BRE's Environmental Building:
Energy Performance in Use

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ABSTRACT

The Environmental Building, often referred to as the Energy Efficient Office of the Future (EOF) or Building 16, was the result of a collaborative project between BRE and eleven other organisations, initiated under the UK Government's Energy Efficiency Best Practice Programme (EEBPP). The primary objective of the EOF Project was to demonstrate that environmental principles can be applied to design, construction and management, to give a comfortable, healthy environment that is also energy efficient. To achieve this objective there was a need to identify new or emerging areas of technology, and to refine existing techniques and design practice.

The energy and environmental performance of the whole building has been monitored in detail. This paper provides results of the in-use performance of the building during the two and a half years of occupancy to date. Monitored data has shown that the building provides a generally comfortable place for occupants, although the gas consumption for space heating has exceeded its target. This is due to problems with building envelope integrity. Remediation of these problems has resulted in a significant improvement, although there are further improvements to be made. This paper focuses on the energy and environmental performance only, other elements have been considered in other work[1,2].

KEY WORDS

- energy
- natural ventilation
- passive environmental control
- thermal mass
- office

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Summary

The Environmental Building, often referred to as the Energy Efficient Office of the Future (EOF) or Building 16, was the result of a collaborative project between BRE and eleven other organisations, initiated under the UK Government's Energy Efficiency Best Practice Programme (EEBPP). The primary objective of the EOF Project was to demonstrate that environmental principles can be applied to design, construction and management, to give a comfortable, healthy environment that is also energy efficient. To achieve this objective there was a need to identify new or emerging areas of technology, and to refine existing techniques and design practice.

The energy and environmental performance of the whole building has been monitored in detail. This paper provides results of the in-use performance of the building during the two and a half years of occupancy to date. Monitored data has shown that the building provides a very comfortable place for occupants, although the gas consumption for space heating has exceeded its target. This is due to problems with building envelope integrity. Remediation of these problems has resulted in a significant improvement, although there are further improvements to be made. This paper focuses on the energy and environmental performance only, other elements have been considered in other work[1,2].

1 INRTODUCTION AND BACKGROUND

During the last 10 years, there has been a tendency for clients to brief design teams to adopt energy-efficient approaches to building design. Clients are keen to show their "green" credentials; the buildings they occupy are perceived as conspicuous demonstrations of environmental commitment. There are already many examples of buildings in the UK that embrace passive and low energy strategies. Some feedback on the performance of a number of the most prominent of these exemplar buildings is now available through DETR-funded dissemination programmes[3,4,5] and the PROBE series of studies[6,7].

BRE as a client for a new office, wanted to construct its own landmark low energy building to house relocated staff. The requirement for the new space (Building 16) also led to an opportunity to test the Performance Specification[8] developed under the Energy Efficiency Best Practice Programme through the EOF project.

1.1 Aim of the Energy Efficient Office of the Future (EOF) Project

The aim of the EOF project was to demonstrate that a replicable building could be constructed to meet the likely energy and environmental targets that would be in place in the early part of this century. The building would not only meet these targets but would provide a comfortable, healthy environment to work in. Also of importance was that the building should be of equivalent capital cost to a conventional design, with low running and maintenance costs.

The target energy consumption of the EOF was a 37% improvement on a current good practice Type II naturally ventilated building[9]. Initiated under the UK Government's Energy Efficiency Best Practice Programme (EEBPP), the EOF project was a collaborative programme run in partnership with eleven other commercial organisations.

The EOF project specifically aimed to:

- Encourage progress towards an office building that satisfies both the energy and environmental targets of the early part of the 21st century;

- Stimulate the development of novel energy efficient technologies, products and systems;

- Produce a performance specification and apply it to the development of exemplar 'host' buildings;

- Monitor the host building allowing analysis of the design and the building in-use;

- Disseminate the monitoring results throughout the industry to encourage replication.

In the first phase of the project, a generic performance specification[8] was devised for a low energy office. In the second phase, the specification was tested through the construction of BRE's Environmental Building. The building was intended as a model for offices in the 21st century and demonstrates many integrated design concepts that represent a holistic approach to low energy design for offices. This study reports on the performance of the Environmental Building.

The building itself is the first of three planned 'Energy Efficient Offices of the Future'. Each of the offices is intended to demonstrate a low energy design solution for its particular situation, use and environment for the Northern European climate band and, in all cases, the buildings will meet targets that are anticipated to be good practice in 2020.

This paper presents energy performance data for the first two full years of building occupancy.

1.2 Key Elements of the Brief

The EOF was designed to provide:

- flexible office space for the FRS and seminar facilities for the whole of BRE;
- 1200 m^2 of office accommodation for 100 staff with spatial planning flexibility; and
- a 420m^2 seminar facility for 100 people with 2 smaller meeting rooms to accommodate 20 people in each.
- a landmark, innovative, low-energy solution, demonstrating replicable concepts in low energy design.

Performance and Design Criteria:

- Achieve a target BREEAM rating of "excellent" [10].
- Provide industry appeal to encourage others to adopt an environmentally-conscious approach.
- Dry resultant temperatures at all points in the occupied spaces should not to exceed 25°C for more than 5% of the year and not to exceed 28°C for more than 1% of the year
- Thermal, visual and aural comfort design criteria to be derived from authoritative references.
- Allow for user control of internal environment.

- Avoid use of conventional air conditioning systems, using natural ventilation.
- Provide good thermal characteristics – high standards of insulation and building envelope integrity with high levels of thermal mass.
- Seek a balanced solution to solar gain control, with glazing proportion selected in line with total energy considerations. This means balancing solar gain control and heat losses against savings made from using natural daylight.
- Keep building services as simple as possible to meet user requirements.
- Achieve a 30% reduction in consumed energy, compared with contemporary low energy buildings.

Specific energy consumption targets were:

Total electricity:	36 kWh m^{-2}
Total Gas:	47 kWh m^{-2}
CO_2 emissions:	34 kg m^{-2}

- The capital and operating costs must lead to a total cost-in-use no greater than contemporary low energy buildings to maintain commercial edge and demonstrate the economic viability of environmentally-conscious designs.

2 BUILDING DESCRIPTION

The building consists of two parts; 1200m^2 of offices for about 100 staff and 850m^2 of seminar facilities. The building has approximately 2050m^2 of total gross floor area (GFA) and 1470 m^2 of net lettable floor area (NLA). The front of the building faces south-west with the main seminar room on the north side of the building. The office and seminar blocks are connected by an entrance atrium.

The offices are on three floors, each 30m x 13.5m with the long axis normal to the prevailing south-westerly winds to encourage cross-ventilation. The linear floor-plate design is divided into a 4.5m deep north zone, a 1.5m corridor zone and 7.5m south zone. Maximum floor-ceiling height on the ground and first floors is 3.4m. The second floor has a south-facing sloping roof that raises the floor-ceiling height from 2.5m to 5.0m in height, with celerestory windows on the north side to give some stack ventilation. The south façade of the office section is “clad” with an array of controllable motorised louvres supported by five passive solar ventilation stacks.

