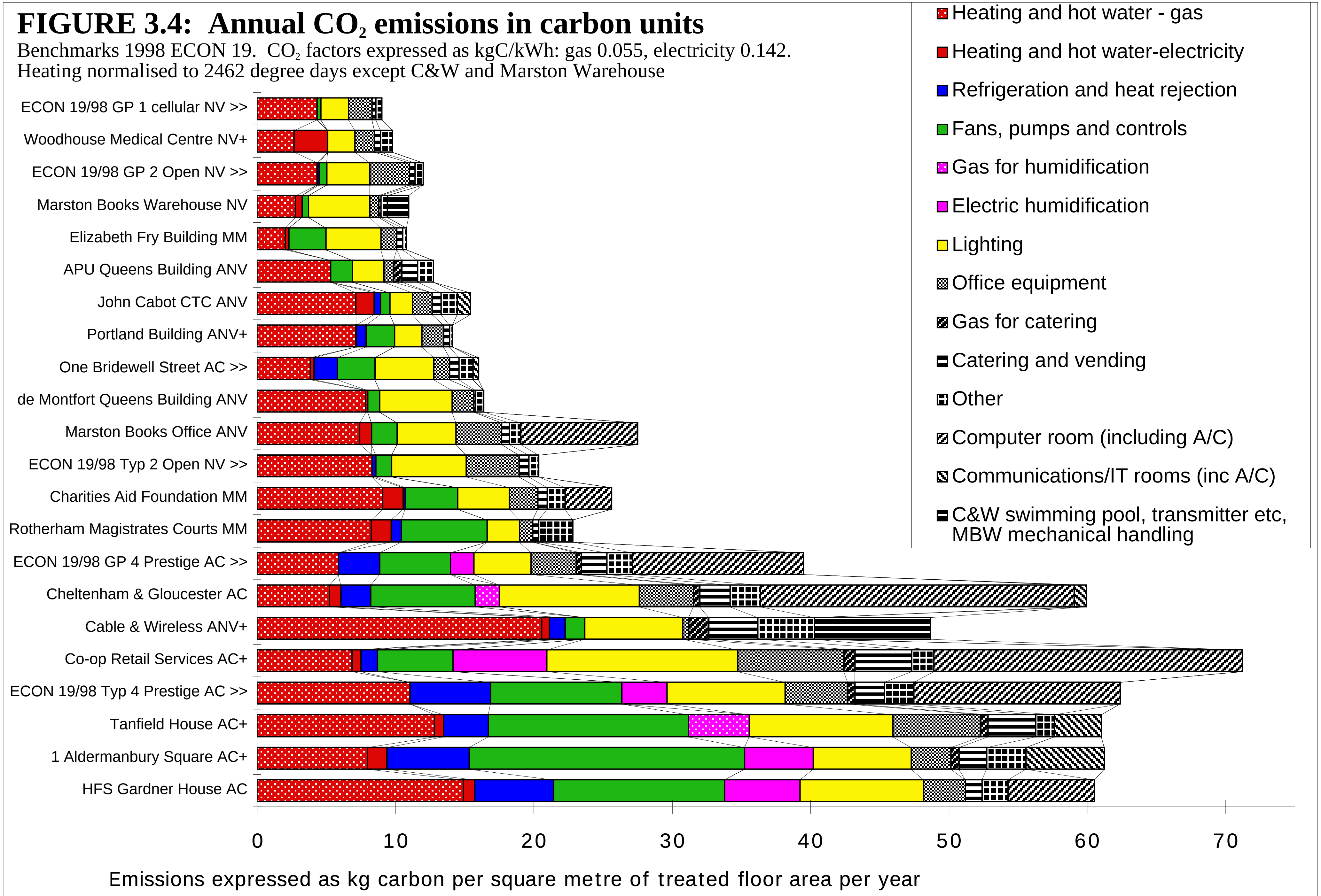


FIGURE 3.4: Annual CO_2 emissions in carbon units

Benchmarks 1998 ECON 19. CO_2 factors expressed as kgC/kWh: gas 0.055, electricity 0.142.
Heating normalised to 2462 degree days except C&W and Marston Warehouse



3.3 Electricity consumption

OVERVIEW OF ELECTRICITY CONSUMPTION
Figure 3.2 shows annual electricity consumption per m^2 of treated floor area for the same buildings and benchmarks as figure 1. This time the data are sorted in order of increasing energy consumption for normal building services, to the left of and including the yellow bar for lighting. To the right of this (in black and white) are items (office equipment, kitchen equipment, computer rooms and their air-conditioning; and so on), which are normally regarded as occupier's equipment and often not included in design calculations; or at best rather sketchily. Such omissions contribute to the big differences that often occur between design claims for energy-efficiency and metered consumption in use.

THE INFLUENCE OF AIR CONDITIONING
As with gas, there is a tenfold range between the highest and lowest electricity consumers. What is going on?

- Clearly, the air-conditioned buildings are at the high end of the scale, the naturally-ventilated and ANV at the low end, and mixed-mode generally in the middle.
- Some of this is the direct result of the HVAC equipment: refrigeration and heat rejection equipment (blue bars), and in particular the green bars: mostly fans but also pumps.
- For the most part, the hours of use of the buildings and the energy used by the occupier's equipment also rises; so air conditioning is not the sole influencer, but one of a cluster of characteristics which tend to be associated with intensively-used, high-energy buildings.

One Bridewell Street - though not a building studied in Probe - can be introduced here as the exception that proves the rule: an AC office completed in 1987, a very energy efficient example of its type; the subject of an EEBPp case study published in 1991; and revisited in 1996 and still found to be performing well [14]. The key to this building's - a pre-let's - good performance was - as at FRY - not so much the technologies used as care: in briefing, in design, in procurement and in management. In this case the tenant commissioned a study to help identify their requirements; insisted on having, influencing (and sometimes paying extra for) some things (such as high frequency lighting with infra-red controls) which the developer said were not necessary or affordable; and took care in appointing an excellent facilities and engineering manager. The result was an AC building with electricity consumption similar to a typical NV one (and with an even lower gas consumption). However, here the energy consumption by tenant's equipment is also similar to those in Probe's NV buildings: which was partly a result of the tenant's operations (e.g. now understood to be using a lot of laptops); and partly the FM's attention to energy management and waste avoidance for these aspects too.

THE LOW ELECTRICITY CONSUMERS
The six lowest electricity consumers (i.e. lower than the ECON 19 Typical benchmark for a NV open-plan office) include all four ANV educational buildings, the quasi-domestic WMC and the warehouse MBW. In most of the buildings, part of the reason is relatively low hours of use, partly with more rigid time schedules than in the office buildings; and with teaching rooms - although densely occupied at times - also empty quite a lot. The occupancy of APU - the lowest electricity consumer - was also well short of design levels at the time of the Probe survey.

Building services electricity use in these buildings tends to be dominated by lighting, which is usually itself relatively low, owing to lower illuminance standards than in the offices and shorter hours of use, owing to better daylight and more effective controls. The exceptions are:

- CAB, with electric water heating for the toilets and cleaners in the classroom wings (HWS in the kitchens and changing rooms is gas-fired); a constantly-running air-conditioner in the conference room, and a relatively large number of heating pumps which kept running when they should have been off, owing to shortcomings in BMS control and management.
- WMC, with high consumption (17 kWh/m^2) including standing losses from large numbers of electric water heaters, particularly in the doctors' and dentists' surgeries, on 24 hours. If its gas boilers had been used for HWS, CO_2 emissions could well have been lower.
- POR, in which the comfort cooling systems in six lecture and seminar rooms run continuously. The main lecture room is also air-conditioned, but better controlled.

These examples indicate how in these successful low-energy buildings, the agenda moves on to relatively small things which may often hardly figure in the design strategy, but can have proportionally significant effects on energy consumption, particularly if they default to ON.

Although good in relation to an office benchmark, even after allowing for its mezzanine and its two-shift operation, MBW's lighting energy consumption is only at about the typical standard in ECON 18 [15], the energy consumption guide for industrial buildings. Essentially, some of the area is underlit and generally the lights tend to be on too much, both in relation to daylight and occupancy.

THE HIGH ELECTRICITY CONSUMERS

The high electricity users - for building services and overall - are distinctively the five air-conditioned head offices. Of these, all use well above the ECON 19's Type 4 Good Practice level; and only at C&G does energy consumption by the building services fall below the Typical benchmark. Tellingly, this was the most conventionally-designed and serviced of the group. C&G had also undertaken more energy management, leading to much lower hours of boiler, chiller and pump operation than in the other AC offices; and somewhat less fan operation too.

These buildings are more intensively-used than the others in Probe, often with major IT installations, catering kitchens, and extended hours of use - at least for a small proportion of their staff[24]. Nevertheless, their energy consumption was very high: for example, in some the electricity used per m^2 by the fans and pumps exceeded the entire electricity use in the naturally-ventilated buildings! However, studies of other similar buildings, for example data gathering for ECON 19 [9] and EnREI projects in the early 1990s [16] indicate that there is nothing unusual about this in prestige air-conditioned offices, even recently-completed ones.

Not only AC offices are affected in this way: for example an award-winning low-energy MM principal office surveyed last year [17] used over three times the electricity the designers had predicted. About half of the extra came from longer running hours and lower operating efficiencies than anticipated, some of which could have been tackled by better facilities and engineering management. The other half came from items (such as catering kitchens, computer and server rooms) not included in the design calculations; and which were also relatively inefficient.

The most common characteristic in all these buildings is for systems to default to ON, and to run for longer and work harder than anyone (particularly the designers) had anticipated. Causes include:

1. A dependency on energy-consuming systems with little choice to use anything else.
2. Deep-plan open spaces in which all systems tend to run even when only a few people are in.
3. Problems with building and systems performance which are most easily countered by extending operating hours; for example air conditioning to counter the effects of air infiltration at HFS; or leaving boilers on to avoid pressurisation unit lockouts at TAN.
4. Tail-wags-the-dog-effects, where large systems have to be left on to support small loads. This particularly applies to cooling systems which serve both comfort requirements and 24-hour equipment rooms. At TAN the management had been undertaking a programme of detaching these rooms from the chilled water system. C&G had also taken two server rooms off a VAV plant which also served one-quarter of the offices. However, dedicated central AC systems for machine rooms can also use relatively large amounts of energy, as at CRS.
5. Default states which are non-optimal, but cause the least trouble for occupants and management. The most common of these is blinds closed - lights on, which has undermined many a daylight and lighting control strategy.
6. Poor interfaces to control systems, which make it difficult or impossible for occupants and management to tune the systems as they would like. For example, in several buildings, the lighting control system brought on all the circulation lights whenever anyone was in. At TAN this included all the lights in the WCs (all individual cubicles) and meeting rooms!
7. Unintended consequences of control systems, for example the occupancy-sensing at HFS which often turned lights on in cellular offices unnecessarily; and had to be over-ridden in open-plan areas owing to the irritation it otherwise caused.
8. Greater pressures on facilities and engineering managers to deliver service, not economy.
9. Contracts for outsourced facilities management and maintenance services which say little or nothing about operational management and energy efficiency.
10. A widespread lack of interest in or application to energy management generally.

While such problems afflict many buildings, their implications for energy wastage tend to be most severe in the more highly-serviced ones.

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[24] The educational buildings often have much higher peak occupation densities, but these have little effect on their energy consumption, which tends to be more related to standards, occupancy times and particularly floor area than to population numbers. The move towards deeper and more open planning and greater intensities of use in educational buildings; and also from local to central control of lighting and other systems, is however tending to change this.

ELECTRICITY CONSUMPTION BY OCCUPIERS' EQUIPMENT

In relation to the ECON 19 benchmarks, four buildings were particularly anomalous:

- MBO's computer room consumption in relation to the Type 2 benchmark. This related to the computers, file servers and printers used to run the business and manage the operating systems in the warehouse MBW. Although the installation was quite modest (averaging some 6.5 kW, split 3 kW to equipment and 3.5 kW to air conditioning), its round-the clock use made this mount up to to a considerable figure for the 962 m^2 building. Such installations are becoming more common, and can easily double the electricity consumption of a NV building.
- CAF's larger computer room had less impact on this larger building, but was still significant. Air-conditioned (or at least comfort-cooled) computer, file server and communications rooms are becoming common today, even in naturally-ventilated buildings, and need to be accounted for in future benchmarks. Sub-metering would be a useful management aid.
- C&G has a particularly high consumption for its large computer suite. This is hardly surprising for the head office of a large national financial services company, but an estimated 45% of this was used by the air conditioning.
- CRS has a similarly high computer suite consumption to support its retailing operation, but here the air conditioning was estimated to use over 60% of the total, partly because the installation was generously sized for the loads that had actually materialised.

Efficient, responsive, and well-managed machine room cooling is an important agenda item for the future.

3.4 Carbon dioxide emissions

Figure 3.3 shows the gas and electricity consumption data, converted to carbon dioxide emissions at UK average factors used in ECON 19 (1998) of 0.20 kg CO_2/kWh of delivered gas and 0.52 kg CO_2/kWh of delivered electricity. This provides a combined ranking of all the buildings and benchmarks in the units which best suit the government's current policy objectives. The international agreements also express emissions in mass of carbon input (not CO_2 output), presumably for greater transparency to the fuel supply industries. The UK factors from ECON 19 [9]) are 0.055 kgC/kWh of delivered gas and 0.142 kgC/kWh of delivered electricity. For ease of reference, figure 3.4 shows the emissions in these units.

The ranking of buildings for carbon dioxide emissions tells much the same story as for electricity - as this is responsible for 2.6 times as much emissions per delivered unit, but includes some interesting outliers, as either high or low energy consumers of both fuels. On a building average, 71% of carbon dioxide emissions from the Probe buildings arose from normal building services (the coloured bars: these do not include dedicated kitchen ventilation and computer room air conditioning systems), but this proportion averaged 65% in the AC offices and 80% in the educational buildings.

For the building services in the low-emissions buildings:

- WMC becomes the lowest consumer per square metre of treated floor area; with a very similar profile to the ECON 19 Type 1 benchmark once CO_2 emissions from the gas heating and the electric hot water are combined. Essentially there has been a trade-off between a very low heating-related requirement owing to the superinsulation and high hot water ones arising from the large numbers of electric water heaters with no time control.
- The MM FRY has similar or better emissions than the ANV educational buildings. This is extremely interesting as FRY is simpler to operate and the occupants think its internal environment is much better, particularly in summer (see Report 3). There is also a good prospect of carefully-designed successors to FRY using even less energy: its lighting is neither very efficient, nor well-controlled (particularly in the circulation areas); and the designers say [18] that given the FRY experience they could design a successor which uses half the fan power. On the other hand, FRY has benefited from a degree of monitoring and management follow-up not encountered in any of the other buildings; and its predominantly cellular office type tends intrinsically to be lower in energy use than more open-planned buildings.

For the high-emissions buildings, it is interesting that the two highest (just) for their building services were HFS and ALD; which were very much less densely occupied than C&G, CRS and particularly TAN. Most of the excess was related to fans and to a lesser extent pumps and chillers; and largely a consequence of fabric and operational problems, which were also less easily tackled in these smaller buildings, which had fewer on-site engineering staff.

TABLE 4.1: CONCLUSIONS ON TECHNICAL ISSUES FROM PROBE 1 AND PROBE 2

ITEM	PROBE 1 CONCLUSIONS	PROBE 2 CONCLUSIONS	COMMENTS AND POSSIBLE ACTIONS
Page 1. Building fabric			
Air leakage*	Problems identified in most of the buildings. Leads to unnecessary plant oversizing and operation. Can have major adverse effects on comfort and energy performance. Most problematic in Probe was an AC office (HFS) owing to the limited capacity of its displacement system to overcome difficulties.	Worries confirmed by Probe 2 airtightness tests. High leakage found in all types of buildings. Motorised natural ventilation openings particularly susceptible, especially louvres. Only one building (FRY) had been designed and tested for airtightness and performed well; and only one other (MBW) acceptably.	Not being able to take envelope performance for granted makes tight sizing and operation of services impossible. Major effort is required to improve the performance of the industry. Problem areas: strategic design, detailing, specification, installation, checking. The principal ingredient is care.
Uncomfortable reception areas	Widespread problems, particularly with inadequate enclosure and heating. Often required major alterations.	Also present, but less widespread. In one building, the reception desk was also in bright sun.	More care needed about achieving comfort of receptionists in an energy efficient manner.
Windows, glare and daylight	Disappointing use of daylight, owing either to tinted glass, poor furniture locations and screen orientations, blinds closed to avoid glare, or unresponsive control of lighting.	Ditto. Some problems with rooflights too.	Major effort required to promote more effective use of daylight, and better and more responsive glare and lighting control.
Windows and ventilation*	Problems with operability and security at WMC and with automation in the educational buildings with advanced natural ventilation (ANV).	More problems. With manual control: unsuitable openings, control shortcomings, insufficient friction, difficult to reach. With automatic control: air leakage, intrusive or inappropriate control, poor user interfaces.	Major effort required on both manual and automated systems and usability aspects.
High insulation	Unusually high only at APU and WMC.	Very high at CRS and FRY	Energy benefits were most apparent at FRY, which had used integrated design with thermal mass, high insulation and controlled heat recovery ventilation to eliminate perimeter heating.

TABLE 4.1: CONCLUSIONS ON TECHNICAL ISSUES FROM PROBE 1 AND PROBE 2

ITEM	PROBE 1 CONCLUSIONS	PROBE 2 CONCLUSIONS	COMMENTS AND POSSIBLE ACTIONS
Page 2. Building services			
Condensing boilers	Only found at WMC and in the educational buildings designed to be low energy (but not POR). None in the office buildings.	Ditto.	At current gas prices, commercial developments cannot justify the added costs of condensing boilers. Should they not be regarded as an essential requirement?
Full fresh-air (FFA) ventilation systems	Increasingly used in AC buildings for health reasons. Some buildings (TAN, HFS) had quite high quantities with no heat recovery.	Probe 2 buildings used more heat recovery and sometimes recirculation outside the occupied period.	Heat recovery should be incorporated as a matter of course with full fresh air systems. FRY is a good example of economical operation with FFA during occupancy.
Excessive humidification*	All four AC buildings surveyed had steam humidifiers. Their energy use was high (with high cost and CO_2 with electric systems) and they often seemed to be operated wastefully	Only one more AC building was included, but this had the same problems.	Need for good practice guidance on the need for, and energy-efficient installation and control of humidifiers.
Advanced natural ventilation	Reasonable energy performance, but comfort levels not as high as had been hoped, owing largely to problems with manual and automatic controls, and their usability.	Comfort problems as in Probe 1. Heating energy consumption often high owing to winter air leakage through openings designed for summer ventilation.	More attention required to the downsides of ANV, in particular control and air leakage. Some aspects currently being studied in a PiI project.
Night ventilation*	In design at two ANV buildings only: in one it was rarely used, in the other it was not working effectively, owing to control problems.	Used very effectively at FRY, otherwise only by manual intervention at MBO	Success at FRY warrants more widespread use. Scope with ANV depends on overcoming problems like security, animal, insect and water ingress, and so on.
Water heating*	Local electric storage water heaters widely used for handbasins, small kitchens and cleaners' sinks. Gas-fired for catering kitchens and sometimes for nearby toilets etc.	Similar. Only one of the electric systems surveyed so far (RMC) is not energised constantly. The RMC timers were only retrofitted to stop floods which occurred when the water overheated and a float valve melted!	More care required in system selection. In relation to most gas systems, electric HWS uses less delivered energy but has higher energy costs and related CO_2 emissions.
Defaulting to ON	Many systems ran for long hours unnecessarily, particularly but not solely in the AC buildings. This particularly applied to ventilation and cooling systems; and also to lighting.	Similar behaviour found.	Reasons include poor usability, ignorance, ON being the least troublesome default state for management, and large systems supporting small 24-hour loads. Intrinsic efficiency and demand-responsiveness need to be
Air-conditioned computer/communications rooms	Could use large amounts of electricity, particularly in the AC buildings, owing to the 24-hour operation of both IT systems and their air conditioning; which were both seldom metered.	Similar behaviour found. AC (or at least mechanically-cooled) IT rooms were also found in non-AC buildings and could add substantially to their electricity consumption.	IT rooms can easily be the major electricity end-use in a building. If not metered, performance benchmarking can be difficult. The efficiency of AC in these rooms needs to be closely scrutinised.
Illuminance standards	Several offices were designed to 500-600 lux plus, but occupant questionnaire responses and unsolicited comments suggested that levels below 400 lux might be more satisfactory.	Still happening. Some indications that indirect lighting at 200-300 lux is liked.	Need to encourage the use of lower illuminance levels, plus the availability of additional task lighting for those who request it. Experience suggests that schemes which permit this choice are better-liked than task-ambient lighting schemes in which task lighting is essential.
BMS*	Present in most buildings; very mixed picture	Again widespread but successful use rarer than in Probe 1, probably because the buildings and their maintenance teams were generally smaller. One might have expected advances in technology with time to have compensated for this, but many problems encountered were not strictly technological, e.g. specification, applications, usability, management, price competitiveness, and contractual arrangements.	A perennial problem, possibly due to the controls industry developing its products too fast for component manufacturers and controls users to keep up. Consolidation with an effective solution ought to be commercially attractive.
Mixed-mode*	Slight tendency at two buildings	Half the buildings were mixed mode: empirical evidence is growing that this can be an effective solution, but it needs careful integration.	Promises potential of using mechanical ventilation and refrigeration only when and where needed. CIBSE AM about to be published presents the opportunity to promote both wider and best practice usage.

TABLE 4.1: CONCLUSIONS ON TECHNICAL ISSUES FROM PROBE 1 AND PROBE 2

ITEM	**PROBE 1 CONCLUSIONS**	**PROBE 2 CONCLUSIONS**	**COMMENTS AND POSSIBLE ACTIONS**
Page 3. Energy-related issues			
Energy performance standards in the brief*	Not normally specified	Not normally specified	Useful avenue for development. Solution could be reviewed against benchmarks as projects progress.
Energy Management	Seldom of much interest (except to corporate unit at C&G, which still had limited scope). For most commercial organisations, energy is too cheap to manage!	Seldom of much interest (except at FRY). For most organisations, energy is still too cheap to manage! FM and maintenance contractors not usually appointed to do operational and energy management.	Need to promote on the basis of environmental responsibility, best-in-class professional competition, and as one of the many attributes of a well-managed building. Need model clauses in contract conditions.
Energy and environmental performance review during design	Where undertaken, often tended to focus on passive aspects rather than plant and equipment efficiency. Little energy prediction data supplied to BSJ.	Where undertaken, tended to focus on passive aspects rather than plant and equipment. More energy prediction data supplied to BSJ to suit its proforma, but figures sometimes missing or wrong.	Generally uneven focus, concentrating on key items, e.g. summer cooling. with less important items such as fan efficiency largely ignored. Scope for developing simple model to keep tabs on all energy-consuming items.
Internal gain allowances	Usually considerably higher than materialised in the air-conditioned buildings, leading to system oversizing, energy wastage and sometimes unnecessary air-conditioning.	Generally more modest requirements, similar to BCO specification. More MM and NV buildings represented.	More realistic approach now. However, energy use by office equipment is rising, particularly in NV buildings which tended to be later bulk adopters of IT systems. Increases are less in load density in the occupied spaces as in increased hours of use with more devices left on permanently, and "leaking electricity" from kit which is on standby or even supposed to be off but with power supplies and control circuits still energised.
Mechanically ventilated and air conditioned buildings	AC energy consumption frequently high, and above ECON 19 Type 4 benchmarks. Three main contributors: intensified use of buildings; systems with relatively low intrinsic efficiency; excessive hours of operation.	Only one AC building added, but this was similar. Probe 2 also looked at four mixed mode buildings. These used less energy, though there was considerable scope for further improvement.	Need for initiative to improve performance, efficiency and control in mechanically conditioned buildings.
Installed boiler capacity	Often large.	Large in most of the buildings. FRY is the main exception.	Need to promote good practice W/m^2 benchmarks, possibly with separate components for fabric and ventilation.
Boiler/LPHW pump running hours	Often high, particularly in the AC buildings	Often high, particularly in the AC buildings, and buildings which have mechanical supply ventilation plant but no heat recovery.	Does not seem to be widely appreciated that mechanical supply ventilation extends the heating season, particularly if non-mixing and if no heat recovery fitted.
Installed chiller capacity	Often large.	Usually large.	Need to promote good practice W/m^2 benchmarks, possibly with separate components for fabric, internal gains and fresh air quantity.
Chiller/pump running hours	Frequently very high, defaults to on.	Somewhat better.	Need for tighter management. Consider staged or variable volume pumping.
Specific fan power	Usually well in excess of good practice levels, though VAV average running levels fair at TAN and C&G.	Usually well above good practice levels. FRY only just for its offices, and for the lecture rooms the average power for its air-quality controlled VAV plant was very good.	FRY the main exception, but even this has significant scope for improvement. Benchmarks need using in briefing, design, evaluation and industry good practice.
Installed lighting load	Sometimes at good practice levels, sometimes high.	Sometimes at good practice levels, sometimes high.	High illuminance does not appear necessary if the scheme is well designed.
Lighting running hours*	High in AC buildings, C&W and to some extent at DMQ.	Generally on the high side.	Widespread difficulties with effective control and use of daylight. Absence detection also needs serious attention.
Computer and communications rooms	High energy use in some of the AC buildings. Computer AC not always very efficient, particularly if shared with space cooling systems.	Continued high energy use. While mainframe computers are declining, the use of air-conditioned file server and hub rooms is growing, and also spreading from AC into NV and MM buildings.	Need careful scrutiny, owing to 24-hour operation. Although mainframes are declining, AC rooms with servers etc. are growing, even in quite small buildings.
Submetering	Seldom present, seldom read, never analysed.	Seldom present, seldom read, analysed only at FRY.	Needs more attention, possibly in Building Regs. Need to relate to things that are tangible to occupants (e.g. buildings, rooms, cost centres, plant items). Needs to be incorporated into energy management procedures.
Utility meter readings	Non-estimated readings rare for gas. Electricity readings sometimes poor.	Non-estimated readings rare for gas. Electricity readings sometimes poor. Perhaps slight improvement on Probe 1.	Could the Regulator insist on fewer estimated readings and routine energy reports by fuel suppliers?

TABLE 4.1: CONCLUSIONS ON TECHNICAL ISSUES FROM PROBE 1 AND PROBE 2

ITEM	PROBE 1 CONCLUSIONS	PROBE 2 CONCLUSIONS	COMMENTS AND POSSIBLE ACTIONS
Page 4. General issues			
Diversity of usage	Designers often seemed to have assumed more routine occupancy and usage than had actually materialised.	Ditto, though some operations were quite routine, e.g. CAF.	Engineering systems often seem to be designed for regular working hours and cannot deal efficiently with patchy occupation. More discussion is necessary in briefing and in client/design reviews.
Manageability	Complication often made things difficult for management. Management could cope more readily in the larger AC financial services buildings (with more in-house staff) than in the smaller ones.	Ditto. Contracted-out services not necessarily the solution, as they tend to provide standard services, not tailoring to occupier's needs. Absence of sufficient management attention was particularly noticeable in the ANV buildings.	Management may need to be better, but buildings also need to be simpler and more manageable where possible. As the design develops, "reality checks" with the client on usability and manageability could be helpful. The industry needs more, and more reliable, cost in use data and to move towards life-cycle costing.
Handover	Often somewhat rushed, services suffered	Often somewhat rushed, services suffered	Final rush is almost inevitable. Consequences can be lessened using techniques like simplification, standardisation, easy adjustment, self-balancing and pre-commissioning. See also the points below.
Optimal solutions	Sometimes upset by changing assumptions.	Sometimes upset by changing assumptions.	Seek robustness against different scenarios.
Innovative solutions	Often proved more difficult to implement reliably than had been expected: bugs and unintended consequences are an inevitable part of the development process. Control-related items were especially problematic: depending on hardware, software, management, reliability, commissioning, and occupant perceptions. Adverse results for comfort and/or energy performance were widespread.	As in Probe 1. The FRY experience demonstrated how what was expected to be a simple, robust and reliable approach to HVAC control behaved unpredictably until better monitoring and management allowed system behaviour to be understood and a - yet simpler - approach developed. In other buildings (e.g. CAB), the occupant had taken action without consulting the design team, who might have been able to provide insight and assistance.	Innovation is difficult, and needs care. Sometimes industry practice also does not offer a sufficiently stable platform for innovation (e.g. low-energy services in envelopes of uncertain airtightness; or advanced control strategies when even conventional systems do not operate as intended. Sufficient resources need to be allocated to develop and test solutions both at the design and sample stage, and to fine-tune them after installation.
Post-handover support*	Variable, but generally disappointing.	Again variable. Value of close attention confirmed at FRY, where problems revealed by monitoring for BRECSU were acted upon.	Traditional concepts of practical completion and defects liability periods do not relate well to the realities of buildings today; and tend to stifle practical action after handover. In all but the simplest buildings and where there are standardised, proven, "right first time" solutions, the need for a "sea trials" review and fine-tuning period needs to be considered by all parties. This will both improve performance of the building concerned and provide valuable feedback to future projects.

4 CONCLUSIONS

4.1 THE BUILDINGS SURVEYED

The buildings reviewed in Probe 1 and 2 were generally well-designed, well-managed, and attractive workplaces (though occasionally with permanent staff located in the less attractive parts of a building designed more to appeal to visitors). People often ask whether they are representative:

- In a statistical sense, no. They have been through three levels of selection: first by their interest to the editor of *Building Services Journal;* second by the team's perceptions of the potential interest of a published Probe; and thirdly by the occupier's assent to a Probe survey.
- As a result, they tend to represent leading-edge and better-managed buildings. However, and with exceptions, architectural icons are few, as some commentators have reminded us. This is partly because iconic buildings have proved more difficult to get into.
- There have also been few speculative and rented buildings: a large and growing part of the commercial market. These have been less widely covered in BSJ, and have also been more difficult to get into owing to the landlord/tenant split.
- On the occupant satisfaction side, and as discussed in Report 2, the Probe buildings are definitely better than average in the Building Use Studies' dataset.
- Regarding energy consumption, the picture is less clear. All Probe buildings have claimed to be energy-efficient, but four major factors have worked against this:
    - i a general intensification of occupancy, use and service to occupants, leading to higher energy consumption, particularly in the office buildings;
    - ii increasing use and running hours of information and communications technology (ICT);
    - iii more complicated and elaborate solutions than might normally be provided; and
    - iv innovations which will always prove difficult to get right initially.

  While the Probe educational buildings are generally relatively low in energy consumption, the others - and particularly the offices - appear to be biased towards the high end.

4.2 ISSUES RAISED

While successful in many ways, the buildings had problems, sometimes minor, but which could have disproportionate effects on performance for management, occupants, or energy efficiency. Some of issues were raised in the Probe 1 conference [PC 2 to 5] and summarised in BSJ and elsewhere [P9, P10]. Many cropped up again in Probe 2, confirming their pervasiveness. Probe 2 also introduced new building and servicing types; new issues; and some examples of problems solved. Table 4.1 summarises common issues, with conclusions from Probe 1 and Probe 2. It comments on these under four main headings: fabric, services, energy, and general. It also identifies items which may merit attention in future work, including briefing, design, management and regulation. Some may of be of interest to DETR in considering research, regulation, innovation, and its Construction and Energy Efficiency Best Practice programmes. Key points from each section are outlined in the paragraphs below, together with some wider issues.

4.3 1. BUILDING FABRIC

It is difficult to justify high insulation at today's low gas prices, but good thermal performance and little need for heating will be important to buildings of the 21st century. Of all the buildings, FRY illustrates how better insulation, good airtightness and effective use of thermal capacity can permit radical changes in engineering systems and overall performance, with no perimeter heating (hence more usable space and less maintenance) and lower summertime temperatures without mechanical cooling. Interestingly, the maintenance cost of the mechanical ventilation at in FRY was said to be less than the external solar blinds in the same design team's previous building on the site; designed in a more conventional manner for lower energy use, but which also used much more energy. In many of the buildings, shortcomings in the performance of the building fabric led to problems with comfort and/or high energy consumption. Recurrent problems included:

- Air leakage. More attention to detail required in design, specification, workmanship and testing, particularly for junctions.
- Reception areas. These frequently needed remedial work to keep receptionists comfortable.
- Window design and control. Windows are perhaps the most complicated elements of a building, combining a variety of functions: view, ventilation, daylight, solar gain control, glare control, heat loss avoidance, and sometimes noise control. It is difficult to get all these things right, particularly in deeper spaces where glare and draughts caused by a window can affect people at considerable distances from it. The system used at MBO was an interesting initiative, but required further development to overcome the shortcomings identified.

These issues need more attention by architects, builders and manufacturers Cost advisers often say that things can't be afforded: but what if they are essential to sound performance?

4.4 2. BUILDING SERVICES

Building services have two main functions:

1 To work with the building fabric to provide a safe, comfortable and healthy environment.
2 To support the occupants' activities and equipment.

Both need to be done in an effective and efficient manner. A widespread problem seemed to be that most design attention had been devoted to environmental control - particularly passive control - in the principal areas of the buildings, with less attention to smaller areas and behind-the-scenes items.

In the past, relatively inefficient services have often operated for unnecessarily long hours to support unnecessarily high loads created by thoughtless or inefficient design and use of the fabric or supporting unnecessarily uneconomical equipment which is left on too much. In moving towards sustainability, we need to seek:

- reductions in loads - through more efficient and better-controlled fabric and equipment;
- gentle engineering, with improvements in effectiveness, efficiency and control; and
- close matches between demand and supply, seeking where possible to use information rather than energy to achieve the required conditions with minimum waste.

The Probe studies have helped to indicate trends and to illustrate where success is being achieved and problems to be avoided. Various issues have emerged:

- Relatively limited use of efficient technology, for example condensing boilers in the commercial buildings where they and their ancillaries have not been considered cost-effective. *Should not such intrinsically efficient technologies be considered as essential features, not added costs?*
- A tendency to full fresh-air ventilation, sometimes at high volumes and with no heat recovery; and leading to much increased demands for heating and humidification. *Should not heat recovery be mandatory for many systems, as it has been in Sweden?*[25]
- Partly as a consequence of this, more humidification - usually with sterile steam for health reasons and often electrically-generated (creating both a high CO_2 overhead, and high energy costs not only owing to the use of electricity, but to peak humidification demands occurring in the coldest weather when pool prices and/or maximum demand charges tend to be at their highest). In the Probe buildings (and others recently surveyed by the team), humidifiers - once present - also tended to be operated unnecessarily and wastefully. *More guidance on the installation and use of humidification is desirable.*
- Widespread use of electric water heating: often a convenient option, but frequently not the lowest in terms of running costs and CO_2 emissions, particularly - as in all the Probe buildings which had it - with no time control and few attempts at water saving. *Updated guidance on hot water systems should be considered. Products with built-in timing facilities should also be considered by manufacturers and designers.*
- A tendency for systems to default to ON, particularly if operating behind the scenes - notoriously chilled water systems, but also boilers, pumps and humidifiers. This state often tends to be the least troublesome for occupants and management; and sometimes the controls do not permit anything else. *There is a great need for systems to be designed, controlled and operated to be more demand-responsive.*
- In spite of the reduction in the use of mainframe computers, air-conditioned machine rooms have become more common: for computer, communications and sometimes printing equipment; and sometimes their UPSs. Typically all this equipment is in 24-hour use; as is the air-conditioning, which typically uses as much electricity as the equipment itself; and sometimes much more. *The monitoring of these areas and their efficient use and servicing is overdue for attention.*
- Developments in the industry (e.g. improved phosphors, high-frequency ballasts and better optics) have tended to make lighting more efficient; though these advances have been partly offset by tighter glare control (to improve computer screen visibility) and the replacement of standard service illuminance with maintained illuminance. Many Probe buildings used high frequency lighting, even though it tended to be more expensive than conventional, partly owing to its claimed health benefits and additional features such as dimming. Illuminance standards in offices were mixed: some to the textbook institutional/CIBSE standard for offices of 500-600 lux (derived from research when office tasks were nearly all paper-based) and others the lower CIBSE LG3 standard (to suit paper and computer screen use). *Evidence from Probe and other studies suggests that the higher illuminance levels are not necessary - and indeed less liked - in modern offices, at least when applied generally.*

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[25] However, heat recovery itself has to be done and controlled well to deliver good benefits.

