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Keith Tovey
HSBC Director of low Carbon Innovation, University of East Anglia, Norwich, UK

Charlotte H. Turner
PhD Researcher, School of Environmental Science, University of East Anglia, Norwich, UK

Carbon reduction strategies at University of East Anglia, UK

K. Tovey MA, PhD, CEng, CEnv, MICE and C. H. Turner BSc

Reducing the adverse effects of global warming and climate change is a critical issue. For the past 15 years the University of East Anglia has been addressing these concerns through a multi-pronged approach using technical means of low-energy building design, installing renewable energy sources, good energy management and raising awareness. Through good energy management, the university has been able to reduce the energy consumption of already low-energy buildings by as much as 50%. A large-scale building-integrated photovoltaic (PV) array has been installed along with on-site generation of heating, cooling and electricity via a 3 MW combined heat and power (CHP) plant and, recently, an adsorption chiller. In this paper, potential improvements in a more effective utilisation of PV electricity will also be discussed, as will future plans to reduce carbon emissions by installing further sources of renewable energy. The last part of this paper focuses on the CRed (Community Carbon Reduction) Programme established in 2003 and based at the university. The CRed programme takes up this challenge through innovative and integrated ways in promoting a low carbon economy and, in particular, promoting awareness.

1. INTRODUCTION

The University of East Anglia (UEA) was established in 1963 on a campus approximately 4 km west of the city of Norwich. It currently has over 13 000 students and over 2200 employees, of whom 465 are academic staff. The initial phase of campus development centred around buildings constructed in the mid to late 1960s, many of which represent the energy-wasteful approaches to building design that were prevalent at the time. Many of these are now Grade II listed buildings and the scope for significant improvements in their thermal performance is thus limited.

Since 1990, university policy for most new buildings has been for construction to standards well in excess of the then and likely future building standards. The buildings fall into two broad types: low-energy highly efficient student residences dating from the early 1990s and four (shortly to be five) education/office buildings employing the ‘Termodeck’ method of construction.

For many years, the university has recognised the importance of a multi-pronged approach towards a low carbon and sustainable future consisting of

(*a*) the construction of low-energy buildings with particular attention to ventilation heat recovery
(*b*) careful monitoring of building performance and adaptation of management regimes to ensure lowest possible energy consumption
(*c*) developing fuel-efficient and alternative methods to provide energy on campus
(*d*) promoting awareness among occupants to complement savings achieved through management strategies.

This paper discusses the experience gained and lessons learnt from these developments.

The majority of campus buildings are supplied with heat via a district heating main from a centralised boiler house that was constructed in the mid-1960s. Some of the more remote buildings are not connected to this heating main and have separate provision for heating. Several significant improvements in the way heat is produced and distributed on campus have been made over the last eight years and substantial savings in carbon dioxide emissions have been achieved. More recently, a large array of photovoltaic (PV) cells have been installed on one of the buildings. Experience gained during operation has revealed ways in which buildings might have an even lower net energy requirement in the future through more effective integration of the PV cells with energy use in the building.

2. LOW-ENERGY STUDENT RESIDENCES

Two new student residences (Constable Terrace (Fig. 1) and Nelson Court) were completed in 1993; each building houses around 390 students. The building fabric components outperform the new 2006 Building Regulations (Table 1). It is likely that the standards of insulation in these components will be better than future regulations until at least 2010, and probably much later.

As standards of insulation increase, ventilation energy required for space heating becomes a significant proportion of the total energy demand, as demonstrated by Tovey and Nunn[2] who note that the energy demand for traditional natural ventilated buildings could be as high as 75% of the total energy requirement. To tackle the issue of ventilation, both Constable Terrace and Nelson Court were built to an airtightness significantly better than comparable buildings at the time. Approximately 50% of the energy required for ventilation is recovered by heat exchangers. Incoming air passes through the exchangers, after which supplementary heat is provided when

Fig. 1. Constable Terrace, built in 1993

	U-value: W/m^{2}K			
	Walls	Windows	Roof	Floor
Actual as-built	0·22	2·0	0·15	0·18
1990 standard	0·45	5·0*	0·25	0·45
1994 standard	0·45	3·0	0·25	0·45
2002 standard	0·35	2·2	0·16	0·25
2006 standard	0·35	2·2	0·16	0·25
2050 for the 40% house[1]	0·10	0·8	0·10	0·10

*There was no specification for U-values for windows in 1990; the figure shown is illustrative of single glazing.

