The Elizabeth Fry Building, University of East Anglia

– feedback for designers and clients

- Energy consumption is half that of a conventional building of this type
- Use of the building's thermal mass provides good levels of comfort
- Occupant satisfaction and productivity is high
- Capital and maintenance costs are low

NEW PRACTICE FINAL REPORT 106

ENERGY EFFICIENCY

BEST PRACTICE PROGRAMME

OVERVIEW

This Report is the second in a series[1] on innovative buildings to be published under the Energy Efficiency Best Practice programme

OVERVIEW

A new building to house the School of Social Work at the University of East Anglia (UEA) was designed to perform better than two adjacent energy-efficient buildings on the University's main campus. Three factors dominated the design requirement:

- minimising heating and air-conditioning
- making the best possible use of daylight
- ensuring compatibility of architecture with the surrounding buildings.

The client's brief called for a building with a lecture theatre, seminar and lecture rooms, offices and administrative facilities to meet the demands of an expected building occupancy of up to 1100.

The architects had to consider the narrow and sloping site when seeking to reconcile the brief with the building design. Another factor for consideration was that the total construction cost was not to exceed that for a conventional building, which would probably have utilised mechanical ventilation and air-conditioning.

The resulting four-storey building consumes less than half the energy required by a conventional university building of this type (Department of the Environment, Transport and the Regions' (DETR) energy benchmarks (see page 9)).

The topography of the site meant that the design team was able to provide access to the building on two levels. The narrow plan form chosen for the building allowed high levels of daylight to reach all the spaces, and enabled all rooms to have openable windows to provide occupants with a sense of control over the internal conditions, and a link with the external environment.

The ventilation strategy utilised a high level of exposed thermal mass. Night cooling in summer, where external daytime temperatures in excess of 30°C have been experienced, was achieved by delivering air by mechanical plant through a hollow core concrete slab. This eliminated the need for air-conditioning.

UEA adopted novel techniques to achieve the environmental and energy performance of the Elizabeth Fry Building by delivering benefits in terms of occupant comfort levels, increased productivity, low carbon dioxide (CO_2) emissions and energy cost savings. The building integrates well with the surrounding architecture, the principal energy efficiency features being an integral part of the overall design rather than added to the finished structure.

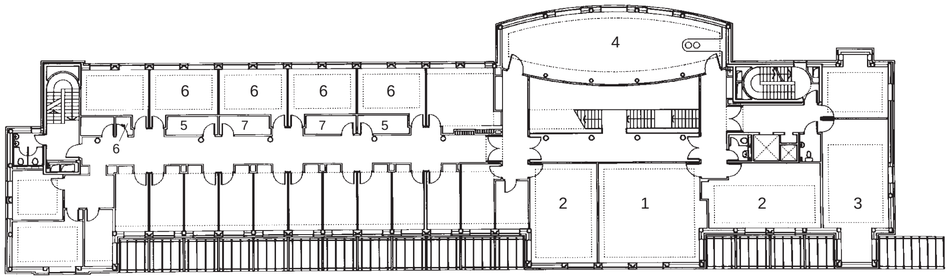
PLAN VIEW OF THE ELIZABETH FRY BUILDING

PLAN VIEWS OF THE BUILDING

KEY – FIRST FLOOR

1 55-seat lecture room
2 Seminar room
3 Research desk room
4 Common room
5 Files/monographs store
6 Storage
7 Photocopying room

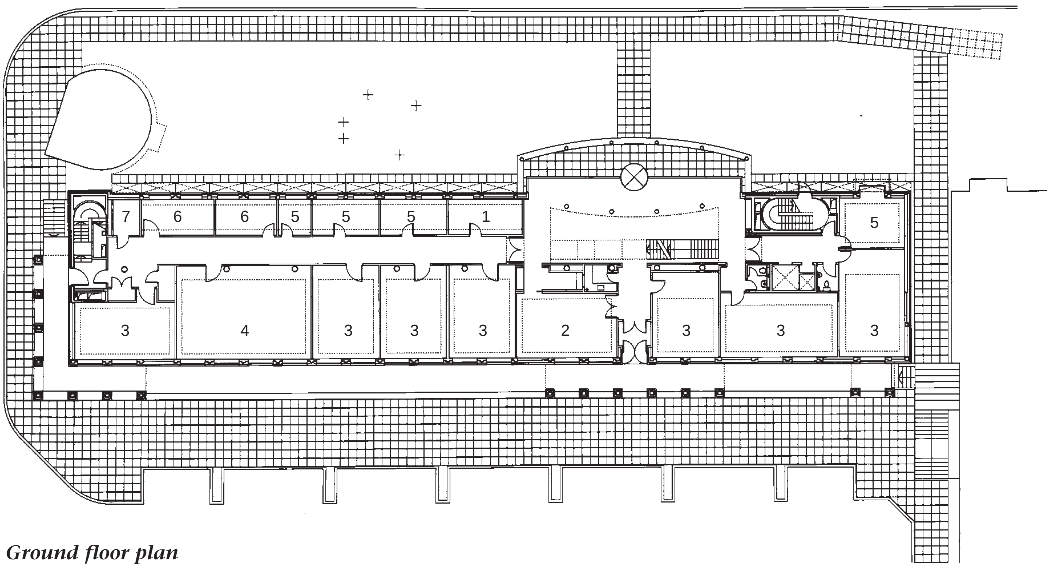
All other accommodation is offices



First floor plan (second floor plan is similar)