The main seminar room is designed for up to 100 people; the two smaller seminar rooms on the first and second floors are designed for 20 people each. The seminar rooms form the main seminar facilities for the entire BRE site and so will be highly visible to all. There is also a foyer, reception and demonstration area. The seminar block is partially clad with a 47m^2 array of thin film silicon (TFS) photo-voltaic panels, with a peak output of 1.5kW.

The site is low-density suburban with good solar and wind access.

2.1 Design Approach to Meet the Brief

The design philosophy was to maximise the use of natural resources through passive strategies, minimally supported by efficient active systems. A robust system of environmental control is achieved through dual supply mechanisms – no strategy depends on a single system or design concept. This approach is made cost-effective by the full integration of strategies in terms of both components and operation. Structural elements are integral to the environmental strategy. Many of the novel components are capable of supporting the operation of more than one strategy.

2.2 Main Features

This paper is focusing on the fabric and energy performance of BRE's Environmental Building, as such; a complete description of the building services is not included. Summary information is provided below, but the reader is advised to consult other references for a fuller account[11,12,13].

2.2.1 Heating

The building is heated using two gas-fired boilers; a 110kW primary condensing boiler and a standby 130kW secondary conventional high-efficiency boiler. The condensing boiler is sized for 40% of the load, enabling it to run at maximum load (and efficiency) for most of the time. The primary boiler efficiency is 86.4% and the secondary boiler 80.5%. These heat water for circulation to a system of under-floor pipes embedded in the screed of the floor and a supplementary standard peripheral radiator system.

2.2.2 Cooling

The building has been designed to minimise the daytime cooling requirement through shading, low internal loads and night-cooled thermal mass. A wave-form (sinusoidal) hollow-core concrete ceiling slab provides the lower two offices with a high surface area of exposed thermal mass and also acts as a conduit for ventilation of air deep into the office space, permitting flexible partitioning without inhibiting natural cross-ventilation. The slab is painted white to diffuse light deflected by external shading devices in summer. The slab also modulates light and excess heat from luminaires suspended beneath the high points of the ceiling. The top floor is of more lightweight construction, with no slab-cooling. Increased floor-ceiling height with celerestory exhaust raises the reservoir of warm air above the comfort zone. Smaller glazed area reduces solar gain here and the north-facing celerestory windows provide additional daylighting to reduce internal gain. For particularly hot periods, comfort cooling using borehole groundwater is utilised. In summer cooling is transferred to the underfloor pipe-work using heat exchangers. This system is designed to trim $2^{o}C$ from the peak summer internal temperatures.

2.2.3 Lighting

The building has been designed to maximise the use of daylight. Electric lighting is provided by Philips T5 lamps which can be dimmed through the full range of illuminance. 300 lux was chosen as the lighting level at the working plane with control provided by occupancy and daylight sensors.

2.2.4 Control

The building is controlled by a dedicated Building Management System (BMS), but the occupants also have control of their local environment (temperature, ventilation, louvre position and lighting levels). Any adjustments made by occupants will be reset at midnight by the BMS; this provides a balance between energy efficiency and occupant comfort.

2.2.5 Fabric

The building is insulated with 100mm of insulation and is of medium thermal mass to shift daytime temperature peaks to night-time. Glazing is low-e, argon-filled double-glazing. A fabric air leakage rating of $7.5m^{3}m^{-2}hr^{-1}$ at 50Pa was expected, though not specified in the contract. The total heat loss through the fabric was projected to be 2 kW K^{-1}. U-values for the building are presented in Table 1.

Element	**Construction**	**U Value (W m^{-2} K^{-1})**
Floor	Concrete	0.33
Walls	100mm brickwork 100mm insulation 150mm blockwork dense plaster	0.32
Roof	Aluminium 150mmm insulation 75mm timber/150mm concrete	0.24
Windows	Double glazed, low E, argon filled	2.0

Table 1: U-Value Construction Data

3 RESULTS[1]

3.1 Thermal Control

The monitoring period has seen three summer periods which represent mean summer temperatures at both ends of the temperature spectrum for that site for the last 30 years, as well as the mean for the site. Stable temperatures were maintained throughout the year in the office space (Fig. 1). Thermal performance in summer exceeded expectations, with little evidence of overheating during the entire monitoring period to date. This includes the last week of August in 1997 (Fig. 2) when external temperatures rose steadily to a peak of 33°C. The thermal design criteria were easily met (Table 2) in all but one area on the top floor. This has exceeded 25°C for 11% of the total monitoring period but most of this occurred during the first summer of full occupancy of this space in 1999. This may be due to a faulty sensor, which could result in initiation of borehole cooling when not strictly required.

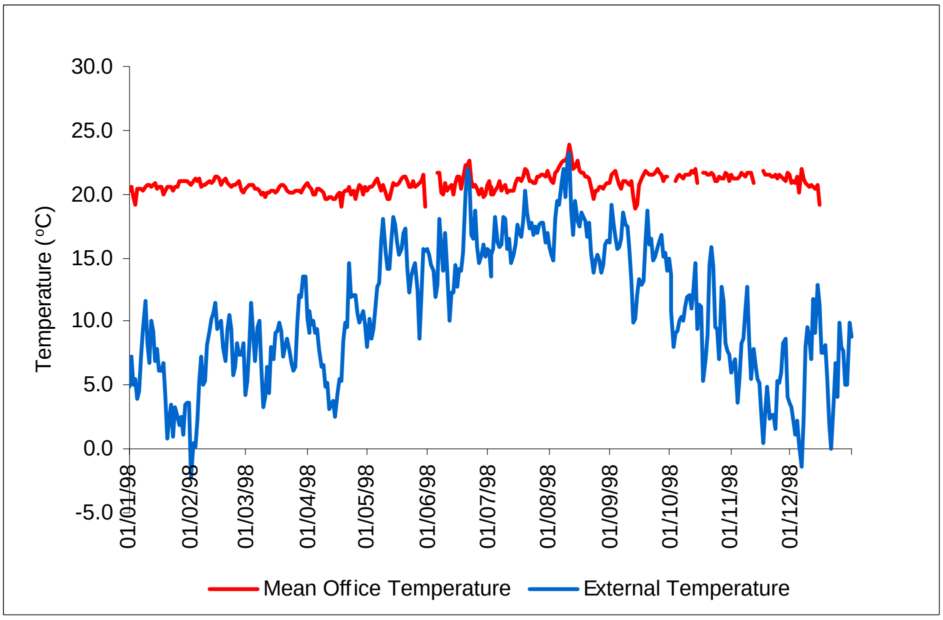

Fig. 1: Mean daily internal and external temperatures for the 1998 calendar year

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[1] On all Figures ‘B16’ means BRE’s Environmental Building.

