Abstract

This paper outlines the results and lessons derived from monitoring the Elizabeth Fry Building at the University of East Anglia (UEA) for a period of 18 months in use. The monitoring, carried out as part of the Department of Environment, Transport and the Region's Energy Efficiency Best Practice programme, sought to examine the performance of the building as a whole rather than focusing on one particular element. The results of this case study form part of a series of case studies as it is recognised this is only one of a range of equally valid responses to a low energy brief.

This paper concentrates on describing and discussing the building's performance from the standpoint of delivering a holistic solution to a very low energy requirement.

Overall the Elizabeth Fry 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. There are additionlly, a number of positive and negative lessons that can be extracted which are given in the paper and summarised in the concluding section "design lessons".

1. Background

Responding to growing national and international pressure to reduce environmental damage associated with fossil fuels BRECSU, on behalf of the Department of Environment, Transport and the Regions, seeks to promote energy efficiency in the built environment throughout the UK.

Key to this work is the promotion of existing solutions which are demonstrably the best of current practice (Good Practice), combined with the examination and dissemination of newer more efficient approaches (New Practice). It is under the latter remit that BRECSU has monitored the Elizabeth Fry building at the University of East Anglia (UEA) for the some 18 months in use.

The intention with such evaluation projects is that they should demonstrate initial applications of innovative energy efficiency techniques and practices. Given this aim these studies are designed to provide information that will stimulate confidence in new measures that are just coming onto the market, offsetting some of the perceived risks involved in their wider application. As such the Elizabeth Fry Case Study, and hence this paper, examines the performance of the building as a whole rather than focusing on any one particular element. In addition the Elizabeth Fry Case Study is one of a series of such studies, in recognition of the fact that it is only one of a range of equally valid responses to a low energy brief.

2. Elizabeth Fry Building

2.1. The Brief

The Elizabeth Fry building was required to provide lecture and seminar rooms along with offices to house the School of Social Work, with an expected occupancy of up to 1100. The building was to be constructed on a site adjacent to two other energy efficient, award winning new buildings on the main campus: the Constable Terrace student residences and the Queen's building, housing the School of Occupational Therapy and Physiotherapy.

The University wanted the Elizabeth Fry building to be more energy efficient than these two neighbouring buildings, an aim that they believed could be realised by:

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

The brief also demanded that energy efficient aspects of the design should be integrated into the building's appearance, which was to be in the same style as the surrounding architecture. Financially the University set a target for the total construction costs of no more than that of a standard building in the same context; this translated into an eventual cost of £820 per m^2 (1995).

Gross Floor Area

Offices	1037 m^2
Seminar & Lecture Rooms	2213 m^2
Total	3250m^2

Occupancy: 1100 maximum, 750 average

2.2. The Design Approach

The design team aimed to achieve low energy use within the set budget and without compromising occupant comfort. The main features of the design that enabled this were:

- A narrow plan building allowing a high level of daylight to reach all spaces
- Extremely air tight construction, high levels of insulation and highly efficiency heat recovery units to reduce the heating requirements
- High levels of thermal mass provided by exposing the structural concrete within the insulated envelope and triple glazing with integral sunblinds to avoid the use of air-conditioning
- Openable windows to provide occupants with a link to the outside environment and a sense of control over their internal conditions

2.3. Main Features - Realised Performance

2.3.1. Fabric

The fabric of the building is highly insulated and well sealed. This has resulted in a heat requirement of only 50W/m^2 a year. The walls have 200mm of insulation. The windows consist of a double glazed unit with low emissivity glass and a third ventilated external pane with integral sunblind.

U-values:

Walls	0.20W/m^{2}C
Roof	0.13W/m^{2}C
Windows	1.30W/m^{2}C

The building specification required that the finished building achieve 1 air change per hour at 50 Pa and that this was independently tested before handover of the building. Both these factors ensured that careful detailing and regular, thorough inspections during the construction of the building were carried out and that low leakage rates and high standards of insulation were achieved as specified. No specialist contractors were required to achieve the extremely low level of air leakage required by the design.

2.3.2. Lighting

The building was intended to be substantially daylit, particularly in the offices and the atrium. The design has achieved a high level of daylighting with an attractive internal visual environment, although there are one or two shortcomings.