KEY – GROUND FLOOR

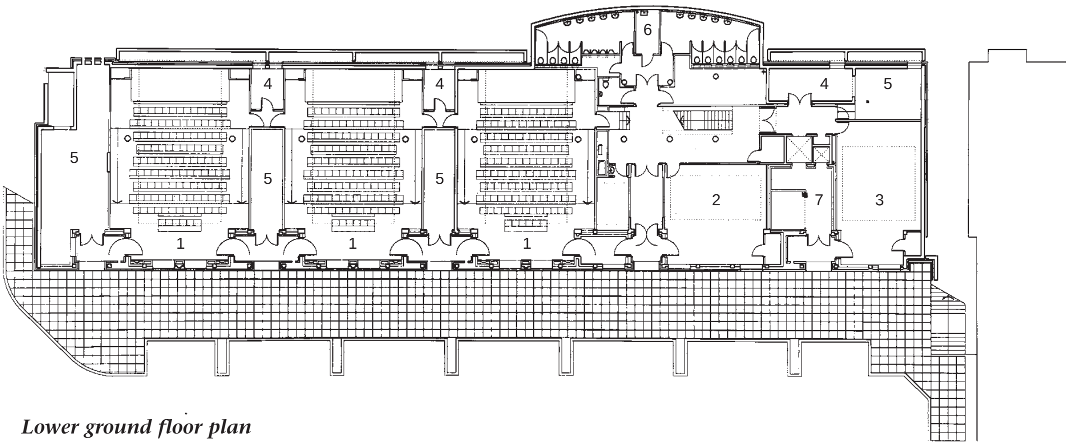
1 Manager's office
2 Arrivals room
3 Short course – seminar room
4 Short course – lecture room
5 Short course – office
6 Skills laboratory
7 Storage



Ground floor plan

KEY – LOWER GROUND FLOOR

1 130-seat lecture theatre
2 60-seat lecture room
3 Information technology room
4 Storage
5 Plant
6 Cleaner
7 Service bay



Lower ground floor plan

INTRODUCTION

This Report is the second in a series[1] on innovative buildings to be published under the Energy Efficiency Best Practice programme

INTRODUCTION

The University of East Anglia (UEA) caters for 9000 students and occupies a 166 000 m^2 campus on the outskirts of Norwich.

In 1992 the University agreed a capital investment programme to construct a new building to accommodate the School of Social Work. The Elizabeth Fry Building was to have an expected occupancy of 1100 (maximum), and incorporate a lecture theatre, seminar rooms and offices.

The new 3250 m^2 building was to be constructed on the main campus, adjacent to two energy-efficient and award-winning new buildings:

- Constable Terrace; student residences
- The Queens building; housing the School of Occupational Therapy and Physiotherapy.

The University wanted the Elizabeth Fry Building to be even more energy efficient than the neighbouring new buildings. This was to be achieved by:

- minimising heating and air-conditioning
- making the best possible use of daylight.

The brief called for an innovative design in a passive building which maximised daylight, and at a cost no more than a standard building. The resultant building demonstrates that it is possible to construct a well-sealed building at low cost with high levels of comfort, low energy consumption and low maintenance costs.

Setting stringent requirements and criteria that can be checked before handover can lead to a good quality building. For example, UEA set an airtightness target for the building and specified that it was to be tested independently. This ensured that the project team provided the attention to detail required to achieve this.

This Report is written for designers and clients. It looks at what was achieved by the University and design team, summarising the key aspects of an environmentally conscious and energy-efficient new building.

A plan view of each floor is provided for reference on page 3.

The design approach

The site called for a narrow plan building, allowing high levels of daylight to reach all spaces. In addition, the narrow plan gives occupants a good link to the external environment because all rooms have windows openable to the outside air.

Night cooling in summer is achieved by the delivery of air through a hollow core concrete slab by mechanical plant. By cooling the thermal mass of the hollow core slab (see figure 1 on page 6), and allowing occupants the flexibility to open windows during the daytime for additional ventilation, a high level of occupant comfort is maintained.

The sloping site allowed the design team to provide ground-level access both to the building's lower ground floor and ground floor levels.

Low energy use was achieved without compromising occupant comfort. The main features of the design that enabled this were:

- high utilisation of thermal mass by exposing the structural concrete within the insulated envelope
- an airtight construction with very low air leakage by UK standards
- high levels of insulation
- triple glazing with integral sunblinds
- the use of high-efficiency heat recovery units
- a narrow-plan building allowing space to be lit substantially by daylight.

BUILDING DESCRIPTION

MAIN FEATURES

Fabric

The fabric of the building is highly insulated and well sealed. The walls have 200 mm of insulation, and the windows comprise a double-glazed unit with low-emissivity (low-e) glass and a third ventilated external pane with integral sunblind. This has resulted in an internal heat requirement of only 50 W/m^2 a year, which is half the typical requirement for an educational building[2]. For details of U-values see the building data on page 13 of this Report.