4.5 3. ENERGY PERFORMANCE

The energy expert Amory Lovins has said “much energy consumption comes from the compounding of unnecessary loads”. This was often so in the Probe buildings, where energy consumption was generally higher than might have been expected. There is a massive range in the energy use and CO_2 emissions indices of the buildings studied per square metre of treated floor area. Normal building services are responsible for between 30 and 175 kg CO_2/m^2. Other items - particularly computer rooms, catering and office equipment - add between 25% and 80% to this.

If expressed per occupant, the variation is yet wider: the two highest building services energy consumers (HFS and ALD) were relatively lightly-occupied; while the low-energy educational buildings had very high peak occupation densities. However:

- Area is more reliably measured than occupancy.
- Many aspects of building energy consumption are more area than occupancy-related.
- Others which should be occupancy-related are only weakly so, owing to plant inefficiencies and a tendency to default to ON.
- Hours of use by nominal occupants can differ widely.

Ideally, energy benchmarks would be separated into area- and occupancy-related parts, and FMs would keep records of say person-hours occupancy to some agreed industry standard. However, we are quite a long way off that yet, so prefer to consider energy breakdowns by area and end-use first and consider occupancy-related and other factors second.

Although assessing energy performance was an important part of Probe, and nearly all Probe buildings claimed to be energy efficient, we found less of a thoroughgoing approach to energy in briefing, design, construction and management than might have been expected. The best all-round example was FRY, but even here the briefing aspects were somewhat weak: the design, while strong on thermal aspects, was less good on lighting, control and air transport efficiency; and the in-use control and management issues were only picked up on following BRECSU’s monitoring.

In general, we found:

- Few energy performance standards in the reported briefs. *Advice on qualitative and quantitative aspects of briefing and design brief management could be improved.*

- Designs often seemed to be more concerned with low-energy features than good all-round performance, with limited review of overall performance during design development and in specification. With a focus on the technical issues of most interest, other aspects were easily ignored; and little benchmarking of the solutions, for example for boiler capacity, chiller capacity, pump capacity and specific fan power. *A regular review of all energy end uses and comparison with client requirements and industry benchmarks would be helpful.*

- There was also much less energy management than might have been anticipated in these leading buildings. Hence measures requiring management input were fragile. Given the competence of the management in these buildings, if energy and the environment were to become a real priority, they could swing into action effectively. However, simple, robust, “fit and forget” measures are preferable, with the emphasis on reducing loads, efficient plant, and waste avoidance. *It is important to promote energy management as an essential component of good management. It is also important to design intrinsically-efficient user-friendly systems which do not demand more from management than is likely to be available; permit simple default operation and if necessary warn of potential problems.*

- In some buildings - particularly in Probe 1 - very high allowances for internal gains from office equipment had led to oversized AC systems. In Probe 2, this had quietened-down. However, energy use by office equipment had continued to rise, owing to longer hours of operation. *Management should encourage people to turn equipment off when not in use: unfortunately some IT managers do the opposite! It should also be easier to select energy-efficient equipment, through labelling and accreditation schemes. Government and customers should also encourage manufacturers to produce equipment which uses the absolute minimum amount of electricity when “off” or on standby.*

- Most of the AC buildings in Probe used large amounts of energy, particularly electricity. Though some of this was an inevitable consequence of their intensity of use and equipment levels, much was potentially avoidable if system efficiency and responsiveness had been higher. Many systems, particularly chilled water, pumps, fans and lighting ran for much longer than the designers had anticipated, owing to technical, management and control-related tendencies to default to ON. *An initiative is required to improve performance, efficiency and control, particularly in mechanically-conditioned buildings.*

- The NV Probe buildings used much less energy than most of the mechanically-conditioned ones, many equalling or exceeding good practice benchmarks. Some had very good performance indeed, but interestingly not without significant opportunities for further improvement. However, the ANV buildings did not seem to deliver significantly better performance than the simpler ones; often with shortcomings in summertime temperatures, controls, occupant satisfaction (see Reports 3 and 4) and higher-than-expected heating energy use owing to air leakage. *There is still a lot to learn about getting the best performance from these innovative approaches, and possible downsides must not be overlooked.*

- Probe 2 included four mixed mode buildings. Two (FRY and POR) performed well in energy terms. The other two (RMC and CAF) had more scope for improvement (fan energy consumption was particularly high - and often seems to be overlooked in the design of energy-efficient buildings). Nevertheless the MM buildings used significantly less energy than most of their AC counterparts. *The MM approach is very promising, and there is much scope for further improving the design and energy performance of AC and MM buildings.*

- Lighting energy use tended to be lowest in the simpler buildings with good, clear user control. While automatic systems did make savings, they also frequently brought lights on unnecessarily; were unable to respond well to occupant requirements; annoyed occupants, and opportunities were missed. *Greater finesse in lighting controls design is required.*

- High energy use in computer and communications rooms. *For effective benchmarking, these need identifying separately from the buildings. Often the design and operation of the systems could be more energy efficient. In particular, the need for close control can often be questioned. Systems could also often be more demand-responsive, with variable capacity operation, better sequencing, and avoiding standby units running unnecessarily.*

- Submeters were seldom installed in Probe buildings, and if installed, seldom read - owing to the limited amount of energy management. Utility meter readings were also patchy, particularly for gas. *An initiative on better energy metering and reporting could be rewarding in fostering better understanding and energy management, with routine sub-metering of main plant items and areas of high energy intensity such as kitchens; and computer rooms and their air conditioning. Standardised reporting of consumption and trends by fuel suppliers could be considered, with fewer estimated readings.*

4.6 4. GENERAL ISSUES

Across all Probe buildings, a number of issues recurred:

- Diversity of usage. Buildings today tend to be less routinely occupied - with out-of-hours use, flexible working hours, and so on; and contain a wider range of activities and equipment. Briefs and designs, however, often assume more routine operation. This tends to lead to services which tend to be relatively unresponsive to changes in occupancy, use and load; and to default to ON. *Services need to become more accommodating and/or responsive to changing demands, in simple and efficient ways.*

- Manageability. While the facilities and engineering staff at the larger financial services buildings, particularly TAN and C&G, were able to look after their buildings and equipment and respond rapidly and effectively to problems and occupant complaints, most other buildings demanded more than their occupiers or the contractors they employed were able to provide, or regarded as affordable. While there may be a misfit between occupant expectations and reality, *there is also a need for designers to make buildings no more complicated than necessary, easy to look after, with systems which are integrated but preferably non-interacting; and controls which are effective and easy to use; and remain so in the context of the changing demands discussed in the first point above.*

- Widespread shortcomings in controls and usability, leading to occupant dissatisfaction, management frustration, and often energy wastage: for example though unnecessary or wasteful operation and poor use of daylight. Recent buildings often seem to deprive occupants of choice, increasing dependence on management and technical systems. *Controls must be more usable and occupants need to be involved in choices where appropriate.*

- Innovation. New technologies often have unanticipated "revenge effects" [19] where a solution to one problem creates unexpected new problems. Themes included difficulties with lighting controls, automated natural ventilation, ice storage, and relatively unfriendly interfaces to BEMS and controls systems. There often appears to be too much optimism about the good aspects of a new idea and less consideration of the possible downsides, including not only technical risk but acceptability to management and users. *Pilot projects, reality-checking and discussion with users is desirable. Often the simpler and more understandable solutions seem to give the better results. How does one innovate imaginatively, effectively and responsibly in an industry which builds and occupies its prototypes? This issue will be returned to in Report 4.*

- Handover of buildings was often rushed. This tends to be a fact of life but eternally seems to come as a surprise. One of the main consequences is a curtailed commissioning period, because practical completion tends to be seen as a matter of physical rather than functional and operational completeness. *Designs which require less commissioning would be helpful, for example with self-balancing, pre-commissioned, or readily-adjustable (e.g. "plug and play") approaches. Controls and usability also need more careful consideration.* See also the points below.

- Although more can and should be "right first time" - for some aspects, particularly operation and controls, it may be impossible to understand and fine-tune performance until the building is occupied and the management begins to take control. It is rather like getting software running smoothly on a computer. However, in the industry at present, problems after practical completion are not easily dealt with: taking the edge of initial occupant enthusiasm and often leading to disillusionment. This is partly because the design and building team is not resourced to deal with problems (other than as defects). In addition, during the defects liability period, occupants, their contractors and designers are also often loth to intervene for fear of ending up up "owning" the whole of the problem; so the result is often relatively ineffective communications and meetings with little forward progress. *A properly-acknowledged and resourced "sea trials" and feedback period following practical completion is recommended.*

ACKNOWLEDGEMENTS

Probe was jointly funded by Building Services - the CIBSE Journal and the UK Department of the Environment, Transport and the Regions (DETR) under the Partners in Technology programme. The Probe Team would like to thank the owners, occupiers and managers of the buildings for the support given during the Probe surveys; their consent to publication of the findings in Building Services Journal. We would also like to thank the designers for their comments and for producing such interesting and imaginative buildings, and the source of the feedback from which we have all been able to learn.

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Paper from Intelligent Buildings: Realising the Benefits conference, BRE (6-8 October 1998).

APPENDIX A

Technical and management findings

APPENDIX A
TECHNICAL AND MANAGEMENT FINDINGS

A1 Introduction

SUMMARY OF TECHNICAL FEATURES
Features of the Probe 1 office and other buildings were reviewed at the Probe conference in 1997 [See references PC2 and PC3]. The format of Table 1 in the office review has been expanded to include all buildings and a much wider range of features. The tables can be found in Appendix A: Table A1 for offices, Tables A2 for educational buildings, and Table A3 for the other buildings. The tables have seven pages each, organised into the groups and topics listed below. This section runs through some key issues and findings in the topic areas below, first for offices and then for other buildings. In the time available, it has not been possible for this discussion to be exhaustive.

PAGE 1: GENERAL

1 *Use, procurement and occupancy.* What the building is used for, who it was built for and how (e.g. the owner or speculatively, or by traditional or management contract), and its typical hours of occupancy and plant operating schedules.
2 *Floor area statistics,* in particular gross, nett and treated areas.
3 *Unusual floor areas.* Particularly areas of high energy intensity (e.g. kitchens and computer rooms), or low intensity, particularly storage areas with reduced levels of HVAC and lighting. Underground parking areas and their energy uses are excluded from the Probe statistics.

PAGE 2: FABRIC

4 *Walls.* Brief description.
5 *Windows,* including natural ventilation facilities.
6 *Roof,* including rooflighting.
7 *Fabric statistics,* in particular characteristic depths, presence of atria, insulation and air infiltration levels; plus notes on any problems, including the reception areas, which in many of the buildings proved uncomfortable initially.

PAGE 3: HEATING, HOT WATER AND COOLING

8 *Heating system,* including plant capacity and controls, and any problems.
9 *Domestic hot water*, systems and problems.
10 *Mechanical cooling plant,* where present.

PAGE 4: HVAC SYSTEMS AND CONTROLS

11 *Mechanical ventilation and air-conditioning systems,* where present.
12 *Control systems,* including BMS, which most of the buildings had.

PAGE 5: LIGHTING

13 *Lighting,* particularly in the main areas, but touching upon other - and particularly circulation areas where appropriate.

PAGE 6: IT AND ELECTRICAL

14 *Office equipment heat gains.* These are often important determinants of the design, and in the choice between natural ventilation and/or mechanical systems.
15 *Computer and communications rooms.* Dedicated and mechanically cooled rooms for computer, communications and related equipment.
16 *Other electrical items.* Standby generation and miscellaneous other comments.

PAGE 7: MAINTENANCE AND UTILITIES

17 *Building services maintenance.* Technical and energy performance and occupant satisfaction levels are often very dependent on the levels of maintenance and management the systems receive, and the responsiveness of the staff to problems and complaints.
18 *Fuel metering and cost data.* Metering, and meter reading, was poor in most of the Probe buildings; but with some exceptions. Unit fuel costs for gas and electricity varied quite widely, with commercial factors sometimes dominant over issues of quantity and load factor. Market changes made rates normally lower in Probe 2.
19 *Water consumption.* Probe 2 looked at water consumption levels and attempted to relate them to benchmarks.

A2 The office buildings

A2.1 GENERAL

Two groups of offices had similar characteristics:

- Three large deep-plan air-conditioned with atria: TAN, C&G and CRS, of around 20,000 m^2, all owner-occupied, extensive catering facilities, parts with 24-hour occupancy, a tendency to increased evening and weekend operation, and overnight cleaning at TAN and CRS.
- Two smaller and less intensively-used principal offices, HFS and CAF, of around 4,000 m^2.

The other three were more different: ALD the medium-sized AC speculative city head office had more in common with the first group, but a lower occupation density. MBO, a naturally-ventilated principal office was much smaller but in terms of occupancy and equipment not dissimilar to HFS and CAF, including a small computer room and limited catering facilities. The offices in FRY (an educational building, see also A3) were quite different, being cellular and less intensively occupied.

Both C&G and HFS have archive stores, C&G with dense storage and an automated retrieval system. CRS's archives were electronic, on special equipment in the computer suite.

TAN's basement parking for 306 cars, added 9000 m^2 to the 24,000 m^2 building above. Its area and electricity consumption for lighting and ventilation (estimated at 24 and 16 kWh/m^2 of car park area) have been excluded from the energy statistics. Both car park lighting and ventilation are reduced outside peak hours: if run constantly both figures would have been around 50 kWh/m^2.

A2.2 BUILDING FABRIC

Generally, the most innovative constructions were found at:

- TAN, with its roof garden, double-skinned wall construction with outer glass curtain walling, inner skin with openable sash windows. The walk-through gap contained perimeter services [5], with pipes and VAV terminals in the glazed part and vertically-mounted air handling units in the stair towers. In spite of its ingenuity, however, this made pipe runs longer than with more central servicing, and maintenance access to plant in the gap was not easy.
- FRY, with its relatively simple but carefully considered approach to high insulation and airtightness, plus its ventilated hollow-core floor slab.
- CRS also had distinctively high insulation levels, which had helped to reduce its heating energy consumption to close to good practice levels; though still somewhat above the less well-insulated but better energy-managed C&G.
- CAF was of interest for the emphasis on buildability in its construction and procurement and relatively high insulation levels (though its gas consumption was not particularly low).

Air infiltration levels sadly, were only good at FRY - an educational building, but with two floors of offices. In the others, where measured, it was average to high; where not measured, spot checks and occupant comments indicated it was likely to have been no better. Most of the air leakage found was through entrance doors, at eaves in buildings without concrete roofs, at junctions between heavy and lightweight elements (particularly around the frames of windows, rooflights and curtain walling) and usually to a lesser extent through openable window elements themselves. Infiltration had often been troublesome in reception areas: major measures to improve the comfort of receptionists had to be taken in four of the buildings. Increased energy consumption arising from the infiltration tends to be more severe than just the additional heat loss; owing to increased temperature settings; extended use of systems (including pumps, fans and ventilation); and introduction of some electric heating. Uncertainty about achievable airtightness must also cause services engineers to oversize systems routinely. FRY demonstrates what can be done if infiltration is brought reliably under control: but the standards it achieved - although excellent for the UK - are well short of routine everyday practice in, for example, Canada and Sweden.

All the windows were aluminium, except FRY's which were timber with aluminium external cladding. ALD, C&G, and HFS's were fixed. The rest were openable: lower sashes only at TAN; top hung projecting windows and upper fanlights at CAF and MBO (MBO's motorised); tilt-and turn at CRS and open-in at FRY. Three buildings had triple-glazing: TAN (with its double skin), CRS and FRY; the two last high-performance with U-values around 1.3. In the tables, we have rated certain aspects of the buildings on 5-point scales from 1 = poor to 5 = good. Effectiveness of solar control is the first of these. For most of the offices it was reasonable: the greatest problems were at C&G which had quite large windows and shading by internal translucent curtains only: the occupier wanted clean lines and not the external shades the designers had intended.

Openable window elements. In the NV and MM buildings, the performance of the openable windows gave some problems for occupants. In particular:

- CAF's upper fanlights were difficult to reach, and both they and the lower ones tended to fall shut by gravity or be blown shut by the wind. This problem with the hardware could be alleviated by regular adjustment; which began to be undertaken following the Probe survey.
- MBO's lower windows suffered a similar problem, and so the upper motorised fanlights were used instead. However, this reduced the amount of ventilation and air movement in hot weather. Push-buttons by each window allowed the motorised fanlights to be driven to any position: a facility which the occupants really liked; but which was absent in some of the other ANV buildings, as discussed in Section A3 below. Sadly, the fanlights did not close tightly.
- FRY's occupants commented that the building's slit casement windows, often only one per room, did not permit sufficient adjustment of quantity and position of ventilation. Previous studies have indicated that people like to be able to decide where to "put the draught".

More attention to window design, control and usability would be very helpful generally.

Motorised openable rooflights were also included at MBO, for added ventilation to the relatively lightweight first floor. Simple time and temperature control (with rain over-ride) had been provided but the occupiers found the local and central (by floor) manual controls more satisfactory. During the day, people used the windows and rooflights as they wished, and everything was shut up at night when the cleaners finished. A manager, however comes in at about 6 AM when the warehouse opens, and if the office seems hot, he uses the general over-ride switches near the stairs to open the windows and/rooflights for pre-cooling before the staff arrive. The occupants then take over and adjust the windows as they see fit. This simple user control has worked well in this small building.

Ceilings varied, with exposed concrete being part of the environmental strategy for temperature stability at TAN, CAF, CRS and FRY. Only HFS, ALD and MBO had lightweight roofs over their the top floor offices: the others had concrete above with either plant, restaurants, or shade roofs above that; plus a roof garden at TAN. The ground floor of MBO had a suspended ceiling with ventilation grilles at the perimeter and in the middle to permit access of air to the soffit; which Dutch studies had shown had a useful stabilising effect [7]. This appeared to have been helpful, though its performance was not monitored. It did however undermine acoustic privacy in the cellular offices and meeting rooms on the ground floor.

U-values in most of the buildings were not outstandingly better than normal at the time of construction; the exceptions being CRS and the highly-insulated FRY. Only at FRY, however, were the consequences clearly evident in the low levels of installed boiler power and heating fuel consumption.

A2.3 HEATING, HOT WATER AND MECHANICAL COOLING

Boilers. None of the Probe commercial offices has condensing boilers; only the offices in the educational FRY. This lamentable state of affairs is common in UK commercial buildings in the recent age of low gas prices. It is sad that such now-proven technology is not regarded as an essential feature of a good new building, rather than having to be justified on its cost-effectiveness; often in relation to an energy consumption estimate considerably lower than the one which materialises in practice. Installed boiler power levels were also high: above 100 W/m^2 in most buildings and over 200 W/m^2 in TAN and C&G. There does, however, seem to be a steep downward trend in capacity with the newness of the building, and FRY (23 W/m^2 boiler capacity for the building as a whole; design heat loss 15 W/m^2) shows the way to radical reductions.

Domestic hot water. The heating boilers also made kitchen hot water at TAN and C&G and all hot water at HFS. CRS and FRY had independent gas-fired water heaters for their kitchens and nearby toilets. As discussed in Section 3, local electric heaters were widely used for toilets in the offices. This was partly for convenience (particularly where prefabricated toilet pods are installed) and partly owing to work in the early 1980s [20] which showed that using heating boilers for hot water could be wasteful - particularly in summer. However, the 1980s results were most convincing in delivered energy terms. In energy cost terms or carbon dioxide, electrical HWS often cost more - unless it was strictly time-controlled and/or used off-peak electricity, as discussed in pages 80-83 of GIR 15 [21]. In the Probe buildings, none of the electric storage water heating was time-switched or on an off-peak supply. In many of the buildings with air-conditioning or mechanical ventilation, the boilers ran in summer for air preheating anyway.

Heating pump operating hours (together with the enabled hours for the boiler plant) vary greatly between the buildings. For heating, in order of increasing use:

- Only C&G, CRS and FRY circulate for an estimated 1500 hours or so a year, a typical heating season's length of occupied hours plus preheat and frost protection. This was due to good energy and operational management at C&G and FRY, and the effect of internal gains at CRS (as discussed later).
- MBO's pumps run for longer, 2400 hours estimated, owing to the heat demands of the toilet air supply plant (which is also shared with toilets and changing rooms in MBW: its use and fuel consumption has also been apportioned between them). Air tempering for this one small plant added significantly to the heating energy use for the whole building, as it was often the sole demand on the system and so incurred all the standing losses then. A heat recovery or extract-only plant here could therefore have produced disproportionately large energy savings.
- The higher estimate, 3000 hours, for CAF resulted from more extended operation after the building was found to be cold initially, probably owing to high air infiltration. This figure is of low reliability because we were not permitted to make full checks or review BMS records.
- The lengthy 5000 hours at ALD resulted from a rather generous time programme and insufficient management capacity to undertake further fine tuning.
- The 5400 hours at HFS was largely a result of extended running to counter air infiltration. In summer 1996, we also found the perimeter heating operating during occupied hours on bright summer days, if outside air temperatures were below the sensor set points, which had themselves been raised to counter solar effects in winter. This was not immediately apparent to occupants as the finned heating pipes were hidden in trenches. Effective operational and energy management could have avoided this; but at the time of the survey HFS were still concerned to minimise underheating problems by running systems liberally.
- At TAN the heating pumps ran continuously, owing to a problem with the pressurisation unit, which otherwise locked out on overpressure when the system heated up or underpressure as it cooled down. The problem appeared to originate from the unusually high stored volume of water in the heating system, owing to so much of the servicing being around its outer perimeter. Although more expansion vessels had been added, the problem persisted and the best the management could do was night setback operation. This is an unusual example of a common tendency for systems to default to "ON", as the most straightforward management solution to circumventing technical problems and/or occupant complaints.
- HFS and TAN also have air supplied from the floor, with no heat recovery. Such underfloor and displacement systems reduce cooling requirements by supplying air at typically 19-20°C, and not the lower temperatures commonly used in mixing systems. However, with no heat recovery or mixing, this air has to be heated, even often on the mornings of hot summer days, leading to more heating energy use and boiler operation than often seemed to have been anticipated by designers and in energy use predictions.

Refrigeration cooling. The five AC offices have chilled water systems, with screw chillers at HFS and reciprocating elsewhere; and air cooled except for the cooling towers at ALD. ALD and CRS also have ice storage systems, which had both been problematic in operation and at the time of the surveys had delivered no running cost benefits. The installed cooling capacity varied widely, in W/m^2 of treated area HFS 211, TAN 172, C&G 139, ALD 97 and CRS 40 (area for CRS excludes the independently-serviced kitchen and restaurant). For ALD and CRS the availability of ice storage for parallel operation approximately doubles the effective cooling capacity in relation to the other three buildings. Cooling performance varied substantially between the buildings:

- HFS appeared to have ample capacity: even on an unusually hot and humid afternoon in August 1996, demand profile recording showed only one chiller running well within its capacity. However, both chillers were enabled and their primary pumps operated constantly.
- TAN's chiller capacity was generous, but operational problems arose owing to the full-fresh-air VAV system and the chosen mode of chiller heat rejection into the exhaust air ducts from the offices. This raised the condensing temperature generally, with consequent ill-effects for the reliability of the chillers. In hot weather, the system also chased its own tail, as to get more condenser airflow, one needed to increase the air change rate through the offices, and hence the air tempering requirement! By experience the management had found that the best way out of this vicious circle was to raise the indoor setpoint on hot afternoons.
- No capacity problems were reported at C&G, where the more conventional system was also most closely managed in relation to demand.
- ALD was generally satisfactory, but sometimes suffered capacity shortfalls on occasions when the ice storage had failed to operate overnight.

- CRS had problems with overheating, particularly after a weekend. However, and in spite of the poor reliability of the ice storage, this appeared to the survey team to be largely an operational problem. Essentially the HVAC plant was run to a rigid weekday time schedule based largely on occupancy hours. At night, however, internal gains from equipment and lights left on, plus stored gains from the uplighting, built up in the structure and preheated the space and the incoming air through the floor void. The ballasts for the uplighters were also located in the floor void and preheated the supply air by an extra 1°C. A solution might well have been some background ventilation at night, and/or an extended pre-cooling period. This would have increased energy consumption, but significantly improved comfort levels.

Chilled water pump running hours, (and chiller enabled times) tended to mirror heating pump running hours in the five buildings that had chilled water systems, but with even more tendency to default to on[27]. In order of increasing hours of use:

- C&G had the smallest number of circulation hours - 1000, owing to effective operational management which found that refrigeration did not normally have to be switched on unless it was above 11°C outside, and could be switched off when it fell to 9°C. (estimated annual chilled water pump consumption 4 kWh/m^2).
- At CRS, the chillers tended to be enabled and chilled water circulating for the whole working day. This may not be essential, particularly in winter, but is commonplace in many buildings studied. There is also a small amount of out-of-hours operation to build ice, but relatively little as the cooling is at present chiller-led, so the store is only depleted by standing losses; or during the day, on the rare occasions when the chiller lacks the capacity to meet the cooling loads. (7 kWh/m^2).
- HFS had hours-run meters on the chilled water pump control system. The management had not made use of them, but this information was invaluable to the Probe team. They indicated that the secondary circulation pumps had run for an average of 4000 hours per year, but the chillers and primary pumps had been enabled on average 24 hours a day, six days a week. Hence the electricity used by the chilled water pumps here was high. (32 kWh/m^2).
- ALD's lengthy 6000 pump running hours arose from the store-led ice storage strategy, with the ice tanks depleted during the day and recharged at night (35 kWh/m^2).
- TAN's chilled water pumps had to operate constantly to feed chilled water air-conditioning units in the communications room, UPS rooms and substations. At the time of the Probe survey, TAN's engineering staff had almost completed converting the cooling in these areas to self-contained units, so that the main chilled water system could be switched off overnight, as described in [22]. (27 kWh/m^2).

A2.4 AIR CONDITIONING AND MECHANICAL VENTILATION

Systems used. The three earliest Probes: TAN, ALD and C&G had VAV air-conditioning, the most widely-used type in the 1980s.

- C&G's is the most conventional, with ceiling supply and plenum return, with four main systems, one for each quadrant of the building, with recirculation available.
- ALD uses 96 fan-assisted terminals (FATs) in the ceiling to circulate the air and blend-in low-temperature air as necessary from three central AHUs. The controls kept the central supply air temperatures to the highest possible levels compatible with the cooling requirements of the most demanding FAT in the system concerned at the time.
- TAN has a full-fresh-air system with sixteen main AHUs for the offices, plus others for the restaurant etc.. Supply is from the floor (but not true displacement ventilation), with low-level VAV boxes ducted to floor outlets, and air exhausted through AHUs at high level in the atria. The extract AHUs also contained the heat rejection coils for the refrigeration compressors, hence removing condenser clutter from the roof or the service yard. However, this visually elegant solution exacted penalties in peak cooling capacity and reliability (as already discussed in A2.3), and in extra exhaust fan power. The effect was significant, as averaged over annual operating hours, only about 7% of the design cooling load was being rejected, while the heat rejection coil resistance was present in the exhaust airstream for 100% of the ran operating time. Some of the office fans also had to be operated at night, whenever there was compressor heat to be rejected.

The three later AC and MM Probe commercial offices all use constant-volume displacement ventilation, two (HFS and CRS) with chilled beams (with local control at HFS) and one (CAF) with indirect adiabatic cooling. The educational office - FRY - is ventilated from its hollow core slab ceiling and back via a corridor bulkhead.

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[27] The computer room cooling systems in the buildings that had them all ran continuously and are discussed later.

Recirculation and heat recovery approaches varied in the AC and MM offices:

- C&G and ALD had traditional AHUs with variable recirculation using face/bypass dampers.
- Rising concerns about air quality and building-related ill-health in the late 1980s caused TAN and HFS to have straight-through fresh-air systems with no heat recovery of any kind, except for run-around coils in the restaurant at TAN.
- The later buildings: CAF, CRS and FRY were all designed for full fresh air with heat recovery. CAF and FRY also had recirculation available for use during the preheat period.
- CAF and CRS have cross-flow heat exchangers of typically 50% efficiency. FRY's regenerative heat exchanger has a claimed and monitored recovery efficiency of 85%, though during the Probe survey the university reported a drop to 80% and a possible need for heat exchanger cleaning. The regenerator works by passing supply and exhaust air through two honeycomb blocks; and using linked fast-acting (1 second) dampers to reverse the flow every minute so that the heat stored in what was the exhaust block is given up to the supply air. The flow reversal also causes some exhaust air to be drawn back into the system; perhaps 5-10% with the duct configuration at FRY. It also caused a detectable surge in regenerated air noise levels in a few rooms closest to the plant; though noise levels were generally low.

Air change rates varied widely:

- The offices at FRY, the well-insulated, trickle-charged thermal flywheel, have the smallest amount, 1.3 ac/h; or about 15 l/s per person in a cellular office.
- The displacement ventilation systems at HFS, CAF and CRS were designed for about 3 ac/h. However, at CAF the commissioning records revealed nearly 4 ac/h. The designers felt that more was better and did not require this to be reduced. However, it did add to fan power (fan motors in the installed plant were bigger than in earlier documentation) and heat losses.
- The VAV systems were designed to much higher peak capacities of 8 to 12 ac/h. However, typical running levels during the occupied period were estimated at 5 ac/h for TAN and C&G. The fan assisted terminal units at ALD, however, recirculate some 18 ac/h.

Specific fan power (SFP) in Watts per litre/sec of air handled (for supply and extract systems combined), was relatively high in most of the buildings, typically between 3 and 4 for the constant-volume systems - except FRY at 2.3. The three VAV systems all had installed SFPs of about 5 at full design loads. However, VAV fan power reduces with volume, and estimated average annual SFPs per l/s of primary air handled were 3 at ALD, 2.5 at C&G and 1.7 at TAN. These compare with ECON 19's Typical benchmarks of 3, Good practice of 2 and Low energy of 1[28].

Night ventilation was an important part of the cooling strategy at CAF and FRY. At CAF it was achieved by early morning optimum start of the ventilation plant. FRY's ventilation plant operated after 10 PM if the hollow core slab temperature was over 23°C and the outside air is at least 2°C less than the core temperature. FRY's monitored performance and occupant perceptions of summertime conditions were good, particularly after the BMS was installed and more effective and economical control had been established. CAF's occupants commented on high summertime temperatures, but because monitoring records were not available it was not possible to find out whether the night cooling strategy - or the indirect adiabatic cooling - was working to its best effect; or indeed at all.

Other mechanical ventilation and cooling related issues

- A common complaint was of draughts and cold air, particularly with floor supplies but also from the ceiling, plus stuffiness at high turndown for VAV systems. This had led to control changes and restrictions in the available VAV control to the middle of the available range.
- With floor supply systems, FMs had often had to raise supply air temperatures from the 16-18°C used in design calculations to 18-21°C. They had also had to move supply diffusers away from workstations and into circulation and filing areas. Unfortunately, all offices had 500 mm square carpet tiles over floor tiles 600 mm square or larger, entailing a lot of tile-cutting and wastage every time a diffuser was moved. A more flexible approach would have been raised floor tiles with a bonded finish, which could simply have been interchanged.
- Where floor diffusers had not been moved, people tended to close the dampers underneath (as at HFS initially), or put boxes or wastepaper baskets over or cling film under the outlets - often leading to more draughts elsewhere.
- At CRS it appeared that some of the cooling capacity of the chilled beams around the perimeter of the atrium was being given to the exhaust air rather than the occupied space.

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[28] SFP appears to be seldom used as a design criterion. In recent project reviews, WBA has asked engineers for information on SFP targets and provision. This has never been available at the time of the request; and seldom produced afterwards.

Humidification was installed in all five AC offices; a change from a few years ago when it was usually either omitted, or disconnected owing to health scares. All systems were sterile steam rather than the evaporative systems often used before; and with much greater potential energy use. TAN has central gas-fired steam generators. C&G has four steam generators, one for each main office AHU. ALD, HFS and CRS have electrode boilers for each relevant AHU. HFS reported poor reliability owing to the local water quality. C&G was relatively sparing in its use of humidification and only tended to run their units in cold weather. The other sites did not: their higher consumption was partly a consequence of the low temperature air supply at ALD and the full-fresh-air systems at TAN, HFS and CRS. We also found humidifiers had been operating in all seasons on these four sites; and not just in the coldest and driest weather, as might have been expected. Most humidifiers appeared to run according to RH set point during programmed hours, with little or no energy management. If for some reason the supply or return air was at a higher temperature than the design had assumed, then more humidification would be required to maintain the set RH, often unnecessarily increasing the dew point in the occupied space.

Controls and BMS. All the large buildings: TAN, C&G and CRS had BMS from the outset, as did the much smaller HFS. ALD had a combination of conventional control modules for the main plant and more sophisticated BMS-like proprietary controls for three main air-handling systems and their associated terminal units: this mixture and the proprietary software was difficult for the operators to come to terms with. FRY had a BMS retrofitted. In general, the BMS worked much better at TAN, C&G and FRY where owner-occupiers had their own engineers on site: otherwise both BMSs and conventional controls proved difficult for the occupiers and their contractors to master. However, even with the well-managed BMSs, Probe found a lot of shortcomings with controls - both manual, automatic, and in their strategy, design, performance, integration, use and usability. These have been discussed in a recent paper by the team [22], attached as Appendix C. In addition, even site engineers' perspectives of controls and performance can differ substantially from those revealed in occupant and energy surveys.

A2.5 LIGHTING

Page 5 of Table A1 summarises issues on artificial lighting, its control and integration with daylight. Information on windows, solar and glare control is covered on page 2 of the Table.

Perimeter daylight. Four of the offices: TAN, ALD, HFS and CRS had tinted glazing which typically transmitted less then one-third or less of the daylight available. Although perimeter lighting had automatic high/low switching controls at Tanfield and dimming at HFS, the reduced daylight (with venetian blinds also permanently lowered at HFS and CRS) made energy savings relatively small. The other four buildings had clear glass (with a solar control coating on the SE and SW facades at CAF) and potentially greater availability of natural lighting, though this was to some extent frustrated by difficulties in controlling both the lighting and glare effectively.

- C&G has principal facades facing E and W. When its external motorised blinds were omitted, it had to rely on translucent curtains for glare control. These themselves became too bright in sunshine, becoming their own glare source; and had to be doubled-up, further reducing daylight levels. As in many open-plan offices, once shut the curtains tended to stay shut for long periods, because blinds-closed-lights-on tends to cause least conflict for the occupants.
- CAF has internal venetian blinds which provide more user control; and in this shallower-plan office were more easily adjusted by people nearby. However, they were often kept in a partially-lowered state (covering the upper windows) in order to avoid glare problems at workstations distant from the windows.
- MBO has innovative windows including a manually-operable reflective internal roller blind on the lower two-thirds of the window, and the same material as a tiltable internal light shelf below the upper fanlight. The reflective coating was thinly-applied, with a residual light transmission of about 5%, allowing some view to be retained. Unfortunately the contrast between the blind and the unshielded window tended to cause the lower blind to be lowered fully and the light shelf shut in glary conditions: a situation which was exacerbated because sun could get in and the sky be seen diagonally beyond the ends of the light shelf.
- FRY had conventional cellular offices, with desks under the window. Daylight was reasonable, but lighting energy use greater than in many cellular offices owing to a high IPD (20 W/m^2); both lights on one switch; and in daylight a dark shadow cast onto the ceiling by the cornice, making some people switch on their lights to reduce the contrast.

Glare from daylight and sunlight can be particularly troublesome where furniture layouts have computer screens either facing or at 45° to window walls, as is common today.