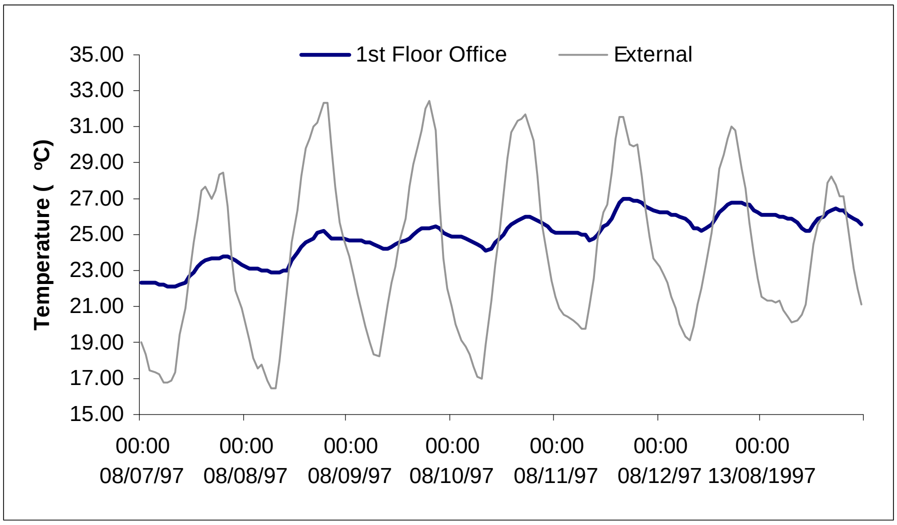

Fig.2: Hourly average temperatures during the August 1997 peak.

Criteria	**>25C**	**>28C**
Point	*% of collected*	*% of collected*
GF South	1.1	0.0
GF SE	**4.9**	1.3
GF SW	0.5	0.0
GF North	0.0	0.0
GF NE	0.2	0.0
GF NW	4.0	1.8
1F South	1.0	0.1
1F SE	0.8	0.0
1F SW	0.7	0.0
1F NE	1.1	0.0
1F North	0.4	0.0
1F NW	0.7	0.0
2F South	2.3	0.2
2F SE	2.8	0.3
2F SW	2.1	0.1
2F North	1.2	0.0
2F NE	1.4	0.0
2F NW	**10.7**	1.0

Table 2: Temperature exceedance statistics for all points for the entire monitoring period (August 1997-December 1999)

Short periods of exceedance on the top floor generally occurred in summer, but on the lower two floors tended to occur in winter. Summer exceedance on the lower two floors occurred in areas that were not constantly occupied, therefore no user-control was being exercised. Comfortable temperatures were largely maintained in winter. Mean winter morning office temperature was 21°C by 8am (before the occupants arrived). However, there was evidence of overheating on all floors for a three-week period during the spring of 1999. The causes for this are unclear; however, the indication is that this is a result of heating system response under highly variable external conditions.

The exemplary thermal performance in summer was largely due to the thermal mass of the building, the night-cooling strategy and, to a lesser extent, user control. Detailed performance analysis of the thermal mass elements will be presented in further work. Borehole cooling was infrequently used, but when used, delivered an estimated 8.6kWh of cooling energy for every 1kWh of electrical (pump) energy. This indicates a very efficient system for summer cooling. There can be few disadvantages to such a compact system which requires no refrigeration plant, no fluid cooling energy and utilises existing equipment (heating pipes) for distribution, even if it only serves as a back up system.

3.2 Ventilation

Mean wind speeds in both summer and winter were more than sufficient for cross-ventilation. This was the dominant ventilation mode in the building during the monitoring period (as well as being the design mode). Daily summer wind speeds were on average 1.9 ms^{-1}, while mean daily winter wind speed was 3.4 ms^{-1}. South-westerlies were dominant, which was the ventilation design condition. Continuous air change rate measurements using the constant injection tracer gas method confirmed that minimum fresh air (0.7 h^{-1}) was delivered to the cellular offices in Winter. Spot measurements (tracer gas decay method) confirmed this for the open plan offices. Ventilation heat losses were minimised without compromising indoor air quality and air speeds in the cellular offices were comfortable. Ventilation and performance of the solar stacks has previously been reported in detail[1].

3.3 Indoor Air Quality

Carbon dioxide (CO_2) levels fell within the acceptable range in all areas during the occupied periods for the majority of the monitoring period. Relative humidity (RH) in summer was exceptionally stable and well inside the comfort band. Winter RH tended to be at the lower end of the comfort range. Occupants occasionally complained of stuffiness in winter, partly because of overheating.

3.4 Daylight Performance

Daylight levels on the ground and first floors fell short of the target. Under overcast sky conditions a daylight factor of 5% was only observed by the windows on the top floor. Average daylight factors for the two lower floors were below 2%, which has placed an increased burden on the lighting energy consumption. The louvred façade has not been operational for much of the life of the building (practical completion December 1996), with the problems finally being resolved in April 1999. Until that date, automatic control was not possible, consequently lighting energy consumption figures have been affected. Full analysis of louvre performance is forthcoming in further work.

3.5 Energy Consumption

Energy consumption data is derived from a sub-metering metering system consisting of 16 electricity meters and 12 heat meters. One main heat meter measures total hot water and one total space-heating. The remaining 10 meters measure heat energy by circuit (eg. 2nd floor office radiators, 2nd floor office heating/cooling etc.). Meters on the underfloor circuits have outputs for both heating and cooling energy.

3.5.1 Energy Benchmarks used for Comparison

As the building is in part office space and in part seminar/conference facility, the following benchmarks have been used in this paper for comparing the energy performance of the building:

- ECON 19 benchmarks for type II and III ***office buildings***[9] – the reasoning here is BRE's office provides the comfort and control standards of a type III building for the energy and capital costs of a type II. The performance has also been compared with available information on two new practice buildings of these types – the Inland Revenue Building in Nottingham[5] and the office section of Martson Book Services'[6].

- ***educational buildings*** which have similar facilities and occupancy patterns – recent low energy designs of this type include the Queen's Building at de Montford University in Leicester[3], the Queen's Building at Anglia Polytechnic University[7] and the Elizabeth Fry Building at University of East Anglia[4].

Performance is given both in terms energy consumption (kWh m^{-2} of Treated Floor Area as applicable) – both total and split by fuel type – and total CO_2 emissions ($kgCO_2$ m^{-2}). The comparative performance of the office and seminar sections is examined in addition to the impact of remedial measures.