The building specification required the finished building to achieve one air change per hour (ach) at a pressure of 50 Pa, and also stipulated that this was to be independently tested before handover. Both of these factors ensured that careful detailing and regular, thorough inspections were carried out during the construction of the building, and that the low leakage rates and high standards of insulation were achieved as specified. No specialist contractors were needed to achieve the extremely low level of air leakage specified by the design.

The building services were kept simple, allowing the higher fabric costs to be justified by savings on services.

Daylighting

The building is lit substantially by daylight, particularly in the offices and the atrium, and provides a visually attractive internal environment.

The fully glazed main entrance leads into an atrium which incorporates a staircase to all floors. This maximises daylighting because of the roof glazing and incorporates photosensitive louvres to control solar gain. The white interior decoration further enhances daylighting.

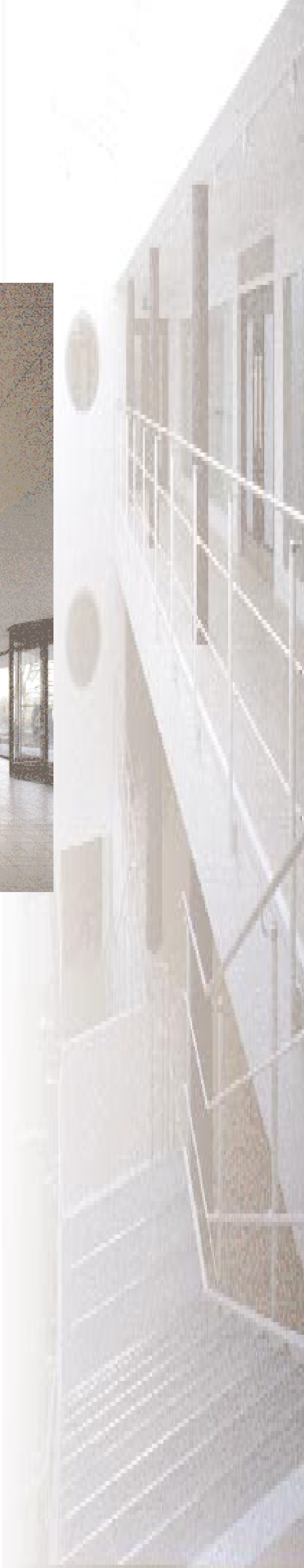
The lights are currently left on regardless of the availability of daylight, due to the lack of lighting controls. Photocell controls, for switching lighting on or off according to the levels of daylight, were withdrawn from the specification for financial reasons. Their omission has resulted in unnecessary use of electric lighting and hence a waste of energy.

Entrance hall and atrium of the Elizabeth Fry Building

Lighting

Perimeter cornice lighting equipped with high-frequency fluorescent lamps provides lighting in the rooms. The lights are positioned to take advantage of the extract airflow, thus reducing the heat gain to the room. Light switches are positioned adjacent to doors, with dimmer controls in the lecture rooms.

The offices and meeting rooms in the building are less than 6 m deep and daylight levels are sufficient for most of the year. However, the rooms have cornices that cast a shadow on the ceiling. This tends to make the offices seem dark despite good daylight at desk level. Because of this, many occupants use artificial lighting to brighten the room even when there is sufficient daylight.



BUILDING DESCRIPTION

In each office, two light switches were installed to allow the parts of the rooms to be lit independently. However, these have been concealed by filing cabinets since occupation, and a single pull cord has been retrofitted.

The corridors are lit by uplighters using compact fluorescent lamps and, as there is no daylight in the corridors, they are left on permanently during occupancy of the building. There are also tungsten halogen emergency lamps.

Heating and ventilation

Air for heating and ventilation is supplied through small circular diffusers from the hollow cores in the concrete ceiling by air handling units (AHUs) with very high heat recovery capabilities. Air is extracted over the cornice at ceiling level. The heat is recovered from the extract air, which is then passed back through the slab into the room.

When the building is occupied there is a continuous supply of fresh air delivered by four AHUs, two supplying the basement lecture rooms and two supplying each end of the three upper floors. The ventilation rate in the lecture theatre is varied using variable speed fans controlled by carbon dioxide (CO_2) levels in the extract air. This ensures that only small amounts of fan power are used unless there is high occupancy, when the ventilation rate increases.

Heating is provided by three gas-fired 24 kW domestic-size wall-mounted condensing boilers. All three boilers are fired at start up, although the building energy management system (BEMS) determines load and turns off those not required. One boiler meets the majority of the building's heating requirements, with the second meeting any additional demand. The heat output goes direct to the four AHUs thus minimising pipe runs,

Hollow core slabs

TermoDeck™ is a patented system which uses the hollow cores in the concrete ceiling slabs as the final part of the air supply duct. The ceiling slabs act as a heat sink and provide radiant heating or cooling and convective heat transfer to the supply air.