Table 1. *U*-values of fabric elements in Constable Terrace compared to standards prevailing at the time (1990) and more recent and future standards

needed to boost the temperature to comfort levels as required. In addition, small individual electric resistive panels (250 W) are provided in each room to allow individual control. Unfortunately, in the final stages of design, the favoured method of providing primary heat in the air ducts had to be changed from heat pumps to direct acting resistive heating on grounds of cost. Nevertheless, the overall measured performance of the building was substantially better than the then current best practice buildings (Fig. 2),[3] with total estimated carbon emissions at 770 t or 84 kg/m^2 per annum—substantially lower than other similar buildings. (It should be noted that these actual figures include all energy uses, including occupant use of desk lamps, computers etc.) In late 2005 further new residences were completed, but at present no data are available from these buildings to assess their performance.

3. LOW-ENERGY EDUCATIONAL BUILDINGS

The UEA was a pioneer in the UK in constructing educational/office buildings to the 'Termodeck' principle. The construction uses lightweight hollow-core ceiling slabs through which both incoming and exhaust air can circulate (Fig. 3); the system provides high insulation standards, good airtightness and a highly efficient heat recovery system. There is provision for individuals to open windows, although this facility is seldom used. Nevertheless, it is important that such provision is available as user acceptability of working environments is important.

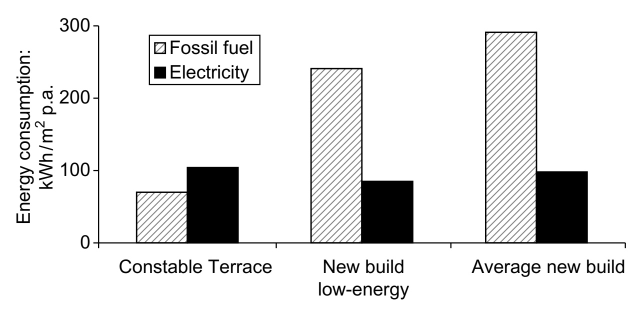

Fig. 2. Constable Terrace performs better than Department of Environment Low and Average Buildings at the time (data derived from BRECSU[3])

There are now four such Termodeck buildings at the university, all of which incorporate a highly efficient mechanical heat recovery unit. In three of the buildings this heat recovery unit is of the twin-channel regenerative type and is 87% efficient. In the fourth and newest building, a heat wheel recovery unit is used. These four buildings, together with a fifth shortly to be constructed, give the UEA campus the highest concentration of such energy-efficient buildings in a temperate climate anywhere in the world.

The principle of operation of the Termodeck construction is summarised in Fig. 4. Incoming air is heated by the heat recovery unit before passing through a filter and a heating bank. In some of the campus buildings this heat is supplied by stand-alone boilers, whereas others are connected directly to the university heating main. The air then passes through the hollow-core sections and emerges through diffusers into various rooms. Stale air from the occupied spaces is captured in separate ducts and taken back to the regenerative heat exchanger where the majority of the residual heat is extracted. The two channels of the heat exchanger switch over at approximately 90 s intervals to provide a very high heat recovery rate. Circulating the heating air through the hollow-core structure allows the full impact of the thermal mass of the building to be utilised in stabilising the internal temperature even with quite large diurnal swings, thus improving the thermal comfort for users. In climates where the nights are cool in summer but the days are hot, the fabric of the building can be pre-cooled over night, thereby reducing (and in many cases eliminating) the demand for space cooling (the

Fig. 3. Construction of a Termodeck building showing hollow slabs in inset

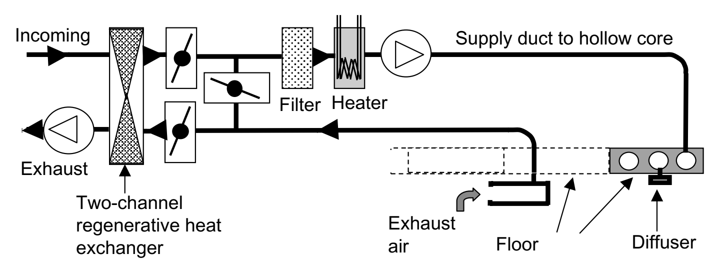

Fig. 4. Schematic diagram showing the principle of Termodeck construction, which results in a particularly low-energy design

strategy adopted at the UEA). In hot climates this can be an important consideration as the peak daytime cooling requirement can be substantially reduced.