Core daylight. Six of the offices used rooflights to bring daylight into the centre of the office space. These were attractive, but of limited success in reducing lighting energy use:

- At TAN, the atria had to be artificially lit virtually constantly, as otherwise plant growth suffered. The rotating sunscreens were effective at blocking out glare.
- C&G's atrium rooflight made an attractive daylit coffee/meeting area off the top floor corridor, but dark finishes at lower levels often required the main electric lighting to be on too. Being manually switched from reception (which could not see into the atrium) it tended to be left on.
- The rooflight in HFS's ground floor office was less of a presence in the space, particularly as the chilled beams and light fittings suspended beneath it were in the same plane as in the surrounding open office areas. The fixed louvres together with the surrounding first floor courtyard reduced the amount of daylight, whilst not excluding glare from some oblique sun angles. Air infiltration and water ingress here had also caused problems. In hindsight, the management said that they would have preferred not to have had it.
- CAF's rooflights introduced not only daylight to the top floors of the wings, but also glare, solar gains and air infiltration. Remedial measures were being considered, but proving tricky owing to health and safety requirements for maintenance access.
- MBO's rooflight was effective in lighting the centre of the top floor and keeping its lights off for the most part. However, the best-lit space immediately underneath was sometimes too bright for work on computer screens, so was used as a rather generous circulation route.
- CRS's atria were attractively daylit. The transparent insulation encapsulated within the double glazing units was also effective at glare control, except when ventilators (originally intended to be used in fire only) were open. Its artificial lighting was often on too: a common problem in atria, public and circulation areas in nearly all the buildings.

Office lighting types and standards.

- 5 offices had high-frequency fluorescents in louvred fittings to meet VDU glare requirements.
- In four of these, they were recessed in the ceiling and to normal standards of of 500-600 lux (with ALD slightly less); and all had IPD ratios in the region of 3 W/m^2 per 100 lux.
- In the other (CAF), the luminaires were surface-mounted in the dimpled coffers in the concrete ceiling, into which the light had also been arranged to spill upwards. The luminaires also concealed air extract points behind. Here the illuminance level was somewhat lower (350 lux) and the IPD a little higher (3.6). This attractive-looking scheme, however, was not as well-liked by occupants as we had anticipated when first seeing it - possibly because the luminaire glare control was not completely effective in all directions.
- The other three offices had indirect lighting: metal halide (MBI) uplighters at TAN and CRS and fluorescent cornice lighting at FRY; at illuminance levels of 300-350 lux. The indirect lighting inevitably took a penalty in IPD, particularly at CRS with its rough-surfaced acoustic ceiling finish and FRY with its corner geometry and conventional control gear; but indirect lighting was well-liked by the occupants, particularly at TAN and FRY.

Automatic lighting controls were found in all the offices except FRY. These were mainly used to "sweep" lights off at intervals after the end of the working day, with other key features as below:

- At TAN the MBI lights were switched on automatically at the start of the day, first for common and circulation areas (circulation routes in the open-plan offices have floor-mounted CFLs, rather like runway lights) and then for the offices, first at full brightness, though this could be reduced by one-third by individual choice at each luminaire (subject to agreement between the four people affected) or automatically by daylight-linking at the perimeter.
- The automatic control at ALD was little used at the time of the Probe survey, but a simple strategy was being introduced and the operators trained.
- At C&G lights were normally switched manually at gridswitches near entrances to spaces. Colour-coded switch rockers: red for circulation, white for lobbies, and silver for general are a helpful touch which avoids the lights being used unnecessarily, particularly once the silver switches were re-wired after completion to correspond with the lighting layouts.
- HFS had "intelligent" luminaires with occupancy sensing, automatic perimeter dimming, and a high degree of central control and adjustment from the Lighting Management System. In use, however, the lights were on more than one would have hoped. In particular, lights in cellular offices came on to maintain 600 lux or more whenever anybody crossed the threshold. In the open-plan areas, occupants complained of distraction from the switching, so here the system here was reprogrammed to keep all lights on all day. Initially the perimeter lights sometimes over-dimmed owing to daylight reflected upwards from the venetian blinds, set points were then raised, leading to unnecessarily high illuminance levels generally.

- CAF used occupancy sensors in meeting rooms and kitchens, telephone switching in the open-plan offices, and manual switches elsewhere. As implemented, the telephone-switching was a mixed blessing: with some systems a standard code dialled on any telephone switches the lights nearby; but here a PIN number was required. This meant that cleaners etc. could not operate the lights, so all had to be switched on automatically for them, leading to unnecessary use. Switching zones also covered several workstations, so individual control became more of a power struggle ... or a stalemate! Contexts of light switch use have been discussed in reference [23].
- MBO also had a somewhat unfriendly automatic lighting control system, with occupancy sensors and photoelectric control. Cellular offices had their own occupancy sensors, which also controlled the lights just outside them, where there were also some secretarial workstations. So when the office was empty, the person outside had to step in from time to time to re-activate all the lights! The open-plan areas had occupancy sensors for larger zones, coupled with photoelectric control at the perimeter and under the rooflight. Initially the control - using external photocells - did not work and required major attention by the supplier. The occupants regard its switching operation as intrusive. It can also misjudge the situation when the blinds are closed to limit glare, leaving people to work in less light than they would have liked. The system also makes it difficult for people to operate the lights at all if they came in outside normal hours,when the occupancy sensors were disabled.
- CRS's lighting controls permit individual user over-ride of each furniture-, wall- or column-mounted uplighter. However, this sounds better than it really is, because each lamp lights several workstations and the illumination of each workstation is affected by several lamps. The inertia in the system is further reinforced because the MBI lamps do not light instantly; and take several minutes to start if they are put on shortly after having been switched off.
- CRS's uplighters also contributed in an unusual way to the office's overheating, both directly from the ballasts located in the floor void; and indirectly as the heat from radiation and convective plumes absorbed in the soffit and conducted through into the floor void.

Estimated average full-load running hours for lights in the office areas were about:
- 1000 in the cellular FRY, somewhat below the GP benchmarks level in ECON 19; though annual energy consumption was a little above typical for cellular offices owing to the high IPD and the permanent corridor lighting.
- Just over 2000 hours in CAF and MBO, similar to ECON 19 typical hours, though annual consumption was less than in typical open-plan offices owing to lower installed power levels.
- 3400 hours in HFS, rather high in relation to AC office benchmarks, owing to triggering and over-riding of the occupancy sensing.
- A high 4000-4400 hours at ALD, C&G and CRS, owing partly to longer occupancy hours than in the offices above; to the larger open areas which are more likely to default to ON, and a lack of responsiveness of the automatic controls.
- A very high 5200 hours at TAN, owing partly to extended working in the large open plan areas, together with the overnight cleaning.

In general, more attention is needed to making lighting controls better able to meet occupant requirements in a more responsive and energy-efficient manner.

Lighting in circulation and other areas was wastefully controlled in many of the buildings. Common problems included:
- Lights on when natural lighting was more than adequate in corridors, stairs and atria. In these areas - provided conditions are safe - people are generally less inconvenienced by automatic operation of lighting than when at their workstations.
- Unnecessary switching-on by automatic systems. A common feature is that for anyone detected by an occupancy sensor or by switching the lights, all the circulation lights come on; and quite often in Probe not just for the zone but for the building as a whole (as at CRS); and sometimes including WCs and meeting rooms as well, as at TAN. Clearly, people need to be able to leave the building in safety, but often there seems to have been overkill, both in the provision of circulation lighting and in its control.
- Occupancy sensors in toilets were a good idea, as at HFS. These worked particularly well if individual self-contained cubicles with washbasins. In shared facilities, extra sensors are really necessary above the cubicles, but are seldom installed.
- HFS's meeting rooms have dimmable lights with hand-held infra-red controls. These worked well technically but the controllers are not labelled, so it was easy to switch the wrong lights; particularly for occasional users of the rooms, so over-lighting often resulted.

A2.6 IT AND ELECTRICAL

Office equipment heat gains and power requirements are important considerations in designing and managing an office, and have a major effect on the choice of air conditioning. Studies in the early 1980s warned of massive increases, and led to an over-reaction, with too much and often oversized air-conditioning. Studies in the late 1980s and early 1990s [24] led to more realistic estimation. The BCO specifications of 1994 and 1997 [25] suggested that over an area of 1000 m^2 or more, power consumption rarely exceeded 15 W/m^2, but that contingency provision should be made in risers, plant space and electrical capacity for an increase to 25 W/m^2.

The Probe studies to date have confirmed that these allowances are reasonable. In Probe 1 they were approached in the office areas of the large financial service companies TAN and C&G (load densities here may have increased since the Probe survey, as the terminals then used by 20% of the staff may have been replaced by PCs). For the office area as a whole (excluding machine rooms) these allowances are more generous because circulation, meeting rooms and executive office suites have much lower equipment densities. Locally, however, power densities can go higher, for example where there are powerful workstations, densely-packed areas (such as customer service/call centres) where nearly all the work is done on a computer screen; and people who use large screens, or several computers or screens at once.

The other two Probe 1 AC offices - ALD and HFS, had lower occupancy levels and typical internal gains in the office areas averaging about 7 W/m^2. In the Probe 2 NV and MM offices, CAF, MBO and FRY, most occupants now had a PC, though use was not as intensive as TAN and C&G, with average heat gain levels around 8 W/m^2. FRY's 20 W/m^2 figure relates to its cellular offices, each with a PC and printer: when diversified for use the average gain fell to about 7 W/m^2 of total office area including corridors.

CRS's office space, however, had a high occupancy and IT density, again around the 15 W/m^2 level. However, its annual energy consumption by office equipment was unusually high, with an estimated 70% of PCs left on overnight in slumber mode (which spot metering indicated only used 10 Watts less than when fully on). Apparently people had got into the habit of this owing to network problems initially. These had now been overcome and at the time of the Probe survey, CRS was planning to encourage staff to switch off machines completely overnight[29].

Air-conditioned computer and communications rooms were found in all the commercial offices, with cooling capacities typically in the range 300-500 W/m^2:

- Standard Life's main data centre is in a separate building adjacent to TAN, not included in the Probe survey. It used twice as much electricity as TAN itself, 45% of which was attributable to its building services - a relatively low proportion. A year after Probe, the computer was replaced, with such large reductions in energy consumption that heating had to be provided!
- TAN itself has a 250 m^2 communications room which, together with other 24-hour loads, had caused the building's chilled water system to run unnecessarily, as already discussed[30].
- ALD has two small rooms, one for communications and one for IT servers etc, with independent close-control DX cooling units. In spite of their small size, annual electricity consumption is significant owing to their continuous use.
- C&G has a 700 m^2 computer room with nine packaged air conditioning units and two water chillers on a common glycol heat rejection circuit with air blast coolers on the roof. In cold weather, typically under 10°C outside, "free" cooling is obtained by passing the return glycol through pre-cooling coils in the packaged units. On very hot summer afternoons, heat rejection capacity initially proved inadequate and the air-blast coolers had to be hosed-down to provide additional evaporative cooling until extra ones were added.
- Gardner House has a 60 m^2 room used for both computer and communications equipment. The air conditioning used similar amounts of electricity to the equipment in the room.
- CAF had a small computer/communications room, with units on the same multi-split DX comfort cooling system that served the main meeting room. In spite of the modest size, this

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[29] Recent surveys suggest that leaving equipment on overnight seems to be increasingly common. Some networks and security systems demand it; but it is often unnecessary. The habit seems to have been encouraged by equipment that goes to sleep (but not necessarily into a very low-energy mode) automatically, and by some IT staff who recommend that not switching off improves reliability.

[30] Buildings the Probe team has surveyed with computer room cooling and office comfort cooling on the same chilled water system have invariably been inefficient, owing particularly to high chilled water pumping loads. In theory it should be possible to design variable-capacity variable-volume combined systems which work efficiently over their full capacity range. In practice such installations seem to be rare.

used 20% of the electricity consumed in the whole building.

- In the smaller MBO, a similar - but yet smaller - computer room with DX comfort cooling used 42% of the building’s electricity.
- CRS had a very large computer suite - including other 24-hour uses requiring cooling such as its automated archive and its main 24-hour print room (producing inventories, labels etc. for all CRS stores). The independent chilled water system had duplicate packaged air-cooled chillers including glycol free cooling. Although about one-third of the close-control room units were off, energy consumption of the air-conditioning system was high, estimated at over 60% of the total. Part of the reason for this was a high fresh air load (4 ac/h) and inefficient humidity control.

If any sense is to be made of understanding and managing a building’s energy consumption, electricity supplies to equipment and air conditioning in these rooms must be sub-metered.

A2.7 FACILITIES MANAGEMENT AND MAINTENANCE

Facilities management was of a high standard in all the office buildings. The level of engineering support varied, with, in order of decreasing support:

- A well-resourced team at TAN, with good understanding and dedicated to customer service.
- A good team at C&G, but less well-resourced than at TAN, and so somewhat less responsive.
- University engineers at FRY, who had taken a special interest in the building - but now it was working well, had moved on to other things.
- ALD had not expected to employ on-site engineers, but had found them necessary to look after the relatively complex systems. They were adequately, but not generously resourced.
- On-site maintenance contractors as part of an outsourced FM services contract at CRS. They were less proactive than in the buildings above, perhaps owing to their contract conditions.
- A landlord’s maintenance contractor at CAF. They were effective at routine maintenance and responsive to call-outs, but - as at CRS - did not appear to have been proactive in seeking to verify and improve the performance of the system.
- A contractor who visited for half a day a week at HFS and was otherwise on call. Again, this seemed more of a caretaking operation than a creative response to the problems that had arisen. However, their contract may well not have required this: and the actions they were able to take may well have been constrained by defects liability issues.
- MBO was the smallest and simplest building and more like a family operation, dedicated to running things well and bringing-in supportive local contractors where necessary. Everybody was, however, somewhat defeated by the lighting controls, which were in hindsight probably too sophisticated for a small building in which people would probably have been more capable of - and prepared to - use simple systems sensibly

Energy management was conspicuous by its virtual absence. In general the cultures were those of “service before economy”. Energy management did not receive a high priority, particularly if it carried any likelihood of degradation in service and performance. Energy costs were thought to be reasonable, particularly in relation to staff costs and the value of the business, and squeezing-down - other than on fuel purchasing - a false economy. In particular buildings:

- TAN was happy to improve engineering systems efficiency, but not to undertake operational energy management where it might threaten service. Changes included gradual conversion of eddy-current to inverter fan drives; stopping warm air dryers in the toilets switching on automatically whenever a paper towel was removed; free cooling of transformer and UPS rooms; occupancy-sensed lighting in the lifts; splitting off the 24-hour security/control room from the main HVAC system; and relating car park fan and lighting operation to usage hours.
- C&G had the best-developed policy and a corporate energy management unit. They had by far the most tightly-managed plant: the annual operating hours of heating and chilled water circuits were about one-third of those in TAN, ALD and HFS. They had also made investments to avoid the “tail wags the dog syndrome”, in particular by installing independent cooling units in small machine rooms; a summer hot water boiler; and additional heating in under-heated areas. Again they were reluctant to make operational change in their chief office. For example, when standby generation capacity was being enhanced, senior management had not approved a proposal for parallel running to reduce the sometimes very high pool prices of electricity (at times exceeding £ 1/kWh) because they feared that reliability might suffer.
- CRS had engaged energy consultants, but only for contract negotiation & fuel bill processing.
- At FRY the university engineers had taken great interest in the monitoring undertaken for BRECSU and in fine-tuning the building. However, they said that this was entirely from a professional interest and in no way could have been considered cost-effective.

Fuel metering and unit costs. All the buildings were metered, the university buildings even where they were on multi-building sites owing to their tendency now to re-charge cost centres for their use of utilities. At POR, however, Probe found that the electricity meter had not been working properly. Sub-metering was rare, with a few exceptions.

- Water metering to the steam generators at TAN allowed humidification energy use to be estimated.
- Kitchen gas was sub-metered at TAN and FRY; and catering electricity too at CRS Recharging to the catering contractors was however not implemented.
- C&G had electrical submeters for each quadrant of the office, but they were of little interest to the management because each contained a mix of areas and uses, often overlapping.
- HFS had a useful set of hours-run meters for fans, pumps, chillers and humidifiers. Hours-run meters were occasionally found elsewhere, for example on the chillers at TAN and the chiller pump control panel at CRS.
- Hours run were sometimes logged through BMSs, but were untrustworthy as the counters might have been reset at any time.
- No computer rooms and their associated air conditioning were metered, but quite often UPSs gave instantaneous readings of the kVA being drawn; and occasionally kW or kVA input.

Fuel bill data. Monthly electricity bills were usually reliable, seldom based on estimates, and contained useful detail on the larger sites with half-hourly metering; though only at C&G was this immediately available from the energy management unit. Gas bills were more haphazard, with the majority of the readings estimated for all but the largest sites. Sometimes we were able to obtain a few additional readings by direct application to Transco. Average units costs for energy varied significantly between sites, and not always as might have been inferred from building size and load characteristics. In general there was a downward trend from the beginning of Probe 1, with a slight upturn towards the end of Probe 2; when a typical rate before VAT was about 1 p/kWh for gas and 5 p for electricity. However, some buildings were anomalous: for example, MBO/MBS had an unusually low rate for electricity and a high one for gas.

Water consumption. The data collected in Probe 2 indicated little impact as yet of the recent concerns about rising water consumption. Consumption per head at MBO and CRS was a little above normal; but both may have ben influenced by leaks: the flood at MBO and the ice store at CRS. CAF did rather better - possibly because there were no urinals and external plant watering was a separate landlord’s service. FRY’s consumption looked good in view of the high student load.

A3 The educational buildings

A3.1 GENERAL

Function. The five educational buildings - four university buildings and one secondary school - are all non-residential. Details are given in Table A2. Three of the university buildings (DMQ, FRY and POR) provide office space for academic staff, seminar rooms and large lecture theatres. The largest of these, DMQ, also has engineering laboratories and workshops.

The other university building, APU, was designed as a learning resource centre (i.e. a traditional library but planned to include 750 networked IT workstations), also with a café/bar as a central meeting point for students and - as a temporary arrangement - office space for administration staff until student numbers and library usage had built up.

The secondary school, CAB, was a City Technology College: the emphasis on technology, and sponsorship by industry, mean that it has more IT and workshop facilities than normal, plus three air-conditioned rooms: for meetings (available to the industrial sponsors), IT equipment, and communications.

The C&W training centre is reviewed with the "other" buildings in Section A4. Although also an educational building, this was very different from the others, being in the private sector and including residential and sports facilities and year-round and weekend use.

APU and POR are flagship new buildings for their new universities (ex-polytechnics), to help attract new students and to pull together their disparate facilities. They are of a similar size, eye-catching appearance, and have substantial atria (a modern forum) and catering facilities. DMQ shared much of this agenda on a grander scale: however, its proposed restaurant was omitted at a late stage. FRY, by contrast, was designed to blend in with its surroundings on a large university campus. CAB also needed to impress prospective parents and their children, but its suburban surroundings and the restrictions applied to its parkland site stopped it being such a high-visibility landmark building as DMQ, APU and POR.

Occupant density. At the time of the Probe surveys, occupancy at CAB was some 15% below design and APU was very lightly occupied, which inevitably meant less pressure on building services, lower electricity consumption (e.g. for PCs, lighting and water heating)[31], lower summertime overheating risk and possibly a more favourable occupant viewpoint, owing to less crowding. DMQ was also below design occupancy, but less significantly; FRY is used much as anticipated; whilst POR has proved so popular that its use is verging on the excessive (exacerbating the consequences of unisex toilets scattered about the building, for example, since it has no central facilities near the main lecture and seminar rooms).

Location and transport issues. All these buildings provide only minimal car parking for their users. FRY is on a largely car-free campus (with most car parking on the perimeter), whilst POR, APU and DMQ are in urban centres, close to good public transport links (bus and train). These four buildings therefore are consistent with a sustainable transport policy, as far as might reasonably be expected, making students perhaps less inclined to feel that they need to get a car as soon as possible. Staff car use might be a more intractable problem, as elsewhere. Transport to CAB was not investigated in any detail, but anecdotal evidence suggested that - as at other schools - many children were driven there in private cars. Most pupils lived beyond walking distance, but CAB's cycle racks were little used: it was not clear if this reflected a lack of interest, or parental concern about road safety. There are school and local buses, but CAB's suburban location and wide catchment (owing to its special nature) would make public transport difficult for many pupils.

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[31] There would also be a small increase in gas consumption due to lower internal heat gains, but this is probably of little significance, not least owing to the lower carbon intensity of gas consumption.

A3.2 BUILDING FABRIC

Insulation of opaque elements. FRY represents a rare example in the UK of a superinsulated non-domestic building (wall, roof and floor 'U' values of 0.2, 0.13 and 0.16 W/m^2K respectively); allowing perimeter heating to be omitted. All the other buildings have fabric that can be considered 'well insulated', for example with wall 'U' values around 0.3 W/m^2K.

Construction. All the buildings except CAB have traditional construction walls (using bricks, blocks, cavity insulation, render, etc.), which enhance the building's thermal mass, and largely 'hole in wall' windows, which - more than curtain walling - lend themselves to judicious window sizing, location and design to facilitate daylighting, glare control and natural ventilation. CAB also had large areas of traditional brick walls, but mixed with sections of curtain walling.

Windows include a mixture of triple glazing (inner sealed low-E double and outer single with a mid-pane blind between) at APU and FRY (DMQ also has triple glazing in the machine hall to inhibit noise breakout) and sealed clear double at the other three. They have a variety of openable elements and mechanisms (conventional catches, manual winders and motorised actuators with local switches or under BMS control) and fixed or adjustable solar shading devices. Design issues relating to ventilation through windows are described in A3.4.

Shading devices. Some design lessons were:

- Occupants can be encouraged to operate elements of a building with common sense. At FRY some office occupants learned to close their blinds prior to a forecast hot weekend in order to achieve fresher conditions on Monday mornings, but newcomers may not figure this out.
- Shading devices should be robust for the conditions in which they must operate. At POR external roller blinds are automatically retracted even before the wind speed reaches the average for the site, completely undermining their glare prevention role using by local manual switches - which are consequently now ignored by occupants with some frustration. The reason for such hair-triggering (as also revealed in previous studies) was that blinds can be damaged by local air turbulence, particularly at the corners of a building. After this happens, the anemometer settings are reduced to help avoid further problems. Sometimes anemometer settings are also lowered to stop annoying rattling.
- Care must be taken to prevent shading devices clashing with natural ventilation. At POR, external roller blinds interfered with the movement of top hung opening windows, whose travel had to be restricted to avoid damage to the blinds. Also at POR, the internal roller blinds for the atrium rooflights tend to hinder the exhaust airflow.
- There comes a point when shading devices become too obtrusive: APU's double light shelves were verging on this. The design-and-build contract for APU did not allow the design team to fine-tune the details of window controls and light shelves with the chosen suppliers, to the extent that had initially been intended.

Rooflights are present in all the educational buildings. In FRY they are fixed and light the main and fire stair wells only; where sadly the electric lighting (on keyswitches operated by the security guards) operates regardless of daylight levels. Rooflights in all the other educational buildings are openable (by BMS controlled or manually switched motorised actuators) to provide an exhaust path for natural ventilation. Some consequences are addressed in A3.4.

Airtightness varied dramatically: in the three buildings subjected to pressure tests, FRY was good; POR average for the UK but well above recommended levels; and CAB very poor - even after many of its high-level louvres had been plated -over. It would have been instructive to have been able to test DMQ with its myriad openings for natural ventilation and APU with its trickle vents and motorised windows and rooflights. It is speculated that DMQ may be quite leaky given its relatively high gas consumption and the scope for infiltration whilst APU may be quite tight given its much lower gas consumption and the encouraging results of some tracer gas leakage measurements. The main conclusion from CAB's result - supporting that of earlier work - was that mechanical ventilation dampers rarely provide a sufficiently airtight seal for natural ventilation openings (at CAB their building-in details were leaky too).

Ceilings in all the buildings are formed by exposed floor slabs, with FRY maximising the thermal mass benefits by employing ventilated cores and APU enhancing the surface heat transfer capacity by using a coffered form (but at some expense to daylight penetration, as discussed later).

A3.3 HEATING, HOT WATER AND MECHANICAL COOLING

Boilers. By contrast with the Probe commercial offices, all the buildings bar POR (despite its underfloor heating) have at least a lead condensing boiler; and at APU and FRY all the boilers are condensing. Additionally at DMQ the lead heat source is a 38 kWe CHP engine.

The installed boiler capacity in four of the buildings is in the fairly typical range of 120 -150 W/m^2, demonstrating a fairly generous plant margin (or over-cautious design for such relatively well-insulated buildings). The exception is FRY, where the calculated design heat loss is just 15 W/m^2 and the installed boiler capacity an outstandingly low 23 W/m^2. Here, the designers' careful attention to fabric insulation and infiltration performance allowed them to dispense with perimeter heating altogether, with winter thermal comfort being maintained by the tempered air supply and internal heat gains.

Domestic hot water. All the design teams appear to have thought carefully about how to generate HWS most efficiently, rather than simply using calorifiers off the space heating boilers. However, in hindsight some of the solutions may be questioned:

- At DMQ the CHP heat output was destined for calorifiers sized to meet the hot water demand of a refectory. This was replaced by vending machines too late to change the HWS strategy. The oversized calorifiers remain to serve widely distributed low loads when local heaters might well have been better.
- At APU the conventional calorifier-off-LPHW strategy is used, but with preheat from the bar cellar chiller condenser. Unfortunately the final product is too hot and takes too long to arrive down lengthy pipe runs.
- POR is similar to APU but with preheat from solar panels. The Probe team thought that condensing boilers - although less of a visible symbol of energy consciousness - would have generated greater energy savings at a lower capital cost.
- FRY and CAB have totally independent HWS provision and probably achieved the most successful solutions: FRY has a direct gas-fired storage calorifier to supply the main toilets and kitchen plus two small electric storage heaters for remote toilets. CAB has separate local gas boiler/calorifier sets, both for kitchen and changing room HWS, plus 14 local electric water heaters for distributed hot water outlets in toilets, classrooms, and cleaners' sinks. Unfortunately - but as in all the Probe buildings - the electric water heaters were not time-controlled.

Cooling. All five buildings aimed to minimise the need for mechanical refrigeration by using the fabric as a climate modifier. All employ measures such as thermal mass, solar protection, daylighting and (except CAB and POR) night ventilation. As a result, refrigerant cooling was totally avoided at DMQ and FRY and restricted to small parts of the other buildings:

- Evaporative cooling via heat exchange for the air supply to the kitchen and bar at APU
- Three small split units for the IT, communications and main seminar room at CAB. These ran constantly; unnecessarily so for the seminar room.
- DX chillers for the main lecture theatre at POR.
- Local split DX units to cool recirculated air for two small lecture rooms and four seminar/IT rooms at POR. These had inaccessible controls and ran constantly, with considerable electricity wastage, particularly for fans.

A3.4 VENTILATION

Natural ventilation. All the educational buildings except FRY are predominantly naturally ventilated using a full repertoire of driving forces: single sided and cross ventilation, stack assisted cross ventilation and stack only ventilation. Openings for ventilation include ordinary windows, trickle ventilators, manually switched or BMS controlled motorised windows, and automatically operated dampers. In many ways these buildings have helped to pioneer the development of advanced natural ventilation (ANV) and many design lessons have become apparent[32]:

- Remote operating mechanisms (e.g. winders) for out-of-sight openings should have some form of local position indicator to let the operator know the status of the opening. At DMQ overwinding caused damage to rooflight opening mechanisms; and at CAB high level windows and louvres were inadvertently left open (risking rain ingress, wasting heat, and sometimes causing excessive overnight cooling).

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[32] Some aspects of this issue are being examined in detail by a current DETR-supported PIT project: "Specification of automatic ventilation opening devices" by Brian Ford & Associates.

- Inaccessible mechanisms need to be particularly robust and maintenance free. Often problems seemed to be related to the integration of the overall assembly: (device, actuator, fixings, controls, manufacture, installation, and commissioning) At DMQ, actuator fixings were working loose, and an actuator arm had sheared off from one of the rooflights and might have injured someone on the floor below. At POR there was a suspicion that the motors for the forum rooflights were undersized - three recently had to be replaced and others were found to have failed at the time of the Probe survey. Access to them was extremely difficult, requiring the hire of a special platform which also had to be tipped on its side to be brought into the building, requiring additional plant and costs. At both POR and CAB, the reliability of rack and pinion window drives had been disappointing.
- Openable windows need to be accessible to occupants without having to clamber on desks, etc. In ground floor classrooms at CAB the 2.45 m height of fanlight handles limits their intended function as high level ventilation openings.
- Openings for summertime ventilation must also perform acceptably in winter. At CAB, the occupier had to blank-off high level louvres due to cold draughts in winter, thus inviting the risk of overheating in summer. Louvres in the main hall also had to be sealed, after complaints from neighbours about noise breakout during evening events.
- Openings must also be able to cope with changing weather. At POR the rain detector and actuators were too slow in operation to prevent significant rain getting into the atrium at the start of a sudden downpour. The rain detector was also confused by bird droppings, which had sometimes prevented the rooflights opening in hot dry weather.
- More care needs to be taken when integrating automatic control with manual override to ensure they do not countermand each other. In the library at POR, one minute after the manual over-ride was applied, the windows motored-back into the position preferred by the automatic system. This caused occupants to cease using the manual override, and so there was to unnecessary overheating. At the time of the Probe survey, the over-ride switches had been completely obstructed behind new bookshelves in the staff office; and newer staff were completely unaware that they existed.
- Designers must bear in mind that security, external noise or blackout requirements can make it impossible to use openable windows for ventilation. The windows in the small lecture rooms at POR suffered from all three problems, so when they were densely occupied, their doors to the forum had to be propped-open to reduce stuffiness.

Mechanical ventilation is used in parts of the four ANV buildings where NV was impractical:

- At DMQ this provision is limited to punkah fans in the ventilation stacks as contingency against reverse flow, plus extract fans for engine equipment test areas.
- At APU in the kitchen and café areas (with heat recovery) and the TV studio (with its high internal gains and blackout requirements), via low velocity displacement systems.
- At CAB for toilets, the kitchen and changing rooms (also with heat recovery) plus fume cupboards, heat bay extract and dust extraction fans in teaching laboratories.
- At POR the main lecture theatre (via displacement ventilation), air supply to offices opening on to the forum and toilet extracts.

Ventilation at FRY is predominantly mechanical via the Termodeck hollow core slabs. Most rooms also have openable windows, making this a mixed mode building with concurrent operation. FRY's good energy and environmental performance is largely (but by no means exclusively) due to the ventilation system, so it is worth highlighting some key factors in this success:

- The openable windows provide the occupants with "adaptive opportunity", when they feel conditions uncomfortable.
- The absence of perimeter heating in most rooms stops occupants wasting heat in winter by opening windows excessively (if they want lots of ventilation, the room will cool).
- Customised systems for different functions: constant volume with 85% efficiency regenerative heat recovery for offices and seminar rooms, air quality controlled variable volume for lecture theatres with lower-efficiency (55%) cross-flow heat recovery, both with BMS time control.
- Heat gains from lighting are extracted at source, via the cornices containing the indirect light fittings. This minimises overheating risk in summer, whilst the efficient heat recovery ensures little heating penalty in winter.
- Relatively low specific fan power, at least in relation to the Probe dataset; and particularly on average for the variable volume lecture room ventilation. The designers also say they could now do much better.
- Night ventilation (see below).

Night ventilation is a key strategy for avoiding summertime overheating at FRY. There is also provision for it at DMQ (where it was rarely needed in practice) and APU (where its controls were not yet working correctly at the time of the Probe survey). It was not a deliberate part of the ventilation strategy at POR or CAB, though at CAB the leaky fabric would allow significant air infiltration at night. Control strategies for night ventilation had mixed success:

- FRY had an elaborate scheme initially, using stand-alone controls. Its behaviour proved difficult to optimise until a BMS was retrofitted. Following trials, a simpler but effective strategy was adopted: after 10 PM, the fans were switched on (with heat exchangers bypassed) if the slab core temperature was 1°C above its set point but only if the outside temperature was at least 2°C below the core temperature. The fans were switched off once the slab core temperature had been cooled to its set point. This strategy proved effective at removing heat without over-cooling the building It was also economic in its use of the fans.
- At APU, night ventilation was designed to be provided by natural ventilation: in via the motorised fanlights of the perimeter windows and out via the atrium rooflights, controlled by the BMS. A self-learning software control algorithm was designed to calculate the build up of heat during the day and decide how much to ventilate at night. At the time of the Probe survey this was not working, probably because the software written did not fully incorporate the design intentions. This highlights the need for special commissioning procedures, built into contractual responsibilities and procedures. Otherwise, since often no-one is in the building when it is supposed to take place, failures and unintended behaviour can go unnoticed; as was revealed in earlier studies [4, 26].

A3.5 CONTROLS AND BMS

All the buildings have a BMS (retrofitted at FRY, as mentioned above). In general they were displaying some or all of the problems described in detail in the paper in Appendix C. In summary (in approximate order of apparent success):

- Only at FRY was the BMS operating really effectively; this was due to the interest and commitment of the Estates Department there, making use of feedback from post-occupancy monitoring and the collaboration of the design team (see A3.7).
- At POR, the BMS was originally intended only for the main mechanical plant: boiler rooms and main lecture theatre AHU. Since occupation it has been extended to some ANV systems, as the Estates Department found the stand-alone systems ineffective (for example with insufficient input information) and unreliable. The Estates Department was also seeking more control generally, regarding the occupants as capricious in the way they operated the building.
- At DMQ, the Estates Department had insufficient resource to grapple with fine tuning the BMS at the time of the Probe survey. However, they planned to do so.
- At APU, the BMS appeared to have remained largely unaltered since occupation. Adjustments can only be made by the contractor’s staff - on whom the university relies - while alarms are responded to by the security staff who have the central control screen on their desk at reception. Neither seemed to have the responsibilities or incentives to be proactive.
- At CAB, the maintenance staff lacked confidence in the BMS operation, which has a poor user interface and seemed never to have been properly commissioned. Routine service visits appeared only to maintain the status quo and not to be making improvements - but this was probably all the occupiers felt they could afford. As a result, most plant is on for very generous hours of operation; and not all of it responds correctly to the BMS signals. Effective control had also been complicated by a prolonged failure of the independent boiler sequencer, which was very expensive to replace and was ultimately repaired by an electronics teacher.
- At CAB and APU, the specifications included site staff training at the BMS supplier. However, the staff sent found the training of little relevance to their specific requirements and left before completing the courses. It appears that the training may have been at the wrong level (too technical and too general) and at the wrong time. Possibly two levels of training are required: the first very specific at handover and the second six months later once experience had been gained; preferably on site, or failing that with remote access from the training centre.

A3.6 LIGHTING

Electric lighting in all these buildings is predominantly fluorescent, high frequency. This ensures reasonable IPDs under 15 W/m^2 in the four buildings with direct lighting. FRY’s attractive indirect lighting in most rooms suffers the penalty of a higher IPD of 20 W/m^2: with more budget, this might have been reduced using HF gear and better optics. Circulation areas are mostly lit by CFLs and large volume spaces by high bay SON (DMQ labs and CAB sports hall) or metal halide (APU and POR atria and CAB main hall and street). APU and FRY also provide task lamps for desks.

Occupancy-related lighting control is provided by a wide variety of systems, all independent of the BMS: central systems at DMQ and APU intended to provide timed and PIR control, local PIR control at POR and purely manual switching at FRY and CAB.