Air is supplied through the TermoDeck slabs to the occupied spaces. During the winter the heating system maintains the temperature of the slabs at around room temperature. This ensures that the radiant temperature in the building is close to the internal air temperature. During the summer the slabs are cooled overnight with fresh air. This provides a heat sink for the daytime heat gains.

The TermoDeck design reduces the need for ducting or perimeter heating and so reduces costs and improves space utilisation. It also uses the available thermal mass efficiently.

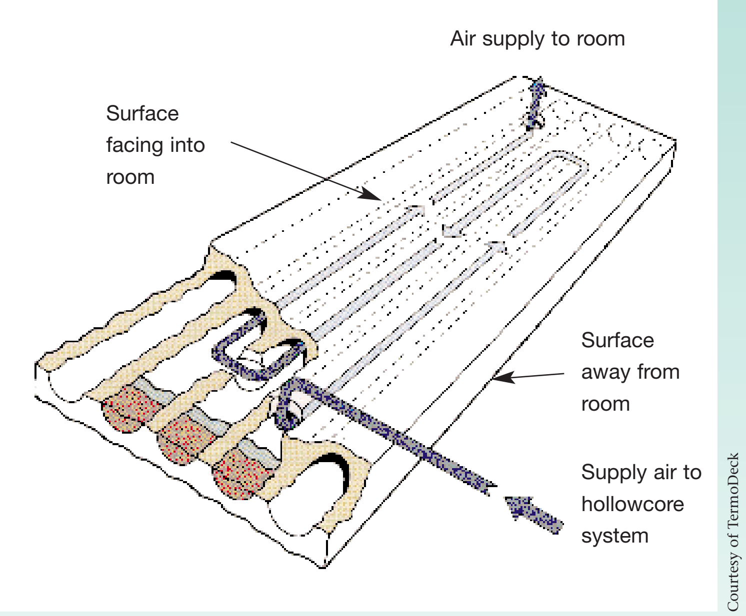


Figure 1 The ventilation principle employed in this building means that the hollow cores in the concrete ceiling act as a heat sink while supplying air to work areas. (For ease of display, the panel is shown with the exposed surface uppermost.)

BUILDING DESCRIPTION

their associated costs and heat losses. Sensors in the hollow core slab control the air supply temperature.

The high levels of insulation and heat recovery mean that most of the heat required to warm the building is generated by occupants and office equipment. Any additional heat is provided by the domestic-size condensing boilers, which have lower capital, running and operational costs than boiler plant found in buildings of a traditional design.

Energy management

Although the original specification called for a BEMS this was downgraded during the final stages of the building's construction to reduce costs. This proved to be a false economy because the building management team needed better access to information to ensure efficient and effective running of the building. The whole system is now controlled by a BEMS that was installed one year after the building's completion.

THERMAL MASS AND HOW IT WORKS

The hollow core ceilings of this building are used as part of the air delivery system and to store heat and coldness (coolth) at different times of year, as shown below:

Summer night	During the hot summer period, cool night time air is blown through the ceiling slab using mechanical assistance. This cools the concrete slab and acts as a cool store for the following day. In this way the need for energy intensive air-conditioning can be avoided. The night cooling is successful in maintaining conditions below 25°C even in the hottest periods. This system also has the advantage of using cheap rate electricity to operate the AHUs.
Summer day	On hot summer days the 'coolth' stored in the hollow core ceiling from the night before improves comfort in two ways. ■ It absorbs heat produced by people and machinery acting like a radiator in reverse. ■ Fresh air is passed through the ceiling slab and cooled down by it before entering the room. Using thermal mass over other methods of cooling allows greater freedom for occupants, as they can open windows if required.
Winter night	The building is sealed at night during the winter to keep in the daytime heat gains. In cold weather it is likely that some heating will still be required, especially in the early morning. Therefore, the ventilation with heating is started at 8 am to ensure that room temperatures are satisfactory at the start of the working day. If the building cools down while unoccupied the plant is called to start by the temperature sensors in the slab and runs on recirculation only. There is no fresh air ventilation when the building is unoccupied.
Winter day	During cold winter periods the tightly sealed and highly insulated building envelope retains most of the heat for the building. Heat produced by occupants and machinery is radiated to the hollow core slab and recovered from the extract air, which is then passed back through the slab into the rooms.

PERFORMANCE IN USE

'Morale is definitely higher because it is such a nice building to be in, visually, furnishings, environmentally.'

MONITORING AND COMFORT

Prior to commissioning, extensive monitoring was undertaken to measure the performance of the building against the design performance specification. The designers and the client held regular meetings to review the monitoring results of the project. This enabled improvements to be made to ensure that the building operated as intended.

Comfort performance

The Elizabeth Fry Building has met the requirements of the University brief in that it should provide comfortable conditions throughout the year without using air-conditioning.

The high levels of thermal mass result in very stable internal temperatures – the building heats up and cools down slowly. This is shown in figure 2 where there are wide fluctuations in external temperatures.