The main entrance, which is fully glazed, is attached to an atrium that incorporates a staircase. This is daylit by roof glazing that incorporates photosensitive louvres to control solar gain. The white interior decoration enhances daylighting. However, the lights are currently left on regardless of the availability of daylight due to the lack of lighting controls. Unfortunately the photocell controls that should have switched electric lighting on or off according to the levels of daylight, were cut from the specification for financial reasons. Their absence has resulted in unnecessary use of electric lighting and hence a waste of energy.

Perimeter cornice lighting equipped with high frequency fluorescent lamps provides lighting in the rooms. The lights are located in the extract airflow to reduce the heat gain to the room. Lights are switched manually at doors with dimmers in the lecture rooms.

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

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

The corridors are lit by uplighters using compact fluorescent lamps. There are also tungsten halogen emergency lamps. There is no daylight in the corridors and so the lights are on all the time the building is occupied.

Lighting levels (lux):

Offices	400
Lecture rooms	250
Circulation	200

2.3.3. Heating and Ventilation

Throughout the building heating and ventilation are supplied via the modified hollow core concrete ceiling (modified in accordance with the patented Termodeck system) by air handling units with very high heat recovery capabilities. For the basement lecture theatres this is complemented by supplying air through the void underneath the seating, essentially allowing additional cooling capacity by “earth coupling”.

There is a continuous supply of fresh air when the building is occupied. Four air handling units, two supplying the lecture rooms and two supplying each end of the three upper floors, deliver this fresh air.

The ventilation rate in the basement lecture theatres is varied with variable speed fans. The speed is varied according to carbon dioxide 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 to ensure good air quality.

In all areas air is supplied through small circular diffusers from hollow cores in the concrete slab ceiling. Air is extracted over the cornice at ceiling level.

Heating is provided by three gas-fired 24kW domestic size condensing boilers, of which normally only one is in use. The heat output only goes to the four AHUs; thus pipe runs and their associated costs and heat losses are minimised.

Sensors in the hollow core slab control the air supply temperature. The whole system is controlled by a Building Energy Management System that was installed one year after the building was completed. The originally installed BMS was downgraded in the cost cutting exercises in the final stages of construction. This proved to be a false economy as the building management team needed better access to information on the plant operation to ensure efficient and effective running of the building. They therefore installed a new system at a later date.

2.3.4. Control Strategy

The design essentially has two modes of operation dependant on time of day and season:

1. Summer

   During the hot summer period, cool night time air is blown through the ceiling slab. This cools the concrete slab and acts as cool store for the warm day following. In this way the need for energy intensive air conditioning can be avoided.

2. Winter

   During cold winter periods the tightly sealed and highly insulated building envelope keeps in most of the heat in the building. Heat produced by occupants and machinery is radiated to the hollow core slab and recovered from the extract air that is then passed back through the slab into the rooms. The building is sealed at night during the winter to keep in the heat gained during the 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.

2.4. Overall Building Performance

2.4.1. Internal Conditions - Users' attitudes to the building

As well as establishing the physical performance of the buildings the monitoring programme sought to give an indication of the users' perception and the quality of the working environment. Two surveys of users of the building have been carried out, the first in the spring and the second in the autumn of 1996. The surveys covered:

- Occupants of offices
- Lecturers
- Students

70% 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. (Based on survey of self assessed productivity where occupants were asked to rate the impact the building had on their productivity in terms of a 7 point scale from +40% to -40%).

During the winter the average temperature in the building was 20°C. Occupants responding to the survey described the conditions in winter as "comfortable" with conditions neither too hot nor too cold. During the summer occupants were also "comfortable" with conditions neither too hot nor too cold.

The ventilation system performed well. Occupants were satisfied with the air quality and their freedom to open windows gave them a sense of control over their own environment.

In general occupants were satisfied with the lighting although a few felt that there was too little natural light. Most occupants felt they had sufficient control of lighting.

