The Elizabeth Fry Building

This latest addition to the University of East Anglia Campus cost 20 per cent less to build than a conventional building of similar proportions and uses 80 per cent less energy.

By David Olivier

The project

The Elizabeth Fry Building (EFB) is a fitting sequel to seven years of relatively energy-efficient buildings on the University of East Anglia (UEA) campus. Design began in 1992, it was built between November 1993 and early 1995, and it has now been in use for two years.

The demand for a high standard of energy efficiency and reduced running costs was already there, in the brief from the client, but no extra capital was available for energy-efficient features. Despite the budget, we felt that we should at least try to match the performance of the Building Research Establishment's (BRE) pioneering Low Energy Office (LEO), which was designed in the 1970s [1]. Amazingly, no other office in the UK has matched its performance since then.

The Department of Energy has suggested that new buildings should be designed to cope with the weather conditions which may pertain in the decade 2050-60. By then, the following may apply:

- If the climatological models have slightly underestimated the risks, the UK could have warmed by 3° K, giving us the summer temperatures seen today in northern Portugal;
- If this stage is reached, we may not be allowed to burn the world's remaining fossil fuels.

So we planned to create an office building which uses little fuel to stay warm in winter and can be kept cooler in summer than any other on the campus, without air conditioning.

Architecture and built form

The site is a confined south-facing slope between other modern buildings. The EFB takes the form of a long, thin four-storey block, 13 meters deep. The lowest floor is a basement, open and glazed to the south but built into the bank to the north. This floor contains three large lecture theatres, 130 seats each, entered from the south and available for use by any UEA department. The other floors have smaller lecture theatres, seminar rooms, kitchens, etc. The two upper floors contain UEA's School of Social Work.

On the north ground floor is a three-storey, top-lit entrance hall and stairwell (figure 1). It contains tapestries, paintings and furniture by local artists and craftsmen.

Externally, the EFB does not look spectacular, but that was never the intent. It did have to conform to UEA's master plan for the campus, and to a layperson in architectural matters, it seems to fit in admirably with its surrounding buildings. It won the 1995 Royal Institute of British Architects RIBA Architecture Award, Eastern Region.

Space heating, cooling and ventilation

Insulation and Airtightness

Structurally, the EFB is a reinforced concrete frame. The infill panels, between the columns, are dense concrete block, and these form an inner leaf of a cavity wall. The outer leaf is a mixture of rendered concrete block and special fair-faced blocks.

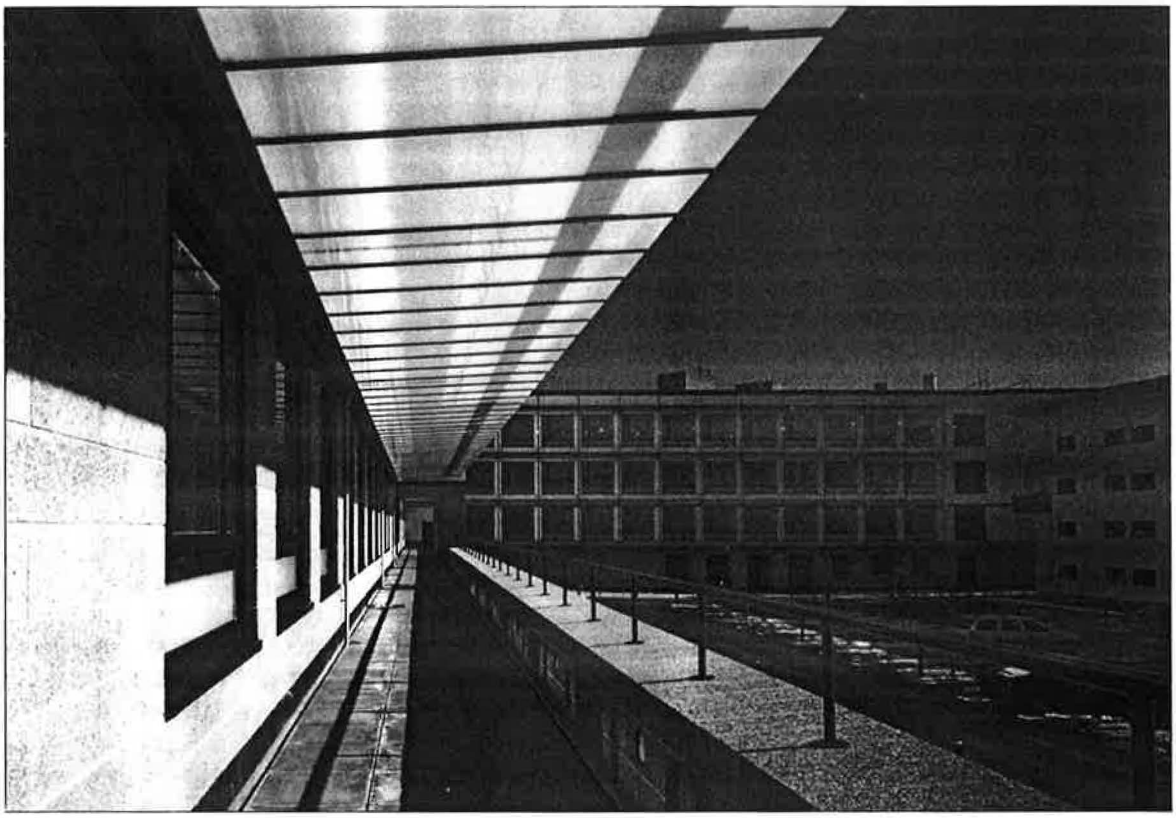
The EFB meets the insulation standards which are now widely applied in Scandinavia and North America. The wall cavity has an average width of 150 mm and is filled with rock fibre batts, plus Danish GRP ties to reduce thermal bridging. The roof is a flat concrete slab with 300 mm of rock fibre on top.