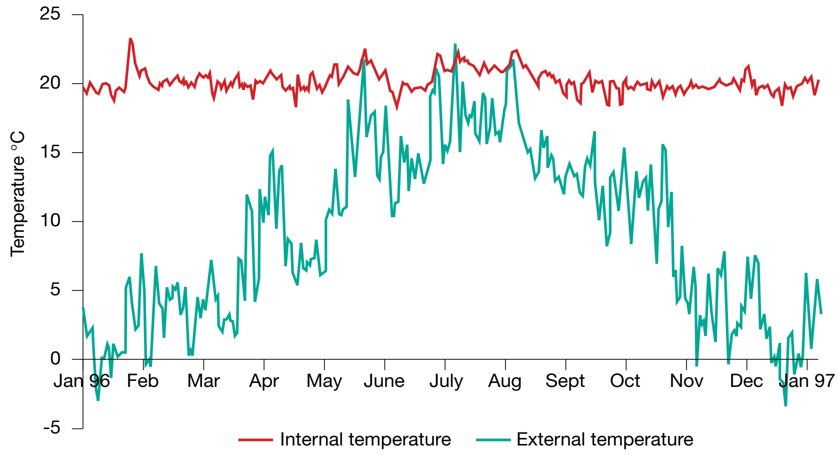


Figure 2 Daily average temperatures for the Elizabeth Fry Building, January 1996 to December 1996

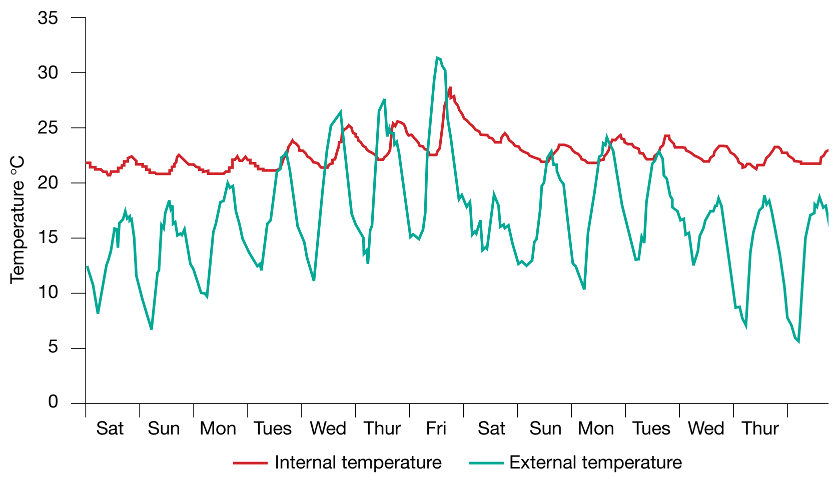


Figure 3 Half-hourly temperatures in a south-facing office 1st-13th June 1996

During one very hot week in June 1996 external air temperatures rose to over 30°C (see figure 3). The internal temperature of the south-facing office remained below 25°C throughout the working day. However, during the week the temperature in the office increased gradually to a peak of 27°C on Friday evening at 7 pm. Over the weekend the building cooled down and temperatures were acceptable the following week. The rise of the internal temperature during the week was probably due to gradual heating up of the thermal mass.

The ventilation in the lecture rooms is controlled by a CO_2 sensor. This results in acceptable levels of CO_2 at around 800-1000 ppm at most times, with occasional peaks at around 1300 ppm during periods of high occupancy.

The lecture room ventilation is brought through the thermal mass and so helps to control temperatures during high levels of occupancy.

USER ATTITUDES

As well as establishing the physical performance of the buildings, the monitoring programme sought to give an indication of user perception and the quality of the working environment. Two user surveys have been carried out, in the spring and the autumn of 1996. Users covered by the survey were:

- occupants of offices
- lecturers
- students.

Seventy percent of office occupants were satisfied with the conditions in the building and only 7% considered conditions to be unsatisfactory. On average, occupants felt that their productivity increased by 7% when they moved into the Elizabeth Fry Building.

During the winter the average temperature in the building was 20°C. Occupants who responded to the survey described the conditions in winter and summer as 'comfortable', with conditions neither too hot nor too cold. Comfortable temperatures were maintained during the hottest part of the summer even with outside temperatures rising above 30°C (see figure 3).

PERFORMANCE IN USE

Occupants were generally satisfied with the lighting although a few felt that there was little natural light (see operational lessons on page 11). Most occupants felt they had sufficient control of lighting.

Students felt that the lecture rooms were no different from others that they used. But both students and lecturers complained that it was hard to see writing on the whiteboards.

ENERGY PERFORMANCE

Energy consumption

The building had a normalised overall energy consumption during 1996 of 102 kWh/m². If the offices alone are considered the energy consumption was 89 kWh/m². Since 1996, the consumption has continued to fall, as more has been learnt about how the building responds during operation.

Energy usage

The energy consumption of the building splits almost equally between gas for heating and hot water, and electricity for all other purposes. Heating accounts for nearly 45% of the energy consumed; with lighting at 25%, and fans in the AHUs accounting for 10%. The remaining energy is used in small power applications, catering and for domestic hot water.

Comparison with other office buildings

The quality of the internal environment provided by the Elizabeth Fry Building appears to be equally acceptable for occupants to that of an air-conditioned building, although the Elizabeth Fry Building uses less than half the energy consumed by the good practice air-conditioned office cited in ECON 19[3]. When compared to BRE's 1981 Low Energy Office, the Elizabeth Fry Building uses slightly less energy and provides a higher level of occupant comfort all year round.