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

2.4.2. Internal Environment - Measured Performance

The Elizabeth Fry building has met the requirement of the University that it should provide comfortable conditions throughout the year without using air conditioning. The high levels of thermal mass resulted in very stable internal temperatures - the building heats up and cools down slowly. Indeed comfortable temperatures were maintained during the hottest part of the summer even under conditions experienced once every four years with outside temperatures rising above 30°C. See Figures 1, 2 and 3 (maximum monitored temperature, frequency distributions and outside air temperature). Note that in figure 2 a curve is given for maximum temperatures excluding room 2.09. This curve is included as the occupant of this south side office often opened the window which demonstrably increased room temperatures compared to other south side offices monitored.

During one very hot week in June 1996 external temperatures rose to over 30°C. The temperature in 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 9pm - from 25°C at 7pm. Over the weekend the building cooled down and temperatures were acceptable the following week. More severe internal conditions were measured during a brief period in August 1997, but as the night-time temperature never fell below 15°C this is to be expected. On balance it is considered justified to quote the peak internal temperature as 26.6°C, although with the exception of the brief period in August 1997 room temperature remained below 25°C.

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

The lecture room ventilation is brought through the thermal mass, provided by the hollow core system and underfloor void. The system has controlled temperatures where there have been high levels of occupancy.

2.4.3. Energy Performance

Energy Consumption

The building had a normalised overall energy consumption during 1996 of 101kWh/m^2. If the offices alone are considered the energy consumption was 89 kWh/m^2. See table 1 and figure 4 and 5.

Comparison with Other Office Buildings

The environment provided in the Elizabeth Fry building is comparable to that of an air conditioned building but the Elizabeth Fry building uses less than half the energy consumed by the good practice air conditioned office cited in ECON 19. When compared to BRE's Low Energy Office the Elizabeth Fry building uses slightly less energy and higher level of occupant comfort is provided year round in Elizabeth Fry.

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.