Despite some reservations, UEA agreed to the recommendation of a fully filled cavity with mineral fibre. This has been standard practice in Denmark for 20 years, with no more problems than partially filled cavities. The architect, Richard Brearley, carefully checked the standard of workmanship on all his visits to the site.

The windows are 2+1, argon-filled, low-emissivity, inward-opening, aluminium-clad redwood, mass produced in Sweden. Those on the south, west and east walls have white venetian blinds in the outer non-sealed airspace. Such blinds stop up to 85 per cent of the solar gain entering the building in the summer.

We detailed the EFB to reduce air infiltration. In the U.K., this led to new solutions being adopted. The contractor queried some drawings and requested permission to do them. Had this request been granted, the air leakage would have been much higher. However, agreement on all the proposed details was reached before work began on site.

The inner leaves of the cavity walls are plastered throughout, from floor to ceiling, to act as an air barrier. Plaster is interrupted by cast-in-place concrete beams and columns were treated as a sufficient air barrier. The precast concrete roof and ground floor have a



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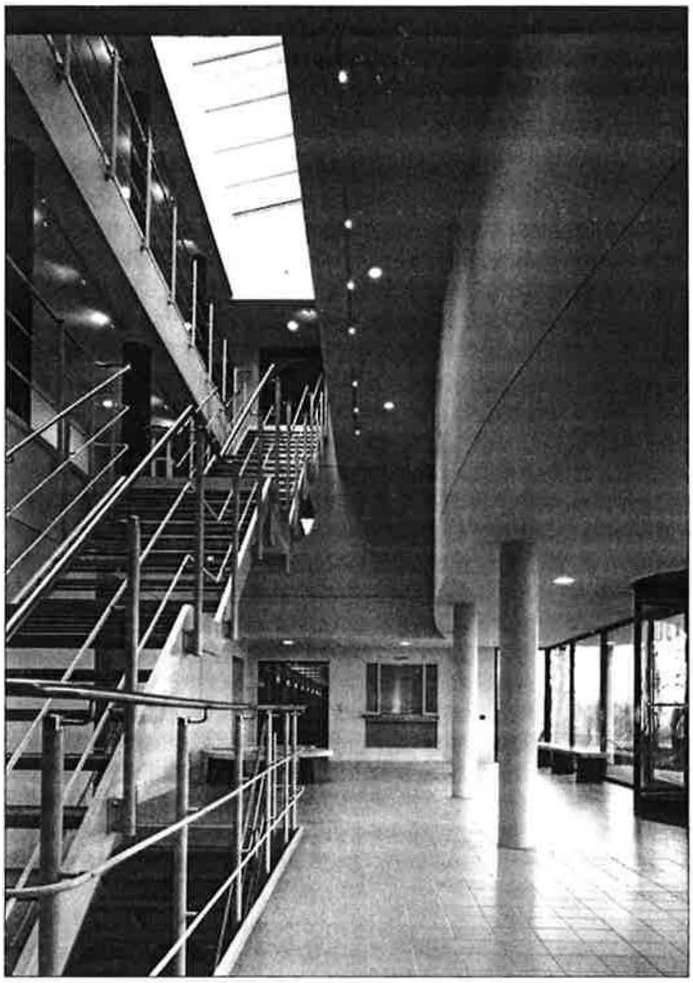

structural screed, which again was treated as the air barrier.