Sadly, but in common with other Probe buildings and some other recent studies, these lighting controls seldom worked as well as intended:

- At DMQ, PIRs for out of core hours presence detection proved insufficiently sensitive so the core period was extended to cover the whole of the building's opening times.
- At DMQ, over-ride settings can persist, so lights in use the previous night may also be automatically switched on in the morning.
- Difficulties occurred with the automatic lighting control system at APU, owing to insufficient documentation and limited on site expertise. Furthermore, unlabelled central grid switches deter manual switching.
- Also at APU, the mainsborne signals could also switch on lights sporadically during the night, owing to spikes in the mains supply.
- On the Probe surveys, occupants did not appear to be as diligent at turning off unnecessary lighting and they claimed to be when interviewed, particularly at DMQ, CAB and FRY.
- At POR, different spaces have various combinations of local control, occupancy sensing and dimming. The resulting use of lighting was somewhat random, but overall appeared to be reasonably successful in responding to user needs without putting all the lights on. However, there was room for improvement: the design intent had not been clearly recorded so the occupants were unclear as to what should happen; and some of the local dimming controls in seminar rooms had ceased to work. The occupancy sensors also tended to turn lights on unnecessarily, but creditably - and unusually - there were over-ride switches to turn them off again: absence sensing - manual on, auto off - could well have been better still.

Nevertheless, lighting energy use in the Probe educational buildings was significantly lower than in most of the office buildings. This was a consequence of lower illuminance levels generally (leading to lower IPDs); low or no occupancy in evenings, weekends and vacations; more use of daylight, many rooms occupied only intermittently; and with controls which, although with much scope for improvement, had less tendency to default to ON.

Daylighting. All the educational buildings are designed to exploit daylight, both for the delight it can bring and for its potential to displace electric lighting. Generally there had been more success with the former than the latter. The reasons include:

- At DMQ the slow run-up and re-striking characteristics of high bay SON lamps in the well - daylit machine hall did not encourage manual switching. This is normal with most high-intensity discharge lighting (viz: the offices TAN and CRS and the EEBPp case study of Refuge House [27]), but does not seem to be well-appreciated by designers.
- At APU the intended photocell switching of perimeter lights was not working - possibly owing to dirt on the photocells or too high a setpoint; and not helped by the lack of understanding already mentioned.
- At APU the ability of the light shelves to reduce contrasts and to throw light more deeply into the building was also reduced when the contractor substituted a coffered ceiling for the designers' intended precast ribbed system.
- POR appeared to have photocell-controlled switching and/or dimming in some spaces but neither the occupants, the Estates Department nor the manuals could confirm this and informal tests proved inconclusive. If present, they either did not work effectively, or had not been properly commissioned.
- Manual switching in response to daylight and to absence is also a fragile strategy - though if daylight is sufficient and people's eyes are appropriately adapted when entering a space they will usually not turn the lights on; while automatic controls can often do so unnecessarily. For example, at CAB teaching space lighting is manually switched in rows parallel to the facade, offering the potential for responding to gradations in the levels of daylight. The Probe survey suggested that this facility was little used: lights were often all off when daylight was adequate everywhere, but all on otherwise.

A3.7 MAINTENANCE AND UTILITIES

Maintenance. The four university buildings are all maintained as part of their University's estate, and looked after by a site team (directly-employed staff at DMQ, FRY and POR; and a contractor managed by the Estates Department at APU). As such, the buildings' needs are addressed only as other priorities permit by teams which are typically seriously under-resourced. New buildings, which are presumed (by administrators if not maintenance staff) to be handed over in perfect working order, are deemed a low priority compared with the substantial requirements of many of the older buildings for maintenance, repair and improvement. The consequence is that little time is allocated for understanding and fine tuning systems. Often this situation is compounded by contractual arrangements which delay the resolution of teething problems during the defects liability period; and occupants who are not told how the building is intended to function;. Occupants are also regarded by some Estates Departments as nuisances, not potential collaborators.

However, the situation was different at FRY which can be considered an exemplar - although somewhat delayed-action - of how to hand over and then manage and operate a building. Three success factors were:

- Commitment and motivation of the Buildings Services Manager and O&M staff.
- Careful and persistent commissioning and handover during the first two years of occupation, including quarterly review meetings on site. NB: this was partly - and perhaps even largely - a consequence of BRECSU's financial support for independent monitoring.
- A user-friendly BMS developed by the controls specialists in co-operation with the design team and O&M staff; and used to test different control strategies and verify performance.

Maintenance of FRY has also been greatly eased because plant capacity has been minimised (and virtually eliminated in the case of perimeter heating). The plant there is out of reach of the occupants but highly accessible to O&M staff, who find themselves able to work much more effectively behind the scenes. This raises the fundamental question of how effectively a building is designed for low maintenance. ANV buildings should have lower plant maintenance costs simply by virtue of having less installed HVAC plant - and this point is underlined at POR where another new university building, fully air-conditioned, was presenting the Estates Department with serious problems. But often air-conditioning plant is replaced by sophisticated ventilation, shading and control devices which can themselves have significant maintenance requirements. For example, the University of East Anglia observed that maintaining all the ventilation plant at FRY costs them less per year than the maintenance contract alone for the external motorised blinds on the adjacent Queens' Building, which is of a similar size and had the same design team.

Setting-up, reliability and access to ANV components can also be problematic:

- At CAB, plant maintenance is considered expensive, not least due to the relatively complex services for a secondary school e.g. motorised shading devices and ventilation openings, a BMS with high support costs, and the complex zoning of the heating system.
- Plantrooms at POR are relatively cramped and at the top of cat ladders: "a sacrifice on the high altar of architecture" was one comment. Also at POR, a semi-external plantroom had been adopted as a roost by pigeons, making maintenance impossible.
- The original control system for some of the ventilation openings at POR used anemometers which proved impossible to reach and to maintain; and were ultimately relocated on an accessible flat roof of an adjacent building.

Energy management With the notable exception of FRY, this had very little attention, surprising given the emphasis on energy in the designs themselves. However, all expressed good intentions:

- It is understood that more proactive energy management is now being practised at DMQ, as was planned at the time of the Probe survey.
- APU had been monitored by an EC funded-research project; which the management had relied-upon to provide feedback, rather than setting-up their own mechanisms. At the time of the Probe survey, this feedback had not led to energy management action, but we understand that improvements have now been made. Diligence in understanding and fine-tuning new buildings presumably also had no part in the maintenance contractor's contract.
- CAB has extensive sub-metering (heating gas, kitchen gas, hot water gas, main electricity, kitchen electricity and kitchen water); potential for their automatic monitoring; and considerable scope for savings.
- Portsmouth University is investing in M&T to manage energy across their whole estate. Following the Probe survey, POR was brought into this system earlier than intended.

A3.8 OVERHEATING RISK

All the educational buildings employ a variety of measures in order to avoid the use of mechanical cooling, except for isolated 'hot spots'. Their success in this respect, in the view of the occupants, is reviewed in Report 3. To summarise, only FRY was considered really satisfactory. As far as designers are concerned, this begs the question of how to predict overheating risk, particularly at early stages in the design process when radical changes are still possible; and how to balance physical, control and management, and individual and psychological measures.

At much the same time as Probe 1, HG were developing a simple, quick pre-design check list rating system to identify the likelihood of overheating risk in non-air-conditioned buildings. The general principle was to offer up to four credits for each of thirteen factors which affect summertime temperatures. The method was calibrated using computer simulation software to ensure that for each factor considered, each additional credit equated to a similar reduction in the risk of overheating (in practice each extra credit was equivalent to a reduction of about 5 W/m^2 in internal heat gain).

In figure A3.1, this risk assessment has been applied to the five educational buildings. The method confirms that FRY generally has the least risk of overheating, although strictly speaking the method should be applied to each individual space in each building. The Probe surveys provided the first empirical evidence which could enable target scores to be set in order to realise an acceptable level of overheating risk for a particular client. Even though the method can only offer rough guidelines, the evidence from these five buildings suggests that for good results practically all possible measures to avoid overheating need to be incorporated.

Having said that, the systems which did not work so well - in all Probe buildings, not just the educational ones - lacked effective control, commissioning and management. Systems also often failed to be clear, comprehensible and usable by the occupants. But none of these features - being downstream - was explicitly included in the pre-design risk assessment! Design for usability and manageability, together with effective commissioning, feedback, management and user information, is essential to the good performance of buildings, but also widely overlooked.

FIGURE A3.1: PRE-DESIGN OVERHEATING RISK ASSESSMENT
(for a detailed description of the method, see reference [28])

Factor affecting overheating risk	Maximum possible score	Average assessed scores:				
		DMQ	APU	CAB	FRY	POR
Fresh air	4	3	3	3	3	3
Exposed mass	4	3	3	3	4	2
Night ventilation	2	2	0	0	2	0
Lighting heat gain	4	2	2	2	3	3
Glazing ratio	4	4	3	2	3	2
Orientation	4	2	2	2	3	2
Shading	4	2	1	4	4	3
Equipment heat gain	4	3	4	4	3	3
Occupant density	4	1	4	2	3	3
Ceiling height	2	2	2	1	1	0
Dress code	1	1	1	0	1	1
Ceiling fans	1	0	0	0	0	0
Openable windows	1	1	1	1	1	1
TOTALS	**39**	**26**	**26**	**24**	**21**	**23**

A4 The Other Buildings

A4.1 GENERAL

This last section reviews technical and management issues relating in the group of buildings which do not fit happily into either the office or the educational categories: C&W, RMC, MBW and WMC.

There are few similarities between these buildings.

- C&W is noteworthy for its innovative wave form roof which provides natural ventilation to an otherwise very deep plan classroom block with heat gains up to 50 W/m^2. Adjacent residential, administration and sports blocks, which account for more than half the floor area adopt more conventional approaches.
- RMC combines mechanical displacement fresh air ventilation to courtrooms with passive design features including south-facing sunspaces and a high attention to the provision of daylight. Cost savings seriously compromised the intended low energy operating strategies, which would have benefited from more fundamental reappraisal, but this would of course have been very difficult in the circumstances.
- The MBW warehouse is the only industrial building covered in Probe so far.
- WMC provides a good example of a small, very well insulated building which delivers the lowest specific CO_2 emissions of all PROBE buildings, and high levels of occupant satisfaction despite some shortcomings, particularly in summertime temperatures.

A4.2 BUILDING FABRIC

Construction of this group of buildings is largely conventional. All use some form of masonry block construction with facing bricks. MBW uses profiled metal sheeting, insulation and liner trays at higher level. Roofs on C&W classrooms and MBW are of profiled metal sheets (at C&W with tiles over), RMC uses slate whilst WMC has concrete tiles.

Air infiltration was measured by BRE fan pressurisation tests at RMC and MBW, giving figures of 17.4 and 8.9 m^3/m^2/hr respectively. The value for RMC is disappointingly high, but close to average for commercial buildings tested by BRE, and most leakage was observed around doors and through toilet ventilators - unusually leakage between frames and window reveals appeared modest despite large areas of glazed spaces. The Probe team also found leakage through some of the natural inlet ventilators, but these were not in the part of the building tested by BRE.

The figure for MBW is good for a UK industrial building, although higher than good practice for warehouses, which the supermarket sector has shown can be built to very high levels of air tightness. At WMC it is likely that airtightness is good due to the use of conventional construction techniques and wet trades together with the evident low heating consumption. Whilst not measured, we suspect a relatively high air leakage rate at C&W, owing to the large number of opening elements, the complex junctions between lightweight roofing, glazing elements and masonry walls (traditional areas for poor sealing) and the evidently high heating energy consumption.

Windows in this group are all double glazed and have frames of aluminium except for WMC which are wooden. The extent of provision for solar control ranged widely:

- The classrooms at C&W have fixed Okalux translucent insulating material (as also used in the atrium rooflights at CRS) in north facing windows, supported by overhangs of the profiled metal roofing north and south and motorised internal diffusing roller blinds under manual control of the occupants.
- At WMC all the consulting rooms were fitted with internal translucent blinds for privacy - which resulted in the need for more artificial lighting.
- At RMC some administrative offices were fitted with internal vertical louvre blinds, which either needed constant adjustment or were kept shut. A particularly troublesome small high level round window facing south west caused intense glare for short periods in the afternoon; and was retrofitted with solar control film, with only partial success. The sunspaces did not have shading, and the size and orientation of windows providing daylight to the courts generally made shading unnecessary, although perimeter windows did have internal vertical louvre blinds.
- The relatively small number of windows, their north westerly orientation and the activities in adjacent spaces made solar shading unnecessary at MBW.

Openable window elements. Only the opening window elements at C&W were widely used, being top-hung, motorised and integral to the natural ventilation strategy of the classrooms in particular. There were also manually-openable windows in the restaurant and office areas and the study bedrooms. At RMC, most areas received fresh air via the mechanical ventilation system, with opening elements only in the administrative office areas. These were generally side-hung casements, with a restricted opening range. MBW has top hung opening elements, but, because of the nature of the space and its industrial usage, many were obstructed by shelving and rarely used: and the first measure adopted to improve ventilation was often to leave to loading doors open At WMC the wide opening casement windows were generally little used: the need for acoustic privacy to adjacent access paths around the building perimeter was paramount; and some windows had had external security grilles added.

The only *motorised windows* are in the classrooms, restaurant and glazed foyer areas at C&W where high level windows could be manually operated by occupants using wall switches. Control is entirely manual, with no automatic or central overrides, leading to a significant task for security staff to check windows individually during locking up. The public spaces at RMC have pneumatically-operated low level inlet louvres and high level roof smoke vents which, depending on internal temperatures, double as stack ventilation outlets for the sunspaces. Both these elements are opaque and under automatic control only. The status of the inlets was invisible behind internal decorative and external weatherproof louvres; and some did not shut properly.

Rooflights. At WMC, ridge mounted opening rooflights provided good daylighting of the central corridor, and were also part of the ventilation strategy. However, being manual, 4 m up and with no remote opening gear, they were not used; even though simple push rods can be supplied for these units; or motors of necessary. MBW includes fixed translucent panels for about 10% of the roof area, these do not open - partly because MBS wanted to avoid any risk of rain ingress which might damage their stock. C&W includes a number of small (less than 1 m diameter) Perspex dome rooflights to introduce light the classroom corridors. In spite of these, the corridor lights tended to be on all the time.

The height and form of the *ceilings* within these four buildings varies widely. Unlike many of the other Probe buildings, none uses thermally massive exposed concrete slabs:

- In the classrooms at C&W the lightweight waveform roof varies in height from 3.6 m to 5.1 m, heights chosen to enhance the cross and stack ventilation strategy and ensure that any warm stratified layer of air would be above head height.
- At RMC ceiling treatment varied widely with the different types of spaces in the court building. In the courtrooms heights rise to at least 3 m, although various floor and ceiling profiles could affect this locally. Ceilings were lightweight plasterboard concealing return air ducts and isolating the space from the concrete floor slabs. First floor offices incorporate a conventional suspended ceiling, whilst second floor offices had either the same or in some areas followed the roof pitch to the ridge, making pleasant high volume spaces, though diminished by the omission of rooflights as part of the tender cost-reduction programme.
- At MBW the ceilings are at about 8 m and are simply formed by the underside of the twin walled profiled roof decking.
- WMC has domestic style lightweight plasterboard ceilings under the roof joists in perimeter consulting rooms, rising with the roof pitch in the central corridor, making for a pleasant double height space.

Fabric U-values at C&W and RMC are above building regulation requirements, whilst at MBW they simply comply with them. WMC stands out though with 150 mm cavity wall insulation and 300 mm insulation in the roof pitch giving U-values of 0.20 and 0.1 W/m^{2}K respectively.

A4.3 HEATING, HOT WATER AND MECHANICAL SYSTEMS

Boilers. Only WMC of this group of buildings has condensing boilers, reflecting the position in the Probe offices. At MBW heating is from suspended direct gas fired warm air heaters with destratification fans. Installed boiler or air heater output power levels varied between a very high 180 W/m^2 at RMC, 120 W/m^2 excluding the leisure centre at C&W, 100 W/m^2 at MBW and 47 W/m^2 at WMC. C&W missed an opportunity to consider CHP, which would have been viable with the year round swimming pool, catering HWS and residential HWS base load. A quick review of full load equivalent boiler hours shows them ranging from a very high 2500 hours per year at C&W, to 800 hrs at WMC, 650 hrs at RMC and about 500 at MBW.

Domestic hot water was heated by electricity in all buildings, including the classroom block at C&W. The kitchen, residential blocks and the leisure centre, at C&W had central calorifiers served by the heating boilers. Timeswitches to prevent 24 hour operation of local electric heaters were sadly rare. They were retrofitted at RMC, but only in response to an unusual failure when one heater (in the ceiling above a WC) overheated during the night, melting the float valve in its attached break tank and causing a major flood! At WMC each consulting room had a small (typically 3 litre) individual electric storage heater for hand washing, 27 units in all. The standing losses from these alone amounted to 5000 kWh, or 15% of the building's annual electricity consumption. Timeclocks set to match occupied hours could have reduced these losses to about 1500 kWh and quickly covered their costs. Ideally, they would be fitted as a matter of course. The relatively high frequency of hand washing by doctors could well also have made hot water from the domestic central heating boilers more appropriate and CO_2-efficient.

Heating pump running hours were close to 7000 hrs at C&W, contributing to the high gas consumption, as heating was enabled between 5.30 AM and midnight - acceptable for the residential block, but in practice few classrooms were used late into the evening. At RMC they run for 1500 hrs, which is typical for a heating season including pre-heat, and comparable to the better managed offices. At WMC with domestic heating circuits, where pumps are interlocked to the boiler, demand hours are estimated to be considerably less than this - full load equivalent boiler hours were just over 800 hrs. At MBW with direct gas fired air heaters, they and the destratification fans were estimated to run for 750 hours; but with the units firing for only about half that time.

Mechanical cooling. C&W and RMC were built with packaged water chillers of 47 kW and 200 kW cooling capacity respectively. At C&W the system served a number of downflow room units in parts of the classroom block where equipment had been expected to push heat gains above the 50 W/m^2 threshold for natural ventilation. There was no interlock with the perimeter heating, or the manually operated windows in these rooms. With no central controls, the chillers were thought to be running for long hours irrespective of true demand. At RMC the chiller provides chilled water to the AHUs for the displacement ventilation in the courts and waiting areas, but operated in hot weather only. MBW had no mechanical cooling. Sixteen split DX room cooling units were retrofitted to office areas at RMC not served by the displacement system, and two DX units were retrofitted to one of the practices at WMC.

A4.4 VENTILATION AND AIR-CONDITIONING

All the buildings except RMC are predominantly naturally ventilated. The mechanical cooling at C&W is only for a small proportion (maximum of 5% of the treated floor area), RMC and WMC include some local retrofitted comfort cooling.

Natural ventilation in the classrooms at C&W is controlled to suit the occupants via motorised high-level opening window elements. Unlike some of the large naturally ventilated educational buildings, there is no central control: while this does not force occupants to accept centrally-determined settings (which has proved inappropriate in other ANV buildings), it does mean that systems (especially heating and cooling) operate with no interlock, and security staff have their work cut out when locking up this large single storey block. The ability to over-ride all the windows open or closed from a central point (as at MBO) would have been convenient.

WMC is also naturally ventilated, but relies on a mixture of simple single sided and cross-ventilation strategies, including opening rooflights. A combination of factors including poor communication of the design intent; unreachable roof windows with no remote controls; the need for acoustic privacy in consulting rooms; and users' misunderstanding of the role of the background mechanical ventilation heat recovery system have all led to reduced levels of summer comfort. In spite of this, occupant tolerance of the conditions was high, probably owing to the quasi-domestic environment.

MBW has limited provision for NV: the main working areas are near to delivery doors, which are often left open in hot weather. MBW's original mezzanine on the west side has windows, but its extension to the north has not: in hindsight more high-level windows would have been a useful contingency - some later buildings the developer have included these, or knockout panels permitting windows (or louvres) to be added quite easily. In summer there is a tendency for hot air to build up beneath the roof: motorised opening rooflights or ventilators would have alleviated this, but at some risk of rain ingress, which the occupier was keen to avoid in order to protect their stock.

Mechanical ventilation predominates at RMC, which uses a total of seven AHUs in roof and semi-basement plant rooms to deliver tempered 100% fresh air to the displacement terminals. Return is via ceiling bulkheads in courtrooms and at high level in the public sunspaces. Building usage is only at about 60% capacity (as it was designed for predicted needs over the next 50 years), but the zoning of the constant volume systems makes it impossible to isolate unoccupied courts: for most of the time some spaces in all zones are in use, so all the systems have to run.

Heat recovery. WMC includes a domestic sized mechanical ventilation heat recovery system, as part of the building's low energy strategy to provide minimum fresh air in winter with minimum heat losses. However, the system is hidden in the loft space, was never fully explained to occupants, and is consequently misunderstood. In two units it first ran continuously, but then failed and was not repaired. In the third it was misconstrued as providing 'air conditioning', and run on demand: when it failed to deliver, two DX room cooling units were fitted.

Cross-flow heat exchangers were fitted to both RMC and WMC's mechanical ventilation systems. By-passes were not required at WMC, being a winter system. RMC only had by-passes on two plants (the ones with no cooling coils serving the cells and ancillary areas) - leading to wasteful extra chiller demand during the cooling season on the five other AHUs. At WMC the whole purpose of the mechanical system was to provide the ability to recover heat from extract air to temper the fresh air requirement. In practice it was unlikely that on such a small volume system the savings in heating running costs, could recoup the capital and maintenance costs, even if operating correctly. The systems were no longer in use at the time of the Probe survey

Air change rates and Specific Fan Power at RMC were relatively high at 4.5 ac/h and 3.8 W/l/s respectively. The large volumes are arguably required at design conditions when the relatively small temperature difference with a displacement system reduces cooling ability, however there is a doubling-up of capacity between the waiting areas and courtrooms; and at all other times of the year and particularly in the unoccupied areas much lower rates would produce sufficient fresh air. The use of variable speed fan drives, and effective zoning as at FRY would yield large savings in the fan consumption which amounts to a around 40% of RMC's electricity consumption. Alternatively, the courtrooms might have been on individual units and the public areas largely naturally-ventilated. The SFP is higher than typical ECON 19 levels and reflects tortuous paths for the supply and extract ducts in this complicated building - which has 150 automatic smoke dampers alone. The system at WMC has no recorded performance data, although even when new it would have supplied very small volumes.

Night Ventilation. None of these buildings use night cooling, although a study by BSRIA of the C&W classrooms suggested that it could be beneficial. However here the lack of automated vent controls could lead to over cooling. At WMC security risks (and the lack of a heat exchanger bypass) prevented its use.

A4.5 CONTROLS AND BMS

Of these buildings only RMC has a BMS, and here it is used predominantly by in house staff for monitoring alarm status. It has no PC front end - just a small and unfriendly LCD display - and any significant alterations have to be made by contractors. Fortunately the use of the building is quite routine, though the resulting programmes tend to be generous to the courtrooms. Despite its size and complexity C&W does not have central controls; instead boiler and chiller plant run according to local control panels, serving separate heating zones. Perimeter radiators have TRVs, but no means to prevent simultaneous heating and cooling, or heating when all windows have been left open. More detailed comments on controls in all the buildings can be found in Appendix C.

A4.6 LIGHTING

Daylight availability varied between these buildings. Its use to displace artificial lighting was generally poor:

- At C&W the potential for daylighting the classrooms, study bedrooms, leisure centre, corridors and glazed communal spaces such as the restaurant is good. Classrooms have generous areas of high level windows facing north, but include translucent glazing and greyish internal finishes which combine to give a slightly gloomy impression, so much artificial lighting was used. Despite the use of translucent panels there still appeared to be a slight glare problem in classrooms, as blinds were also used.
- At RMC good daylight was a requirement of the brief, and the public and magistrates' circulation areas are well daylit. All areas except the high-security court room also have at least some of daylight, although sometimes borrowed from circulation spaces. RMC's relatively low lighting energy consumption results largely from a low intensity of use, with local controls which although not rigorously used are helpful in avoiding waste.
- At WMC there is good potential for daylight, with a very well rooflit central corridor and perimeter consulting rooms having both windows and door fanlights borrowing from the corridor. In practice the requirement for privacy means that blinds are needed in the consulting rooms (there is a public pavement adjoining one side of the building), but lighting here is on-demand and lighting use in corridors etc. is low.
- MBW has translucent roof panels which cover about 10% of the roof area and usefully contribute to lighting of the warehouse space (but do not displace much electric lighting, although the supervisor does turn the main SON lighting off on very bright days).

Electric lighting at C&W was potentially efficient with high-frequency T8 fluorescents used to provide a modest 300 lux in the classrooms. However, installed power densities were only average at 17 W/m^2 , due to the high ceilings and greyish finishes. The most efficient - though fairly normal for a warehouse - is at MBW where high bay SON lighting with an installed power of 5 W/m^2 provides about 200 lux. WMC also has low IPDs of about 8 W/m^2 - slightly higher than designed, but the occupiers all added more lighting shortly after handover because the original levels were not adequate. Levels are now typically 200 lux - still borderline but at an acceptable domestic level. Ironically for such a low energy building, one practice chose a small number of 300 W halogen floor-standing uplighters. RMC's total of nearly sixty different light fittings provides maintenance staff with a headache: IPDs here varied between a good practice 11 to a high 20 W/m^2 in some of the cellular offices. Magistrates reported reflected glare from polished metal fittings on their bench and also uncomfortable radiant heat from incandescent spot lights used to illuminate a coat of arms behind each bench; but were otherwise delighted with their building.

The only *centralised lighting controls* in this group was an integrated controller operating all lighting in the C&W leisure centre. This suffered from major usability problems and - as seen before in these situations - the users' recourse was to default all lighting to on during the 18 hour day, irrespective of occupancy and available daylight. Lighting in the two other C&W buildings is manually switched, and classroom and corridor lighting tends to stay on late until security staff lock up. Particularly long hours of use are found at MBW and C&W. At MBW lights are usually all on for the whole working day, despite large unoccupied parts of the storage areas, but the coarse switching resolution is not able to respond to this. Night shiftwork adds to the operating hours. After allowing for this and the mezzanines, MBW's annual lighting use is typical for a warehouse.

A4.7 IT AND ELECTRICAL

None of these buildings has high equipment loads. One or two pockets of high office equipment use at C&W and RMC now have local cooling. Each consulting room at WMC has a single PC, which reflects the changes in GP business since 1989.

C&W also has some representative telecoms equipment for training purposes, plus a communications tower which is both a live network and a training facility. This was not metered, but was alleged to be a high electricity consumer. However, when the Probe team monitored it, their measurement was 20% of the estimate.

MBW included some process equipment, in particular chargers for the heavily-used forklift trucks, which consumed an estimated 9 kWh/m^2. The packing line conveyor systems tended to run constantly during the main weekday shift, in spite of irregular use; together with their air compressor, which was leaking at the time of the survey, they used an estimated 3 kWh/m^2 - a relatively small number, but one which could probably have been halved had waste been avoided.

RMC has a 250 kVA diesel generator, which was estimated by staff to have about three times the capacity of essential services. C&W has two sets of UPS batteries for essential loads, but no standby generator.

A4.8 FACILITIES MANAGEMENT AND MAINTENANCE

Facilities management varied between the fully contracted out services at C&W - where the residences, catering and leisure centre were managed by contract staff; through RMC where a team of building supervisors provided general reception, security, caretaking and basic building management; to MBW and WMC where office managers dealt with everything. The small size and friendly atmospheres at MBW and WMC ensured that this operated well in terms of staff satisfaction, though - as commonly happens - without much of a proactive approach to tuning the engineering and control systems.

Maintenance of buildings and services was contracted-out in all these buildings. At C&W this amounted to the equivalent of 1 or 2 staff on site each day, largely implementing the planned maintenance programme. RMC's contractor made routine visits for planned maintenance, plus call-outs as necessary: their staff had been involved in commissioning the services and seemed to know them very well (this also happened at CRS, where individuals had been retained from handover). These staff were very helpful to the smooth running of the building, but their perspectives on the systems were not as broad as a designer's, which meant that they were more involved with maintaining the status quo than considering whether the systems and their operation might be improved or made more energy efficient. At MBW good local contractors are employed on call out. WMC only requires boiler maintenance on a domestic scale, and uses a local heating contractor for annual services.

Energy management was not practised in any of these buildings. The lack of sub-metering at C&W made analysis of the three separate buildings impossible for the site staff, and very difficult for the Probe team to audit. A short history of meter readings was available from the maintenance staff, but these were taken on their initiative and so, as often happens, abandoned when not acknowledged - let alone encouraged - at a more senior level. Sub-meters to separate MBW and MBO's gas and electricity consumption were installed specially for PROBE. Although budget pressures at RMC (partly caused by its low occupancy) had put energy costs high on the management agenda, little had yet been done to identify savings. At WMC energy costs were both low and relatively stable and perhaps rightly not seen as a major issue by the occupiers - if only all buildings could default to such a low energy state with so little management input!

	TABLE A1: Probe offices - summary of key characteristics	**Tanfield House**	**1 Aldermanbury Square**	**Cheltenham & Gloucester**	**HFS Gardner House**	**Charities Aid Foundation**	**Marston Book Services Office**	**Co-op Retail Services**	**Offices in Elizabeth Fry**
		TAN	**ALD**	**C&G**	**HFS**	**CAF**	**MBO**	**CRS**	**FRY**
	PAGE 1: GENERAL								
A1.1	**Use, procurement and occupancy**								
	Main use	Admin centre	Head office	Head office	Head office	Main office	Main office	Head office	Staff offices
	Form	Very deep + atrium	Shallow	Deep + atrium	Deep + shallow	Shallow U-shape	Shallow linear	Deep + atrium	Shallow linear
	Principal orientations	S,E,W,NW	NNE,ESE	ESE,WNW,SSW	NE,SE,SW	NE,NW,SE,SW	N,S	N,S,E,entrance W	N,S
	ECON 19 nearest type	4	4	4	4	Hybrid 2/4	2 + computer	4	1 with MV
	Built for	Occupier	Developer	Occupier	Occupier	Developer	Developer	Occupier	Occupier
	Procurement route	Traditional	Speculative	Traditional	Traditional	Pre-let	Pre-let	Traditional	Traditional
	Contract type	Traditional JCT	Probably traditional?	Traditional JCT	Traditional JCT	Management contractor	Construction management	Traditional JCT	Traditional JCT
	Handover	Excellent, anticipated by experienced client.	Not very smooth: no continuity as empty for a long time before letting.	Hasty: in property boom. Took long time to assemble record info.	A final rush which particularly affected the services.	Quite good, but took some time to obtain adequate heating.	Good: carefully planned with briefing by landlord and designers.	Complicated by a substantial fire in the late stages of construction.	Helped by client Clerk of Works on site. Slight start of academic year rush.
	Likely building cost level	£££££	££££	££££	££££	£££	££	££££	£££
	Computer and physical modelling used in design?	BSRIA test rig for office A/C.	Routine design tools only	Routine design tools only	Physical tests of ch. beams & displ vent	Routine design tools only	Routine design tools only	Physical and CFD models	Termodeck and routine models
	Year first occupied	1990	1990	1990	1994	1995	1996	1996	1995
	Number of storeys	3	9	4	3	3	2	5	4 (offices 2)
	Design occupancy (people)	1300	350	700	200	230	57	650	70 (offices only)
	Actual occupancy (people)	1300	217	930	140	200	53	930	62 (offices only)
	Normal weekday working hours	0800-1900	0800-1800	0800-1730	0830-1730	0800-1800	0800-1700	0800-1800	0800-1800
	Normal weekday HVAC hours	0730-2100	0600-1900	0650-1900	0700-2000	0830-1800	0540-1830	0630-1830	Varies by BMS
	Weekday cleaning hours	2100-0500	0600-0800	1800-2030	0500-0800	1700-1930	1800-1930	2100-0600	1800-2100
	Normal Saturday occupancy hours	0900-1300	4 days/year	Few, half day	Few, half day	Very rare	AM occasional	Seldom	Not in offices
	Normal Saturday HVAC hours	0730-1700	4 days/year	0650-1300	0800-1300	Off	0540-1830	Off	To keep temp.
	Sunday occupancy	Increasingly	4 days/year	Occasionally	Contractors	None	Not normally	No	Not in offices
	Notes	One 24-hour area. HVAC zoning difficult in this large space		24-hour use of computer area	HVAC left on a lot in winter to counter airtightness problems	Occupancy hours very routine. 200 m^2 vacant: HVAC runs and often lit.	A few come in very early. Also shiftwork in the warehouse	24-hour use of print room (close control on 24-hr computer suite plant)	All offices cellular. BMS control at night to maintain fabric temperature.
A1.2	**Floor area statistics**								
	Gross floor area (m^2)	24000	8000	19900	4094	3900	1011	18400	3250
	Treated floor area (m^2)	19781	7000	17400	3800	3700	962	17300	3130 (offices 987)
	Nett floor area (m^2)	16314	5774	16390	3189	3250	800	8000 (main offices)	2300 (estd)
	Treated:gross ratio	82%	88%	87%	93%	95%	95%	circa 90%	96%
	Nett:gross ratio	68%	72%	82%	78%	83%	79%	circa 75%	71%
	Estimated proportion to cellular offices	2%	10%	15%	25%	20%	10%	10%	100%
	Design m^2 nett/person	13	16	23	16	14	14	circa 15	14
	Actual m^2 nett/person	13	27	18	23	16	15	circa 10	16
	Area comments	9000 sq. m of basement car park not included.		Gross (and all) areas exclude escape stairs		Gross & treated include escape stairs 90 sq. m	Nett area guessed	Nett area is for main office spaces only	Nett area guessed for offices only
A1.3	**Unusual areas included above**								
	AC Archive store (m^2)	No	No	674	230	None	None	In below	None
	AC Computer room (m^2)	Not included	No	701	60	35	10	1316	None
	AC Comms room (m^2)	250	Two	In above	In above	None	None	In above	None
	Kitchen and dining (m^2)	1258	Two	Yes, large	approx. 100	Staff room	in warehouse	1340	195
	Kitchen/dining type	Large restaurant, sep. snack bar	Large restaurant + management dining	Large restaurant + management dining	Vending+hot soup/ snack 2 days/week	DIY domestic kitchen in staff room	DIY kitchen in staff room (in MBW)	Lge restaurant sep. serviced+metered	Catering kitchen for special events only.