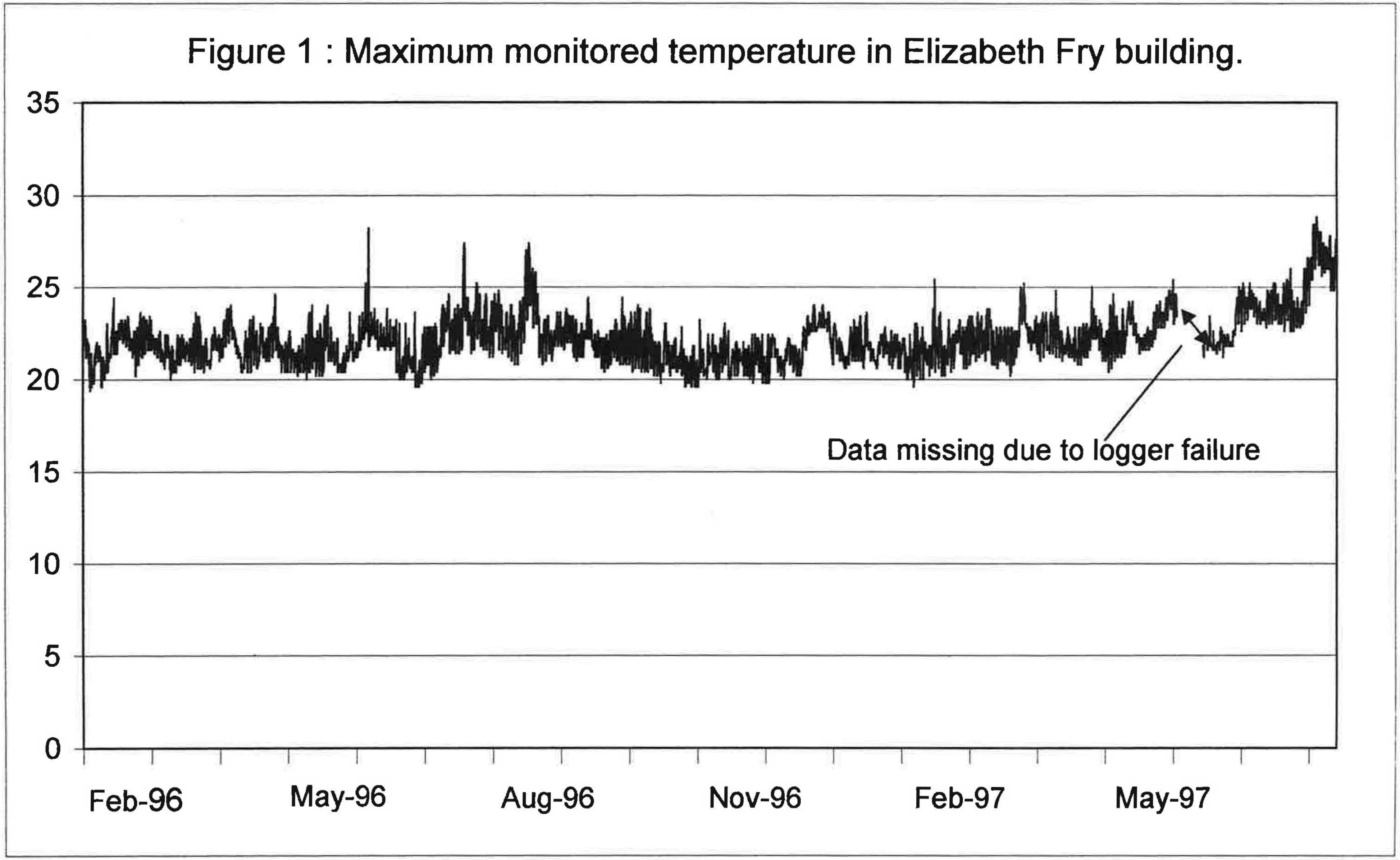


Figure 1 : Maximum monitored temperature in Elizabeth Fry building.
35
30
25
20
15
10
5
0
Feb-96
May-96
Aug-96
Nov-96
Feb-97
May-97
Data missing due to logger failure