Given the 'heavy, wet' construction, plaster or concrete make up the airtight layer over the whole building envelope. The specification also required for the door, window and service penetrations to be sealed to the walls and the roof.

EFB air leakage was measured in autumn 1994, shortly before completion. This showed one air change per hour (ac/h) at 50 Pascals. This was achieved while the contractor was still working on the building, and some visible holes remained, so it was expected that the finished building would have a leakage of 0.5-0.75 ac/h at 50 Pa.

In fact, a retest in early 1998 showed a leakage of 1.5 ac/h. The design team have been unable to get full access to the test reports, but it appears that there are quite a few leaks around openings which were not well sealed by the builder, and that the Swedish windows leak between opening lights and the frame. The revolving door leaks; we were unable to find one in the time which didn't. Finally, some external doors were respecified at the last minute to reduce costs, and leak badly. This was clearly a false economy.

The author used to hear the expression that if one adds up the disparate cracks and gaps in a UK house, it has the equivalent of four missing bricks. Normal new offices this size have enough holes to add up to a permanently open 3 x 3 m loading bay.[2] The EFB is 20-times tighter than a normal office and challenges U.K. orthodoxy head on; no publication seems to acknowledge the possibility of such low air leakage.

The EFB's air leakage is in the range which Canadian researchers would define as 'tight' ... but that was 21 years ago[3]. But, if openings do account for most of the leaks, then the EFB could be made considerably tighter just by simple improvements to workmanship and specification. Since the EFB is already ten times tighter than new U.K. buildings, this would certainly be an interesting conclusion.

The EFB is a concrete frame and the concrete columns and a concealed walkway which continues to neighbouring buildings, produces some very stubborn thermal bridges. Complete success in eliminating them was not achieved, but the extra heat loss is tolerably low.

Space Heating System

As a result of the low heat loss, we completely discarded the usual perimeter central heating system. There are no radiators anywhere in the building, there are minimal heaters below the windows and there is no pipework except for the hot and cold water services.

In a normal four-storey office block, a large space is set aside as a boiler room. The EFB has three wall-mounted 24 kW balanced-flue condensing gas boilers and the third of the boilers is for backup only.

Heat is delivered by tempering the ventilation air, using water-to-air heat exchangers in the ductwork. The incoming air passes into the spaces via the hollow cores in the floor slabs. Typically, in winter, 90 per cent of the heat from the outgoing stale air is recovered by Swedish-made heat exchangers to preheat the incoming fresh air, and thermal comfort is regulated by controlling the temperature of the concrete floor slabs, not the air. In some ways, a modern hypocaust.

The U.K. outside design temperature (on a 97.5 per cent basis) is approximately -3°C. Despite this Building Services journal's PROBE project shows that the average capacity of the boiler plant in new non-domestic buildings is still 150 W per m^2 floor area. The 1978 BRE Low Energy Office had 75 W/m^2; the new BRE Office has 100 W/m^2; the 1987 Woodhouse Heath Centre had 40 W/m^2. As far as we know, no other U.K. non-domestic building has less than 50 W/m^2.

Omitting the conventional heating plant may therefore have saved a five figure sum. It is not sure that this savings fully paid for the improved fabric insulation and airtightness, but the total cost of the EFB is the same as any other good-quality Norwich educational building; see below. Also, the heating equipment which we left out would need to be replaced every 20-25 years whereas the extra insulation, etc which we put in will last as long as the building. This should save the UEA money in the long term.

Space Cooling System

It was clear that the EFB would have high occupancy rates. On occasions, the whole building could accomodate 850 people. This is a much higher density of occupants than in most offices, certainly more than the original BRE LEO.