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	PAGE 2: FABRIC								
A1.4	**Walls**	Glass double skin with walkable gap.	Stone and aluminium cladding	Stone and aluminium cladding	Stone + aluminium curtain wall inserts.	Brick with sections of curtain wall	Brick with hole in wall windows.	Brick and stone with hole in wall windows	Block, ext insulated & rendered over
A1.5	**Windows & natural ventilation**	2+1	Double	Double	Double	Double	Double	2+1	2+1
	Frame type	Aluminium	Aluminium	Aluminium	Aluminium	Aluminium	Aluminium	Aluminium	Timber. Al clad
	Upper element	Sash for fire	No	No	No	Projecting	Projecting	No	No
	Main/lower element	Manual sash	Fixed	Fixed	Fixed	Projecting	Projecting	Tilt & turn	Casement open in
	Tint/transmission	20%	Heavy tint	Clear	34%	Suncool SE,SW Lo E elsewhere	Clear	Tinted, low-E, 33%	Clear, low-E, Argon filled.
	Primary solar protection	Overhang, walk way, glass tint	Overshadowing + tinted glass	None (designed awnings omitted)	Tinting	Sunbreakers & some suncool glass	Restricted area & sunbreakers	Restricted window area	Limited area, some milky glass on S
	Secondary solar protection and glare control	Pair translucent and opaque roller blinds	Vertical internal louvre blinds	Two layers of translucent curtains	Mid-pane venetian. Only tilt permitted.	Internal venetian blinds	Internal rollers + tilt-able light shelves	Mid-pane tilt-only venetian blind	Mid-pane perf venetian blind
	Cross-ventilation	NA	NA	NA	NA	Good	Good, plus rooflight	NA	No
	Window automation	As smoke inlet	No: sealed	No: sealed	No: sealed	Manual	Fanlights only	None	None
	How controlled?	FM discourages manual opening	NA	NA	NA	By occupants, but fall shut	Motorised: manual + override	Occupants open: FM discourages.	By occupants as safety valves
	Solar gain levels (1=too high, 5=v.gd)	4	2	1	3	3	4	3	4
A1.6	**Roof**	Garden	Flat/mansard	Metal & flat	Slate pitched	Flat & metal pitched	Metal pitched	Mostly pitched	Flat concrete
	Rooflights	To the 3 atria	None	To the atrium	To ground floor	Top floor wings	First floor office	To the atria	To stairs only
	Ventilation via rooflights?	Fixed	NA	Fixed	Fixed	Fixed	Motorised	Smoke vents	Fixed
	Rooflight solar shading	Rotary motorised segments	NA	Fixed	Fixed louvres	No: but glare and overheating caused	By geometry	Fixed louvres	Motorised louvres to main stair
	Rooflight shading control	Timed to track sun	NA	No adjustment	No adjustment	Shades to be added	No adjustment	No adjustment	Usually kept closed
	Roof daylight available (1=poor,5=vg)	3	NA	2	2	4	4	2	To stairs only
	Roof useful daylight (1=poor,5=vg)	2	NA	2	2	3	3	2	Lights stay on
	Ceilings	Exposed	Suspended	Suspended	Suspended	Exposed	Suspended-ground floor ventilated	Exposed	Exposed-hollow cores ventilated
	Ceiling height (m)	3.60	2.5?	2.75	2.70	2.85	3.0	3.1	
A1.7	**Fabric statistics**								
	Atrium	3 atria	No	One large	No, but rooflight	Reception only	No	3 atria	Main stairwell only
	Typical depth glass:glass or atrium (m	30	12	18	30 (main floor)	13.5	13.5	8 to 15	12
	Airtightness (5=tight<5, 4=good<10, 3=av'ge<20, 2=high<30, 1=leaky>30	Probably 3	Probably 3	Probably 3	2	Probably 2	2	3	4 (3 when first built)
	Measured leakage ($m^3/m^2/hr$@50 Pa)	No	No	No	High: 27 reported	No	High: 27.1	Average: 17.2	Good: 6.2
	Comments/observations on leakage	Management increased positive pressure to improve perimeter comfort.	Façade cladding details may be leaky.	Walls initially poor. Improved but still problematic, esp. management area.	Persistent problems at eaves and via and around windows/ curtain walling	Leaky at window: wall junctions and particularly around planar glazing.	Leakage at motor-ised windows, ext. doors, at junction to MBW and via floor.	Leakage through windows, doors , frames and ceiling & floor voids.	Careful attention in design and on site to minimise leakage. Completion test 4.2
	Reception area comfort levels	Initially cold.	Initially cold.	Cold. Air curtains and heating added to improve comfort.	No additional problems reported.	Limited heating. Draughts from doors and planar glazing	Good: design had revolving door and ducted heating.	Has underfloor + perimeter heating. No problems rptd.	OK. Entrance buffer space. Reception behind window.
	Consequences of infiltration levels	Reception enclosed and extra heating added to improve comfort.	Reception enclosed and extra heating added to improve comfort.	No compensation on one facade. Elec heaters in exec. offices.	Pressure test, extra sealing, extended running hours of A/C plant & preheat	Time and temp settings adjusted. New electric door heaters in reception	Radiators added near escape doors at west end of offices.	!	Good standard. Residual leakage via doors, rooflights, some window seals.
	Quoted wall U-value (W/m^2K)	0.5 (estd)	0.6	Not Recorded	0.42	0.29	0.39	0.26	0.20
	Quoted window U-value (W/m^2K)	2 (estd)	3.4	Not Recorded	1.90	1.80	3.00	1.36	1.3 mid pane
	Quoted roof U-value (W/m^2K)	0.4 (estd)	0.6	Not Recorded	0.42	0.19	0.45	0.17	0.16
	Quoted floor U-value (W/m^2K)	0.5 (estd)	0.6	Not Recorded	0.28	0.32	0.40	0.29	0.13
	U-value and infiltration comments	Floor to bsmt car pk.	from engineers		Spandrel 0.28			Roof for pitched area	Careful QA
	Insulation score (1=poor,2=ave, 3=good,4=v.gd,5=outstanding)	2	Probably 2	2	3	3	2	4	5

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	PAGE 3: HEATING, HOT WATER AND MECHANICAL COOLING								
A1.8	**Heating**					CRS restaurant has separate boilers 2 x 348 kW			
	Gas boilers	Steel	Light modular	Cast Iron	Light modular	CI modular	CI modular	Cast Iron	Wall-hung Aluminium
	Condensing?	No	No	No	No	No	No	No	All, 65°C max flow
	Number of boilers	3	10	3	6	4	2	2	3
	Capacity of each boiler (kW output)	1455	82	1200	100	100	50	715	24
	Boiler output power W/m^2 treated	221	117	207	158	108	104	122 incl. restaurant	#VALUE!
	Power score (1=hi>150, 2=ave>100, 3=gd>70, 4=v.gd>40, 5=exclnt<40)	1	2	1	1	2	2	2	5
	Heat emitters in main offices	Perimeter radiators	Fan assisted VAV A/C terminals (FAT)	Perimeter convectors	Trench convectors	Perimeter radiators	Perimeter radiators	Perimeter radiators +trench convectors	Via air only + 3 local 200 W elec htrs
	Heating compensation control	OK: by facade, using gap temp. between the skins.	No, temperature control largely via VAV VVT units.	By facade: one now const. temp owing to infiltration losses.	By facade: had to be turned up: solar gain on sensors.	OK: Central, trimmed by TRVs on all radiators..	By floor. Trimmed by TRVs in some areas.	By facade	No, AHU control keeps fabric temp. between limits.
	Local heating control trim	By facade	Via FAT VAV	By facade	By facade	Individual TRVs	Some TRVs	By facade	The 3 elec htrs only
	Heating operation.	Constant run: night primary setback to 60°C to avoid expans'n/contract'n problem with pressurisation unit.	Time controlled, but frost protection initially brought on everything incl. AHUs and chillers: changed in 1993.	Carefully managed to suit weather and occupancy. When boilers off, no reheat for conf. rm. multi-zone plants.	Early start and boost preheat required to overcome effects of high infiltration overnight. Inc A/C energy by estd 20%	Optimum start for preheating (on recirc) or early morning cooling.	0540 earliest search for 0630 start.	Yes, but precise details unclear.	Plant runs to keep fabric within high and low temperature limits outside occupied period.
	Typical LPHW circulating hours per yr	8760	5000	1600	5400	3000	2400	1600	1500
	Heating issues and problems	Cold reception. Extra frost protection needed for plant in gap.	Cold reception initially. Room temperature setting tricky for VVT units.	Cold reception initially. Infiltration. Boiler flue dampers stuck: abandoned.	Temperature raised to reduce infiltration and solar effects. Can now run if hot!	Pre-packaged and commissioned plant worked well. Cold reception initially.	Infiltration by escape doors: radiators added.	Infiltration. Stratification. Heat gains into floor void overnight.	Impossible to get good control until BMS was fitted. Now works well.
A1.9	**Domestic Hot water**								
	HWS generation	Kitchen LPHW calorifier	Local electric immersion heaters	Kitchen LPHW calorifier with summer boiler	Calorifier off LPHW	Local electric immersion + instantaneous showers	Local electric immersion heaters	Kitchen gas storage, rest local elec.	Gas storage heater for main toilets + kitchen
	HWS distribution	Toilets local electric	Toilets local electric	Toilets local electric	Pipes trace heated	13 heaters 2 showers	4 heaters	Tops of stairs: pipes trace htd	Remote toilets 2 No local electric
	DHW issues and problems	Electric heaters on permanently.	Electric heaters on permanently.	New summer boiler small, so dish washer electric boost used a lot.	Persistent problem with hot water pressure: traced to check valve spring.	Electric heaters on permanently.	Electric heaters on permanently.	Electric heaters on permanently.	Electric heaters on permanently.
A1.10	**Mechanical cooling plant**								
	Cooling system	Floor VAV	FAT VAV VVT with ice store	VAV	Const vol + chilled beams	Adiabatic	Contingency plan only	Const vol, chilled beams + ice store.	Thermal mass + night ventilation.
	Number of water chillers	4	2	3	2	none	none	1	none
	Capacity of each chiller (kW)	852	340	806	400	none	NA	580	NA
	Chiller W/m^2 treated	172	97	139	211	NA	NA	40 (ex kitchen etc)	NA
	Chiller type	Reciprocating	Reciprocating	Reciprocating	Screw	NA	none	Reciprocating	none
	Ice store kWh if fitted		5360 kWh					2900 kWh	
	Heat rejection	Air cooled	Cooling tower	Air cooled	Air cooled	Exhaust air	NA	Air cooled	Night cooling
	Chilled water operating hours per yr	8760	6000	1750	4000	NA	NA	3100	NA
	Chiller management	Constantly enabled	On if >10°C outside and for ice building.	On if >11°C outside	Primaries on const.	NA	NA	On 12 hrs/weekday and for ice building	NA
	Other comments on cooling system	Chiller ht rejection into exhaust ducts increases losses & means some fans must run at night.	Ice storage complicated for occupier. Tariff benefits didn't apply to overall day/ night load balance.	Most conventional AC in Probe, but gave the lowest energy use of the Type 4 offices.	Chillers not sequenced: but even on design day only one proved necessary.	Occupant comment + water consumption suggest adiabatic cooling might not be working.	NA	Atrium vents opened when hot to meet capacity shortfall (but plant not run at night).	Hollow core floor slabs cooled by night air as necessary. This worked very well.

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	PAGE 4: AIR CONDITIONING AND MECHANICAL VENTILATION								
A1.11	**Main mechanical ventilation or air conditioning system**								
	Main type	Air conditioned with openable windows	Air conditioned	Air conditioned	Air conditioned	Mixed mode: concurrent operation.	Natural ventilation	Air conditioned with openable windows	Mixed mode with ventilated structure
	Office ventilation system	VAV	Fan-assisted variable temp VAV	VAV	Displacement ventilation	Displacement ventilation	Natural ventilation except WCs	Displacement ventilation	Constant volume in offices.
	Office specific fan power (W/(l/s)): ma	5.0	4.6	5.0	4.0	3.1	NA	4.0	2.2
	Office specific fan power (W/(l/s)): age	1.7	3.0	2.5	4.0	3.1	NA	4.0	2.2
	SFP score (1=high>3.5, 2=ave>2.5, 3=good>1.5 4=v.gd>1, 5=exlnt<1)	3	2	2	1	2	NA	1	3
	Fan speed control method	Eddy current drives	VAV inverter plus 2-speed fan terminals	Variable frequency inverters	Constant volume	Constant volume	NA	Constant volume with inverter trim	Office plant constant volume
	Supply from	Raised floor duct	Suspended ceiling		Raised floor plenum	Raised floor plenum	NA	Raised floor plenum	Holes in soffit
	Return via	Atria	Luminaires	Ceiling void	Ceiling void	Behind lights into underfloor ducts	NA	Atria	Cornice to corridor duct
	Typical air change rate (ac/h)	Maximum 12, Typical 5	Pri max 9, Recirc 18	Maximum 8, typical 5	Const 3	Const 3.9 *(design 3.0)*	NA	3.5	1
	Typical air change rate (l/s per person)							30	
	Fresh air proportion	100%	Variable	Variable	100%	100%, xcpt preheat	NA	100%	nearly 100%
	Heat recovery	Restaurant system only	Recirculation only	Recirculation only	None	Cross-flow & preheat recirc	None (toilet vent only plant)	Cross-flow	Reverse flow, preheat recirc
	Typical ventilation hours per year	4500	3500	3500	4200	3000	NA	3100	2500
	Humidification fitted	Cent gas steam	AHU elec steam	Cent gas steam	AHU elec steam	None	NA	AHU elec steam	None
	Humidity control operation	Liberal	Fair	Reasonable	Liberal	NA	NA	Liberal	NA
	Night cooling facilities	Not used	Not used	Not used	Not used	Early start	Natural only	Not used	BMS controlled
	Ventilation and air conditioning issues and problems	Window opening by occupants is discouraged and seldom used. Floor diffusers moved to avoid draughts.	Temp control initially difficult. Ice control and maintenance problems: ice charge lost about once a fortnight.	Reported draughts or air shortages from VAV. 2 multizone plants need LPHW reheat but boilers now off in summer	Floor diffusers moved away from desks and dampers removed. Room stats shielded from warm and cool air.	Occupancy hours more routine than in most offices. Can be too cold or too hot, particularly on the top floor.	Preheating WC AHU supply air greatly increases boiler plant use and annual gas consumption.	Gets hot overnight. Window opening is discouraged but used. Draughts from floor diffusers. Ice store failures.	Good conditions obtained without opening windows.
	Actions taken in respect of above	VAV range cut to avoid local discomfort. VAV supply temp compensated to avoid re-cooling.	Software modified. Thermosyphoning depleted ice tanks: 3 port valves added. Ice reliability problems persist.	VAV range cut to 30 70%.	Control valves for chilled beams blocked by sludge: strainers fitted. Air supply temp raised and compensated.	Comfort survey suggests little adiabatic cooling effect.	None (but extract-only or heat recovery ventilation would have been more economical).	Ice storage reliability and glycol leaks a persistent problem. Smoke vents opened overnight in hot weather.	BMS control was added. It improved control, and cut fan running hours and gas consumption.
	Result of changes	Comfort improved.	Better, not perfect.	Comfort improved.	Still some problems	Still some problems	Still some problems	Still some problems	Now works very well
A1.12	**Controls and BMS**								
	BMS present	Yes	No: Carrier ACS for VVT system, Staefa for htg+clg plant.	Yes	Yes	Outstations only	No, dedicated controls	Yes	Not originally. Now retrofitted.
	Occupier has head end	Yes	Yes	Yes	Yes	No head end.	NA	Yes	In estates office
	Main occupier user	Site engineering staff	Site engineering staff	Site engineering staff	FM staff, for time & temp settings only.	None: contractor plugs in laptop.	Warehouse manger adjusts controls.	No: by contractor's resident supervisor.	No: adjusted by university estates staff.
	Occupier technically knowledgeable	Yes	Reasonably	Yes	Simple settings	No: for landlord	Partially	Partially	Yes
	BMS effectiveness rating (5=v.good)	4	2	4	2	1	NA	2	5
	Comments				System v. slow	Landlord service		System slow	
	Other controls issues	After Probe, owner changed VAV fan drives to inverters	Occupier knows they could do more but too expensive.	Tighter control possible but not acceptable to senior management.	More input desirable, e.g. plant hunting undetected until Probe survey.	Fine tuning difficult with no BMS head end. Heating override switches are in locked cupboards.	Electronic controls not user friendly and difficult to reach. User over-ride switches good.	Once ice is reliable, it could be used more. Strategic review of all controls would be desirable.	FRY makes a good case for BMS monitoring and management, even for simple systems.

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	PAGE 5: LIGHTING								
A1.13	**Main office lighting**								
	Main office lamp type	MBI	T8 Fluorescent	T8 Fluorescent	Dimmable CFL	CFL	T8 Fluorescent	MBI	T8 Fluorescent
	Control gear type	Conventional	High frequency	High frequency	High frequency	High frequency	High frequency	Conventional	Conventional
	Main office luminaire type	Furniture uplighters	Recessed	Recessed	Recessed	Surf fix in dimple	Recessed	Furniture uplighters	Cornice lighting
	Office supplementary luminaires	Wall uplighters Corridor floor	Not generally	Wall uplighters near doors	CFL uplighters on columns	None	Surface fluos in rooflight	Column and wall MBI uplighters	Task lamp if wanted
	Lighting installed power (W/m^2 design)	13	20	15 to 20	18	13	13.5	17	12
	Lighting installed power (W/m^2 actual)	13.0	12.0	17.0	18.0	12.5	13.4	21.8	20.0
	W/m2 score (1=high>20, 2=ave>15, 3=good>12,4=v.gd>10,5=exclnt<10)	3	3	2	2	3	3	1	2
	Typical artificial illuminance level (lux)	300	425	500	550	350	500	350	350
	Typical W/m^2 per 100 lux	4.3	2.8	3.4	3.3	3.6	2.7	6.2	5.7
	Average full load lighting hours per yr	5200	4000	4300	3400	2030	2080	4400	1000
	Automatic lighting controls	Timed and photoelectric switch on and off.	Timed switch-off, starting after 7 PM.	Timed switch-off.	Timed, occupancy sensed and photoelectric.	Timed off (and on for clnrs) & telephone-switched.	Entirely timed or occupancy-sensed, even in cellular.	Timed on/off, with occupancy sensing in meeting rms etc	None.
	Manual controls for office lights	Each uplight high/ low switchable. No local control in WCs and meeting rooms.	Typical office gridswitches plus local switches in cellular offices.	Useful coloured switches. White:lobby, Silver: normal Red: special Perimeter separate.	Open offices: override on at poorly marked grid switches. Off auto only: timed or empty	Via telephones in quite coarse zones (30 sq. m). Staff room and reception dimmable.	For corridor and toilet lighting only. Occ sensors in cellular offices bring on spaces outside.	For individual luminaires, but automatically switched-on and seldom used.	Local switches in offices+other rms. Key switches in circulation areas, by security guard.
	Occupancy sensing	No	No	No	Yes, in all offices.	In meeting rooms and kitchens.	In cellular and open offices.	In meeting rooms.	None
	Perimeter photoelectric linking?	Auto switching	Manual, local	Manual, local	Auto local dimming	Manual, as above	Auto switching	Manual, as above	None
	Circulation lighting use	Wasteful auto on when anyone in.	Manual control, often wasteful.	Manual control, somewhat random.	Manual control, often wasteful.	Manual control, somewhat random.	Manual control, somewhat random.	Wasteful auto: all on if anyone in.	Keyswitch on for all occupied period.
	Lighting control comments	All circulation, WC, meeting, lights on centrally. Switches needed in mtg rms.	System initially poorly understood owing to delayed occupation of bldg.	Atrium lighting manually switched.	Lights come on when people enter the zone, if light is wanted or not.	Inconvenient: requires individual PINs. Cleaners can't use.	Occupants regard as intrusive, unresponsive and wasteful.	Local switches of limited value: lights affect many people and warm up slowly.	Poor: circulation lights key switched by security stay on all day regardless.
	Alterations after completion	Starter lights in uplighters removed: circulation lights sufficient. Meeting room switches fitted	System reprogrammed and operators trained.	Gridswitch arrangements reorganised to relate to plan.	Dimming adjusted for more hysteresis. Blinds throw light up -confuse photocells	All lights now programmed on from 5 to 8 PM for cleaners.	Initial technical problems required replacement of control equipment.	None reported. Investigating why lights seem to be on more than wanted.	Office switches moved to create space for filing cabinets.
	Occupant use of office lighting controls.	A few welcome the high/low switching facility.	Limited.	Switch marking helps to avoid unnecessary use.	Very little: nearly all automatic. Circulation lights also left on a lot.	Occupants do not switch lights on if daylight is good on arrival.	Little user control available. Difficult to reprogramme for weekend work.	Little used. Lights stay on a lot: control problems/night cleaning, circulation	Reasonable, but used more than in some cellular offices.
	Lighting ctrl score (1=poor,2=ave, 3=good,4=v.gd,5=outstanding)	1	1	1	1	2	2	1	2
	Daylight potential (1=poor,5=v.good)	2	2	2	2	3	4	2	3
	Occupant use of glare control devices (see A1.5 for description).	Often used only if glare is a problem.	Used as necessary.	Curtains are closed a lot.	Tend to be used satisfactorily. Roof blind does not block some sun angles.	Venetians used quite well. Glare from rooflights is a problem.	Roller blinds tend to be down quite a lot and light shelf tilted up to reduce glare.	Quite effective for glare control, but limited daylight and view.	Reasonably good in offices, by individual occupants. Atrium blinds usually shut.
	Daylight utilisation(1=poor,5=v.good)	1	1	1	2	3	3	1	3
	Reason for non-optimal daylight utilisation (if it occurs)	Deep, tinted glass, MBI lights can only be put low, not off. Atrium petal-shaped screens timed only. Atrium plant growth.	Tinted glass, plan form, overshadowed	Both sets of curtains are often closed to stop glare.	Glass tint. Management likes blinds to tilt only. Occupancy sensing and dimming puts on lights too much.	Glare, particularly on first and second floors. Coarse zoning of lights in open plan areas.	Glare, leading to closure of blinds, coarse zoning, little occupant over-ride. No desks under top floor roof light.	Deep plan, tinted glass, venetian blinds tilt-only. MBI lights on a lot owing to controls and long restrike times.	Only 1 switch for 2 luminaires in typical office. Daylight casts dark shadow from cornice onto ceiling.

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	PAGE 6: IT and ELECTRICAL								
A1.14	**Office equipment heat gains: allowances and actual**								
	Office equipment gain (W/m^2 design)	25	30	45	30	15	20	20	20
	Boosted internal gain design capability	45	60	100	Not included	Contingency	Contingency	Not included	NA
	Means of boosting	Reallocation of capacity.	Reduce primary air temperature	Reallocation, remove ceiling pads.	Add more chilled beams	Add chilled beams or other options	Add underfloor fan coils/other options	Add more chilled beams	Increase amount of night cooling
	Office equipment gain (W/m^2 actual)	15	7	15	7	10	8	15	20
	Average gains as percent of design	60%	23%	33%	23%	67%	40%	75%	100%
	Local heat gain pockets	25	Not recorded	25	Not recorded	16	20	Not recorded	Not recorded
A1.15	**Computer and communications rooms**								
	Computer room present	In separate building, not included in Probe survey.	Small suite, included	Large suite: 12 CC + 2 mainframe ChW units included.	Small suite, included.	Small suite, included.	Small suite, included	Large suite with 23 close control units, included.	None
	Air conditioning type	NA	Local DX Close control	Water cooled DX + glycol free cooling	Local DX close control.	Local DX VRV comfort cooling	Local DX comfort cooling	2 Air cooled chillers. Glycol free cooling	NA
	Approx. computer suite area (sq. m)		60	701	60	20	20	1300	NA
	Approx. cooling capacity (kW)		34	350	30	10	8	390	NA
	Cooling capacity (W/m^2)		567	499	500	500	400	300	NA
	UPS draw at time of visit (kVA)				10.6	6		125	NA
	Room units (CC = close control)		CC Downblow	CC downblow	2 No CC downblow.	VRV room units.	Wall DX unit	CC downblow	NA
	Communications room	Yes	Yes PABX	In computer room	In computer room	In computer room	No	In computer room	NA
	Comms room AC	DX CC units	DX CC units	Local DX units					
	Comments	Taken off ChW syst.		Does glycol save?	Both units running	Comfort cooling	Comfort cooling	High fresh air 4 ac/h	NA
A1.16	**Other electrical items**								
	Standby generator type/kVA	From adjacent computer centre	Dorma Type 8-SETCA2 No	Diesel 2500 kVA	No: UPS for computers.	No: UPS for computers.	No: UPS for computers.	Diesel 1500 kVA	No: but some available from site CHP
	Other electrical issues	Harmonics from PCs and fan motors gave poor power factors, hot spots, and some switchgear problems. Power factor correction (PFC) upgraded. UPS added for call centre.	Overheating supply cables owing to harmonics: PFC added.	Standby generation enhanced. Delayed start to exhaust fans causes clouds of diesel fumes and fire brigade. CHP option rejected owing to management's concern for reliability.	None reported.	None reported.	Major dryout needed after floor void flooded.	None reported.	Not enough power and data outlets. Light switches had to be moved from behind filing cabinet position.

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	PAGE 7: MAINTENANCE AND UTILITIES								
A1.17	**Building services maintenance**								
	Site team	Yes	Yes	Yes	None	None	Coordination only	Resident contractor	University estates
	Staffing level in relation to normal	High	Normal	Normal	Normal but low	Normal but low	Normal but low	Normal	Normal
	Use of contractors	For specialist tasks only, e.g. chillers.	For specialist tasks only, e.g. chillers.	For specialist tasks only, e.g. chillers.	For all work. On site 0.5 days/wk	For all work, via landlord's contractor for site.	Responsive local contractors on call for all work.	Contractor with full time site supervisor	For specialist tasks only.
	Energy management	Limited to engineering type alterations, as service paramount	Limited: occupant regards the systems as too demanding of attention already.	Some corporate & site, constrained by Head Office service requirement.	None as yet: in survival mode until air infiltration problems sorted.	None. HVAC regarded as a landlord's responsibility.	No, but some environmental management. Automatic controls regarded as rather unfriendly.	No: separate contract appointment, but so far does billing only.	Yes, during "sea trials" period, but now FRY is working well the university has other priorities.
	FM responsiveness (1=poor,5=xclnt)	5	3	4	3	3	4	4	4
	Operation and maintenance manuals	Have needed some revision: client thought this was inevitable as they got to understand the building.	Shortcomings owing to vacant period before the building was occupied.	Had difficulty in extracting what they required as the building industry was busy at the time.	Had difficulty in getting the information they required as building industry was busy at the time.	Kept by landlord and maintenance contractor.	Comprehensive for a relatively small building but not always informative.	Comprehensive but not always complete or informative. Plain language descriptions patchy.	Reasonable quality.
	Reliability issues	Rubber flexibles on steam lines burst. Now stainless steel.	A/C and ice storage systems generally too demanding.	Computer rm. heat rejection capacity had to be increased	Water quality seems to affect electric humidifier capacity.	Uncertain performance of adiabatic cooling.	Plastic fittings on incoming water main failed (twice).	Ice store coils failed (six times). Glycol lost every time.	Wrong initial sensor locations caused control problems.
	Maintenance issues reported by occupiers.	Difficult, sometimes cold to work on AHUs + terminals in gap between wall skins. Pressure set: bottles added.	Ice tank problems with bursts, inventory control and restricted access for maintenance.	Attention required to floor drainage in plant room. AHU filters upgraded to avoid dust choking airflow sensors.	Restricted access in boiler plant room and to some parts of vent plant. Humidifier corrosion. Chilled beam valves initially sludged.	Lack of adequate window friction a problem: needs frequent adjustment.	Regular replacement of low voltage lamps in reception.	Problems with drainage in plant room and leakage to offices underneath, AHU drains being enlarged.	Building very easy to look after: no radiators in rooms. Vent plant costs less to maintain then ext blinds.
	Alterations made to systems after completion.	Steam condensate return line. Local AC in equipment rooms & transformer free cooling to avoid 24-hour Ch. water.	Extra cooling fitted in executive offices, meeting and dining rooms. VVT software altered to improve control.	Local split AC fitted in server rooms to avoid 24-hour use of one VAV plant. Light switch panels reorganised.	Dampers removed from floor supply diffusers: occupant adjustment gave cascading balance problems.	Motorised blind and electric door heaters added in reception.	Supplier replaced lighting controllers, which did not fulfil all specified functions. Water fittings replaced in metal.	R134A refrigerant changed to R 407C to increase chiller capacity. Air baffle to avoid condenser short circuit.	BMS added to allow management to gain control of slow-response system. With monitoring, now works well.
A1.18	**Fuel metering and average unit costs**								
	Sub metering	Catering gas. Steam boiler make-up water. Chiller compressors: hours run.	None.	Electricity to quadrants: not thought very useful as unrelated to space use.	None, but a useful range of hours run meters on most items of HVAC plant.	None.	None initially. Landlord fitted office submeters for gas and electricity for Probe Team.	Kitchen and restaurant area gas and electricity. Some hours run meters.	Gas to water heater for kitchen and main toilets, plus temp. submeters for BRECSU's work.
	Electricity unit cost ex VAT (p/kWh)	NA	5.89	5.50	5.31	6.40	3.76	4.42	4.22
	Gas unit cost ex VAT (p/kWh)	NA	1.33	1.29	1.37	0.90	1.49	Not Available	0.86
A1.19	**Water**								
	Annual water consumption (m^3)	NA	NA	NA	NA	1400	1550	11750	880
	Relevant numbers of people					200	120	930	70
	Applicable to					All staff	Office + warehouse shifts	All staff	Office staff only, not students
	m^3 per person per year					7.0	12.9	12.6	12.6
	Typical benchmark					10	12	10	10
	Benchmark source					BRE	Office toolkit	BRE	BRE
	Benchmark assessment					Good, but what about adia. cooling?	Normal	Somewhat higher than average.	Good, once student use is allowed for.

	TABLE A2: Probe educational buildings - key characteristics	**de Montfort**	**APU Queens Building**	**John Cabot CTC**	**Elizabeth Fry**	**Portland Building**
		DMQ	**APU**	**CAB**	**FRY**	**POR**
	PAGE 1: GENERAL					http://www.port.ac.uk/estates/portlan
A2.1	**Use, procurement and occupancy**					
	Main use	University teaching	Learning Resource Centre	Secondary school	University teaching	University teaching
	Form	Deep+stacks+atrium	Deep plan (30m) with two atria, 3 storey rising to 4	Crescent-shaped main street runs between main hall and sports hall, with 3 teaching wings off it.	Shallow linear	E-shaped fortress with glazed insert.
	Principal orientations	SE,SW,NW	All + sky	NE,SW	N,S	N,S,E,W
	Energy benchmark reference type	EEO academic building	ECON 19: Type 2 office	Yellow Book for secondary school without swimming pool	ECON 19 Type 1 with allowance for mechanical vent.	Electric: ECON 19 Type 2 office CO2: EEO non-residential academic
	Built for	Occupier	Occupier	Educational Trust	Occupier	Occupier
	Procurement route	Traditional	Performance spec	Traditional after limited competition	Traditional	Construction management.
	Contract type	Traditional	D & B, design team novated	JCT80	Traditional JCT	Traditional JCT
	Handover	Design team intended fine tuning in 1st year but final account dispute meant two years with no attention.	Some commissioning problems with ventilation systems and controls.	Fixed opening date (term start) lead to compressed commissioning	Somewhat rushed with academic year start. Thorough monitoring by BRECSU led to effective fine tuning.	Estates team had little involvement until last stages of construction
	Likely building cost level	££££	££	£££	£££	£££
	Computer and physical modelling used in design?	Thermal (ESP), daylight and CFD	Artificial sky; Bulk air movement (VENT); Dynamic thermal (ROOM)	Routine design tools only	Termodeck model and routine design tools	ESP thermal model, CFD for wind ventilation, VR model to describe vent design intent
	Year first occupied	1993	1994	1993	1995	1996
	Number of storeys	4	3 and 4	2	4 (offices 2)	3 and 4
	Design occupancy (people)	2000	750	1000	70 + students	Much less than actual
	Actual occupancy (people)	1500	260	700	70 staff plus variable students (nominally 1100; typical max 850)	60 staff + 1200-1300 students/day
	Normal weekday working hours	0900-1730	0830-2130	0700-2030	0800-1800	0900-2000
	Normal weekday HVAC hours	0700-2030	0830-2130	0600-2000	Varies by BMS	0730-2100
	Weekday cleaning hours	0600-2200	0500-0800	1700-2000	1800-2100	Not recorded
	Normal Saturday occupancy hours	Some	0900-1700	Sports hall	Lecture and seminar rooms	None: but students would like
	Normal Saturday HVAC hours	0700-2030	0900-1700	Off	Programmed in BMS	None
	Sunday occupancy	Variable	0900-1700	Sports hall only	None	None
	Notes	Mix of teaching, office and engineering laboratory space.	At time of survey student occupancy was low and BMS not working well.	BMS does not control well to times: poor interface +user understanding	Cellular office plan. More on offices in Table A1 and associated text.	Staff have access at weekends but reportedly seldom go in
A2.2	**Floor area statistics**					
	Gross floor area (m2)	9850	6018	8867	3250	6230
	Treated floor area (m2)	8400	5656	8800	3130	6000
	Nett floor area (m2)	6500	Not known	Not known	3130	6000
	Treated:gross ratio	85%	94%	99%	96%	96%
	Nett:gross ratio	66%	Not available	Not available	96%	96%
	Estimated proportion to cellular	1%	5%	2%	30%	30%
	Design m2 nett/person	3				
	Actual m2 nett/person	4				
	Area comments		Top floor of library being used as office space	Sports hall and main hall under separate control via BMS	Lecture theatres on separate VAV vent plant with air quality control.	2 lecture and 4 large seminar rooms have DX cooling constantly running.
A2.3	**Unusual areas included above**					
	AC Archive store (m2)	NA	NA	None	NA	NA
	AC Computer room (m2)	NA	NA	Small	NA	NA
	AC Comms room (m2)	NA	NA	Small	NA	NA
	Kitchen and dining (m2)	Initially intended but cut out.	approx. 200	Dining hall & kitchen	Kitchen available, used 2-3 times a month, often then as servery only. Small tea room.	Busy snack bar but little cooked food.