3.5.2 Annual Energy Consumption vs. Targets and Benchmarks

Actual (measured) total annual energy consumption was 60% higher than expected (Fig. 3), with an overall annual total consumption of 144 kWh m^{-2} in 1998, falling to 135 kWh m^{-2} in 1999, compared with the target of 83 kWh m^{-2}. When water heating (gas) is adjusted for the standard 2462 degree days per annum this rises to 176 kWh m^{-2}. Of this, actual water heating (gas) accounts for 87 kWh m^{-2}. Adjusted for degree days gives a water heating bill of 127.8 kWh m^{-2}, well in excess of the EOF target of 47 kWh m^{-2}. Electrical energy consumption is closer to its target of 36 kWh m^{-2} at 48 kWh m^{-2}.

Corrected gas is 30% higher than ECON 19 type III good practice and 62% higher than type II good practice. However, corrected gas delivered to the office section only, where the majority of low energy features are concentrated, exceeds type II good practice by only 5%. This is nearly 80% higher than the EOF target, which has been very disappointing. Electricity for the whole building, on the other hand is 10% lower than type II good practice. However, office electricity is 20% higher than ECON 19 recommends for a naturally ventilated type II good practice building and nearly double the anticipated EOF target. The unexpectedly high office electrical load is largely due to a high-performance computer suite in the ground floor office , which operates continuously at a base (night-time) load of 2-3kW rising above 4kW during the day. This had not specified in the brief or included in the design calculations when trying the design to target. When this is deducted from the office consumption, office electrical energy is within 20% of the EOF target.

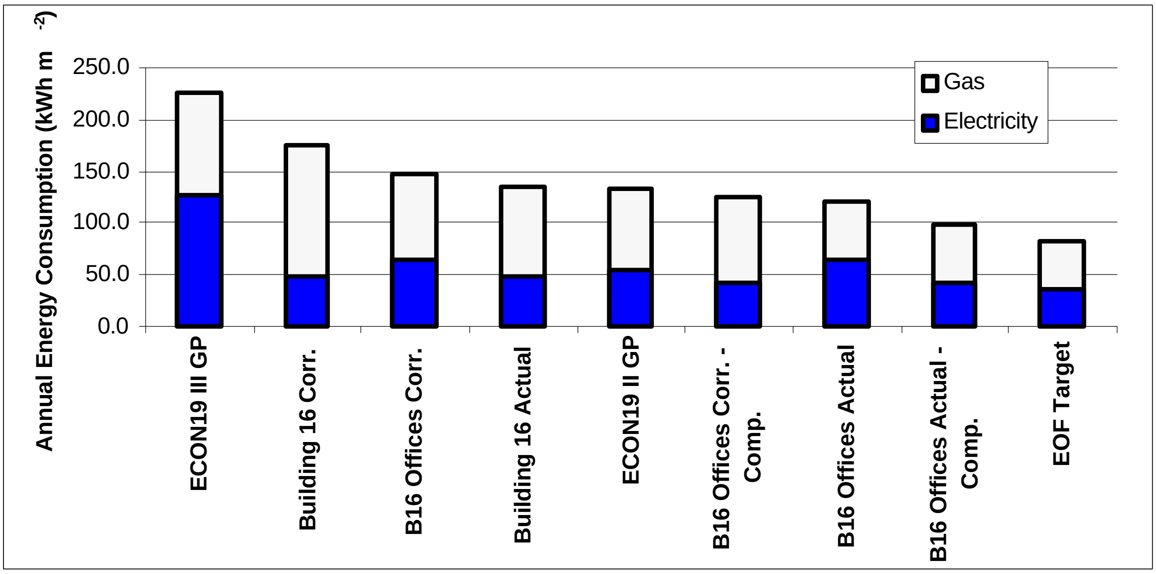

Fig. 3 Annual energy consumption for gas and electricity compared with ECON 19 benchmarks and EOF targets

The impact of general electrical energy economy in the building as a whole is clear from the resulting total CO_2 emissions which currently run at 39 kgCO m^{-2} –50% higher than the EOF target of 26 kgCO m^{-2} (80% higher, when corrected)(Fig. 4). Corrected emissions exceed type II good practice by only 16%. Corrected emissions for the offices only give a similar figure. However, when the computer suite load is deducted from this, office CO_2 emissions are within 40% of the EOF target and 11% lower than type II good practice.

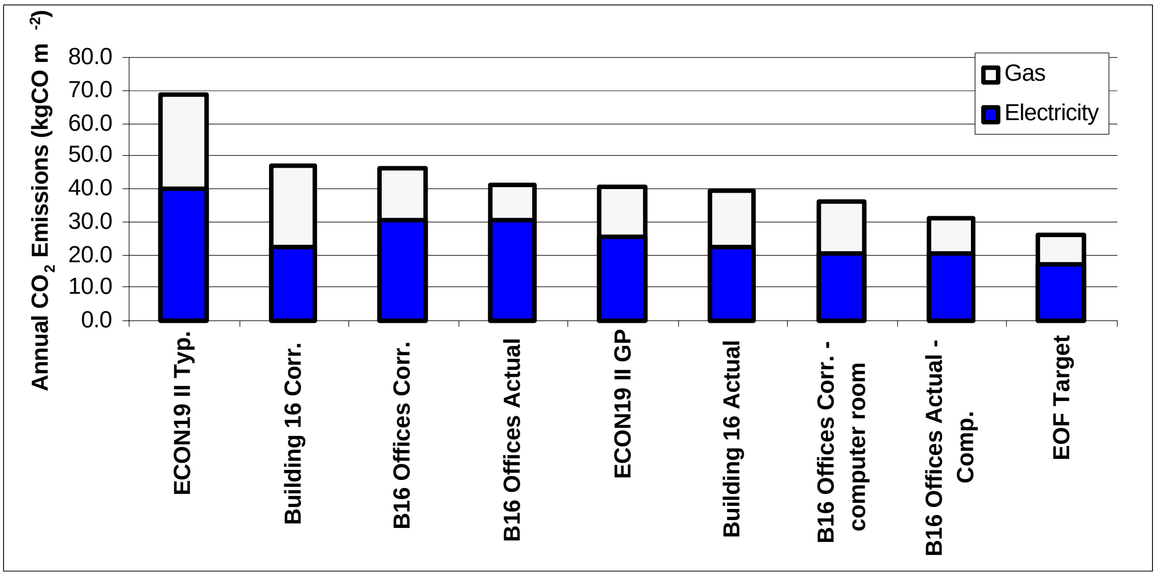

Fig. 4 Annual CO_2 emissions compared with ECON 19 benchmarks and EOF targets. Conversion factors used were kWh/kgCO = 0.19 (gas) and 0.47 (electricity).