Despite the high heat gains associated with high occupancy rates, UEA's policy ruled out a refrigeration plant. Summer ventilation by openable windows and a high thermal capacity structure might suffice in the first and second floor offices, but did not seem enough to cool a 100 m^2 basement lecture theatre, which might be occupied by 125 students for several hours.

In summer, the Swedish Termodeck system really comes into its own. Termodeck was developed in the 1970s and to date, Sweden and Finland have about 300 Termodeck buildings with no other cooling plant. Termodeck is also in use in climates as warm as Saudi Arabia, with a small backup chiller, which is run mainly at night.

The principle behind Termodeck is to utilize the hollow-core concrete floors which are common in office buildings to store surplus heat on winter days, or to store cool air in summer nights. By flushing heat out of the building mass, using the cool night air, it is prechilled for the following day. The building fabric becomes an integral part of the HVAC system, and acts to stabilize internal temperatures.

Summers in East Anglia are similar in temperature to Swedish summers. We expected Termodeck to perform as

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well as it does in Scandinavian buildings. Subject to certain conditions being met, Termodeck's supplier guarantees its performance. Independent measurements demonstrate that the air temperature during heatwaves could be maintained below 25°C.

By the selection of good quality fans, and by designing the ductwork for low air speeds, Fulcrum kept the fanpower of the ventilation systems carefully in check. Considering the rate of fresh air supply to the rooms, the resulting use of electricity is very low.

Lighting

The system was custom-designed by Fulcrum. Each room has a number of concealed high-efficiency fluorescent tubes, with electronic ballasts and custom-built metal reflectors. These reflectors direct light onto the white-painted exposed concrete ceilings, from where it bounces off onto the work surfaces.

Indirect lighting provides good conditions in spaces where computers are in use, and it can be economical on electricity (Watts used for a given standard of visibility). Unfortunately the lighting controls designed to displace artificial light by daylight were discarded on grounds of cost.

Measured energy performance

From late 1995, the government, via the then BRE, provided funds to monitor the EFB for a year. Some of the data quoted comes from these reports and the rest is from UEA's and Fulcrum's own measurements.

Electricity consumption is constant and is divided between the largest use, lighting; the second largest, office equipment; and ventilation fans, pumps and catering, which together comprise 30 per cent.

The gas consumption is falling steadily as the controls are refined and initial errors made in 1995 and 1996 are corrected. By late 1996, the running total had reached 35 kWh/m^2*yr. By March 1998, it had dropped to 25 kWh/m^2*yr, but this partly reflects one of the five mildest winters in UK history. Electricity costs UEA five times more than fossil fuel, measured in pence per kWh. the gas costs are said to be 'negligible' compared to the other running costs of the building; e.g., cleaning, security, staff, etc.

Thermal comfort

Winter

An occupant of a corner office said that the floor under her desk was a little cold. Part of ther office lies above the south wall walkway, with two outside walls and an 'outside floor'. Given the layout of the hollow-core slabs, these offices have no heat source. A 200 W electric heater was installed; the problem went away. A few corner rooms with too little Termodeck slab had this same problem

Otherwise, few complaints. The frugal gas consumption, 88 per cent less than a normal office, provides an air temperature of 20-21°C all winter, warm walls and no draughts. In other words, a far from frugal comfort standard.

The EFB has a very high thermal capacity and a very low-powered heating system. The space heating operates any time there is a call for heat, day or night. Short cold spells have no effect on internal comfort. In January 1995, someone accidentally switched off the heat recovery in the offices for the whole of January. No one noticed until February, when it was observed that the third boiler was operating! The thermal sluggishness of Termodeck buildings has always been a *quid pro quo* for their summer performance and their ability to store surplus daytime heat gains from solar, equipment, etc, in the building mass. If one did such a building again, experience suggests that the third boiler may be redundant; even if one boiler broke down in mid-January, the other could still function and the building might only cool 1°C while repairs went ahead!

Summer

In 1995, the EFB remained comfortable over one of the hottest summers of the century. Most buildings suffered serious overheating but conditions in the EFB were said to be excellent, and much cooler than anywhere else on the campus. At the peak, about 125 students are present in the lecture theatre for an hour. When they leave, they are replaced by another 100 or so students.