The Elizabeth Fry Building (Fig. 5) was the first educational building of this type in the UK and was first occupied in early 1995. When constructed it was hailed as 'The best building yet' in a PROBE 14 report.[4] The design complied with 1990 Building Regulations and, despite costing less than 10% more than a building of the same size built to the same standards, achieves such an impressive energy performance that heating for the whole building is supplied by a single domestic heating boiler. The original design required the installation of three such boilers but, except in the most extreme conditions when temperatures are very much lower than 0°C, only one is actually ever used. Exhaust air from the rooms collects waste heat from the low-energy lighting and is passed through the ducts to the regenerative heat exchanger. Even when the outside temperature is as low as 9°C it is rare for any heat to be supplied by the boiler except in early morning before waste heat recovery from building use is fully operational. The *U*-values improve on those of Constable Terrace—the windows have the equivalent of quadruple glazing. (The *U*-value is a measure of how quickly heat conducts through a particular surface, measured in $W/m^2/°C$. A low *U*-value specifies a good quality insulator.)

The Elizabeth Fry Building initially performed well and energy efficiency exceeded that of conventional buildings. With careful energy management over the first two years the space heating requirement was reduced by 50% to just 33 kWh/m^2 per annum. This figure represents the temperature-corrected value; when added to the 4 kWh/m^2 per annum requirement for hot water, the building yields an aggregate consumption figure of just 20% of the standard for academic buildings.[4] Continued monitoring (Fig. 6) shows that there has been a slight rise in space heating requirements in recent years, partly due to a deterioration of the building's airtightness.

Fig. 5. The Elizabeth Fry Building, completed in 1995

In 2003 and 2004 there was a significant rise in hot water use associated with the opening of a temporary catering outlet in the building. Electricity consumption was initially static at 60 kWh/m^2 per annum, but this figure has risen by 33% with the introduction of more computing and catering facilities. However, when these catering facilities vacate the building (expected spring 2006), electricity consumption is expected to fall.

An independent survey carried out and reported in *Building Services Journal* of user satisfaction in the Elizabeth Fry Building[4] demonstrated that in all the measured categories the perception of the building was above average (Table 2).

The year 2003 saw the completion of an even more innovative building on the campus—the Zuckerman Institute for Connective Environmental Research (ZICER) (Fig. 7). This developed the concept of the Elizabeth Fry Building and included a 34 kW PV array on the façade of the top floor and the roof of the building. The lower four floors (including the basement) were Termodeck construction (an exhibition area on the top floor, designed to demonstrate the use of PV cells, is outside the Termodeck envelope). Through improvements in design, the heating requirement of the Termodeck part of the building was expected to be around 90% of that of the Elizabeth Fry Building. The early results of the performance of the new building were, however, not encouraging.

In the first six months after completion, the heating requirement in terms of energy requirement per square metre was double that of the Elizabeth Fry Building. In autumn 2004, a new management strategy was implemented in the ZICER. Essentially, instead of using supply air and return air temperatures, control was achieved using the temperature of the concrete slabs themselves. This strategy provided more stable temperatures with the consequence of a dramatic improvement in energy performance and the ZICER now outperforms the Elizabeth Fry Building for most of the winter (Fig. 8). Thus, if optimum performance is to be achieved, low-energy sustainable buildings require not only good initial design, but also careful management of heating strategies. From the time the new management strategy was initiated throughout the following winter, the energy consumption in the ZICER was always below that of the Elizabeth Fry Building. However, from the end of March the demand rose again slightly above that of the Elizabeth Fry Building. Two factors were causing this slight increase. First, there is a difference in activity as the Elizabeth Fry Building is primarily a teaching building and has much lower usage of hot water from April to September, whereas activity levels are high throughout the year in the ZICER. Second, unlike in the Elizabeth Fry Building, a few radiators in the ZICER basement area and