	TABLE A2: Probe educational buildings - key characteristics	**de Montfort**	**APU Queens Building**	**John Cabot CTC**	**Elizabeth Fry**	**Portland Building**
		DMQ	**APU**	**CAB**	**FRY**	**POR**
	PAGE 2: FABRIC					
A2.4	**Walls**	Brick/block	Brick/insulation/block	Brick skin	Block, ext insulated+rendered	Block/insulation/block, ext rendered
A2.5	**Windows & natural ventilation**	Double	Most 2+1 with argon fill. Some	Double	2+1	Double
	Frame type	Timber	Wood framed, Al clad externally	Aluminium	Timber	Timber frames, Al opening elements
	Upper element	Varies	Motorised opening (BMS)	Potentially openable but some catches 2.5m above ground	No	
	Main/lower element		Locked to prevent book theft	Openable	Hinged, open in	Openable
	Tint/transmission	Clear	Low e coating	None	Clear, low e coating	Clear
	Primary solar protection	Overhangs, reveals, lightshelves	Overhangs, lightshelves, calico sails in atrium	Louvre overhangs; External roller blinds on west and some east-facing	Restricted window area	Fixed external sunscreens. External motorised roller blinds on west
	Secondary solar protection and glare control	Architectural devices	Mid-pane perforated venetian blind	Internal venetian blinds	Perforated mid-pane venetian blind	Atrium roof: motorised roller blinds. Offices+teaching rms: internal blinds
	Cross-ventilation	Stack driven	Buoyancy assisted via atria rooflights	Buoyancy assisted via builders work ducts to ridge louvres	No	Buoyancy assisted via atria rooflights and stair towers
	Window automation	Motorised and manual	Window top lights in concert with atria rooflights	Low level: manual. High level: manual teleflex. High level louvres: BMS motorised (see below).	None	Mixture of motorised and manual
	How controlled?	BMS and winders	BMS Manual in few cellular offices	BMS by temperature, ground floor vent extract via keyswitched fans.	By occupants as safety valves	BMS and manual
	Solar gain levels (1=too high,	4	4	2	5	3
A2.6	**Roof and ceilings**	Tiles	Slate tiles	Metal sheet	Flat concrete	Metal sheet
	Rooflights	Extensive	In atria	Main halls and streets	To stairs only	Yes
	Ventilation via rooflights?	Yes	Yes	Via high level motorised louvres.	No	Yes
	Rooflight solar shading	None	Internal calico sails	Sports hall: sails	Motorised louvres to main stair	Yes
	Rooflight shading control	NA	No	Fixed	Usually closed	BMS
	Roof daylight available	5	5	4	3	5
	Roof useful daylight (1=poor,5=vg)	5	5	4	1	5
	Ceilings	Exposed	Exposed concrete coffers	Mostly exposed on ground floor	Exposed, cores ventilated	Exposed
	Ceiling height (m)	3.0 - 3.3	3.2; 6.8 max on top floor	2.4 upwards	2.5 in offices, more elsewhere	2.7; more into pitch on top floor
A2.7	**Fabric statistics:**					
	Atrium	Central concourse	Two	No	Entrance stairway/lightwell	Yes: main circulation
	Typical depth glass:glass or atrium		12	NA	NA	9
	Airtightness (5=tight<5, 4=good<10, 3=av'ge<20, 2=high<30, 1=leaky>30	Probably 2	Probably 4	1	4	3
	Measured leakage (m^3/m^2/hr@50	No	No	35	6.2	15.6
	Comments/observations on leakage		Winter tempering of incoming fresh air with through-the-wall grilles behind perimeter heating	Most leakage via high level ridge vents for summer ventilation. These caused winter discomfort and were blanked off by CAB (but still leak).	main leakage through juncture of stair well rooflights with wall	Leaky eaves: visible gaps bet RSJs & timber beams. Ventilation towers somewhat leaky and 2 vent motors stuck. External doors very leaky.
	Reception area comfort levels		Poor: draught lobby small, so auto doors each side can open together	OK, effective draught lobby, and underfloor heating in foyer area	Good - use of revolving door	OK: Reception desk housed in glass fronted small office
	Consequences of infiltration levels		Not known	Cold Draughts in first floor spaces	good heating performance & comfort	
	Quoted wall U-value (W/m^{2}K)	0.29 - 0.36	0.30	0.31	0.20	0.33
	Quoted window U-value (W/m^{2}K)	2.5 - 3.6	1.95	3.20	1.3 mid pane	3.30
	Quoted roof U-value (W/m^{2}K)	0.2 - 0.31	0.30	0.30	0.13	0.29
	Quoted floor U-value (W/m^{2}K)	0.19 - 0.45	0.25	0.31	0.16	0.45
	U-value and infiltration comments	High thermal mass exposed, probably quite a lot of air leakage.	Well insulated. Conference room double glazed to cut cost. Radiators	Many motorised louvres plated-over to reduce leakage+noise breakout.	High insulation+airtightness allowed perimeter heating to be omitted.	Visible gaps at turrets and eaves. Poor reliability of rooflight actuators.
	Insulation score (1=poor,2=ave, 3=good,4=v.gd,5=outstanding)	3	4	3	5	3

	TABLE A2: Probe educational buildings - key characteristics	**de Montfort**	**APU Queens Building**	**John Cabot CTC**	**Elizabeth Fry**	**Portland Building**
		DMQ	**APU**	**CAB**	**FRY**	**POR**
	PAGE 3: HEATING, HOT WATER AND MECHANICAL COOLING					
A2.8	**Heating**					
	Gas boilers	38kWe CHP + boilers	Low NOx	Lead condensing 250kW, plus two high efficiency 400 kW each	Wall-hung domestic, with aluminium heat exchangers.	Cast iron atmospheric
	Condensing?	1 of the three	Both	1 of the three	All	No
	Number of boilers	3	2	3	3	12
	Capacity of each boiler (kW output)	CHP 109, Cond 350, Hi eff 2x375	373	350	24	60
	Boiler power W/m2 treated	144	132	119	23	120
	Power score (1=hi>150,2=ave>100, 3=gd>70,4=v.gd>40,5=exclnt<40)	2	2	2	5	2
	Heat emitters	Perimeter radiators, natural convectors, radiant panels in mechanical labs, ahus in labs	Perimeter convectors	Classrooms: perimeter radiators Main halls and street: underfloor	Predominantly via air only. 5 No 200 Watt electric panel heaters added in exposed rms.	Perimeter radiators in offices Underfloor in large spaces
	Heating compensation control	Yes	Yes, but sensor on W wall in sunlight gave control problems.	Yes with separate zones with local pumps for each wing	No, airside	Yes. Five separate boilerhouse locations.
	Local heating control trim	10 control zones via 2 port motorised valves, TRVs	Dampers on convectors	Individual TRVs	Elec panel heaters only	Rads: TRVs; underfloor pumped zones: wall thermostats.
	Heating operation		Optimum start and compensated flow temps. Compensation may be over ridden.	Controlled from Staefa BMS	Now enabled continuously in winter to maintain slab setpoint	Boilers controlled from central BAS 2800 - although comms problems were evident during survey visits and u/floor htg zones not controlled
	Typical LPHW circulating hours per	2840	4200	2000	1500	2050
	Heating issues and problems	3 port valve failures, so can't isolate heating circuit or have compensated flow	Underheating in Conference facility owing to change from triple to double glazing.	High infiltration in winter led to ridge louvres being blanked off. BMS control uncertain.	Agreed strategy to add panel heaters in any rooms which proved cold. Only 5 needed, in rooms with exposed floor.	5 plant rooms, 22 underfloor circuits, 50 pumps. Maintenance access poor.
A2.9	**Domestic hot water**					
	HWS generation	Central calorifier off LPHW Designed for refectory not built CHP output matched to refectory HWS load	Calorifier off LPHW with preheat from bar cellar chiller condenser	1 gas fired boiler each for sports changing and kitchen, electric trace heating for distribution; local electric for basins	Gas storage heater for main toilets and kitchen (very little used).	From space heating gas boilers with solar preheat. Electric heater for snack bar.
	HWS distribution	Widely distributed low loads Local heaters would be better	Long pipe runs and tap water too hot	Thermostatic mixing valves on showers and taps (which are self closing)	Compact pumped secondary. Remote toilets have 2 No small electric storage heaters.	Pumped secondaries from three locations.
	HWS issues and problems		HWS uses main boiler in summer - which may limit extent of condensing operation	No time control on the fourteen local electric water heaters	None	4 of 5 plantrooms contain HWS calorifiers.
A2.10	**Mechanical cooling plant**					
	Cooling system	None	Evaporative cooling for bar/kitchen	3 split units for above + seminar room	Thermal mass + night vent	DX chillers for main theatre ahus. Local split dx for small theatre
	Number of water chillers	NA	NA	None	none	2
	Capacity of each chiller (kW)	NA	NA	24 + 15	NA	40
	Chiller W/m² treated	NA	NA	NA	NA	
	Chiller type	NA	NA	NA	none	R22
	Ice store *(none in these buildings)*					
	Heat rejection	NA	NA	NA	Night cooling	Air cooled
	Chilled water operating hours per yr	NA	NA	NA	NA	
	Chiller management					
	Other comments on cooling	NA		Seminar room chilled 60hrs/wk but rarely used	BMS control needed adding. Now works well.	No BMS or time control of local split dx units & temp settings in locked riser cupboard

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	PAGE 4: MECHANICAL VENTILATION					
A2.11	**Mechanical ventilation**					
	Type (for NV buildings, comments for specific systems *in italics)*	None bar punkah fans in stacks	*Mech. vent to student bar/café/kitchen and TV studio*	*Mech. vent to toilets, labs, kitchen and changing rooms*	MM	*Main lecture theatre, toilets and a few offices*
	Ventilation system	NA	*Low velocity displacement*	*Extract fans*	Const Vol	*Displacement in main lecture rm.*
	Specific fan power (W/(l/s)): max	NA	*3.5*	*Not known*	2.2	
	Specific fan power (W/(l/s)): average	NA	*3.1*	*Not known*	2.2	
	SFP score (1=poor>3.5,2=ave>2.5, 3=good>1.5,4=v.gd>1,5=exlnt<1)	NA	*2*	*Not known*	3	
	Fan speed control method	NA	*2 - speed manual control*	*Constant volume*	Lecture rooms: variable volume with carbon dioxide sensing. Seminar rooms & offices: constant volume.	*2 ahus operate in stages according to air quality sensors*
	Supply from	NA	*Displacement terminals*		Ceiling	*Grilles under seats*
	Return via	NA	*Cooker hoods*		Corridor duct	*Extracts above doors*
	Typical air change rate (ac/h)	NA	*7 max*		2	*not recorded*
	Typical air change rate (l/s per person)		*Not recorded*			*not recorded*
	Fresh air proportion	NA	*100%*	*100%*	nearly 100%	*100%*
	Heat recovery	NA	*Recuperators in winter evaporative cooling in summer*	*For changing rooms*	85% by regenerators	*None*
	Typical ventilation hours per year	NA	*3000*	*3000*	2500	
	Humidification *(none fitted in these b*	None	*No*	*None*	None	*None*
	Humidity control (not applicable)					
	Night cooling facilities for principal spaces	Nat vent via motorised dampers in stacks	Via natural ventilation: BMS control algorithm calcs heat stored in mass but persistent teething problems	Via natural ventilation and infiltration.	Fundamental: controlled (by retrofitted BMS) to keep temperatures of hollow core floors within a preferred range.	None
	Ventilation and air conditioning issues and problems		Night venting	NA	Initial control strategy too complicated & problems with sensor location	Small lecture rooms with local dx have no fresh air supply - very stuffy. One of Main lecture theatre supply fans may have failed - pigeon roost over ahus prevents access
	Actions taken in respect of above		Algorithms re-written	NA	sensors relocated. Temp control made independent of outside air	None yet. Aim to screen ahu plant from pigeons using net
	Result of changes		Un-known	NA	very simple control	NA
	Other comments	Punkah fans provide contingency against reverse flow down stacks	BMS controlled nat vent monitors internal temp, CO2, rain and wind speed/direction	*Fans are controlled by BMS*	None	small lecture local dx have no BMS control or timeswitching - run 24 hrs. Temp settings are in locked riser
A2.12	**Controls and BMS**					
	BMS present	Yes	Yes	Yes	Retrofitted	Yes
	Occupier has head end	Yes (but Estates Dept)	Yes	Yes	Yes (but Estates Dept)	Yes (but Estates Dept)
	Main occupier user				Electrical Engineer responsible for	Mech. Engineer
	Occupier technically knowledgeable	Yes (but Estates Dept)	Limited	Limited	Yes	Fair
	BMS effectiveness rating (5=v.good)	3	2	1	5	2
	Comments			Poorly functioning BMS	FRY BMS is part of campus wide network	BMS is part of campus wide BAS 2800
	Other controls issues			None	None	Only plant rooms under BMS. Heating zone and passive vent device control are not.

	TABLE A2: Probe educational buildings - key characteristics	**de Montfort**	**APU Queens Building**	**John Cabot CTC**	**Elizabeth Fry**	**Portland Building**
		DMQ	**APU**	**CAB**	**FRY**	**POR**
	PAGE 5: LIGHTING					
A2.13	**Main lighting**					
	Main lamp type	58W T8 fluorescent	36W T8 fluorescent	36W and 58W T8 fluorescent	T8 Fluorescent	T8 fluorescent
	Control gear type	High frequency	High frequency	High frequency	Conventional generally. HF dimmable in lecture rooms.	High frequency, dimmable in teaching rooms.
	Main luminaire type	Suspended twin lamp	Suspended on top floor, recessed in coffers elsewhere	Surface mounted, some recessed on ground floor.	Fluorescent cornice lighting	Surface mounted, single tube, louvred fittings.
	Other luminaires	CFLs in circulation SON in mechanical labs	Desk mounted task lights Metal halide projectors in atria	Corridors: CFLs Main hall and street: Metal halide pendant. Sports hall: SON pendant	Offices: task lamp if wanted Corridors: CFL wall lights	CFLs in circulation areas. CFL uplighters in top floor studios. Metal halide in atrium.
	Lighting installed power (W/m2 design)	Not known	16	9	12	13
	Lighting installed power (W/m^2 actual)	13.0	13.0	14.5	20.0	11
	Installed power score (1=poor>20, 2=ave>15,3=good>12,4=v.gd>10, 5=excellent<10)	3	3	3	1	4
	Typical artificial illuminance level (lux)	Offices/computer rooms: 300 Circulation areas: 150/200 Mechanical labs: 1000 General labs: 750	400	350	350	350 Circulation areas often 100 or less.
	Typical W/m^2 per 100 lux	4.3	3.3	4.1	5.7	3.1
	Average full load lighting hours per	2850	1200	1200	1000	estimated at 1300
	Central lighting control	Timed enabling	Thorn JOEL central control, mains borne, with timed, PIR, photocell, & manual switching.	External lighting under timeclock and photocell; all else manual	Circulation on keyswitch	None
	Local lighting control	Local manual switches	Manual override	Manual	Manual	Manual + some dimming and PIR
	Lighting ctrl score (1=poor,2=ave, 3=good,4=v.gd,5=outstanding)	2	2	2	2	3
	Occupancy sensing	Doubled up with intruder sensors but not used as insufficiently	Yes in toilets	None	None	In teaching rooms, with manual over ride (not reset) switches.
	Daylight linking & photoelectric	Available but not commissioned	Photocell switching not working	None	None	Not working
	Circulation lighting use	On whenever enabled	Wasteful manual	Wasteful manual	Keyswitch on: all open hours.	Random but quite often off.
	Lighting control comments		There appears to be some sporadic night time operation of lighting which might be due to noise on mains signalling	Parallel switching of luminaires gives potential for daylight saving	Less successful in well daylit foyers	Fraught with usability problems but quite effective in practice
	Alterations after completion		None	None	None	None
	Occupant use of office lighting controls			Poor	Manual switching in cellular offices works well.	Occupancy detectors are very effective
	Daylight potential (1=poor,5=v.good)	4	5	5	3	4
	Occupant use of glare control devices		Mid pane venetian blinds on south west facade		All offices have translucent panel & mid-pane blind	Wide range of shading devices. Mostly auto control overrides occupant desire. Some rooms have internal roller or venetian blinds.
	Daylight utilisation(1=poor,5=v.good)	3	2	3	2	4
	Reason for non-optimal daylight utilisation (if it occurs)	Auto switch off system not commissioned. Staff not diligent with manual off. SON response too slow	Photocell switching not working; occupants not diligent with manual switching; too much emergency lighting permanently on	Occupant indifference	1 switch/room controls window and corridor lights. Daylight casts shadow from cornice. Shared spaces not owned	Daylight dimming not working. Local dimmers somewhat unreliable. Occupant use of local switches patchy.

	TABLE A2: Probe educational buildings - key characteristics	**de Montfort**	**APU Queens Building**	**John Cabot CTC**	**Elizabeth Fry**	**Portland Building**
		DMQ	**APU**	**CAB**	**FRY**	**POR**
	PAGE 6: IT AND ELECTRICAL					
A2.14	**Office equipment heat gains:**					
	Office equipment gain (W/m^2 design)	Not known	16 in study areas 0 in library areas	Not known	20	Not known
	Boosted internal gain design capability	NA	NA	NA	NA	NA
	Means of boosting	NA	NA	NA	More night cool	NA
	Office equipment gain (W/m^2 actual)	9	3	4	20	Variable
	Average gains as percent of design	NA	NA		100%	NA
	Local heat gain pockets		TV studio	IT teaching rooms	Student computer room	Student computer rooms
A2.15	**Computer and communications rooms**					
	Computer room present	No	No	Network manager's office	No	No
	Air conditioning type	NA	NA	Split a/c heat pump	NA	NA
	Room units	NA	NA	As above	NA	NA
	Communications room	NA	NA	Telecoms room	NA	NA
	Comms room AC	NA	NA	Split a/c heat pump	NA	NA
A2.16	**Other electrical items**					
	Standby generator type/kVA	38kWe CHP	No	No	UEA has central CHP	No
	Other electrical issues				None	Access to cable trays under floor is very difficult.

	TABLE A2: Probe educational buildings - key characteristics	**de Montfort**	**APU Queens Building**	**John Cabot CTC**	**Elizabeth Fry**	**Portland Building**
		DMQ	**APU**	**CAB**	**FRY**	**POR**
	PAGE 7: MAINTENANCE AND UTILITIES					
A2.17	**Building services maintenance**					
	Site team	Estates Dept	No: management only	Two	Estates Dept	Estates Dept
	Staffing level				Non fulltime but clear responsibilities	Local caretaker plus estates staff when needed
	Use of Contractor	No	Balfour Beatty O&M 40 buildings for APU central team of 5.	Used for main plant	Only for specialist work	Satchwell for BMS
	Energy management	Keen but not yet effective at the time of the Probe survey.	Only through research student for Comfort 2000 project	None	Yes, in Estates Department	Not so far, but student project was starting.
	FM responsiveness (1=poor,5=xclnt)		2.0	3.00	5.00	2.00
	Operation and maintenance manuals		Consisted mainly of supplier datasheets	Reasonable	Good	Reasonable
	Reliability issues		No problems reported	Some unreliable sensors	No perimeter heating therefore no student interference	Problems with rooflight actuators
	Maintenance issues reported by occupiers.		None	External solar blinds need regular servicing	Very low maintenance. Easy external access to plant areas	Access to atrium roof needs special cherry picker. Fixed panels hide u/floor
	Alterations made to systems after completion.		None	Replacement of wind sensors	Only BMS stuff	
A2.18	**Fuel metering and average energy cost rates**					
	Sub-metering		Kitchen electricity & gas	Heating gas, HWS gas, kitchen gas, electricity and water	htg gas, HWS gas	
	Electricity unit cost ex VAT (p/kWh)	5.48	Not known: central purchasing	6.20	4.22	Not known: central purchasing
	Gas unit cost ex VAT (p/kWh)	1.26	Not known: central purchasing	0.65	0.86	Not known: central purchasing
	Probe metering comments		None	Very good provision of sub-metering. All plus main meters can be logged by BMS	Good submetering	Probe team found faulty main electricity submeter. Replaced for the study but only a few weeks' readings then available..
A2.19	**Water consumption and cost**					
	Annual metered consumption (m^3)	Not collected	Not collected	2370	880	Not available
	Annual water costs (if known)			£ 4,059	Not known: central purchasing	
	Annual water costs £/m^2 treated			12859		
	Ave costs £/m3 including sewerage			£ 1.71	NA	
	Attributable number of people			450	70	
	Type of people attributed			Pupils in 1995-96	Office staff only	
	Usage per person (m^3/yer per person)			5.3	12.6	
	Annual cost per person (£/person)			£ 9.02	NA	
	High benchmark (m^3/yr per person)			12.0		
	Typical benchmark (m^3/yr per				10	
	Low benchmark (m^3/yr per person)			4.0		
	Benchmark source			Managing School Facilities Guide 1: Saving Water, HMSO (1993)	BRE	
	Water consumption comment			Good.	Very good: index is based on the 70 office staff only. Hundreds of students also visit the building.	

	TABLE A3: Other Probe buildings - summary of key characteristics	**Cable & Wireless**	**Rotherham Magistrates Courts**	**Marston Book Services Warehouse**	**Woodhouse Medical Centre**
		C&W	**RMC**	**MBW**	**WMC**
	PAGE 1: GENERAL				
A3.1	**Use, procurement and occupancy**				
	Main use	Residential training centre	Ten courtrooms with offices, cells and public areas	Warehouse with high bay racking+mezzanines on 2 sides	Accommodation for two doctor's surgeries and a dentist's practice
	Form	Three low rise blocks: Teaching - deep plan with high level ventilation; Residential - shallow plan; Leisure centre - deep plan	Rectangular blocks around a central open courtyard, with an extra wing to the East.	Portal frame box shed (with MBO attached at one corner).	Single storey rectangular building with surgeries taking terraced units
	Principal orientations	Teaching - N,S	N,S,E,W	N,S,E,W	N,S with entrances on west
	Energy benchmark reference type	TFA weighted composite: Hotel, University academic, Leisure centre + swimming pool.	Yellow Book for Crown + County Courts	ECON 18 for Distribution Buildings	ECON19 Type 1
	Built for	Occupier	Borough Council, using its own architects	Developer	GP Practice
	Procurement route	Traditional	Traditional	Pre-let	Traditional
	Contract type	Traditional	Traditional	Construction management	Traditional
	Handover	2 years after occupation, clerk of works still on site snagging, but owners v pleased with building	Difficult to commission 150 smoke vents	Smooth, but some difficulties with subsequent mezzanine fitout work. Lighting added under mezzanine relatively poor.	Communication of the design intent was considered very poor by the occupants
	Likely building cost level	££££	£££	£	££
	Computer and physical modelling used in design?	Salt bath 1:25 scale model for classroom ventilation	Yes: EC 2000 study with SERI-RES & GNOME (but major cost cuts were made afterwards, causing compromises)	No	No
	Year first occupied	1994	1994	1996	1989
	Number of storeys	3	3 + roof plant rooms	1 + part mezzanine	1 + partially converted loft space
	Design occupancy (people)	168 bedrooms	Staff 35-45, Magistrates 15-20, public varies	50	About 25 staff + patients
	Actual occupancy (people)	Variable	Over 40 staff. Pool of 130 magistrates available.	46	Practice A: 15 full-time, 3 time; B: 15 full-time, 4 time; Dentist C: equivalent to 5 full-
	Normal weekday working hours	Teaching: 0730-1730, Leisure: 0600-2300	0800-2000	0800-1700, plus night shift 2100-0700	8.30-1800
	Normal weekday HVAC hours	0530-2400	0800-1900	To maintain minimum 10°C	Practice A: 24 hrs at low setting; B: 6.30-18.00 Mo-Tu, 7.30-18.00 We-Fr
	Weekday cleaning hours	Teaching: 1800-2200	0500-0700	1800-1930	18.00-21.00
	Normal Saturday occupancy hours	Teaching variable, Leisure: 0800-2330	0800-1200 for Remand Court 10 only	2100-0700, Sometimes 0700-1200	Practice A: 8.30-12.00, Practice B:10.00-
	Normal Saturday HVAC hours	0530-2400	To suit above	To maintain minimum 10°C	Practice A: 24hrs low; B: 1 hr Sa-Su
	Sunday occupancy	Variable	None	1000-1800	Fleeting visits by Doctors on call
	Notes	Initially built for technical training but used largely for management training.	Zoning of ventilation plant not well related to usage of building, partly owing to cost	Unit heaters over-ridden manually to suit occupants (on if too cold; off if too hot at top	All rooms have TRVs. MVHR misunderstood by all occupants and not
A3.2	**Floor area statistics**				
	Gross floor area (m2)	12019	5450	5028	640
	Treated floor area (m2)	11400	4350	5028	640
	Nett floor area (m2)	Not known	3015	5028	415
	Treated:gross ratio	95%	80%	100%	100%
	Nett:gross ratio		55%	100%	65%
	Estimated proportion to cellular offices	NA	40%	8 small offices	90%
	Design m2 nett/person			NA	17
	Actual m2 nett/person			NA	12
	Area comments	Teach & Admin GFA/TFA = 7041/5803 Residential GFA/TFA = 3595/4238	Triple circulation system required for staff/public, magistrates & defendants.	Added mezzanines have an area of 1840 m².	Practice B has retrofitted a 2 person office into the loft space
A3.3	**Unusual areas included above**				
	AC Archive store (m2)	NA	NA	NA	NA
	AC Computer room (m2)	NA	NA	Included with MBO	NA
	AC Comms room (m2)	NA	NA	NA	NA
	Kitchen and dining (m2)	Full restaurant	Small snack bar serving drinks, sandwiches etc.	Staff room with DIY cooking equipment and vending machines.	NA

	TABLE A3: Other Probe buildings - summary of key characteristics	**Cable & Wireless**	**Rotherham Magistrates Courts**	**Marston Book Services Warehouse**	**Woodhouse Medical Centre**
		C&W	**RMC**	**MBW**	**WMC**
	PAGE 2: FABRIC				
A3.4	**Walls**	Block	Block/insulation/facing brick	Blockwork/insulation/facing brick at low level. Liner tray/insulation/ profiled steel cladding	Plaster/blockwork/insulation/facing brick
A3.5	**Windows & natural ventilation**	Double	Double	Double	Double
	Frame type	Aluminium	Aluminium	Aluminium	Wood
	Upper element	Classroom: Motorised high level windows with manual control	Top-hung fanlights in a few locations	Top-hung fanlights.	None
	Main/lower element	Classroom: No low level windows	Side hinged, some centre pivot	Top hung projecting.	Side-hung casement
	Tint/transmission	Some tinting	None	None	None
	Primary solar protection	Teaching: roof overhang and use of translucent Okalux TIM	Relatively small hole-in-wall windows, except in sunspaces.	Few windows, and only at the NW corner.	Relatively small hole-in-wall windows.
	Secondary solar protection and glare control	Translucent motorised roller blinds	Vertical internal blinds in offices: occupants find adjusting difficult, so tend to leave shut.	None.	Internal blinds but primarily used for privacy.
	Cross-ventilation	Buoyancy assisted in teaching areas via wave form roof	From louvres or windows to roof windows in sunspaces.	Only across the corner.	Ideally Cross-vent from windows to rooflights
	Window automation	Motorised high level windows	For inlet louvres and roof windows and outlet louvres in sunspaces used as public circulation/waiting areas only.	No.	None. Velux Rooflights can be operated by poles (not provided)
	How controlled?	Manual wall switch	Temperature, using separate system + pneumatic actuators, by manufacturer	Manual, with supplementary by opening loading doors on N side.	Manual
	Solar gain levels (1=too high, 5=v.gd)	4	3	5	2
A3.6	**Roof and ceilings**	Metal sheet wave form	Pitched slate	Pitched twinwall profiled metal.	Pitched concrete tiles
	Rooflights	Perspex Domes in corridors	To sunspaces	Approx. 10% translucent profile.	To spine corridor
	Ventilation via rooflights?	No, domes are fixed	Yes, motorised louvres+windows	None	Yes design intent. No in practice
	Rooflight solar shading	None	No: area restricted for cost savings	None	None
	Rooflight shading control	NA	None	NA	NA
	Roof daylight available (1=poor,5=vg)	1	2, found to be largely unnecessary	3	3
	Roof useful daylight (1=poor,5=vg)	1	4	3	3
	Ceilings	Exposed (but lightweight)	Partly exposed	Underside of roof liner tray.	Plasterboard under roof trusses
	Ceiling height (m)	3.6 - 5.1	Varies	Up to 8 m	Mainly 2.1m, but up to 4m at ridge
A3.7	**Fabric statistics:**				
	Atrium	No	No, but double height sunspaces	No	No
	Typical depth glass:glass or atrium (m)	Varies, some deep plan	Varies	NA	NA
	Airtightness (5=tight<5, 4=good<10, 3=av'ge<20, 2=high<30, 1=leaky>30	Probably 1	3	4	4
	Measured leakage (m3/m2/hr@50 Pa)	No	17.4	8.9	No
	Comments/observations on leakage	Several direct opening doors cause wind draughts	Toilet ventilators and external doors were quite leaky. No obvious leaks through cracks in the structure etc.		Leakage likely to be low. Wet trades.
	Reception area comfort levels	Reasonable, revolving door on one side. Electric fan convector pillars proved unreliable: portable units are used instead.	Reception desk was fully enclosed for security reasons anyway	Not applicable, reception via adjacent office MBO.	Good. Entrance lobby for each unit.
	Consequences of infiltration levels		NA		MVHR intended to provide winter fresh air
	Quoted wall U-value (W/m2K)	Tchng: 0.35; Res: 0.34-0.37; Leis: 0.26-0.35	0.36	0.39	0.20
	Quoted window U-value (W/m2K)	Probably about 3.5	3.20	3.20	1.60
	Quoted roof U-value (W/m2K)	Teaching: 0.26; Res: 0.19-0.42; Leisure: 0.36	0.23	0.45	0.10
	Quoted floor U-value (W/m2K)	Residential: 0.39	NA	0.15 from CIBSE Guide	0.15
	U-value and infiltration comments	Probably quite a lot of air leakage.	Reasonable insulation. Disappointing airtightness. Some vent. louvres do not shut.	Insulation normal. Infiltration levels relatively good for a UK industrial building.	Super-insulated (350mm in roof, 150mm in walls)
	Insulation score (1=poor,2=ave, 3=good,4=v.gd,5=outstanding)	3	3	2	5

	TABLE A3: Other Probe buildings - summary of key characteristics	**Cable & Wireless**	**Rotherham Magistrates Courts**	**Marston Book Services Warehouse**	**Woodhouse Medical Centre**
		C&W	**RMC**	**MBW**	**WMC**
	PAGE 3: HEATING, HOT WATER AND MECHANICAL COOLING				
A3.8	**Heating**				
	Gas boilers	High efficiency	Cast iron atmospheric with fan assisted flues (idle heat losses)	NO: suspended unit warm air heaters and destrat fans.	Domestic Trisave Turbo 30 condensing gas boiler in each surgery
	Condensing?	No	No	No	Yes
	Number of boilers	Site exc leisure:24; Leisure: 6	4	10	3
	Capacity of each boiler (kW output)	50	200	50	10
	Boiler power W/m2 treated	Site exc leisure:120 Leisure incl. for swimming pool: 230	184	99	47
	Power score (1=hi>150,2=ave>100, 3=gd>70,4=v.gd>40,5=exclnt<40)	2	1	3	4
	Heat emitters	Generally: perimeter radiators Sports hall: underfloor.	Perimeter radiators plus air tempering.	Fan assisted convection from the unit heaters.	Perimeter radiators
	Heating compensation control	Yes	Separately-compensated north and south zones.	NA	No
	Local heating control trim	Each residential block can be isolated by 3 port valve	Manual wheelhead valves only	Switches and thermostats, usually operated by supervisor.	Individual TRVs
	Heating operation	Heating in all zones to 21 oC 05.30 to 24.00			One practice operates boilers on low thermostat setting for 24 hrs, the other uses 7 day timer. Very little difference between the two.
	Typical LPHW circulating hours per yr	Site exc leisure:6570	1500	NA: Typical fan hours 750	Between 1000 and 2000 hrs
	Heating issues and problems	Underheating in East block of classrooms. Missed opportunity for CHP or condensing boilers	High local infiltration observed in one area owing to sticking of automated natural ventilation inlet louvres.	Stratification (forklift drivers) and poor distribution around and under the mezzanine.	Seems to be tendency for low temps on Mon morning
A3.9	**Domestic hot water**				
	HWS generation	Central calorifiers for kitchen, residential and leisure. Toilets local electric.	25 local electric storage water heaters of various capacities distributed about the building and on 24 hrs until recently.	Supplied from electric heaters in adjacent offices.	From total of 27 local electric undersink heaters
	HWS distribution	Pumped local circulation from calorifiers. Water temps found to be ideal.	Local	Local from the electric heaters.	Point of use
	HWS issues and problems	None recorded	Time switches have been fitted to the electric HWS		None of the heaters have time controls. Handwashing only, actual consumption is probably very low
A3.10	**Mechanical cooling plant**				
	Cooling system	Packaged Carrier	Chilled water system for AHU coils.	NA	None
	Number of water chillers	1	1	NA	NA
	Capacity of each chiller (kW)	47	204	NA	NA
	Chiller W/m2 treated	Treated area not recorded	70 (assuming approx. 3000 m^2 treated)	NA	NA
	Chiller type	Reciprocating	Packaged air cooled reciprocating	NA	NA
	Heat rejection	Air cooled	Air cooled	NA	NA
	Chilled water operating hours per yr	4200	350	NA	NA
	Chiller management	ChW 'left to look after itself'			NA
	Other comments on cooling	No interlock to prevent simultaneous heating and cooling	Cross-flow heat exchangers not by-passable in summer for the 5 plants with cooling coils. 15 DX split units retrofitted in offices locally controlled and permanently enabled.	NA	NA

	TABLE A3: Other Probe buildings - summary of key characteristics	**Cable & Wireless**	**Rotherham Magistrates Courts**	**Marston Book Services Warehouse**	**Woodhouse Medical Centre**
		C&W	**RMC**	**MBW**	**WMC**
	PAGE 4: MECHANICAL VENTILATION				
A3.11	**Mechanical ventilation**				
	Type (for NV buildings, comments for specific systems in italics)	Not for classrooms. *Local systems for kitchen, pool etc.*	Concurrent mixed mode system: mech.vent running and windows openable	Naturally-ventilated (but limited ventilation facilities).	Naturally ventilated with domestic MVHR for winter fresh air.
	Ventilation system	*NA*	Constant volume	Mechanical vent to toilets only	MVHR
	Specific fan power (W/(l/s)): max	*NA*	3.8	NA	Unknown
	Specific fan power (W/(l/s)): average	*NA*	3.8	NA	Unknown
	SFP score (1=poor>3.5,2=ave>2.5, 3=good>1.5,4=v.gd>1,5=exlnt<1)	*NA*	1	NA	Unknown
	Fan speed control method	*NA*	None	NA	2 speed manual
	Supply from	*NA*	Largely displacement terminals	NA	ceiling diffusers
	Return via	*NA*	Ceiling and high level	NA	grilles
	Typical air change rate (ac/h)	*NA*	4.5	NA	Fresh air ONLY
					NA
	Fresh air proportion	*NA*	100%	NA	100%
	Heat recovery	*NA*	Cross-flow heat exchangers in all seven AHUs (by-passes in two only)	NA	Cross flow but no by-pass
	Typical ventilation hours per year	*NA*	2850	NA	Thought to be continuous
	Humidification (none fitted in these	*None*	None	NA	None
	Night cooling facilities for principal spaces	Not used but BSRIA study said it would reduce overheating in the classrooms.	No. Chilled water coils incorporated in 5 of the 7 AHUs for top cooling in warm weather.	NA	Not used. Security risk prevents leaving windows & rooflights open
		Large amount of condensation in highly glazed pool hall at night when vent not running.	Despite low occupancy levels it is not possible to disable ventilation in unoccupied court rooms		Tendency for summer overheating - especially in waiting rooms. Some occupants thought MVHR was for cooling. No means to open Velux roof lights.
		Operate pool hall vent 24 hours	None		Practice A has installed split DX wall units for summer cooling
		Condensation problem solved	NA		improved comfort in treated rooms
	Other comments				Summer overheating and ac response largely due to poor explanation of design intent.
A3.12	**Controls and BMS**				
	BMS present	No	Yes	No: switches and stats only	NO
	Occupier has head end	NA	In main office, but only small display	NA	NA
		NA	Building supervisor		NA
	Occupier technically knowledgeable	Fair	No	NA	NA
	BMS effectiveness rating (5=v.good)	NA	2	NA	NA
			Used only for alarm monitoring		NA
			None		Heating is on 7 day timer, MVHR is on manual switch

	TABLE A3: Other Probe buildings - summary of key characteristics	**Cable & Wireless**	**Rotherham Magistrates Courts**	**Marston Book Services Warehouse**	**Woodhouse Medical Centre**
		C&W	**RMC**	**MBW**	**WMC**
	PAGE 5: LIGHTING				
A3.13	**Main lighting**				
	Main lamp type	36W T8 fluorescent	T8 fluorescent	150W and 250W SON	9W CFL, 24W PL-L, 300W torchieres
	Control gear type	High frequency	Conventional	Conventional ballasts	Conventional
	Main luminaire type	Suspended twin lamp	Suspended up/downligher in offices, recessed+surf in courts.	Suspended high-bay downlighters.	Translucent bulkhead.
	Other luminaires	CFLs + LV 20W halogen in corridors, reception and library	Wide variety, (60 types) mostly CFL.	T8 fluorescent twin-tube trough reflector fittings under the mezzanines.	Some recessed 100W GLS in Dentist's practice
	Lighting installed power (W/m2 design)	15	Not stated	4.7	5
	Lighting installed power (W/m2 actual)	17.0	11 average (but some offices up to 20)	5.0	8
	Installed power score (1=poor>20, 2=ave>15,3=good>12,4=v.gd>10, 5=excellent<10)	2	4	5, but warehouse standards are lower than office ones owing to lower illuminance levels and SON	5
	Typical artificial illuminance level (lux)	300	Variable, typically about 300	200	200
	Typical W/m2 per 100 lux	5.7	3.7	2.5	4
	Average full load lighting hours per yr	3300	Varies greatly with areas	5250	2500
	Central lighting control	Manual throughout. Lighting control system in leisure centre disabled	None	None: time switched on each day (to allow for run-up) and off by supervisor.	None
	Local lighting control	Local manual switches	Conventional: layout unsystematic	None	Wall switches
	Lighting ctrl score (1=poor,2=ave, 3=good,4=v.gd,5=outstanding)	1	2	1	2
	Occupancy sensing	No	No	None	None
	Daylight linking & photoelectric control	Manual	No	No	None
	Circulation lighting use	Wasteful manual	Random. Quite often on. Some internal.	Same as main lighting.	Same as main lighting.
		Leisure centre has complex controller which is manually overridden	Internal switching of lights in courtrooms and elsewhere appears randomly wired		Manual lighting controls
			None		All 3 practices added artificial lighting . Practice A chose 300 W uplighters.
		Reasonable	Generally poor		Artificial lighting is normally required due to poor daylight
	Daylight potential (1=poor,5=v.good)	2	5 in sunspaces, 3 elsewhere	3	2
		Extensive use of the internal blinds	Vertical blinds for use by occupants		Very little glare
	Daylight utilisation(1=poor,5=v.good)	1	3 in sunspaces, 2 elsewhere	2	1
	Reason for non-optimal daylight utilisation (if it occurs)	Needs some automatic controls as the visiting occupants on courses feel no ownership of the spaces.	Little management overseeing of switching in public areas. Blinds often closed in offices.	Rather lumpy control by supervisor. Shadows under mezzanines. Rooflight not well distributed onto racking.	Most side windows are into consulting rooms. Blinds drawn for privacy.