The venetian blinds are correctly deployed to minimise summer temperatures. The ventilation cools the structure at night. It also operates when students are in the lecture theatre, the rate being controlled by the air's CO_2 content. Some first and second floor offices in the EFB reached 25°C at the end of a four day hot spell in July 1996, although the surfaces of the building mass were cooler. In heatwaves, if the occupants of these offices open the windows, they find that the air gets warmer, not cooler. It may rise to 28°C if they open the window on a very hot day.

People may well wish to admit the summer breezes, which partly compensate for a higher air temperature. But if they want cool air, it could be better for the university to lower the venetian blinds in June and leave the slats horizontal and raise

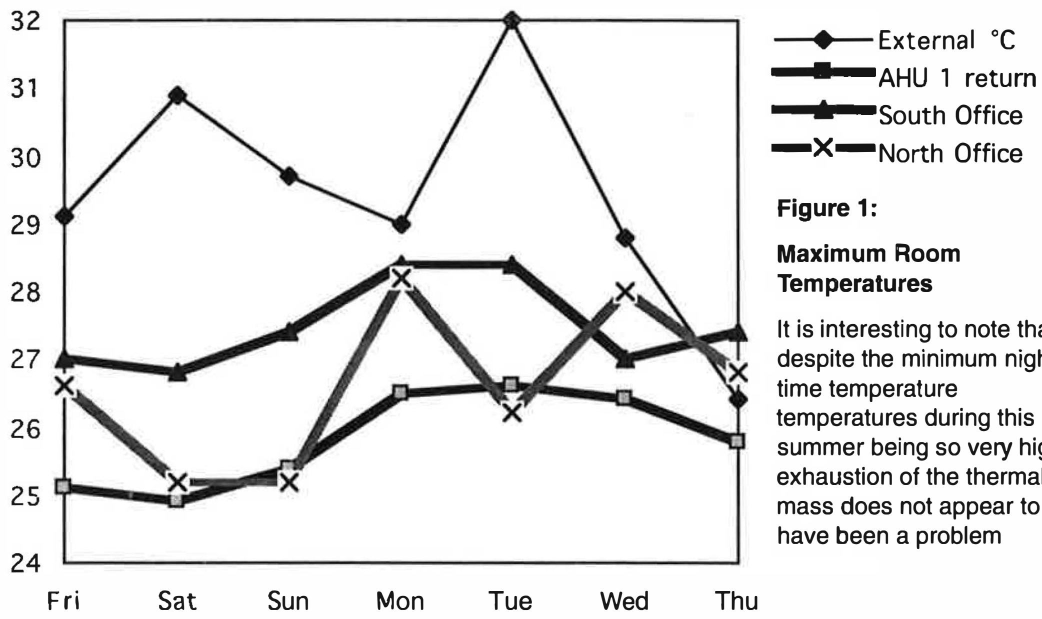

Figure 1:

Maximum Room Temperatures

It is interesting to note that despite the minimum night time temperature temperatures during this summer being so very high, exhaustion of the thermal mass does not appear to have been a problem

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them in early autumn. This is how the blinds are used in Termodeck buildings in Sweden.

Construction costs

The contractor's price to build the EFB was £820 per m², measured at 1995 values. This excludes minor external works. The sum was negotiated with the lowest tenderer. The project was designer-led throughout. Design-and-build was not favoured as a route to innovative, low-energy, good-quality buildings. £820/m² is a normal cost for office buildings of this type. Recent Termodeck buildings in Sweden may even offer potential cost savings, to be explored in future.

Other green issues

Robert Vale, now at the University of Auckland, New Zealand, said many times that a *sine qua non* of green buildings was minimum use of fossil fuels. This seems incontrovertible. If the world's climate does change, it will make it totally irrelevant that the building materials are recycled, the floor coverings do not off-gas, the hard core is made of waste materials, the landscaping is native species and the grey water is recycled.

The EFB's design team therefore concentrated on energy - the biggest environmental issue - but we tried to consider other factors. This had to be done within the restrictions which governed office building design and within UEA's budget for building construction and design fees:

- The wall and roof insulation (rock-based fibres) both represent low amounts of embodied energy;
- The embodied energy in the steel roof is lower than it would be for aluminium;
- The window frames are wood not PVC. Their thin aluminium rainscreen cladding represents energy use in its manufacture but the client required a maintenance-free finish, and it eliminates the need for stains, paints, etc;
- The dominant concrete and dense blocks both represent less embodied energy than clay bricks. They were locally sourced, reducing their transport energy;
- The sand/lime/cement render to the walls is naturally coloured; no paint will be needed;
- The topsoil from the site was moved a short distance and used as a base for the planting of 40 new trees;
- The rainwater runoff from the development is collected in a sunken tank and used to irrigate these trees in dry weather.