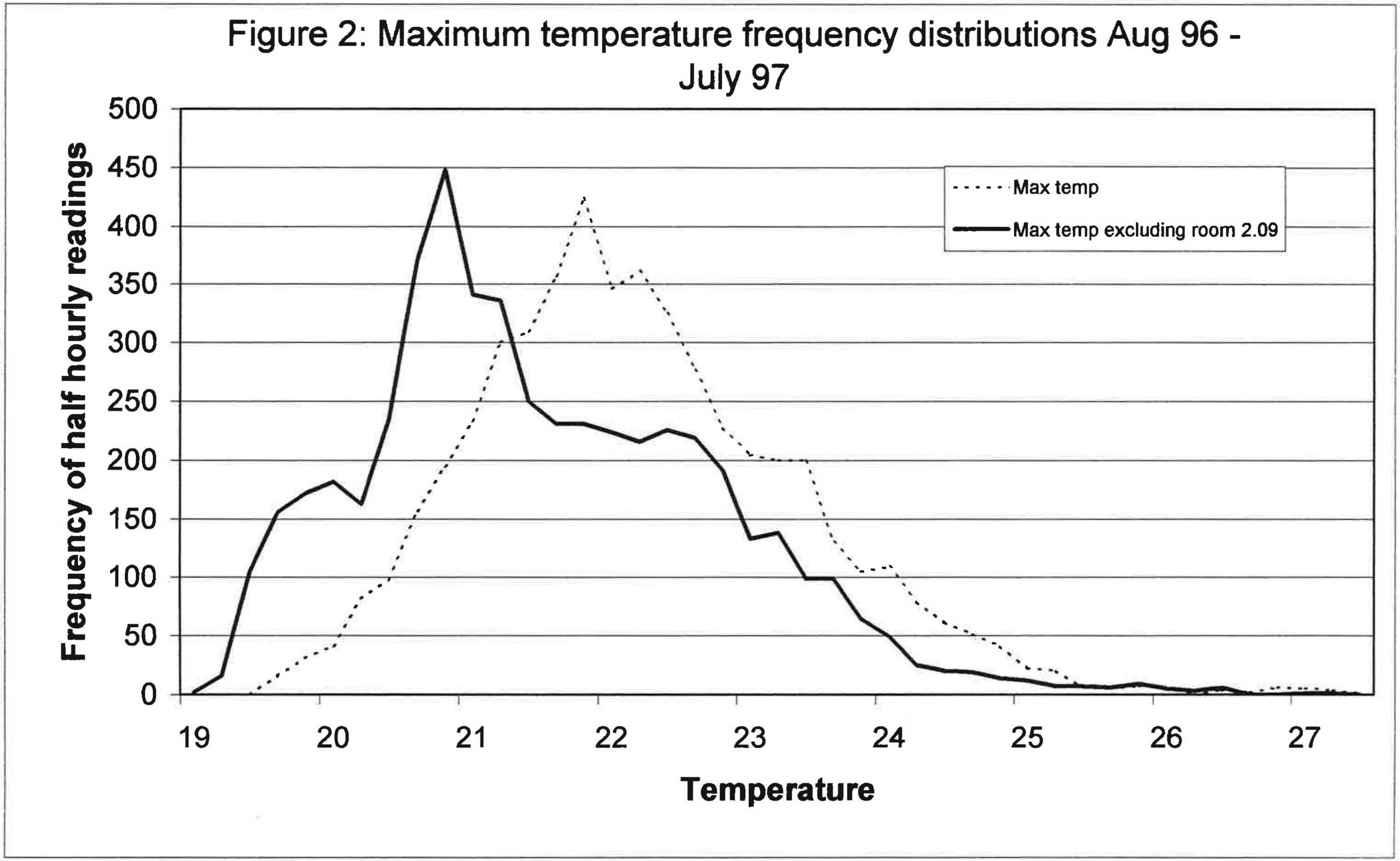


Figure 2: Maximum temperature frequency distributions Aug 96 - July 97
Frequency of half hourly readings
500
450
400
350
300
250
200
150
100
50
0
19
20
21
22
23
24
25
26
27
Temperature
Max temp
Max temp excluding room 2.09