	TABLE A3: Other Probe buildings - summary of key characteristics	**Cable & Wireless**	**Rotherham Magistrates Courts**	**Marston Book Services Warehouse**	**Woodhouse Medical Centre**
		C&W	**RMC**	**MBW**	**WMC**
	PAGE 6: IT AND ELECTRICAL				
A3.14	**Office equipment heat gains:**				
	Office equipment gain (W/m2 design)	Not known	Not known	NA	Not known
	Boosted internal gain design capability	NA	Not known	NA	Not known
	Means of boosting	NA	Local DX air conditioners added.	NA	Local DX added in Practice A
	Office equipment gain (W/m2 actual)	2	Not known - but quite low	NA	4
	Average gains as percent of design	NA	None	NA	
	Local heat gain pockets	Significant in some classrooms and laboratories	One or two admin areas on west side	NA	Large vintage photocopier and torchieres.
A3.15	**Computer and communications rooms**				
	Computer room present	No	No, but terminals stay on constantly	Yes, but fed from office and recorded there, see MBO	None
	Air conditioning type	NA	NA	NA	NA
	Room units	NA	NA	NA	NA
	Communications room	NA	NA	NA	NA
	Comms room AC	NA	NA	NA	NA
A3.16	**Other electrical items**				
	Standby generator type/kVA	2 sets of batteries for essential loads	Diesel, 250 kVA (staff reckon this is 3 x too big for essential services)	No	None
				Compressed air plant for packing line duties operating rather wastefully	
				Packing line motors tend to run constantly during main daytime shift.	
				Much of the "other" electricity is used by the fork lift trucks.	

	TABLE A3: Other Probe buildings - summary of key characteristics	**Cable & Wireless**	**Rotherham Magistrates Courts**	**Marston Book Services Warehouse**	**Woodhouse Medical Centre**
		C&W	**RMC**	**MBW**	**WMC**
	PAGE 7: MAINTENANCE AND UTILITIES				
A3.17	**Building services maintenance**				
	Site team	Yes	No	No	No
			NA		
	Use of Contractor	Yes	Yes, routine visits plus call-out.	Good local contractors on call-out.	Boiler maintenance
	Energy management	Negligible	Very little	No	No
		Not recorded	3.00		NA
		Not recorded	reasonable		None
		Aesthetic screens for freezer condensers restricted cooling air flow	None		MVHR seems to have been run continuously to destruction
		None	None		
		None	None		
A3.18	**Fuel metering and average energy cost rates**				
		None	None		Each practice is separate
	Electricity unit cost ex VAT (p/kWh)	5.30	5.31	3.76	8
	Gas unit cost ex VAT (p/kWh)	1.07	1.03	1.49	1.5
	Probe metering comments	Probe team found gas metering inconsistency had not been picked up owing to long time between readings.	Many bills were on estimated readings. RMC were sure that more had been taken. After some effort, Probe got more hard readings from Transco.	Gas bill is nearly all estimated. Two extra readings were obtained after much research! On domestic gas tariff!	Each practice is on a domestic tariff
A3.19	**Water consumption and cost**				
	Annual metered consumption (m3)	Not collected	550	1550	Not none
	Annual water costs (if known)		Not available	Not available	Not none
	Annual water costs £/m2 treated		NA	NA	Not none
	Ave costs £/m3 including sewerage		NA	NA	Not none
	Attributable number of people		55	120	Not none
	Type of people attributed		Average staff and magistrates	Office+warehouse including shifts	Not none
	Usage per person (m3/yer per person)		10.0	12.9	Not none
	Annual cost per person (£/person)		NA	NA	Not none
	High benchmark (m3/yr per person)				Not none
	Typical benchmark (m3/yr per person)		10	12	Not none
	Low benchmark (m3/yr per person)				Not none
	Benchmark source		BRE	BRE office toolkit with MBW/MBO characteristics input.	Not none
	Water consumption comment		Good, given that facilities are also used by the public etc.		Not none

APPENDIX B

Energy and CO_2 emissions data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	**TABLE B1: BREAKDOWN OF ANNUAL ENERGY CONSUMPTION - ALL PROBE BUILDINGS**																		**kWh/m2 of treated floor area by fuel**				
2	WITH ENERGY BENCHMARKS FROM THE 1991 EDITION OF ENERGY CONSUMPTION GUIDE 19 (ECON 19)																						
3																							
4	Normalised heating & hot water for graphs corrected to 2462 degree days (15.5°C base) per year (not C&W and Marston Warehouse). Simple correction used unless in bold.	1 Aldermanbury Square AC+	HFS Gardner House AC	Tanfield House AC+	Co-op Retail Services AC+	ECON 19/91 Typ 4 Prestige AC >>	Cheltenham & Gloucester AC	ECON 19/91 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Cable & Wireless ANV+	Charities Aid Foundation MM	One Bridewell Street AC >>	ECON 19/91 Typ 2 Open NV >>	Marston Books Office ANV	Elizabeth Fry Building MM	de Montfort Queens Building ANV	Marston Books Warehouse NV	ECON 19/91 GP 2 Open NV >>	Portland Building ANV+	Woodhouse Medical Centre NV+	John Cabot CTC ANV	APU Queens Building ANV	ECON 19/91 GP 1 cellular NV >>
5																							
6	**GAS:**																						
7	Total actual gas	117	253	331	118		101		142	400	151	53		113	35	127			100		98	115	
8	Heating and hot water gas	106	253	242	103		61		142	374	151	53		113	35	127			100		98	104	
9	Degree days	1800	2237	2559	1980		1620		2332		2253	1799		2061	2312	2206	2061		1896		1717	2531	
10	Simple normalisation (Htg/HW	145	278	233	128		93		150		165	73		135	37	142			130		141	101	
11	Heating+hot water gas (norma	145	**271**	233	**125**	259	95	124	150	374	165	**70**	200	135	37	**143**	51	95	130	49	**130**	**97**	95
12	Gas for catering	11	0	9	15	14	8	8		26												11	
13	Gas for humidification	Electric	Electric	80	Electric	Not included	32	Not included	None	None	None	None	Not included	None	None	None	None	Not included	None	None	None	None	Not included
14																							
15	**ELECTRICITY:**																						
16	Heating and hot water - electricity	10	6	5	4.5	Included	6	Included	10	4	10.5	2		6	2	1	3		0	17	9		
17	Refrigeration and heat rejection	42	40	23	8.6	41	15	24	5	8	1.0	12			0				5		3		
18	Fans, pumps and controls	140	87	102	38.3	69	53	45	44	10	26.7	19	6	13	19	6	3	5	15		5	11	3
19	Electric humidification	35	38	Gas	47.7	Not included	Gas	Not included			None												
20	Lighting	50	63	73	97.3	82	71	47	17	50	26.3	30	53	30	28	37	31	32	14	14	12	16	16
21	Office equipment	20	21	45	53.9	29	28	29	7	3	14.6	8	16	23	8	11	5	16	11	10	10	5	11
22	Catering and vending	14	8	24	28.7	14	16	12	3	25	4.7	5	5	4	3	1	1	4	3	3	4	8	3
23	Other	20	13	10	11.4	20	15	16	17	29	9.2	7	5	6	2	4	3	4	2	6	8	8	4
24	Computer room (including A/C)	None	44	Separate	157.1	106	160	88	None	None	23.7	None	None	60	None	None	None	None	None	None	None	None	None
25	Communications/IT rooms (in	40	Above	24	Incl	Incl	6	Incl				3									7		
26	transmitter etc, MBW									59							11						
27																							
28	**TOTALS** (for sorting):																						
29	**Total gas**	**156**	**271**	**322**	**140**	**273**	**135**	**132**	**150**	**400**	**165**	**70**	**200**	**135**	**37**	**143**	**51**	**95**	**130**	**49**	**130**	**108**	**95**
30	**Total electricity**	**371**	**321**	**305**	**448**	**361**	**370**	**261**	**103**	**188**	**117**	**86**	**85**	**142**	**62**	**60**	**58**	**61**	**49**	**50**	**58**	**48**	**37**
31	**Electricity for building services** (sort category)	277.0	234.5	202.5	196.4	192.0	145.5	116.0	75.5	72.0	64.5	63.0	59.0	49.1	48.9	44.0	38.0	37.0	33.7	31.0	28.9	27.0	19.0
32																							
33																							
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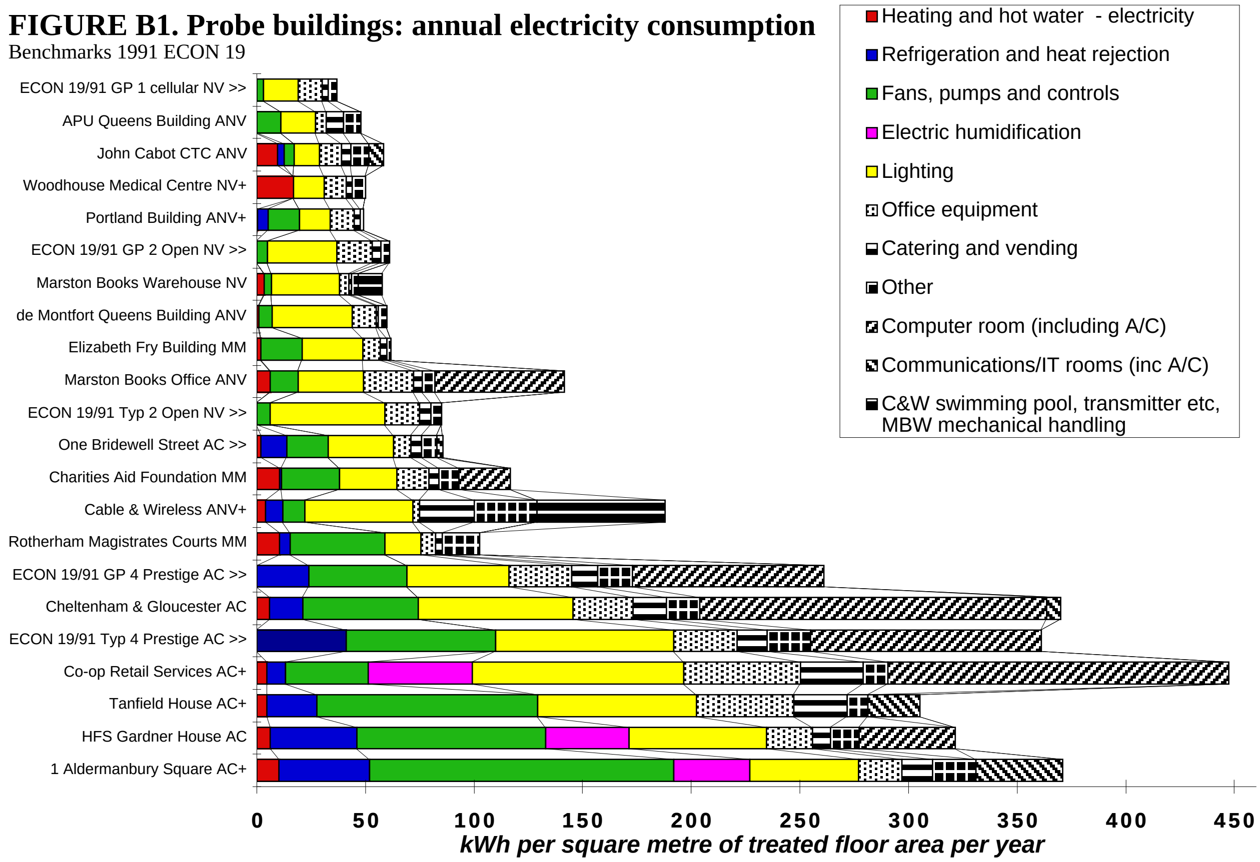


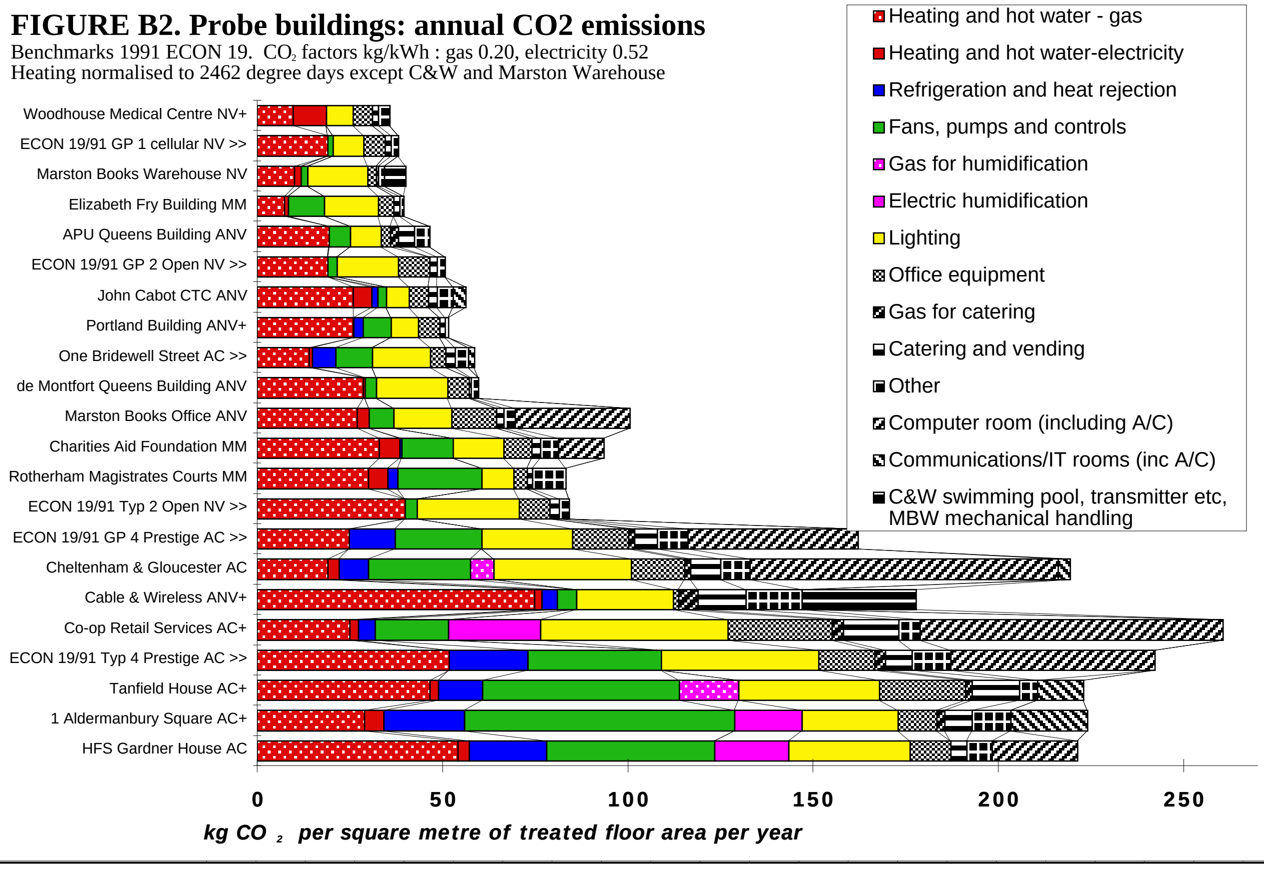
FIGURE B1. Probe buildings: annual electricity consumption

Benchmarks 1991 ECON 19

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
96	**TABLE B2: SORTED ELECTRICITY CONSUMPTION AND ANNUAL CARBON DIOXIDE EMISSIONS**																	**kg CO2/m2 of treated floor area per year**					
97	WITH ENERGY BENCHMARKS FROM THE 1991 EDITION OF ENERGY CONSUMPTION GUIDE 19 (ECON 19) AND CO2 CONVERSION FACTORS FROM THE 1998 EDITION																						
98	*CONVERSION FACTORS (kg/kWh)*			***Gas:***	*0.20*		***Electricity:***		*0.52*														
99	**Sorted in order of annual electricity consumption for normal building services only**	1 Aldermanbury Square AC+	HFS Gardner House AC	Tanfield House AC+	Co-op Retail Services AC+	ECON 19/91 Typ 4 Prestige AC >>	Cheltenham & Gloucester AC	ECON 19/91 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Cable & Wireless ANV+	Charities Aid Foundation MM	One Bridewell Street AC >>	ECON 19/91 Typ 2 Open NV >>	Marston Books Office ANV	Elizabeth Fry Building MM	de Montfort Queens Building ANV	Marston Books Warehouse NV	ECON 19/91 GP 2 Open NV >>	Portland Building ANV+	Woodhouse Medical Centre NV+	John Cabot CTC ANV	APU Queens Building ANV	ECON 19/91 GP 1 cellular NV >>
100																							
101	Heating and hot water - gas	29.0	54.2	46.6	25.0	51.8	19.0	24.8	30.0	74.8	33.0	14.0	40.0	27.0	7.4	28.6	10.1	19.0	26.0	9.8	26.0	19.4	19.0
102	Heating and hot water-electric	5.2	3.1	2.4	2.3		3.1		5.4	2.1	5.5	1.0	0.0	3.2	1.0	0.5	1.8	0.0	0.1	8.8	4.9	0.0	0.0
103	Refrigeration and heat rejectic	21.8	20.9	11.9	4.5	21.3	8.0	12.5	2.7	4.2	0.5	6.2	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	1.6	0.0	0.0
104	Fans, pumps and controls	72.8	45.2	53.0	19.9	35.9	27.6	23.4	22.7	5.2	13.9	9.9	3.1	6.8	9.9	3.1	1.8	2.6	7.5	0.0	2.5	5.7	1.6
105	Gas for humidification			16.0			6.4																
106	Electric humidification	18.2	20.0		24.8				0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
107	Lighting	26.0	32.8	38.0	50.6	42.6	37.1	24.4	8.6	26.0	13.7	15.6	27.6	15.6	14.6	19.2	16.2	16.6	7.3	7.3	6.0	8.3	8.3
108	Office equipment	10.4	11.0	23.3	28.0	15.1	14.4	15.1	3.6	1.6	7.6	4.2	8.3	12.0	4.2	5.7	2.3	8.3	5.7	5.2	5.2	2.6	5.7
109	Gas for catering	2.2	0.0	1.8	3.0	2.8	1.6	1.6	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0
110	Catering and vending	7.3	4.4	12.7	14.9	7.3	8.1	6.2	1.5	13.0	2.4	2.5	2.6	2.1	1.6	0.5	0.6	2.1	1.6	1.6	2.3	4.2	1.6
111	Other	10.4	6.9	5.0	5.9	10.4	8.0	8.3	9.0	15.1	4.8	3.6	2.6	3.0	1.0	2.1	1.7	2.1	0.8	3.1	4.4	4.2	2.1
112	Computer room (including A/C)		22.9		81.7	55.1	83.1	45.8			12.3			30.9									
113	Communications/IT rooms (in	20.8		12.4			3.3		0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0
114	C&W swimming pool, transmit	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0
115																							
116	**TOTALS** (for sorting):																						
117	Total CO2 from gas	**31**	**54**	**64**	**28**	**55**	**27**	**26**	**30**	**80**	**33**	**14**	**40**	**27**	**7**	**29**	**10**	**19**	**26**	**10**	**26**	**22**	**19**
118	Total CO2 from electricity	**193**	**167**	**159**	**233**	**188**	**192**	**136**	**53**	**98**	**61**	**45**	**44**	**74**	**32**	**31**	**30**	**32**	**26**	**26**	**30**	**25**	**19**
119	Total CO2 from both	*224*	*221*	*223*	*261*	*242*	*219*	*162*	*83*	*178*	*94*	*59*	*84*	*101*	*40*	*60*	*40*	*51*	*52*	*36*	*56*	*47*	*38*
120	**CO2 from building services**	**173**	**176**	**168**	**127**	**152**	**101**	**85**	**69**	**112**	**67**	**47**	**71**	**53**	**33**	**51**	**30**	**38**	**44**	**26**	**41**	**33**	**29**
121																							
122	**Sorted in order of annual carbon dioxide emissions from gas and electricity used for normal building services only**	HFS Gardner House AC	1 Aldermanbury Square AC+	Tanfield House AC+	ECON 19/91 Typ 4 Prestige AC	Co-op Retail Services AC+	Cable & Wireless ANV+	Cheltenham & Gloucester AC	ECON 19/91 GP 4 Prestige AC >>	ECON 19/91 Typ 2 Open NV >>	Rotherham Magistrates Courts MM	Charities Aid Foundation MM	Marston Books Office ANV	de Montfort Queens Building ANV	One Bridewell Street AC >>	Portland Building ANV+	John Cabot CTC ANV	ECON 19/91 GP 2 Open NV >>	APU Queens Building ANV	Elizabeth Fry Building MM	Marston Books Warehouse	ECON 19/91 GP 1 cellular NV >>	Woodhouse Medical Centre NV+
123																							
124	Heating and hot water - gas	54	29	47	52	25	75	19	25	40	30	33	27	29	14	26	26	19	19	7	10	19	10
125	Heating and hot water-electric	3	5	2	0	2	2	3	0	0	5	5	3	1	1	0	5	0	0	1	2	0	9
126	Refrigeration and heat rejectic	21	22	12	21	4	4	8	12	0	3	1	0	0	6	3	2	0	0	0	0	0	0
127	Fans, pumps and controls	45	73	53	36	20	5	28	23	3	23	14	7	3	10	8	2	3	6	10	2	2	0
128	Gas for humidification	0	0	16	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
129	Electric humidification	20	18	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
130	Lighting	33	26	38	43	51	26	37	24	28	9	14	16	19	16	7	6	17	8	15	16	8	7
131	Office equipment	11	10	23	15	28	2	14	15	8	4	8	12	6	4	6	5	8	3	4	2	6	5
132	Gas for catering	0	2	2	3	3	5	2	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0
133	Catering and vending	4	7	13	7	15	13	8	6	3	2	2	2	1	2	2	2	2	4	2	1	2	2
134	Other	7	10	5	10	6	15	8	8	3	9	5	3	2	4	1	4	2	4	1	2	2	3
135	Computer room (including A/C	23	0	0	55	82	0	83	46	0	0	12	31	0	0	0	0	0	0	0	0	0	0
136	Communications/IT rooms (in	0	21	12	0	0	0	3	0	0	0	0	0	0	2	0	3	0	0	0	0	0	0
137	C&W swimming pool, transmit	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
138												0			0								
139	**TOTALS (for sorting):**											0			0								
140	Total CO2 from gas	**54**	**31**	**64**	**55**	**28**	**80**	**27**	**26**	**40**	**30**	**33**	**27**	**29**	**14**	**26**	**26**	**19**	**22**	**7**	**10**	**19**	**10**
141	Total CO2 from electricity	**167**	**193**	**159**	**188**	**233**	**98**	**192**	**136**	**44**	**53**	**61**	**74**	**31**	**45**	**26**	**30**	**32**	**25**	**32**	**30**	**19**	**26**
142	Total CO2 from both	*221*	*224*	*223*	*242*	*261*	*178*	*219*	*162*	*84*	*83*	94	*101*	*60*	59	*52*	*56*	*51*	*47*	*40*	*40*	*38*	*36*
143	**CO2 from building services**	176.1	173.0	167.9	151.6	127.1	112.2	101.1	85.1	70.7	69.3	67	52.5	51.5	47	43.5	41.0	38.2	33.4	32.8	29.9	28.9	25.9

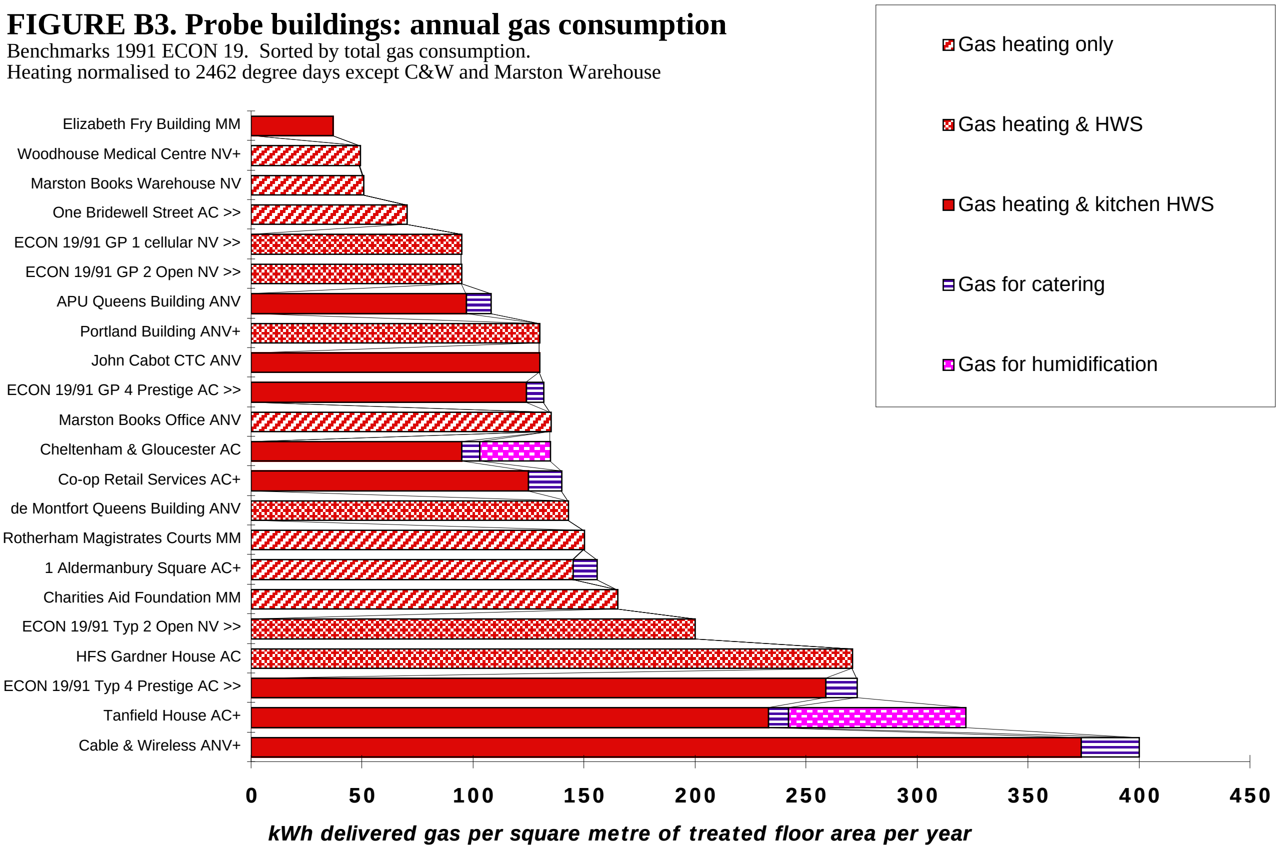
FIGURE B2. Probe buildings: annual CO2 emissions

Benchmarks 1991 ECON 19. CO_2 factors kg/kWh : gas 0.20, electricity 0.52
Heating normalised to 2462 degree days except C&W and Marston Warehouse



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
194	**TABLE B3: ANNUAL GAS CONSUMPTION**																						**kWh/m2 of treated floor area by fuel**
195	WITH ENERGY BENCHMARKS FROM THE 1991 EDITION OF ENERGY CONSUMPTION GUIDE 19 (ECON 19)																						
196																							
197	Normalised heating & hot water for graphs corrected to 2462 degree days (15.5°C base) per year (not C&W and Marston Warehouse). Simple correction used unless in bold.	1 Aldermanbury Square AC+	HFS Gardner House AC	Tanfield House AC+	Co-op Retail Services AC+	ECON 19/91 Typ 4 Prestige AC >>	Cheltenham & Gloucester AC	ECON 19/91 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Cable & Wireless ANV+	Charities Aid Foundation MM	One Bridewell Street AC >>	ECON 19/91 Typ 2 Open NV >>	Marston Books Office ANV	Elizabeth Fry Building MM	de Montfort Queens Building ANV	Marston Books Warehouse NV	ECON 19/91 GP 2 Open NV >>	Portland Building ANV+	Woodhouse Medical Centre NV+	John Cabot CTC ANV	APU Queens Building ANV	ECON 19/91 GP 1 cellular NV >>
198																							
199	Total actual gas	117	253	331	118	0	101	0	142	400	151	53	0	113	35	127	0	0	100	0	98	115	0
200	Heating and hot water gas	106	253	242	103	0	61	0	142	374	151	53	0	113	35	127	0	0	100	0	98	104	0
201	Degree days	1800	2237	2559	1980	0	1620	0	2332	0	2253	1799	0	2061	2312	2206	2061	0	1896	0	1717	2531	0
202	Simple normalisation (Htg/HWS)	145	278	233	128	0	93	0	150	0	165	73	0	135	37	142	0	0	130	0	141	101	0
203	Heating+hot water gas (normalised)	145	271	233	125	259	95	124	150	374	165	70	200	135	37	143	51	95	130	49	130	97	95
204	Gas heating only	145							150		165	70		135			51			49			
205	Gas heating & HWS		271										200			143		95	130				95
206	Gas heating & kitchen HWS			233	125	259	95	124		374					37						130	97	
207	Gas for catering	11	0	9	15	14	8	8	0	26	0	0	0	0	0	0	0	0	0	0	0	11	0
208	Gas for humidification			80			32																
209	Total corrected gas	156	271	322	140	273	135	132	150	400	165	70	200	135	37	143	51	95	130	49	130	108	95
210																							
211	Sorted in order of annual gas consumption for graph	Cable & Wireless ANV+	Tanfield House AC+	ECON 19/91 Typ 4 Prestige AC >>	HFS Gardner House AC	ECON 19/91 Typ 2 Open NV >>	Charities Aid Foundation MM	1 Aldermanbury Square AC+	Rotherham Magistrates Courts MM	de Montfort Queens Building ANV	Co-op Retail Services AC+	Cheltenham & Gloucester AC	Marston Books Office ANV	ECON 19/91 GP 4 Prestige AC >>	John Cabot CTC ANV	Portland Building ANV+	APU Queens Building ANV	ECON 19/91 GP 2 Open NV >>	ECON 19/91 GP 1 cellular NV >>	One Bridewell Street AC >>	Marston Books Warehouse NV	Woodhouse Medical Centre NV+	Elizabeth Fry Building MM
212		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	Total actual gas	400	331	0	253	0	151	117	142	127	118	101	113	0	98	100	115	0	0	53	0	0	35
214	Heating and hot water gas	374	242	0	253	0	151	106	142	127	103	61	113	0	98	100	104	0	0	53	0	0	35
215	Degree days	0	2559	0	2237	0	2253	1800	2332	2206	1980	1620	2061	0	1717	1896	2531	0	0	1799	2061	0	2312
216	Simple normalisation (Htg/HW	0	233	0	278	0	165	145	150	142	128	93	135	0	141	130	101	0	0	73	0	0	37
217	Heating+hot water gas (norma	374	233	259	271	200	165	145	150	143	125	95	135	124	130	130	97	95	95	70	51	49	37
218	Gas heating only	0	0	0	0	0	165	145	150	0	0	0	135	0	0	0	0	0	0	70	51	49	0
219	Gas heating & HWS	0	0	0	271	200	0	0	0	143	0	0	0	0	0	130	0	95	95	0	0	0	0
220	Gas heating & kitchen HWS	374	233	259	0	0	0	0	0	0	125	95	0	124	130	0	97	0	0	0	0	0	37
221	Gas for catering	26	9	14	0	0	0	11	0	0	15	8	0	8	0	0	11	0	0	0	0	0	0
222	Gas for humidification	0	80	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0
223	Total corrected gas	400	322	273	271	200	165	156	150	143	140	135	135	132	130	130	108	95	95	70	51	49	37
224																							
225																							

226
227 **FIGURE B3. Probe buildings: annual gas consumption**
228
229 Benchmarks 1991 ECON 19. Sorted by total gas consumption.
230 Heating normalised to 2462 degree days except C&W and Marston Warehouse

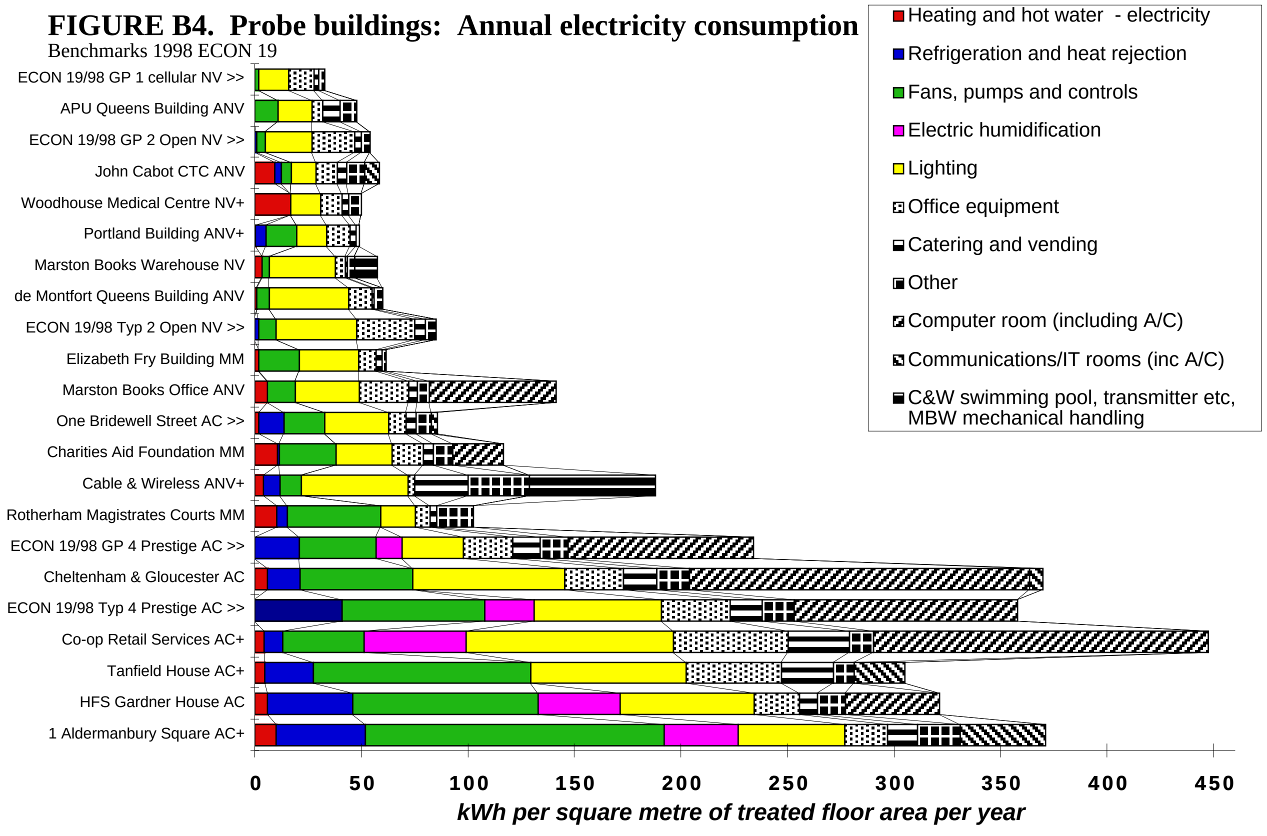


231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	**TABLE B4: BREAKDOWN OF ANNUAL ENERGY CONSUMPTION - ALL PROBE BUILDINGS**																	**kWh/m2 of treated floor area by fuel**						
2	WITH ENERGY BENCHMARKS FROM THE 1998 EDITION OF ENERGY CONSUMPTION GUIDE 19 (ECON 19)																							
3																								
4	Normalised heating & hot water for graphs corrected to 2462 degree days (15.5°C base) per year (not C&W and Marston Warehouse). Simple correction used unless in bold.	1 Aldermanbury Square AC+	HFS Gardner House AC	Tanfield House AC+	Co-op Retail Services AC+	ECON 19/98 Typ 4 Prestige AC >>	Cheltenham & Gloucester AC	ECON 19/98 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Cable & Wireless ANV+	Charities Aid Foundation MM	One Bridewell Street AC >>	Marston Books Office ANV	Elizabeth Fry Building MM	ECON 19/98 Typ 2 Open NV >>	de Montfort Queens Building ANV	Marston Books Warehouse NV	Portland Building ANV+	Woodhouse Medical Centre NV+	John Cabot CTC ANV	ECON 19/98 GP 2 Open NV >>	APU Queens Building ANV	ECON 19/98 GP 1 cellular NV >>	
5																								
6	**GAS:**																							
7	Total actual gas	117	253	331	118		101		142	400	151	53	113	35		127		100		98		115		
8	Heating and hot water gas	106	253	242	103		61		142	374	151	53	113	35		127		100		98		104		
9	Degree days	1800	2237	2559	1980		1620		2332		2253	1799	2061	2312		2206	2061	1896		1717		2531		
10	Simple normalisation (Htg/HW	145	278	233	128		93		150		165	73	135	37		142		130		141		101		
11	Heating+hot water gas (norm	145	**271**	233	**125**	201	95	107	150	374	165	**70**	135	37	151	**143**	51	130	49	**130**	79	**97**	79	
12	Gas for catering	11	0	9	15	9	8	7		26												11		
13	Gas for humidification	Electric	Electric	80	Electric	Not in-cluded	32	Not in-cluded	None	None	None	None	None	None	Not included	None	None	None	None	None	Not in-cluded	None	Not in-cluded	
14																								
15	**ELECTRICITY:**																							
16	Heating and hot water - electricity	10	6	5	4.5	Included	6	Included	10	4	10.5	2	6	2		1	3	0	17	9				
17	Refrigeration and heat rejection	42	40	23	8.6	41	15	21	5	8	1.0	12		0	2			5		3	1			
18	Fans, pumps and controls	140	87	102	38.3	67	53	36	44	10	26.7	19	13	19	8	6	3	15		5	4	11	2	
19	Electric humidification	35	38	Gas	47.7	23	Gas	12			None													
20	Lighting	50	63	73	97.3	60	71	29	17	50	26.3	30	30	28	38	37	31	14	14	12	22	16	14	
21	Office equipment	20	21	45	53.9	32	28	23	7	3	14.6	8	23	8	27	11	5	11	10	10	20	5	12	
22	Catering and vending	14	8	24	28.7	15	16	13	3	25	4.7	5	4	3	5	1	1	3	3	4	3	8	2	
23	Other	20	13	10	11.4	15	15	13	17	29	9.2	7	6	2	5	4	3	2	6	8	4	8	3	
24	Computer room (including A/C)	None	44	Separate	157	105	160	87	None	None	23.7	None	60	None	None	None	None	None	None	None	None	None	None	
25	Communications/IT rooms (in	40	Above	24	Incl	Incl	6	Incl				3								7				
26	transmitter etc, MBW									59							11							
27																								
28	**TOTALS** (for sorting):																							
29	**Total gas**	**156**	**271**	**322**	**140**	**210**	**135**	**114**	**150**	**400**	**165**	**70**	**135**	**37**	**151**	**143**	**51**	**130**	**49**	**130**	**79**	**108**	**79**	
30	**Total electricity**	**371**	**321**	**305**	**448**	**358**	**370**	**234**	**103**	**188**	**117**	**86**	**142**	**62**	**85**	**60**	**58**	**49**	**50**	**58**	**54**	**48**	**33**	
31	**Electricity for building services** (sort category)	277.0	234.5	202.5	196.4	191.0	145.5	98.0	75.5	72.0	64.5	63.0	49.1	48.9	48.0	44.0	38.0	33.7	31.0	28.9	27.0	27.0	16.0	
32																								
33																								
34																								
35																								