International comparisons

Energy performance is indicated by kWh of delivered energy; that is, gas plus electricity, used per m² of floorspace every year (kWh/m²*yr). One notes that:

- Existing air-conditioned buildings inthe UK use 400-600 kWh/m² *y;
- Non-air-conditioned UK buildings use 200-300 kWh/m²yr;
- New U.S. and Canadian office buildings consume 200 kWh/m² *yr, despite warm, humid summers and often colder winters;
- Leading-edge North American offices - still air-conditioned - use 70-100 kWh/m² *yr;
- So do well-designed offices on the European continent
- Few recent UK 'low-energy' offices have been low-energy in practice.

Some use more energy than air-conditioned buildings of the early 1970s! [4]

- The LEO, Woodhouse and EFB are among the UK's lowest energy consumers. It is hard to compare the three - Woodhouse is much smaller and for most of its life, the LEO has had a low occupant density.

UK policy/programs

The EFB uses a little more energy than recent examples in North America and on the European mainland, some of which appear to use [5,6] only 70 kWh/m^{2}yr. However, as it did not have the backup and assistance which was available to these projects from federal and local government and other agencies, perhaps it is excusable that it lags a little behind the world's best.

Most of the technology which is needed for such buildings is already available, even in the UK, albeit sometimes with great efforts. It seems to be its correct application which is lacking, the setting of priorities so as to achieve good energy efficiency within limited budgets, design integration, and of course, the need to avoid basic errors.

Since 1989, the UK has had a 'green label' for office buildings called BREEAM. At last count, 20 per cent of new office buildings had BREEAM labels but no post-construction tests or measurements are yet made. This is a distinct weakness, because it makes it possible for a building to have a good label despite poor energy performance. It seems that labelling is not the full answer; we need a national UK program which delivers more low-energy non-domestic buildings.

Policies which have worked abroad could easily be applied here, both to ordinary new buildings and to 'leading-edge' ones. In principle, one starts with the basic technology and one seeks to integrate it into successful demonstration projects which show clearly what works. Finally, after a long time - perhaps as much as 20 years, depending on how long one thinks the learning process should take - one can make this all part of standard, everyday building practice.

Conclusions

The EFB provides the sort of summer and winter comfort standards which were the original *raison d'etre* for air conditioning, but it probably cost 20 per cent less to build than an air-conditioned office building. Meanwhile, it costs 80 per cent less to run and it causes 80 per cent less $C0_2$ emissions.

Such a winning combination is rare in the housing field. There, energy efficiency usually adds to initial costs. Negative costs for added energy efficiency have arisen before with non-domestic buildings. But it is not usually as clear cut as this. In the words of Amory Lovins, this is not just a free lunch; it is a lunch which one is paid to eat. By replicating such technology, one would actually abate global warming at a profit.

So, as we approach the millennium, why are buildings of this measured energy performance still so rare in the U.K.? One can only speculate, but it seems appropriate to close with a quotation from the U.K. architectural press. The Professor of Architecture at Nottingham University commented: "... The EFB represents a worthy addition to three decades of distinguished building at UEA, but above all it demonstrates that such architectural achievements are impossible without enlightened patronage and a sensible process of building procurement. Other similar institutions could with benefit follow this example" [7].

Acknowledgements

Thanks go to the University of East Anglia and particularly its former Deputy Buildings Officer, Peter Yorke. UEA was willing to pioneer high standards of energy efficiency in a UK building and thereby to move the UK in a genuinely low-energy direction.

Those involved

Client: University of East Anglia.

Architects: John Miller and Partners, London.

Services Engineers: Fulcrum Consulting, London.

Energy Consultant: Energy Advisory Associates, Leominster.

Structural Engineer: F J Samuely and Partners, London.

Quantity Surveyor: Stockings and Clarke, London.

Contractor: Wilmott Dixon (Eastern) Ltd.

Wall Ties: K G Kristiansen A/S, Denmark.

Hollow-Core Floors: Termodeck UK Ltd., London.

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