Figures 4 and 5 show the favourable comparison of the building's performance when compared against the DETR's energy and CO_2 benchmarks.

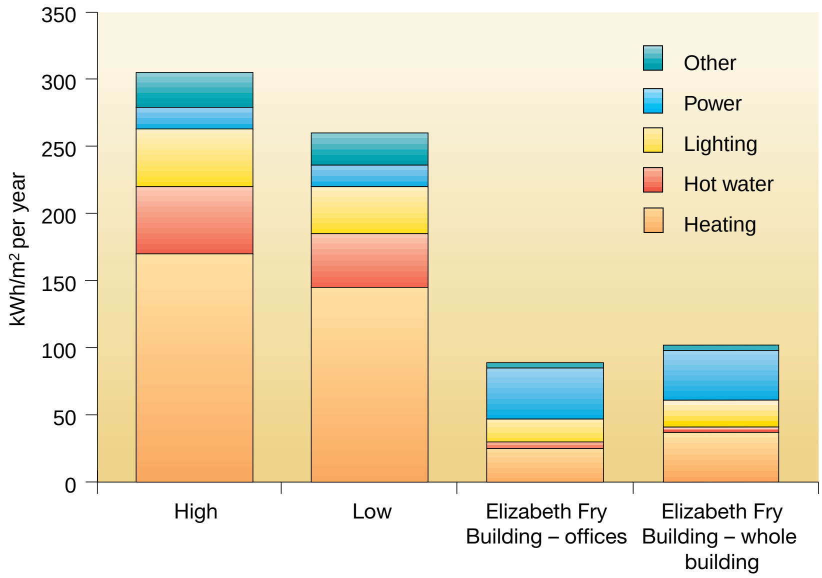


Figure 4 Annual energy consumption compared to DETR's 'low' and 'high' benchmarks

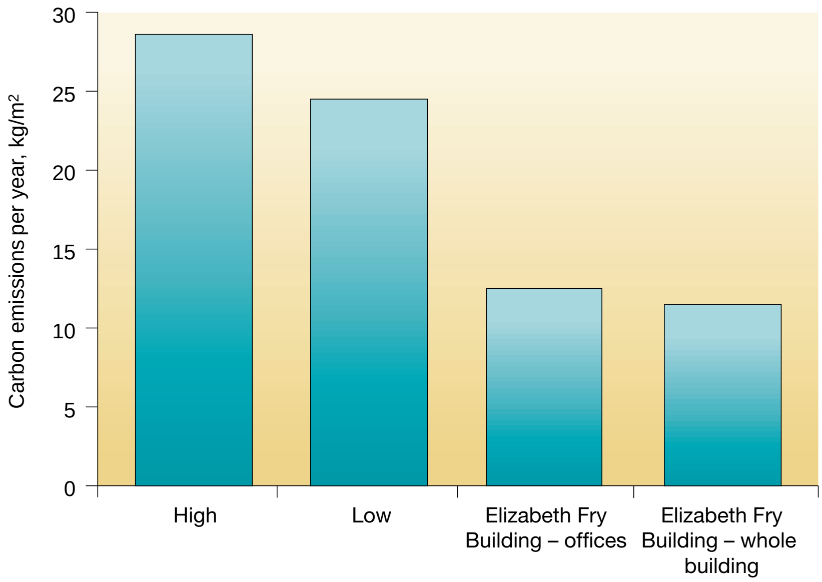
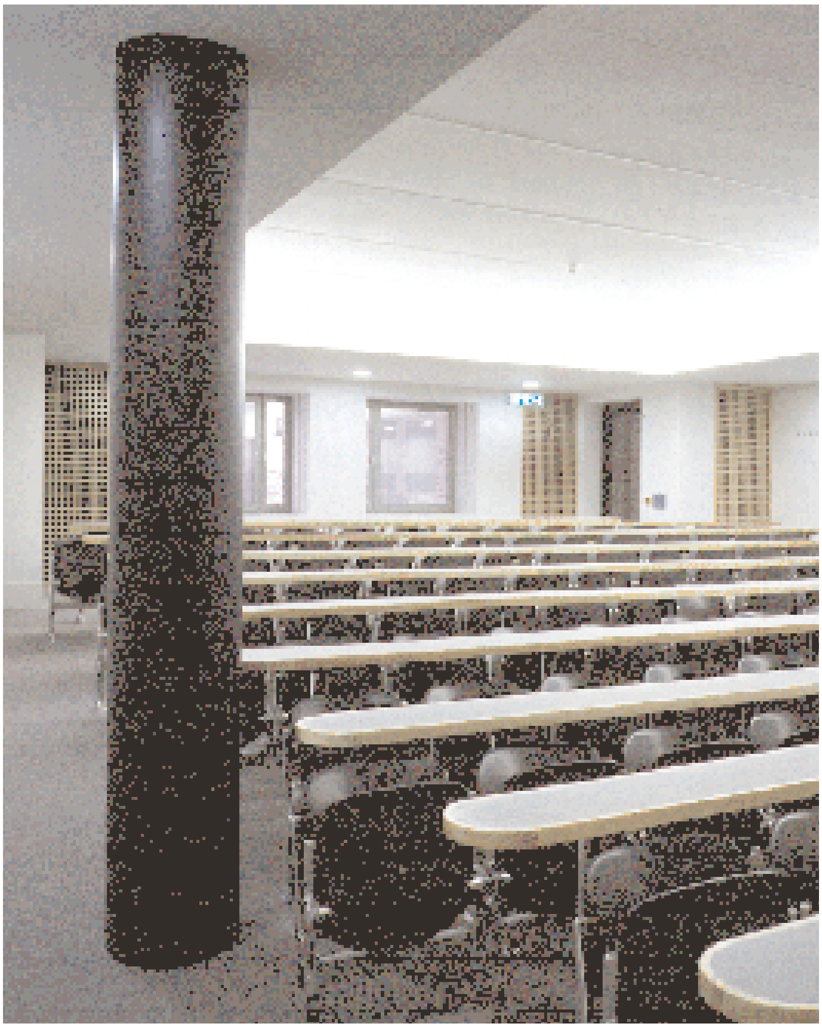