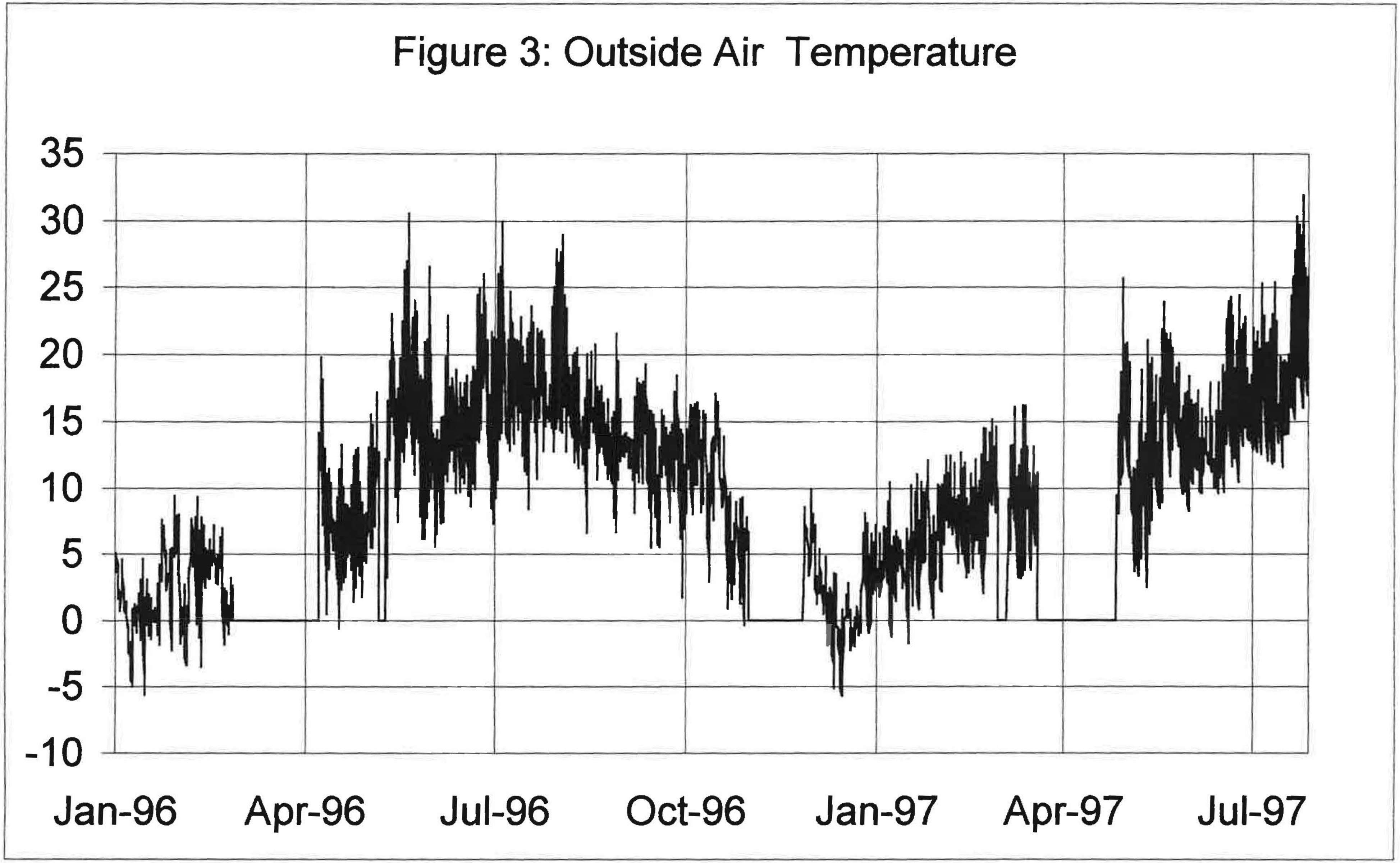


Figure 3: Outside Air Temperature
35
30
25
20
15
10
5
0
-5
-10
Jan-96
Apr-96
Jul-96
Oct-96
Jan-97
Apr-97
Jul-97

Table 1 - Energy Consumption

		Elizabeth Fry		Natural Ventilation (Cellular)	Natural Ventilation (Open Plan)	Air Conditioned
		Office	Whole bldg	Type 1	Type 2	Type 3
Gas	Heating	25	37	95	95	100
(kWh/sq.m	Other	5	4	3	4	7
Electirical	AHU's, pumps	13	16	3	5	39
(kWh/sq.m	Lighting	17	20	16	32	39
	Small power	25	21	11	16	22
	Other	4	4	3	4	23
Total Gas	(kWh/sq.m p.a.)	30	41	98	99	107
Total Electrical	(kWh/sq.m p.a.)	59	61	33	57	123
Total Energy	(kWh/sq.m p.a.)	89	102	131	156	230
Total CO_2 (kg/sq.m p.a.)		42	46	40	55	98

Figure 4 - EQUIVALENT CO_2 PRODUCTION (kg/m^2 p.a.)

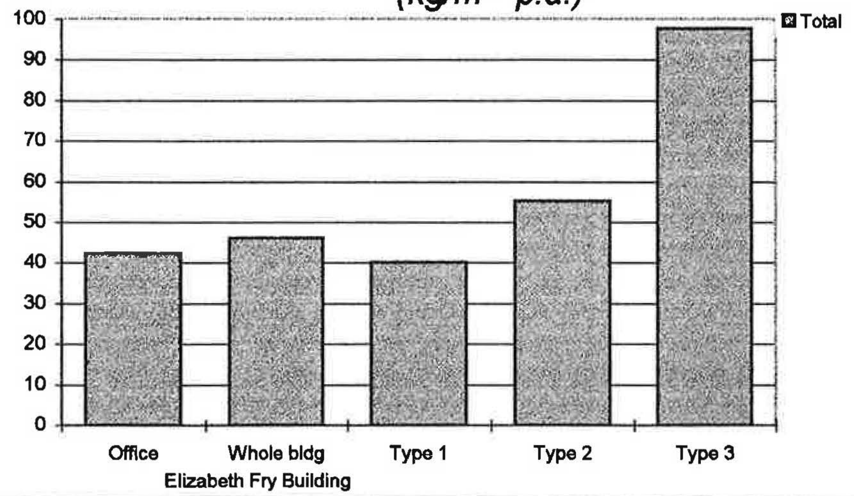
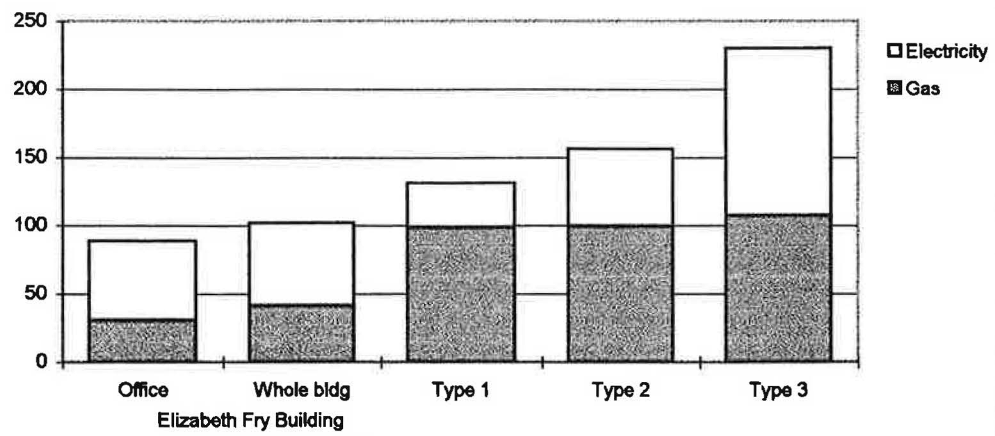


