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SUSTAINABLE ARCHITECTURE

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Bill Bordass
ENERGY PERFORMANCE

Fig 1.09 Wessex Water Headquarters

1 H J Schellnhuber (ed), *Avoiding dangerous climate change*, Cambridge University Press; 2006. ISBN: 13 978-0-521-86471-8. Downloadable from www.defra.gov.uk/environment/climt

2 See, for example, J Leggett, *Half gone*, London: Portobello Books; 2005.

3 DTI, *The Energy White Paper, Our energy future – creating a low-carbon economy*, Department of Trade & Industry; February 2003. Downloadable from www.dti.gov.uk/files/file10719.pdf

Scientists are now widely agreed that greenhouse gases from human activity are not just causing measurable effects, but could even tip the planet into a period of rapid and destructive climate change this century.[1] The main culprit is carbon dioxide (CO_2) emissions from burning fossil fuels. In order to provide the sound platform upon which the wider aspects of sustainability can rest, CO_2 concentrations in the atmosphere need to be stabilised. The current concentration is just over 380 parts per million by volume (ppmv), about 100ppmv above pre-industrial levels and rising by 1.5ppmv or more per year. Taking other sources into account, the total anthropogenic effect is estimated to be equivalent to some 430ppmv of CO_2. In the past, 550ppmv has been widely cited as the safe maximum level, but lower limits, e.g. 450ppmv, are now being advocated.

The energy used by buildings in operation accounts for 47% of the UK's CO_2 emissions. Construction, maintenance and building materials' production accounts for 10% or more; and much of the UK's transport-related emissions (25% of CO_2) is for moving people and goods between buildings. Building energy performance is therefore critical to bringing emissions under control.

Even without the climate change imperative we would still need to make more efficient use of energy. The UK is becoming a net importer of gas and oil and is therefore exposed to increasing costs and unreliability of supply. Some experts also expect that global oil production will soon start to decline.[2] The 2003 Energy White Paper[3] *Towards a low-carbon economy* stressed the importance of diversity and decentralisation of energy supply: "In reducing CO_2 emissions our priority is to strengthen the contribution of energy efficiency and renewable energy sources…"

The UK government is already committed to reducing CO_2 emissions by 60% by 2050 in comparison with 1990 levels. Recent understanding of climate change suggests that we may need to go further and faster, with 80% or even 90% cuts in developed countries. And most of the buildings that will make up the UK stock in 2050 are already here. Designers and builders will therefore need to make new buildings use as little energy and carbon as possible, while existing buildings will need a lot of re-tuning.

Unfortunately there is not nearly enough information on how recently completed low-energy buildings in the UK are actually performing in use. In 2004, The Edge (a multi-disciplinary ginger group set up to debate topical issues in the built environment) agreed on the need for a Voluntary Energy and CO_2 Declaration (VECD) procedure. The Pilkington Energy Efficiency Trust (PEET) kindly provided funding to help to develop and test the opportunities and difficulties of doing this while collecting data on some of the non-residential buildings being considered for this publication. Twelve of these are featured in the following chapters:

- Chapter 1 – Arup Campus, Solihull, Foundation Building, Eden Project, Wessex Water HQ, Bath.
- Chapter 2 – Centre for Mathematics, Cambridge University, Kingsmead School, Cheshire, Michael Young Building, Open University, ZICER Building, University of East Anglia.
- Chapter 4 – Beaufort Court, Kings Langley, Kynance Café, Cornwall, Cambridgeshire Women's Institute, West End House, London.
- Chapter 5 – Jubilee Library, Brighton.

Data collection took place between Summer 2005 and Spring 2006 using a four-page questionnaire on the building, its occupancy levels and hours of use, its annual energy consumption by fuel (from bills and/or site records) and the amount of on-site production of renewable energy. Design data was also sought and buildings with potentially good data were visited. Energy in kWh for each fuel was then converted to annual kg of CO_2 emissions using published standard conversion factors.

Some of the buildings had been monitored and five of these provided much useful detail. However, the quality of data readily accessible from others was often disappointing. Eventually only half the buildings contacted provided sufficient data for analysis. Some buildings were relatively new and had not developed a clear pattern of energy use. Several others, which were on larger sites, did not even have their own meters. (This is a problem that should diminish because the 2006 Building Regulations Approved Document L2 for England and Wales now requires metering and often sub-metering. However, vigilance will be needed to ensure that this metering is effective.) Where sub-meters had been fitted we often found problems with commissioning, calibration and record keeping. The new Regulations also require building log books.[4] These will be a good source of design data and energy predictions, and can also hold records of in-use performance.