Figure 5 Annual CO_2 emissions (expressed as kg/m² emissions of carbon) compared to DETR's 'low' and 'high' benchmarks

PERFORMANCE IN USE

Factors affecting the energy performance

- Lighting energy use is low due to the energy-efficient lighting used. However, the lack of controls means that it is not as low as might be achieved.
- The proportion of the electricity used by office equipment is about average. This is to be expected as building design has little effect on small power usage.
- The heating energy usage is very low. This is because of the high insulation and airtightness levels in the building.
- Ventilation energy is very low. This is especially so for a building which provides such high levels of occupant comfort.



One of the lecture theatres in the Elizabeth Fry Building

Comparison with air-conditioning

Summer conditions in the Elizabeth Fry Building are more variable than those in an air-conditioned building, but appear to be equally acceptable to occupants. During the 18 months' monitoring period there was only one occasion when internal temperatures rose over 25°C.

The summer conditions in the Elizabeth Fry Building are achieved by using fresh air at night to cool the hollow core slabs. These act as a heat sink during the day to remove the heat generated by the lighting, equipment and occupants. The only energy used for night cooling is the electricity required to operate the fans.

If the Elizabeth Fry Building was air-conditioned it would use twice as much energy as is currently used for night cooling. Night cooling has a further advantage in that it uses off-peak electricity while air-conditioning operates at the daytime tariff. Taking this into account, the cooling costs in the Elizabeth Fry Building are 37% of those that would have been incurred if an air-conditioning system had been used to cool the building.

LESSONS LEARNED

Operational lessons

The heating system was originally set up to heat the hollow core panels overnight. However, as there are large heat gains during the day this was found to be unnecessary. After the first winter's monitoring period the operation of the heating was changed so that heat was provided only when necessary. This has reduced energy consumption in the building and has helped to achieve the consumption performance given on page 9.

During the first part of the monitoring period a poor relationship between daylight and energy use for office lighting was found. This suggested that little use was made of daylight. A memo giving advice on how to optimise daylight, and how to save energy by using the lighting carefully was subsequently circulated to occupants in August 1996, and significant improvement followed.

Design lessons

The Elizabeth Fry Building serves its users well. It provides excellent levels of comfort with low capital and running costs. The building has provided some important lessons in how to design, construct and use successful energy-efficient buildings.

LESSONS LEARNED

Insulation	It is possible to construct highly sealed, well-insulated buildings at reasonable cost, without the use of any specialist labour.	**Low hollow core pressure drop**	The pressure drop across the hollow core system is low and represents a small proportion of the total pressure drop across the ventilation system.
Thermal mass	Thermal mass is effective in stabilising temperatures in summer and winter. This avoids the use of complex services and minimises energy consumption.	**Low overall capital costs**	The building fabric costs were higher than average, but were more than offset by the savings made on mechanical and electrical services.
Night cooling	Night cooling combined with thermal mass is an effective way of cooling office buildings. The Elizabeth Fry Building maintained internal temperatures of 25° or less when outside temperatures were over 30°C.	**Maximised usable floor area**	The use of thermal mass in the ceiling and the absence of perimeter services such as radiators maximised the net usable floor area of the Elizabeth Fry Building.
CO_2 controls	Using a measurement of CO_2 levels to control the ventilation rate in rooms with highly variable occupancy ensures that energy is not wasted on unnecessary ventilation.	**Savings made by cutting controls were false economies**	At the time of construction, costs were saved on the BEMS and lighting controls. These proved false economies, because the BEMS had to be upgraded after a year and the lack of automatic lighting controls has lead to unnecessary lighting use.
Variable speed drives	Variable speed drives were used on two of the four AHUs in the building. In areas where occupancy varies considerably this ensures the elimination of unnecessary ventilation.	**Occupant behaviour**	An improvement in the use of daylight was achieved after a memo was circulated to staff advising them of the best way to use blinds and lights.
High-efficiency heat recovery systems	The highly efficient heat recovery systems reduced energy consumption significantly.	**Involvement of the design team**	The continuing involvement of the design team in the operation of the building has proved valuable in enabling improvements to be made and in identifying design lessons.