The aim was to produce a building with a 30% reduction in consumed energy compared with contemporary low energy buildings. This has not yet been met, but the figures are encouraging. Whole building (corrected) energy consumption is at the "office building" end of the spectrum, though with higher heating and lower electricity than its contemporaries. New educational buildings appear to be the current best performers, despite the erratic use and load patterns. Lower electrical loads with higher heating energy appear to be the patterns for this type of building – a pattern currently also replicated in Building 16. Actual building and corrected office energy consumption is lower than all but the Elizabeth Fry building at the University of East Anglia. Whole building consumption exceeds this building by up to 30% for corrected office performance (Fig. 5), but the performance of the office section without the computer suite is 10% lower. Heating is consumption is higher but electrical loads are lower.

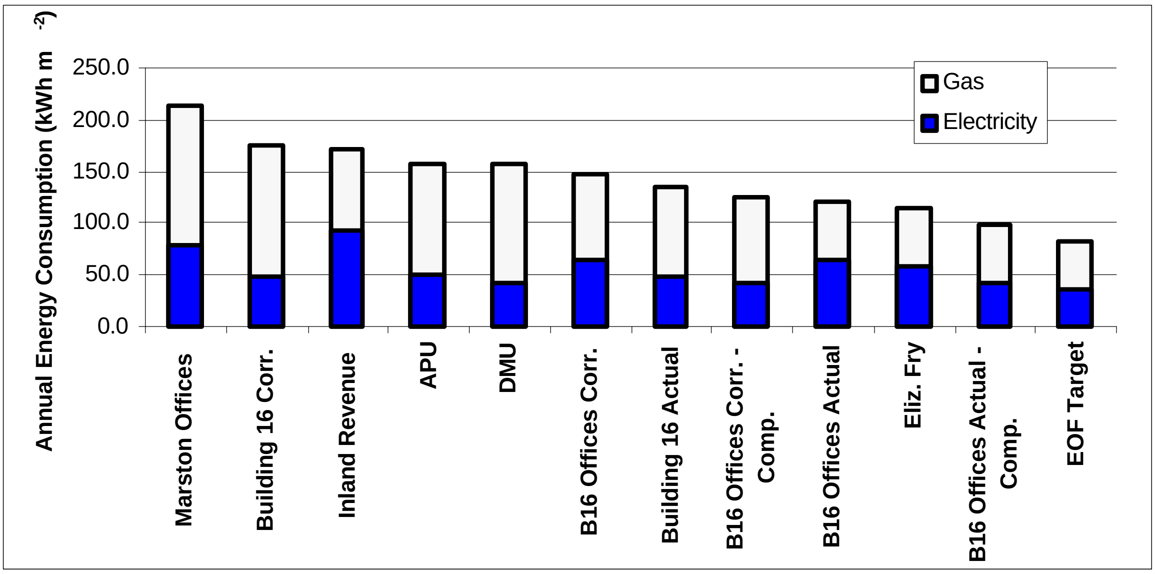

Fig. 5 Comparison of normalised annual energy consumption against other contemporary low energy buildings.

In terms of CO_2, the figures are even more encouraging, with the whole building producing 20% less than the Inland Revenue building but 6-11% greater than the APU and DMU educational buildings, although the actual emissions are some 7% less. The office section, with the computer suite has similar CO_2 emissions to the building as a whole. However when the computer suite is deducted, actual emissions are 20% lower, but corrected consumption only 7% lower. It should be noted here that the office section shares circulation areas and plant with the seminar block. These facilities are located within the seminar block itself, which is less well-metered than the office section. The office section contains most of the passive conditioning features of the building, while the seminar block employs more active systems to cope with the variability in the loads. Therefore the energy apportionment between office and seminar is difficult to estimate.

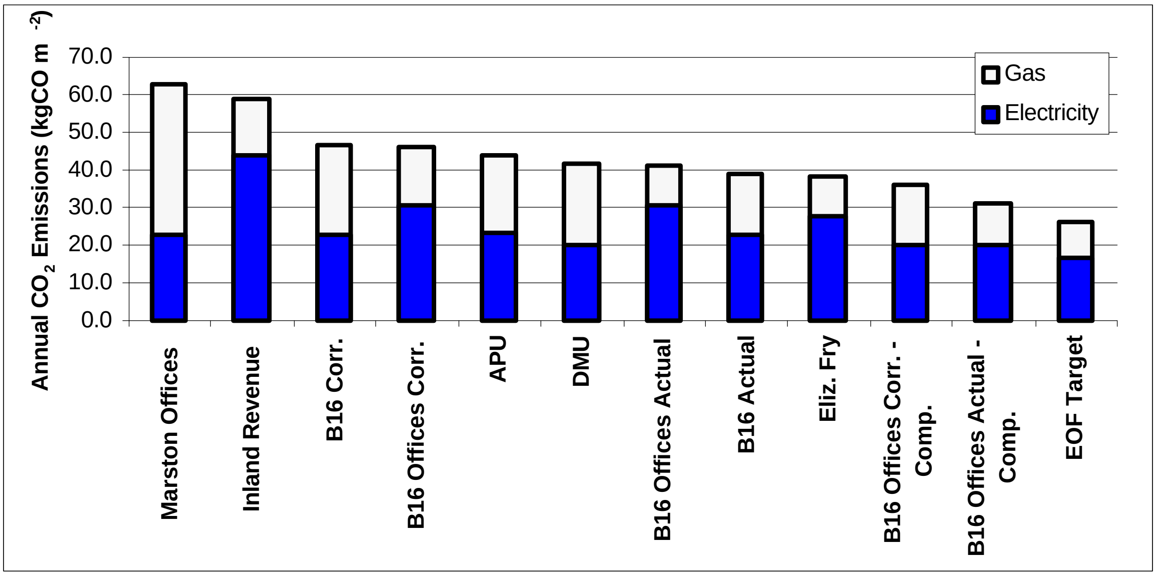

Fig. 6 Comparison of normalised CO_2 emissions against other contemporary low energy buildings.

3.5.3 Break-down by End-use

Comparing the energy split with ECON 19 benchmarks for office types II and III (no humidification) it is clear that energy usage in the building as a whole is dominated by water heating, which is mostly space-heating (Figure 7). Estimates place services hot water at only 5% of total water (gas) heating. 1999 actual figures place space heating at 10.5% higher than good practice type II buildings, but 10% lower than good practice type III. When this is corrected for degree days, heating is 32% higher than good practice type III and 62% higher than type II.

Active (borehole) cooling energy consumption is negligible, at 0.4 kWh m^{-2} due to the success of the night-cooled thermal mass strategy. Fans and pumps (excl. borehole) are more than double a type II GP building but 70% lower than a type III building, with which the levels of comfort conditioning equates. , Despite problems with the external louvres and daylight levels which were lower than expected, lighting consumption is nearly 30% lower than good practice type II GP building at 15.8 kWh m-2 and 40% lower than a type III GP building. This is however, about 15% higher than the EOF target. With the computer suite separated out here from the office general small power into a separate computer “room”, small power is about half that of a type III GP building, which was expected. This is also 40% lower than a GP type II building. The computer room is 30% smaller than expected for a type III GP building. All figures here are normalised by the TFA of the building.