The European Union's Energy Performance of Buildings Directive[5] will make energy data much more accessible. Building Energy Certificates, based on theoretical calculations (asset ratings), will be required at the time of construction, sale or rental. Some public buildings of over 1000m^2 in area will also have to display energy certificates based on actual energy use (operational ratings); a requirement that the government hopes to extend to many more non-domestic buildings, both public and private. The information collected was therefore also used to test an approach to operational ratings being developed in an EU research project.[6]

Published typical (median) levels of annual heating fuel use for the public, office and educational buildings reviewed are about 150–200 kilowatt-hours per square metre (kWh/m^2) of treated (heated, ventilated and lit) floor area.[7] The buildings studied tended to use between 60 and 120kWh/m^2, which although some 25% lower than the published good practice levels (between 80 and 150kWh/m^2 depending on building type), was disappointing in relation to many design expectations. Important reasons for the differences are high air infiltration, poor control (with more attention to detail required in design, installation, commissioning, fine-tuning, documentation, training and usability), and avoidable waste – particularly where the control and operation of systems is not well matched to the needs of end users. Only one building – the Jubilee Library in Brighton – use the carbon equivalent of less than 50kWh/m^2 per year of gas for heating and hot water.

Although there is potential to reduce heating energy use much further, electricity use is now becoming a big problem. Nearly all the buildings used much more electricity than predicted; and sometimes even than published 'typical' levels. For example, at Wessex Water only one third of the electricity actually used was directly comparable with the design predictions. The rest was due to things not counted (e.g. the kitchen, external lighting, and the server room), or occupant requirements (e.g. night use of the control room and office equipment on standby that had been expected to be off). Nearly all the

4 CIBSE, *Technical Memorandum 31, Building log book toolkit*, London: Chartered Institution of Building Services Engineers; 2006. This provides a specification and template for a log book.
5 Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings, Official Journal of the European Communities, L1/65-71 (4 January 2003). Downloadable from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0091:EN:NOT
6 See www.eplabel.org
7 Existing benchmarks are summarised in: CIBSE Guide F, *Energy Efficiency in Buildings*, Chapter 20, London: Chartered Institution of Building Services Engineers; 2004.

offices and public buildings had similar experiences. Only at the small, simple and relatively lightly used Cambridgeshire Women's Institute was annual electricity consumption both low and not far from the design estimate.

Why the growth in electricity use?

- More electrical equipment was installed than the designers anticipated.
- The buildings tended to be used for longer hours than the designers had anticipated, and often by more people too.
- More mechanical ventilation and cooling had often been provided – even in buildings that were not air-conditioned, to deal with increased equipment and occupancy densities, and in response to recent hot summers.

Inadequate energy management regimes were practised, e.g. equipment operating for longer hours than anticipated, often unnecessarily.

A major influence has been growth in ICT – information and communications technology – not only in the rooms (for example in schools, which are becoming more like offices in their use and patterns of electricity consumption); but behind the scenes (in particular server rooms and their associated air-conditioning). Other electrical equipment – vending machines, water coolers, security and access control systems, and so on – relentlessly take their toll, particularly if they remain on (as they often do) when the building is empty. Even relatively small standby loads can then mount up to relatively large annual consumption. To get buildings that are genuinely low-carbon, we need to look well beyond the normal concerns of architects and engineers.

Over two-thirds of the buildings investigated used automatic lighting control systems to avoid waste and to maximise the use of natural light. However, lighting energy use was often many times the design estimates, for reasons including:

- Energy use by automatic control systems, both for their electronics and for some dimming systems which never turn the lights right out.
- Poor usability, with insufficient provision for manual control, in particular where occupancy sensors bring the lights on whether people feel they need them or not. Some meeting rooms, where blackout is often needed, did not even have any local on/off switches. Manual ON, manual and automatic OFF is a good rule.
- Ineffective daylight-linked control, for example through poor calibration and commissioning, sensor placement, or poor grouping of light circuits in relation to space use and daylight availability.
- Unusable daylight owing to lack of screen visibility, for example where electronic whiteboards had been installed in school classrooms.

- Using artificial light in glare situations (where blinds often come down and then stay down) or to reduce contrasts from poorly designed daylight. Designers should take account not only of daylight factors on the working plane, but of what the space will look like under daylight only.
- All common and circulation areas lit whenever the building was open, and sometimes continuously.
- Often more electricity could be saved much more cost-effectively by reducing installed loads and designing, commissioning and managing control systems to work effectively, than could be generated, say, by photovoltaic systems.