CONCLUSIONS AND COSTS

Conclusions

The Estates Management at UEA is very pleased with the Elizabeth Fry Building, as it is an attractive addition to the campus and is liked by users.

In particular the building has demonstrated that:

- low-energy buildings save money
- high comfort levels can be achieved through passive techniques
- some aspect of control for occupants over the internal environment is an important consideration
- cutting costs can be a false economy
- thermal mass is successful as a primary climate modifier.

The building has fulfilled the brief; it has low running costs for energy and maintenance, and cost no more to build than a standard building. Overall, UEA's estates management is completely satisfied with the Elizabeth Fry Building and would certainly consider a similar building design in the future.

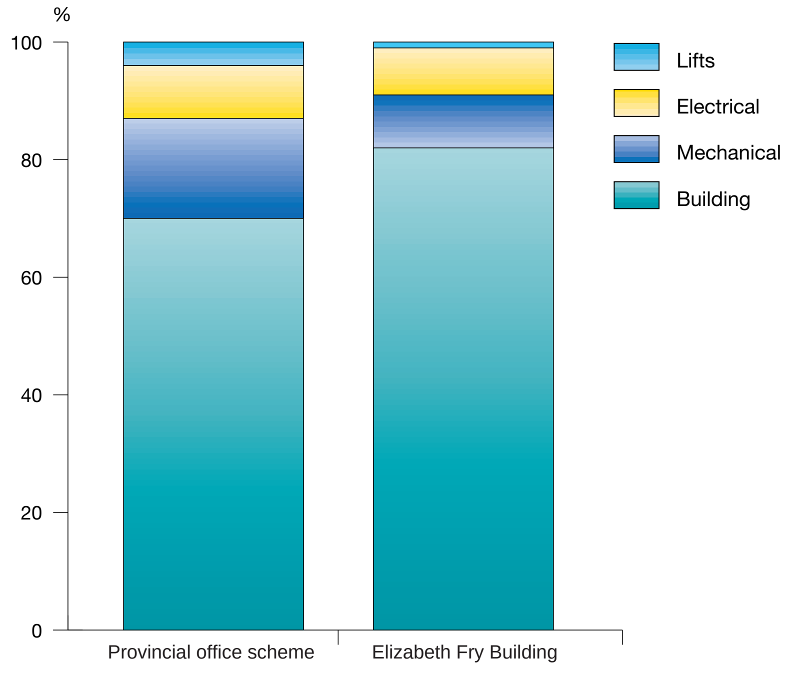


Figure 6 Comparative costs

Costs

The cost of the building was £2.77 million, equivalent to £820 per m^2 gross at 1995 prices. The breakdown of the costs is shown in figure 6, below. These costs are equivalent to those of a standard naturally ventilated building and significantly less than an air-conditioned building. The comparison with an air-conditioned building[4] illustrates how, by specifying low-energy buildings, cost savings can be made.

Despite the building's narrow plan it has a high net usable area because no space is required for ducting or perimeter heating. Maintenance costs to date have been low at £1.40 per m^2 per year. It is unlikely that maintenance costs will increase significantly because of the low level of plant and equipment in the building.

Energy costs are also low. Gas and electricity costs for the building are approximately £9700 per year. It is also worth noting that UEA negotiated excellent tariffs with its energy suppliers (electricity at 4.7 p/kWh), which contributed to the cost reduction.

The high levels of airtightness and insulation that have been implemented have reduced the heating requirement to the extent that normal domestic boilers can be installed. These provide a number of advantages:

- initial capital costs are reduced
- fuel consumption and cost reduced
- maintenance, cost and complexity are reduced
- space is saved as the boilers are small wall-mounted units.

REFERENCES AND FURTHER INFORMATION

ACKNOWLEDGEMENTS

Databuild undertook the monitoring of the Elizabeth Fry Building on behalf of BRECSU for the DETR. Both organisations would like to thank the management and staff of the UEA Estates Department, Fulcrum Consulting, TermoDeck (UK) and ECS Anglia. Gratitude is also expressed to the occupants of the Elizabeth Fry Building for their assistance in this study.

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BUILDING DATA

Design team:

Architect	*John Miller & Partners*
M&E Consulting Engineer	*Fulcrum Consulting*
Energy Consultant (Fabric)	*Energy Advisory Associates*
Structural Consulting Engineer	*FJ Samuely & Partners*
Quantity Surveyor	*Stockings & Clarke*

Gross floor area (m^2)	
offices	1037
seminar and lecture rooms	2213
total	**3250**
Occupancy:	1100 maximum 750 average
U-values (W/m^2K):	
walls	0.20
roof	0.13
windows	1.30
Lighting levels (lux):	
offices	400
lecture rooms	250
circulation	200

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Fuel Efficiency Booklets: give detailed information on specific technologies and techniques.

Introduction to Energy Efficiency: helps new energy managers understand the use and costs of heating, lighting, etc.