FIGURE B4. Probe buildings: Annual electricity consumption

Benchmarks 1998 ECON 19



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
101	**TABLE B5: SORTED ELECTRICITY CONSUMPTION AND ANNUAL CARBON DIOXIDE EMISSIONS**																	**kg CO2/m2 of treated floor area per year**						
102	WITH ENERGY BENCHMARKS AND CO2 CONVERSION FACTORS FROM THE 1998 EDITION OF ENERGY CONSUMPTION GUIDE 19 (ECON 19)																							
103	*CONVERSION FACTORS (kg/kWh)*			***Gas:***	*0.20*		***Electricity:***		*0.52*															
104																								
105	**Sorted in order of annual electricity consumption for normal building services only**	1 Aldermanbury Square AC+	HFS Gardner House AC	Tanfield House AC+	Co-op Retail Services AC+	ECON 19/98 Typ 4 Prestige AC >>	Cheltenham & Gloucester AC	ECON 19/98 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Cable & Wireless ANV+	Charities Aid Foundation MM	One Bridewell Street AC >>	Marston Books Office ANV	Elizabeth Fry Building MM	ECON 19/98 Typ 2 Open NV >>	de Montfort Queens Building ANV	Marston Books Warehouse NV	Portland Building ANV+	Woodhouse Medical Centre NV+	John Cabot CTC ANV	ECON 19/98 GP 2 Open NV >>	APU Queens Building ANV	ECON 19/98 GP 1 cellular NV >>	
106																								
107	Heating and hot water - gas	29.0	54.2	46.6	25.0	40.2	19.0	21.4	30.0	74.8	33.0	14.0	27.0	7.4	30.2	28.6	10.1	26.0	9.8	26.0	15.8	19.4	15.8	
108	Heating and hot water-electri	5.2	3.1	2.4	2.3		3.1		5.4	2.1	5.5	1.0	3.2	1.0	0.0	0.5	1.8	0.1	8.8	4.9	0.0	0.0	0.0	
109	Refrigeration and heat rejecti	21.8	20.9	11.9	4.5	21.3	8.0	10.9	2.7	4.2	0.5	6.2	0.0	0.0	1.0	0.0	0.0	2.6	0.0	1.6	0.5	0.0	0.0	
110	Fans, pumps and controls	72.8	45.2	53.0	19.9	34.8	27.6	18.7	22.7	5.2	13.9	9.9	6.8	9.9	4.2	3.1	1.8	7.5	0.0	2.5	2.1	5.7	1.0	
111	Gas for humidification			16.0			6.4																	
112	Electric humidification	18.2	20.0		24.8	12.0		6.2	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
113	Lighting	26.0	32.8	38.0	50.6	31.2	37.1	15.1	8.6	26.0	13.7	15.6	15.6	14.6	19.8	19.2	16.2	7.3	7.3	6.0	11.4	8.3	7.3	
114	Office equipment	10.4	11.0	23.3	28.0	16.6	14.4	12.0	3.6	1.6	7.6	4.2	12.0	4.2	14.0	5.7	2.3	5.7	5.2	5.2	10.4	2.6	6.2	
115	Gas for catering	2.2	0.0	1.8	3.0	1.8	1.6	1.4	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	
116	Catering and vending	7.3	4.4	12.7	14.9	7.8	8.1	6.8	1.5	13.0	2.4	2.5	2.1	1.6	2.6	0.5	0.6	1.6	1.6	2.3	1.6	4.2	1.0	
117	Other	10.4	6.9	5.0	5.9	7.8	8.0	6.8	9.0	15.1	4.8	3.6	3.0	1.0	2.6	2.1	1.7	0.8	3.1	4.4	2.1	4.2	1.6	
118	Computer room (including A/C)		22.9		81.7	54.6	83.1	45.2			12.3		30.9											
119	Communications/IT rooms (in	20.8		12.4			3.3		0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0	
120	C&W swimming pool, transmi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	
121																								
122	**TOTALS** (for sorting):																							
123	Total CO2 from gas	**31**	**54**	**64**	**28**	**42**	**27**	**23**	**30**	**80**	**33**	**14**	**27**	**7**	**30**	**29**	**10**	**26**	**10**	**26**	**16**	**22**	**16**	
124	Total CO2 from electricity	**193**	**167**	**159**	**233**	**186**	**192**	**122**	**53**	**98**	**61**	**45**	**74**	**32**	**44**	**31**	**30**	**26**	**26**	**30**	**28**	**25**	**17**	
125	Total CO2 from both	*224*	*221*	*223*	*261*	*228*	*219*	*144*	*83*	*178*	*94*	*59*	*101*	*40*	*74*	*60*	*40*	*52*	*36*	*56*	*44*	*47*	*33*	
126	**CO2 from building services**	**173**	**176**	**168**	**127**	**140**	**101**	**72**	**69**	**112**	**67**	**47**	**53**	**33**	**55**	**51**	**30**	**44**	**26**	**41**	**30**	**33**	**24**	
127																								
128	**Sorted in order of annual carbon dioxide emissions from gas and electricity used for normal building services only**	HFS Gardner House AC	1 Aldermanbury Square AC+	Tanfield House AC+	ECON 19/98 Typ 4 Prestige AC	Co-op Retail Services AC+	Cable & Wireless ANV+	Cheltenham & Gloucester AC	ECON 19/98 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Charities Aid Foundation MM	ECON 19/98 Typ 2 Open NV >>	Marston Books Office ANV	de Montfort Queens Building ANV	One Bridewell Street AC >>	Portland Building ANV+	John Cabot CTC ANV	APU Queens Building ANV	Elizabeth Fry Building MM	Marston Books Warehouse	ECON 19/98 GP 2 Open NV >>	Woodhouse Medical Centre NV+	ECON 19/98 GP 1 cellular NV >>	
129																								
130	Heating and hot water - gas	54	29	47	40	25	75	19	21	30	33	30	27	29	14	26	26	19	7	10	16	10	16	
131	Heating and hot water-electri	3	5	2	0	2	2	3	0	5	5	0	3	1	1	0	5	0	1	2	0	9	0	
132	Refrigeration and heat rejecti	21	22	12	21	4	4	8	11	3	1	1	0	0	6	3	2	0	0	0	1	0	0	
133	Fans, pumps and controls	45	73	53	35	20	5	28	19	23	14	4	7	3	10	8	2	6	10	2	2	0	1	
134	Gas for humidification	0	0	16	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
135	Electric humidification	20	18	0	12	25	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
136	Lighting	33	26	38	31	51	26	37	15	9	14	20	16	19	16	7	6	8	15	16	11	7	7	
137	Office equipment	11	10	23	17	28	2	14	12	4	8	14	12	6	4	6	5	3	4	2	10	5	6	
138	Gas for catering	0	2	2	2	3	5	2	1	0	0	0	0	0	0	0	0	2	0	0	0	0	0	
139	Catering and vending	4	7	13	8	15	13	8	7	2	2	3	2	1	2	2	2	4	2	1	2	2	1	
140	Other	7	10	5	8	6	15	8	7	9	5	3	3	2	4	1	4	4	1	2	2	3	2	
141	Computer room (including A/	23	0	0	55	82	0	83	45	0	12	0	31	0	0	0	0	0	0	0	0	0	0	
142	Communications/IT rooms (in	0	21	12	0	0	0	3	0	0	0	0	0	0	2	0	3	0	0	0	0	0	0	
143	C&W swimming pool, transmi	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	
144																								
145	**TOTALS (for sorting):**																							
146	Total CO2 from gas	**54**	**31**	**64**	**42**	**28**	**80**	**27**	**23**	**30**	**33**	**30**	**27**	**29**	**14**	**26**	**26**	**22**	**7**	**10**	**16**	**10**	**16**	
147	Total CO2 from electricity	**167**	**193**	**159**	**186**	**233**	**98**	**192**	**122**	**53**	**61**	**44**	**74**	**31**	**45**	**26**	**30**	**25**	**32**	**30**	**28**	**26**	**17**	
148	Total CO2 from both	*221*	*224*	*223*	*228*	*261*	*178*	*219*	*144*	*83*	*94*	*74*	*101*	*60*	*59*	*52*	*56*	*47*	*40*	*40*	*44*	*36*	*33*	
149	**CO2 from building services**	176.1	173.0	167.9	139.5	127.1	112.2	101.1	72.4	69.3	66.5	55.2	52.5	51.5	46.8	43.5	41.0	33.4	32.8	29.9	29.8	25.9	24.1	
150																								

FIGURE B5. Probe buildings: annual CO2 emissions

Benchmarks 1998 ECON 19. CO_2 factors kg/kWh: gas 0.20, electricity 0.52
Heating normalised to 2462 degree days except C&W and Marston warehouse

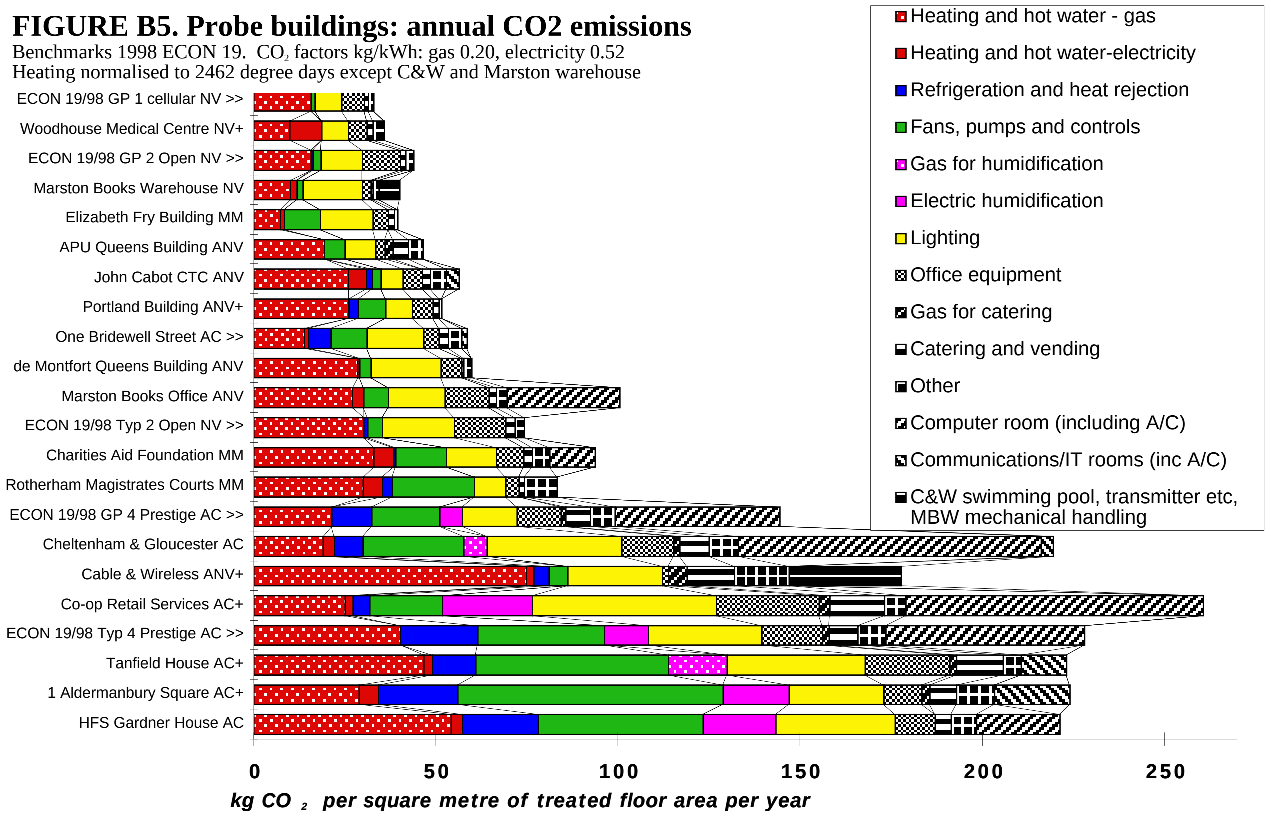


TABLE B6: ANNUAL GAS CONSUMPTION **kWh/m2 of treated floor area by fuel**

WITH ENERGY BENCHMARKS FROM THE 1998 EDITION OF ENERGY CONSUMPTION GUIDE 19 (ECON 19)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
201																								
204																								
205	Normalised heating & hot water for graphs corrected to 2462 degree days (15.5°C base) per year (not C&W and Marston Warehouse). Simple correction used unless in bold.	1 Aldermanbury Square AC+	HFS Gardner House AC	Tanfield House AC+	Co-op Retail Services AC+	ECON 19/98 Typ 4 Prestige AC >>	Cheltenham & Gloucester AC	ECON 19/98 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Cable & Wireless ANV+	Charities Aid Foundation MM	One Bridewell Street AC >>	Marston Books Office ANV	Elizabeth Fry Building MM	ECON 19/98 Typ 2 Open NV >>	de Montfort Queens Building ANV	Marston Books Warehouse NV	Portland Building ANV+	Woodhouse Medical Centre NV+	John Cabot CTC ANV	ECON 19/98 GP 2 Open NV >>	APU Queens Building ANV	ECON 19/98 GP 1 cellular NV >>	
206																								
207	Total actual gas	117	253	331	118	0	101	0	142	400	151	53	113	35	0	127	0	100	0	98	0	115	0	
208	Heating and hot water gas	106	253	242	103	0	61	0	142	374	151	53	113	35	0	127	0	100	0	98	0	104	0	
209	Degree days	1800	2237	2559	1980	0	1620	0	2332	0	2253	1799	2061	2312	0	2206	2061	1896	0	1717	0	2531	0	
210	Simple normalisation (Htg/HWS)	145	278	233	128	0	93	0	150	0	165	73	135	37	0	142	0	130	0	141	0	101	0	
211	Heating+hot water gas (normalised)	145	271	233	125	201	95	107	150	374	165	70	135	37	151	143	51	130	49	130	79	97	79	
212	Gas heating only	145							150		165	70	135				51		49					
213	Gas heating & HWS		271												151	143		130			79		79	
214	Gas heating & kitchen HWS			233	125	201	95	107		374				37						130		97		
215	Gas for catering	11	0	9	15	9	8	7	0	26	0	0	0	0	0	0	0	0	0	0	0	11	0	
216	Gas for humidification			80			32																	
217	Total corrected gas	156	271	322	140	210	135	114	150	400	165	70	135	37	151	143	51	130	49	130	79	108	79	
218																								
219	Sorted in order of annual gas consumption for graph	Cable & Wireless ANV+	Tanfield House AC+	HFS Gardner House AC	ECON 19/98 Typ 4 Prestige AC >>	Charities Aid Foundation MM	1 Aldermanbury Square AC+	ECON 19/98 Typ 2 Open NV >>	Rotherham Magistrates Courts MM	de Montfort Queens Building ANV	Co-op Retail Services AC+	Cheltenham & Gloucester AC	Marston Books Office ANV	John Cabot CTC ANV	Portland Building ANV+	ECON 19/98 GP 4 Prestige AC >>	APU Queens Building ANV	ECON 19/98 GP 2 Open NV >>	ECON 19/98 GP 1 cellular NV >>	One Bridewell Street AC >>	Marston Books Warehouse NV	Woodhouse Medical Centre NV+	Elizabeth Fry Building MM	
220		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
221	Total actual gas	400	331	253	0	151	117	0	142	127	118	101	113	98	100	0	115	0	0	53	0	0	35	
222	Heating and hot water gas	374	242	253	0	151	106	0	142	127	103	61	113	98	100	0	104	0	0	53	0	0	35	
223	Degree days	0	2559	2237	0	2253	1800	0	2332	2206	1980	1620	2061	1717	1896	0	2531	0	0	1799	2061	0	2312	
224	Simple normalisation (Htg/HV	0	233	278	0	165	145	0	150	142	128	93	135	141	130	0	101	0	0	73	0	0	37	
225	Heating+hot water gas (norm	374	233	271	201	165	145	151	150	143	125	95	135	130	130	107	97	79	79	70	51	49	37	
226	Gas heating only	0	0	0	0	165	145	0	150	0	0	0	135	0	0	0	0	0	0	70	51	49	0	
227	Gas heating & HWS	0	0	271	0	0	0	151	0	143	0	0	0	0	130	0	0	79	79	0	0	0	0	
228	Gas heating & kitchen HWS	374	233	0	201	0	0	0	0	0	125	95	0	130	0	107	97	0	0	0	0	0	37	
229	Gas for catering	26	9	0	9	0	11	0	0	0	15	8	0	0	0	7	11	0	0	0	0	0	0	
230	Gas for humidification	0	80	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	
231	Total corrected gas	400	322	271	210	165	156	151	150	143	140	135	135	130	130	114	108	79	79	70	51	49	37	
232																								
233																								

FIGURE B6. Probe buildings: Annual gas consumption

Benchmarks 1998 ECON19. Sorted by total gas consumption.
Heating normalised to 2462 degree days except C&W and Marston Warehouse

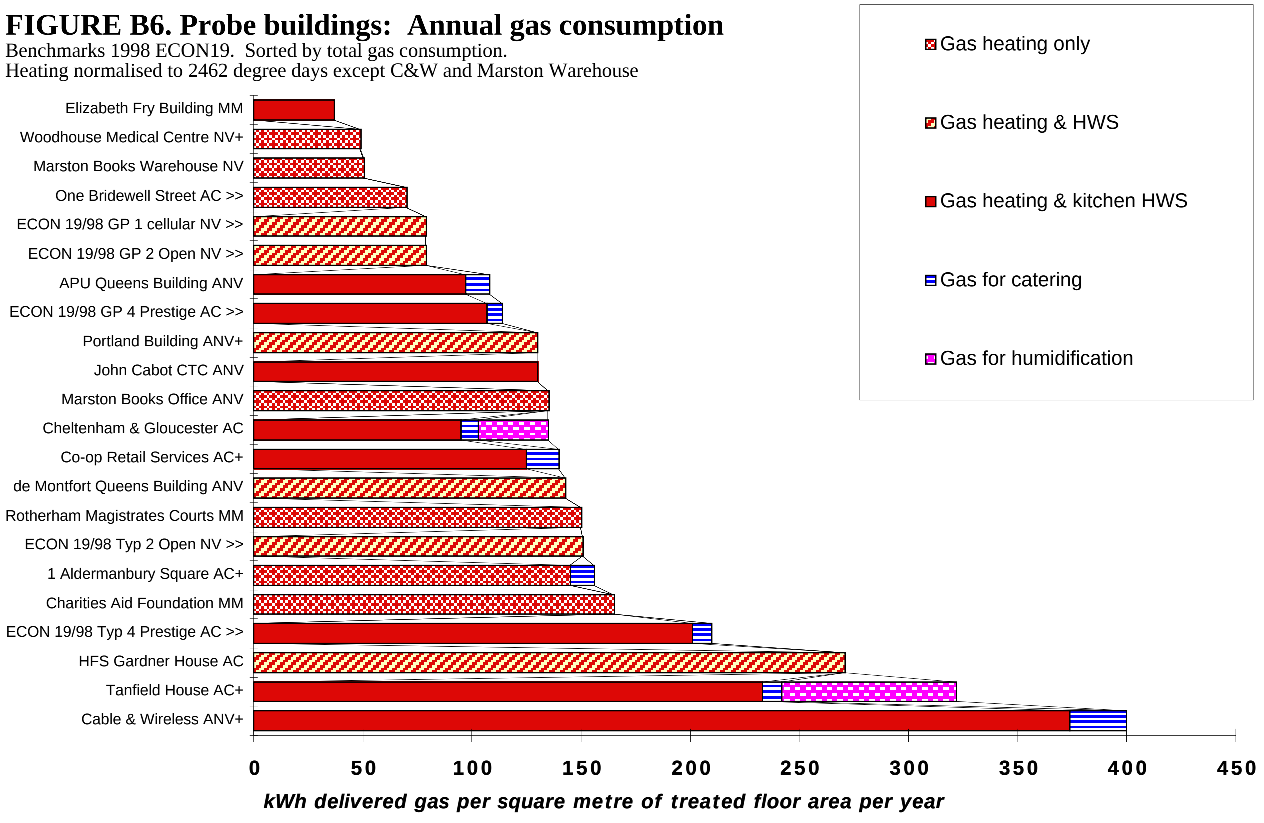


TABLE B7: SORTED ANNUAL ELECTRCITY CONSUMPTION AND CO_2 EMISSIONS (EXPRESSED AS CARBON) **kg C/m² of treated floor area per year**

WITH ENERGY BENCHMARKS AND CONVERSION FACTORS IN CARBON UNITS FROM THE 1998 EDITION OF ENERGY CONSUMPTION GUIDE 19 (ECON 19)

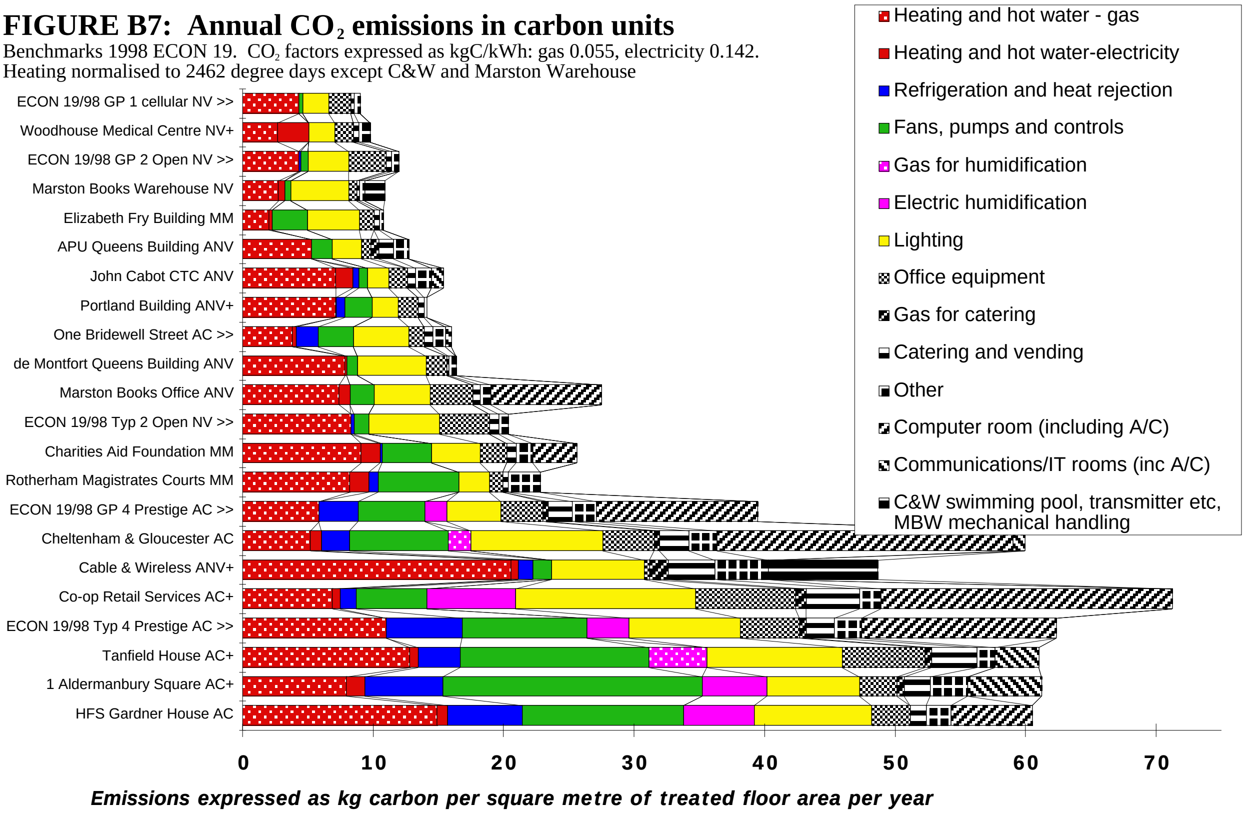
CONVERSION FACTORS (kgC/kWh) ***Gas:*** *.055* ***Electricity:*** *.142*

Sorted in order of annual electricity consumption for normal building services only	1 Aldermanbury Square AC+	HFS Gardner House AC	Tanfield House AC+	Co-op Retail Services AC+	ECON 19/98 Typ 4 Prestige AC >>	Cheltenham & Gloucester AC	ECON 19/98 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Cable & Wireless ANV+	Charities Aid Foundation MM	One Bridewell Street AC >>	Marston Books Office ANV	Elizabeth Fry Building MM	ECON 19/98 Typ 2 Open NV >>	de Montfort Queens Building ANV	Marston Books Warehouse NV	Portland Building ANV+	Woodhouse Medical Centre NV+	John Cabot CTC ANV	ECON 19/98 GP 2 Open NV >>	APU Queens Building ANV	ECON 19/98 GP 1 cellular NV >>
Heating and hot water - gas	8.0	14.9	12.8	6.9	11.1	5.2	5.9	8.3	20.6	9.1	3.9	7.4	2.0	8.3	7.9	2.8	7.2	2.7	7.2	4.3	5.3	4.3
Heating and hot water-electrici	1.4	0.9	0.7	0.6		0.8		1.5	0.6	1.5	0.3	0.9	0.3	0.0	0.1	0.5	0.0	2.4	1.3	0.0	0.0	0.0
Refrigeration and heat rejectio	6.0	5.7	3.2	1.2	5.8	2.2	3.0	0.7	1.1	0.1	1.7	0.0	0.0	0.3	0.0	0.0	0.7	0.0	0.4	0.1	0.0	0.0
Fans, pumps and controls	19.9	12.4	14.5	5.4	9.5	7.5	5.1	6.2	1.4	3.8	2.7	1.8	2.7	1.1	0.9	0.5	2.1	0.0	0.7	0.6	1.6	0.3
Gas for humidification			4.4			1.8																
Electric humidification	5.0	5.5		6.8	3.3		1.7	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lighting	7.1	8.9	10.4	13.8	8.5	10.1	4.1	2.3	7.1	3.7	4.3	4.3	4.0	5.4	5.3	4.4	2.0	2.0	1.6	3.1	2.3	2.0
Office equipment	2.8	3.0	6.4	7.7	4.5	3.9	3.3	1.0	0.4	2.1	1.1	3.3	1.1	3.8	1.6	0.6	1.6	1.4	1.4	2.8	0.7	1.7
Gas for catering	0.6	0.0	0.5	0.8	0.5	0.4	0.4	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Catering and vending	2.0	1.2	3.5	4.1	2.1	2.2	1.8	0.4	3.6	0.7	0.7	0.6	0.4	0.7	0.1	0.2	0.4	0.4	0.6	0.4	1.1	0.3
Other	2.8	1.9	1.4	1.6	2.1	2.2	1.8	2.5	4.1	1.3	1.0	0.8	0.3	0.7	0.6	0.5	0.2	0.9	1.2	0.6	1.1	0.4
Computer room (including A/C)		6.2		22.3	14.9	22.7	12.4			3.4		8.4										
Communications/IT rooms (inc	5.7		3.4			0.9		0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0
C&W swimming pool, transmit	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
TOTALS (for sorting):																						
Total carbon in gas	**9**	**15**	**18**	**8**	**12**	**7**	**6**	**8**	**22**	**9**	**4**	**7**	**2**	**8**	**8**	**3**	**7**	**3**	**7**	**4**	**6**	**4**
Total carbon in electricity	**53**	**46**	**43**	**64**	**51**	**53**	**33**	**15**	**27**	**17**	**12**	**20**	**9**	**12**	**9**	**8**	**7**	**7**	**8**	**8**	**7**	**5**
Total carbon in both	*61*	*61*	*61*	*71*	*62*	*60*	*39*	*23*	*49*	*26*	*16*	*28*	*11*	*20*	*16*	*11*	*14*	*10*	*15*	*12*	*13*	*9*
Carbon for building services	**47**	**48**	**46**	**35**	**38**	**28**	**20**	**19**	**31**	**18**	**13**	**14**	**9**	**15**	**14**	**8**	**12**	**7**	**11**	**8**	**9**	**7**
Bldg servs C as % of total	77%	80%	75%	49%	61%	46%	50%	83%	63%	71%	80%	52%	83%	74%	86%	75%	84%	72%	73%	68%	72%	73%
Averages % BS carbon for:					**AC**	**65%**							**Educ**	**80%**			**All Probe (ex 1BS and benchmarks)**					**71%**

Sorted in order of annual carbon dioxide emissions from gas and electricity used for normal building services only	HFS Gardner House AC	1 Aldermanbury Square AC+	Tanfield House AC+	ECON 19/98 Typ 4 Prestige AC >>	Co-op Retail Services AC+	Cable & Wireless ANV+	Cheltenham & Gloucester AC	ECON 19/98 GP 4 Prestige AC >>	Rotherham Magistrates Courts MM	Charities Aid Foundation MM	ECON 19/98 Typ 2 Open NV >>	Marston Books Office ANV	de Montfort Queens Building ANV	One Bridewell Street AC >>	Portland Building ANV+	John Cabot CTC ANV	APU Queens Building ANV	Elizabeth Fry Building MM	Marston Books Warehouse	ECON 19/98 GP 2 Open NV >>	Woodhouse Medical Centre NV+	ECON 19/98 GP 1 cellular NV >>
Heating and hot water - gas	15	8	13	11	7	21	5	6	8	9	8	7	8	4	7	7	5	2	3	4	3	4
Heating and hot water-electrici	1	1	1	0	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0	0	2	0
Refrigeration and heat rejectio	6	6	3	6	1	1	2	3	1	0	0	0	0	2	1	0	0	0	0	0	0	0
Fans, pumps and controls	12	20	14	10	5	1	8	5	6	4	1	2	1	3	2	1	2	3	0	1	0	0
Gas for humidification	0	0	4	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electric humidification	5	5	0	3	7	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lighting	9	7	10	9	14	7	10	4	2	4	5	4	5	4	2	2	2	4	4	3	2	2
Office equipment	3	3	6	5	8	0	4	3	1	2	4	3	2	1	2	1	1	1	1	3	1	2
Gas for catering	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Catering and vending	1	2	3	2	4	4	2	2	0	1	1	1	0	1	0	1	1	0	0	0	0	0
Other	2	3	1	2	2	4	2	2	2	1	1	1	1	1	0	1	1	0	0	1	1	0
Computer room (including A/C	6	0	0	15	22	0	23	12	0	3	0	8	0	0	0	0	0	0	0	0	0	0
Communications/IT rooms (inc	0	6	3	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
C&W swimming pool, transmit	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
TOTALS (for sorting):																						
Total carbon in gas	**15**	**9**	**18**	**12**	**8**	**22**	**7**	**6**	**8**	**9**	**8**	**7**	**8**	**4**	**7**	**7**	**6**	**2**	**3**	**4**	**3**	**4**
Total carbon in electricity	**46**	**53**	**43**	**51**	**64**	**27**	**53**	**33**	**15**	**17**	**12**	**20**	**9**	**12**	**7**	**8**	**7**	**9**	**8**	**8**	**7**	**5**
Total carbon in both	*61*	*61*	*61*	*62*	*71*	*49*	*60*	*39*	*23*	*26*	*20*	*28*	*16*	*16*	*14*	*15*	*13*	*11*	*11*	*12*	*10*	*9*
Carbon for building services	48.2	47.3	46.0	38.2	34.8	30.8	27.6	19.8	19.0	18.2	15.1	14.4	14.1	12.8	11.9	11.3	9.2	9.0	8.2	8.2	7.1	6.6

FIGURE B7: Annual CO_2 emissions in carbon units

Benchmarks 1998 ECON 19. CO_2 factors expressed as kgC/kWh: gas 0.055, electricity 0.142.
Heating normalised to 2462 degree days except C&W and Marston Warehouse



APPENDIX C

Building intelligence in the Probe buildings

Building intelligence in use: lessons from the Probe project

by
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Bill Bordass, William Bordass Associates
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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.

Acknowledgements

The Probe project is a joint initiative between the Building Services Journal and the team members Halcrow Gilbert Associates, William Bordass Associates and Building Use Studies Ltd. It is supported by the DETR's Construction Sponsorship Directorate under its Partners in Technology programme. Grateful thanks are also due to the owners, occupiers, designers and mangers of the buildings surveyed, who permitted us to undertake the surveys and to report on the results.

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