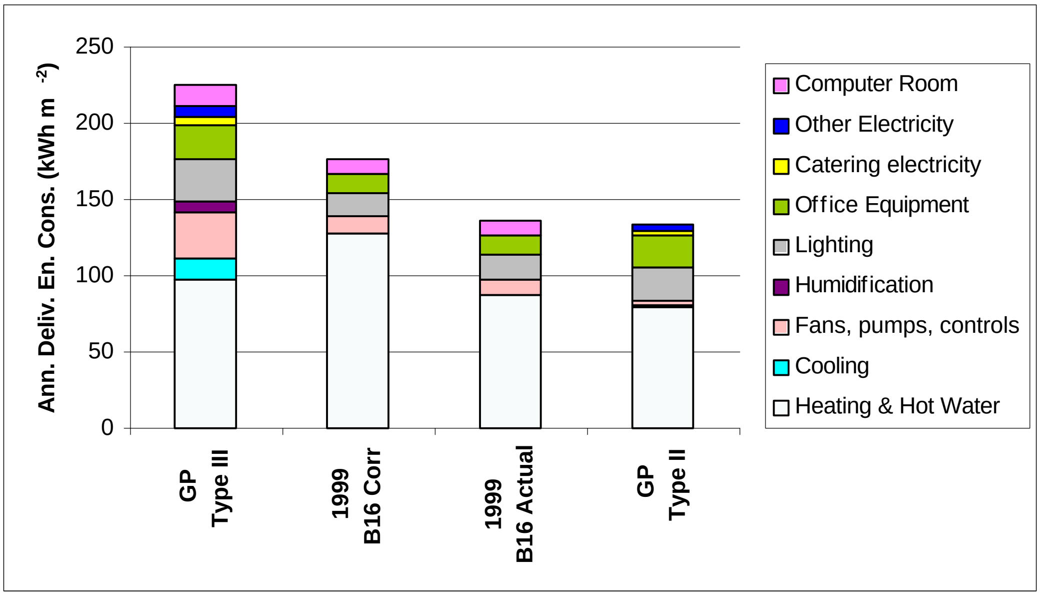

Fig. 7 Breakdown of annual energy usage for the whole buidling against ECON 19 Good practice benchmarks

The south-facing photo-voltaic cladding on the seminar block has to date contributed the equivalent of 17% of the ground floor office lighting energy consumption annually.

3.5.4 Office vs. Seminar Block

Lighting and ring main consumption are not metered separately in the seminar block. Electrical consumption here is dominated by lighting energy. Ring main usage is limited to short periods of cleaning, catering and audio-visual equipment. Although there is a kitchen in the seminar block, most catering for conferences is carried out in another building on the site. Seminar small block power and catering is therefore estimated as 5% each of the total metered electricity here. This is probably an overestimate. The total annual mechanical plant and borehole energy are split between the blocks in the ratio of their treated floor areas. Electrical consumption for the offices has been split between two floors, as the top floor was unoccupied for most of the monitored period. This was heated and cooled, therefore heating and cooling is split between the three floors. While it is accepted that common areas are shared between blocks (toilets etc.), these spaces would be significantly smaller for an office building and therefore consumption of these areas is attributed here to the seminar block.

As can be seen, the performance of the unoccupied (seminar block and common) areas significantly compromises the overall efficiency of the building (Fig. 8). It should be noted again here that it is the office section which is largely conditioned by novel components (for lighting, heating and daylighting). Actual office heating is currently 57 kWh m^{-2}, 20% above the EOF target, while the actual seminar consumption is 2.5 times this at 141.2 kWh m^{-2}. When corrected, this rises to 206.8 kWh m^{-2} and is therefore a cause of some concern. Corrected office heating in close to type II GP and 10% lower than type III GP.

Office lighting energy consumption, although higher than expected due to a daylighting shortfall, is still good at 13.8 kWh m^{-2} (type II is 22 kWh m^{-2}). This can be attributed to the highly efficient miniaturised lighting system & controls. Seminar lighting is almost double this at an estimated 25 kWh m^{-2} (which may be conservative) and equivalent to type III GP. Office small power, without the computer suite, is larger than its ECON 19 counterparts, although it is understood that PC's are generally switched off at night.

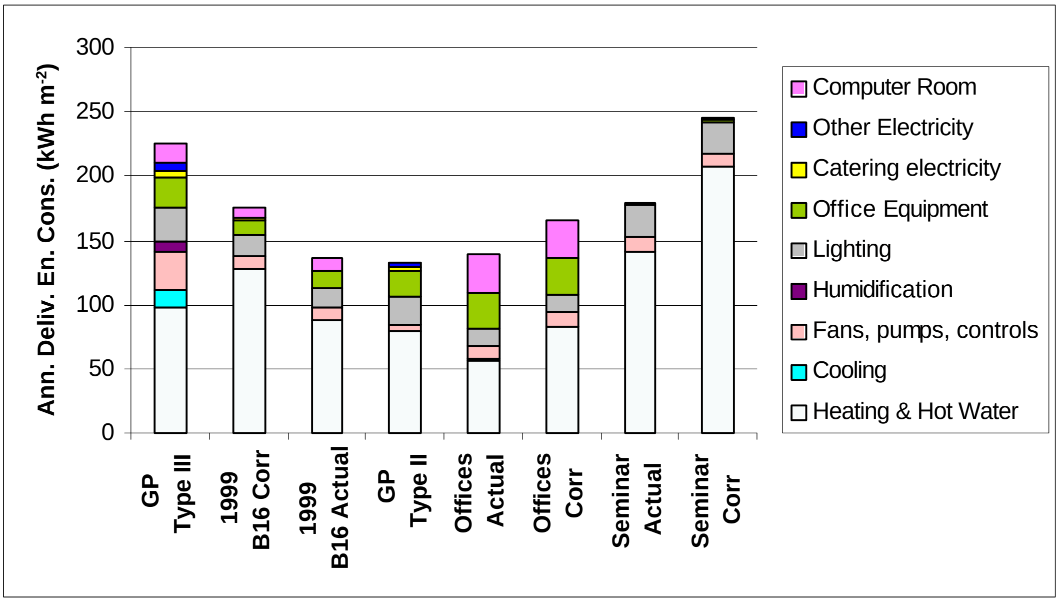

Fig 8. Breakdown of energy consumption for office and seminar blocks against benchmarks and whole building consumption.