Figure 5 - ENERGY CONSUMPTION (kWh/m^2 p.a.)



- The heating energy usage is very low due to the high insulation levels and airtightness in the building
- Ventilation energy is very low especially for a building which provides such high levels of occupant comfort

Operational Lessons Learned

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 only provided when necessary. As a result the building's heating energy consumption has been reduced by almost 50%.

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 save energy by using the lighting carefully was subsequently circulated to occupants in August 1996 and there was a significant improvement afterwards.

2.4.4. Comparison with air conditioning

Summer conditions in the Elizabeth Fry building are comparable to those in an air-conditioned building. During the 18 month monitoring period there were only two brief occasions when internal temperatures rose over 25^0C, rising to a peak of 26.6°C.

The summer conditions in Elizabeth Fry 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 during the night. The energy used by night cooling has been assessed from the monitored data.

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

2.4.5. Owner's Attitude to the Building

Estates management at UEA are very pleased with the Elizabeth Fry building. It is an attractive addition to the campus and liked by users. Moreover, the building has fulfilled their brief; it has low running costs for energy and maintenance and cost no more to build than a standard building.

The cost of the building was £2.7m, equivalent to £820 per m^2 gross. The breakdown of the costs is shown in the chart below. These costs are equivalent to those of a standard naturally ventilated building and significantly less than an air-conditioned building.

By not using perimeter heating a higher net usable area has been achieved, given the building's size and function.

Maintenance costs to date have been low at £1.40 per m^2 p.a. Because of the low level of plant and equipment in the building it is unlikely that maintenance costs will increase significantly in the future.

Energy costs are low too. These have been £4,400 during the year's monitoring period.

Overall UEA's estates management are very satisfied with the Elizabeth Fry building and would certainly consider a similar building in the future.

2.5. 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.

Insulation	It is possible to construct highly sealed well-insulated buildings at reasonable cost, without the usage of any specialist labour.	**Low pressure hollow core system**	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 higher than average building fabric costs were more than balanced 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. Elizabeth Fry 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	Controlling the ventilation rate in rooms with highly variable occupancy by CO_2 level ensures that energy is not wasted in unnecessary ventilation.	**Savings made by cutting controls were false economies**	At the time of construction, money was saved on the BEMs and lighting controls. These proved to be false economies as the BEMs had to be upgraded after a year and the lack of automatic lighting controls has led to unnecessary lighting use.
Variable speed drives	Variable speed drives were used on two of the four air handling units in the building. In areas where occupation 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 the 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 in the operation of the building and in identifying design lessons.

References

New Practice Final Report. 'The Elizabeth Fry Building, University of East Anglia - feedback for designers and clients'.

Energy Consumption Guide 19. 'Energy efficiency in commercial and public sector offices'.

Both available from BRECSU enquiries on 01923 664258