The most widely used sources of integrated renewable energy in the buildings studied were:

- Photovoltaics (PV). Most installations were small and made minor contributions. The only large installation reviewed was at the ZICER building, which provided 9% of the building's electricity requirements. The glass conservatory used to display it was less successful. Occupying about 10% of the total floor area, its annual sub-metered heating energy use was almost as much as for the whole of the rest of the building (which was well-insulated and thermally massive) and it was not very electrically efficient. Consequently this space more than used up all the benefits of the PV in reducing CO_2 emissions. The fundamental importance of reducing demand in low-energy buildings cannot be overstressed: for example at the Cambridgeshire Women's Institute a small PV installation forming the roof of the entrance porch was able to reduce the electricity purchased by nearly 20%.
- Solar thermal. Several buildings had small solar hot water systems, which worked well but made minor only contributions to reducing heating fuel consumption. The exception was at Beaufort Court, which incorporates a large underground seasonal heat store and is comprehensively monitored.[8]
- Biomass. This seems most effective in the small-scale wood pellet boiler used at BowZED or where it was integrated into the agricultural economy of the National Trust for Scotland site at Glencoe. Wood chip burners had also been used on relatively small commercial and educational sites. The results were less satisfactory for two main reasons: greater attention needed to operate and maintain the equipment; and poor control of the links to gas and oil fired back-up heating systems which therefore ended up carrying more of the load, but less economically than if they had been the sole heat source.

The biggest source of renewable electricity was at Beaufort Court where, in the course of a year, an on-site wind turbine provided almost exactly the same amount of electricity that the building used, albeit with different demand profiles. About one-quarter of the building's heating requirements were also site generated, from solar and biomass.

In summary, there are six basic steps to reducing energy use and CO_2 emissions from buildings:

- Get the loads down, for example by good strategic design, thermal insulation, natural light and ventilation.

8 Monitoring data can be seen at www.*beaufortcourt.com*

- Service them efficiently, with plant and equipment that uses the least energy, and including the equipment added by the occupier.
- Make effective use of renewable and low-carbon energy supplies.
- Control them properly both in the engineering sense and with good user interfaces, so that energy is used only when and where it is really needed.
- Build and commission them effectively, and follow through into use to help ensure that the design intent is realised.
- Use and manage them well, to minimise waste.

In each step, a golden rule is to keep things simple and to do them well; complicated solutions tend to introduce problems, which lead to inefficiency in use. So first try to design things out, make the energy-consuming things you still need as efficient as possible and put time into getting user-friendly control systems that really work properly and avoid wastage. It is much more sustainable (and usually much more cost-effective) to get rid of unnecessary energy demands than to provide energy supplies – renewable or not – to meet them.

Fortunately for designers and their clients, effects multiply, so you can contemplate reducing CO_2 emissions by 80% or more by using techniques, technologies and practices which are already available, if not yet widespread or always cost-effective. For example, if you can halve the loads and make the building services systems and electrical equipment twice as efficient, you have already cut demand to one-quarter. Then, if you can also halve the CO_2 emitted per unit of energy supplied (e.g. by improving supply efficiency and making more use of renewable energy), the overall carbon dioxide emissions to do the same job would be cut to one-eighth. Already people are aiming to do better, increasingly with zero-carbon aspirations for some end-uses, if not for the whole building. The arrival of building energy certification should provide major incentives for such improvements, making both design intent and actual performance clearly visible and so encouraging people to do the things that really work.

A NOTE ON UK CARBON DIOXIDE EMISSION FACTORS

Carbon dioxide (CO_2) is a by-product of burning fuels principally coal, oil and gas. CO_2 emissions from buildings are now usually expressed in terms of kilogrammes of carbon dioxide ($kgCO_2$), the convention we use in this book. CAUTION: Sometimes emissions are reported as the mass of the carbon atoms in the CO_2. To convert carbon figures to CO_2, multiply by 3.67.
The Carbon Trust's published fuel conversion factors for energy delivered to a building from UK fuel supplies[9] are as follows:

Natural gas – 0.19$kgCO_2$ per kWh

Heating oil – 0.25$kgCO_2$ per kWh

Coal – 0.3$kgCO_2$ per kWh

Grid electricity – 0.43$kgCO_2$ per kWh

At the time of writing, the UK government is reviewing the factors to be used with the EU Directive, in particular for grid electricity, for which the actual value was about 0.55$kgCO_2$ per kWh in 2004–06 owing to changes in the generation mix.

9 Carbon Trust, *Energy and carbon conversions, Leaflet CTL 004,* London: Carbon Trust; March 2006. Downloadable from *www.carbontrust.co.uk/energy*