3.5.5 Optimisation Measures

High space heating consumption brought about in part by building envelope integrity problems, while control aspects also play a significant role, both in heating and lighting energy consumption. The target air leakage index of 7.5 m^3hr^{-1} per m^2 of envelope area at 50Pa was discussed but not specified in the contract. Air leakage was measured using the BREFAN (BRE's Large Fan pressurisation system). An air leakage index more than 60% greater than this value was measured in the office section, with the building as a whole giving more than twice this value. Background air change rates were measured using the tracer gas decay method. For the offices (vents fully closed) these ranged from 0.18 h^{-1} under still summer conditions to 0.31 h^{-1} in moderate winter conditions. A very high background of 0.88 ach^{-1} was measured in the main seminar room during winter under moderate wind conditions. Office heating consumption was highest on the top floor due to heat losses through the roof (Fig. 9).

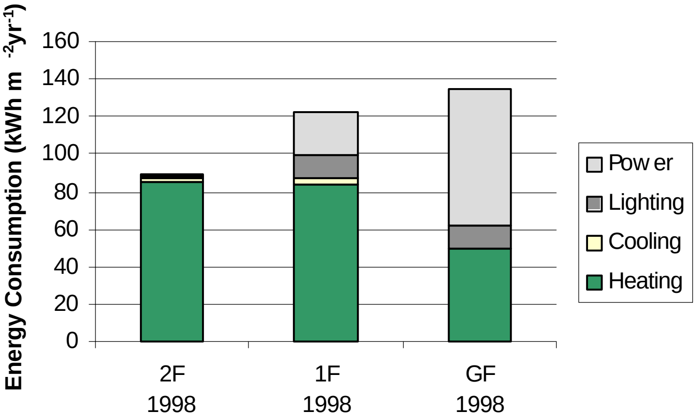

Fig. 9 Offices Energy Consumption for all floors in 1998.

A full air leakage audit was subsequently commissioned and areas requiring urgent attention were identified: most importantly the top floor and ground floor offices and the main seminar room.

Remedial work carried out between 1998 and 1999 improved air-tightness by 12% whole building, resulting in a fall in heating energy consumption of 11%.

The differences in climate between these periods were:

- 1998 experienced 1747 heating degree-days (in terms of Energy Efficiency Best Practice data for the Thames valley region), while 1999 was warmer with a slightly lower 1681 degree days (~4% less). Degree-days measured at the site were slightly higher than this but linear in comparison.
- Mean December solar radiation was higher in 1999 than 1998 – mean global solar radiation in the horizontal plane was 25% higher, while south vertical plane was 63% higher. So there was a potential increase in useful solar gain between years.

Space heating, however was 97.5 kWh m^{-2} in 1998 and 87 kWh m^{-2} in 1999, an 11% reduction – while degree-days only saw a 4% reduction. The pre-remediation heating consumption was 0.06 kWh m^{-2} degree day^{-1}, which reduced to 0.05 kWh m^{-2} degree day^{-1} post-remediation. Correcting for standard degree (2462) days gives a space-heating bill of 137 kWh m^{-2} in 1998 and 127 kWh m^{-2} in 1999 – an adjusted reduction of 7.3%.

Key differences between the BRE building and the Elizabeth Fry building are building envelope factors and mechanical ventilation heat recovery, which kept space-heating energy consumption down to 50 kWh m^{-2}. U-values of the walls, roof and windows were almost half those of the BRE building and air leakage rates lower. Glazed area is also smaller.

Offices: 1998 vs. 1999

Office heating still stands at 57 kWh m^{-2}, which is still above target, however this is 22% less than 1998, with the lowest consumption on the ground floor. However, some remedial work was carried out on the building fabric on both the ground and 2nd floors between 1998 and 1999. Additionally the 2nd floor became occupied during the summer of 1999, ceasing to be used as a “seminar/common” type space. These measures have resulted in a decrease in actual energy consumption of almost 30% on the ground and 2nd floors, compared with only a 12% reduction on the 1st floor. Corrected reductions 24%, 8% and 26% for the ground, 1st and 2nd floors respectively (Fig. 10). No particular action was taken on the 1st floor with regard to heat losses, therefore this reduction in energy appears to be largely associated with the differences between heating seasons in operation, which may also apply to the other floors.

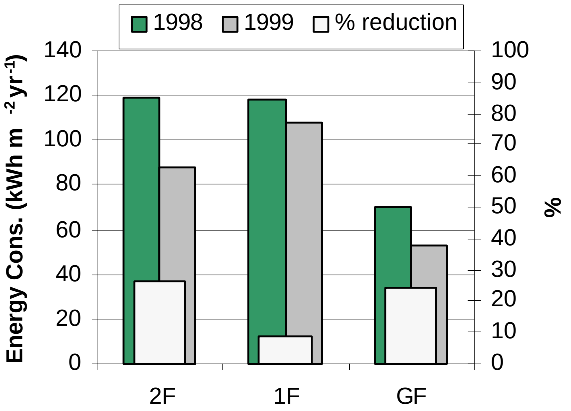

Fig. 10 Comparison of office heating energy consumption for 1998 and 1999.

Seminar Block: 1998 vs. 1999

Main seminar room actual heating fell by 7% between 1998 and 1999, but corrected decrease was only 3.5%. Heating in the seminar block saw no overall actual change, but corrected figures show an overall increase of 3.5%, which will be due to the common areas and small seminar rooms, not the main seminar. A 15% reduction in lighting energy was, however, noted in the seminar and common areas, while office lighting, on the other hand increased by 8%. The reduction is 5 kWh m^{-2} of the seminar and common floor area. Consumption now stands at 27.5 kWh m^{-2}. It is understood that previous recommendations for tighter controls on lighting usage when these areas are unoccupied may have been implemented, although the indication is that this could probably be reduced further without compromising the needs of the tenant.

3.5.6 Areas for Further Optimisation

Ranking of end-uses in terms of 1999 energy consumption places heating of the main seminar at the top, both in terms of the total consumption and normalised consumption per m^2 (Fig. 11), which is currently a disproportionate 357 kWh m^{-2}. Heating of the 1st floor office, 2nd floor office and small power to the computer room follow in the ranking. In terms of consumption by floor area, heating of the seminar and common areas occupy the top three slots, followed by the three end uses previously mentioned. It is in these six end-use areas where optimisation will have the most impact in driving the overall energy consumption figures (kWh m^{-2}) down towards the targets. There is little that can be done about the high levels of small power consumption in this case.

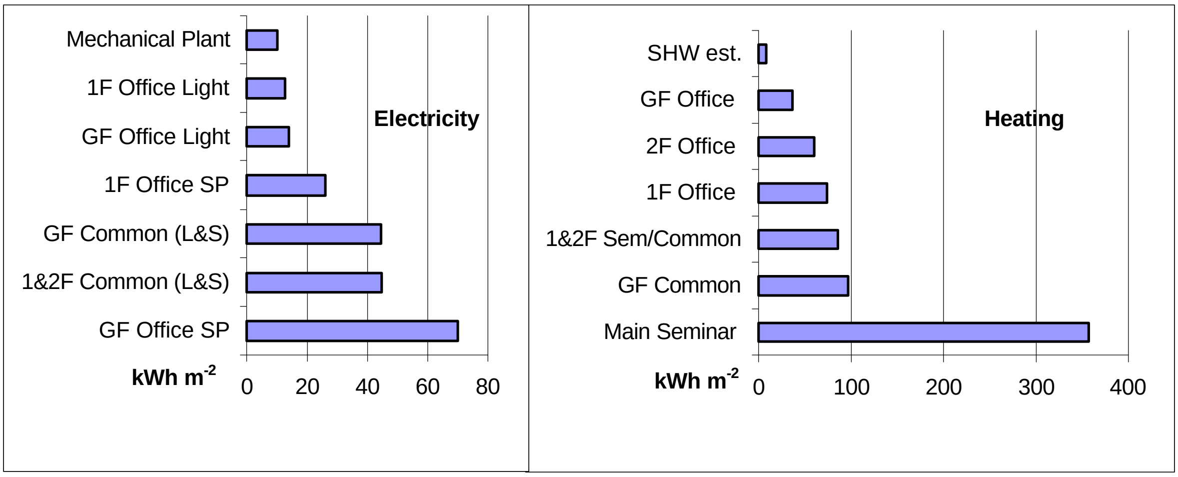

Fig. 11 Normalised energy consumption ranked by end-use for heating and electricity. (SP=Small Power; L&S=Lighting and Small Power)

Both heating and lighting consumption are high in the seminar and common areas, which account for roughly 60% of the heating and lighting bills, although they are just 36% of the treated floor area. Significant savings can still be achieved on space heating, especially in the main seminar room, which accounts for a disproportionate 50% of the space heating consumption (Fig. 12). Although electrical energy consumption in the building as a whole is dominated by office small power, lighting can be as much as 50% in winter, and 35% over the whole year. While savings can certainly be made in the offices, there is a more urgent need to economise further on lighting and heating of the common areas through tighter control when they are not in use. Mechanical power was responsible for only 20% of the electrical energy consumption.

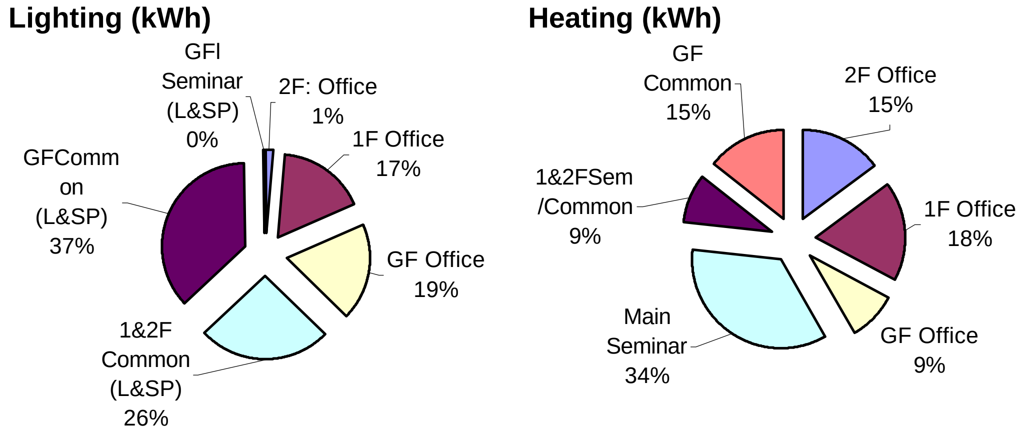

Fig. 12 Breakdown of total energy consumption by area for heating and lighting.

4 SUMMARY OF FINDINGS

In conclusion, the performance of BRE's Environmental Building is proving to be successful to date, although some areas for improvement have been identified. The building is providing:

- Excellent summer thermal environmental control;
- Good standards of relative humidity, indoor air quality and ventilation;
- Good levels of daylight, although these are slightly lower than expected;
- An energy performance that exceeds good practice, but needs optimisation;
- A pleasant, comfortable working environment for staff.

5 LESSONS LEARNED

- Night-cooled thermal mass can be effective in providing comfortable spaces;
- Daylighting strategies can minimise electric lighting consumption;
- It is important to specify the desired level of airtightness in a contract to minimise fabric losses;
- Strategies for control of unoccupied spaces should be in place early in occupancy, to meet the tenant's needs and minimise energy wastage.

6 FURTHER WORK

BRE has identified areas for improvement and optimisation of the low energy building:

- Improve air-tightness of the seminar spaces as remediation carried out in the offices has been successful;
- More controls are needed for the unoccupied/owned spaces in the building.

The relative merits of novel prototype elements and the layering of strategies is being investigated in terms of the justification of their over-cost in terms of the overall desired economy and replicability of the building. These lessons will be taken on board in the future, so that the building performance can be improved even further.

7 REFERENCES

[1] Ní Riain C, Kolokotroni M, Davies M, Fisher J, White M, Littler J, Cooling effectiveness of south façade passive stacks in a naturally ventilated office building – case study, *Indoor + Built Environment,* 8:309-321, 1999.

[2] Ní Riain, C and Littler, J, The Integration of Energy Technologies in the ‘Office of the Future’. *Interim Technical Report No. 6,* CEC/DGXII Project No. BU/00337/95/UK/DE/NL, October 1998.

[3] The Queens Building, De Montfort University - feedback for designers and clients, *New Practice Final Report 102,* DETR, London, 1997.

[4] The Elizabeth Fry Building, University of East Anglia - feedback for designers and clients, *New Practice Final Report 106,* DETR, London, 1998.

[5] The Inland Revenue Headquarters Nottingham - feedback for designers and clients, *New Practice Case Study 114*, UK Government Energy Efficiency Best Practice Programme, London, 2000.

[6] The PROBE Team, PROBE 16: Marston Book Services, *Building Services Journal*, August, 1998.

[7] Cohen R, Leaman A, Robinson D and Standeven M, PROBE 8: APU Learning Resource Centre, *Building Services Journal,* December, 1996.

[8] A Performance Specification for the Energy Efficient Office of the Future, *General Information Report 30,* DETR, London, 1995.

[9] Energy Consumption in Offices, *Energy Consumption Guide 19 (ECON19),* DETR, London, 1998.

[10] BREEAM Assessment.

[11] *Building Services Journal* Centenary Supplement with CD-ROM, London, October 1997.

[12] The Environmental Building, Watford - feedback for designers and clients, *New Practice Case Study*, UK Government Energy Efficiency Best Practice Programme, London, 2000 (in press).

[13] Cook, J, Towards a sustainable office building, *Solar Today: J of the American Solar Energy Society*, July/August 1998.

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