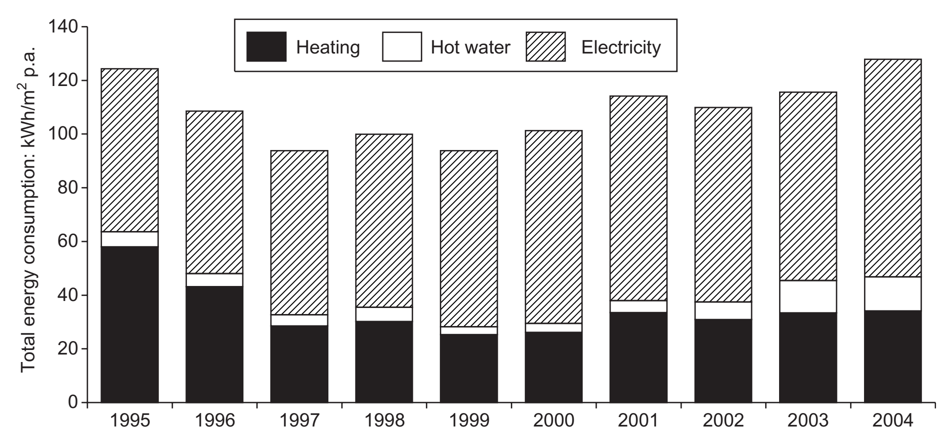

Fig. 6. Performance of the Elizabeth Fry Building

stairwell may be operated by occupants. It was found that these were being left on even when the outside temperature increased. When these radiators were manually locked in the off position for the remainder of the summer, the energy demand once again fell below that of the Elizabeth Fry Building. Once again, this demonstrates the importance of continual monitoring and analysis of the performance of a building.

In the summer 'no-heating' period, the dynamic performance of the building is excellent with a daily temperature variation of ±0·25°C throughout most of the building when the external diurnal temperature range is 13°C. The greatest variation is on the ground floor, but here it is still less than ±0·75°C. For further details on the monitoring and energy consumption of the Termodeck buildings at the UEA, see Raydan and Turner[5] and Turner and Tovey.[6]

4. LOW-ENERGY STRATEGIES FOR HEATING, COOLING AND ELECTRICITY SUPPLY

Of the buildings described so far, only the ZICER is supplied directly from the UEA central heating main. However, the majority of the older buildings are all connected to the district heating main, and significant improvements in overall energy efficiency may be achieved by tackling the supply of energy to these buildings as the scope for reducing space heating demand is limited by the restrictions arising from the Grade II listings. The central boiler house originally housed three 8 MW boilers installed in the early 1960s and running on residual fuel oil. While efficient under full load, these boilers were very inefficient under low load and a more modern 4 MW boiler was installed in the mid-1980s, primarily for use in the summer months. A further development saw the conversion of all boilers to run on either residual fuel oil or gas in 1987. This had attractive financial implications as relatively cheap interruptible gas tariffs could be used. In the late 1990s, one 8 MW boiler was removed and three 1 MWe combined heat and power (CHP) units were installed. The CHP units have 16 cylinder gas engines as prime movers providing 1 MWe of electrical output per machine and up to 4·2 MW heat in total. The primary supply of heat for the campus thus comes from this source, with the boilers used as top-ups as needed during the winter. The new configuration of the boiler house showing the three CHP units and one of the 8 MW boilers is shown in Fig. 9. In the year following installation, the CHP units produced a saving of around £400 000 per annum in energy bills from of a total of £1 million. Table 3 shows the proportion of electricity generated by the CHP units.

Criterion	Relative to a standard building
Thermal comfort	28% better than average
Air quality	36% better than average
Lighting	25% better than average
Noise	26% better than average

Table 2. Users' perceptions of the Elizabeth Fry Building[4]

Initially, the proportion of electricity generated was high and indeed there were a few months when the scheme was a net exporter of electricity. This advantageous position has declined somewhat over recent years. This is, first, because of the increased total electricity demand as a result of university growth and, second, due to New Electricity Trading Arrangements (NETA) that came into force on 27 March 2001 with subsequent replacement by the British Electricity Transmission and Trading Arrangements (BETTA) on 1 April 2005. The consequence of both of these changes in electricity supply has had adverse effects on the financial viability of export prices; at the same time the raw fuel prices for gas have increased.

Electricity generated in small localised schemes such as these are particularly beneficial in promoting low-energy strategies. The electricity is used locally and this therefore avoids the normal losses of electricity associated with transmission. In the UK, despite the relatively short distances involved compared with many countries, these transmission losses amount to 8·5%.[7]

In the complete final year before CHP unit installation, the data relating to energy consumption at UEA are shown in Table 4 together with the associated carbon dioxide emissions. The

Fig. 7. The Zuckerman Institute for Connective Environmental Research (ZICER) showing the photovoltaic array on the top floor

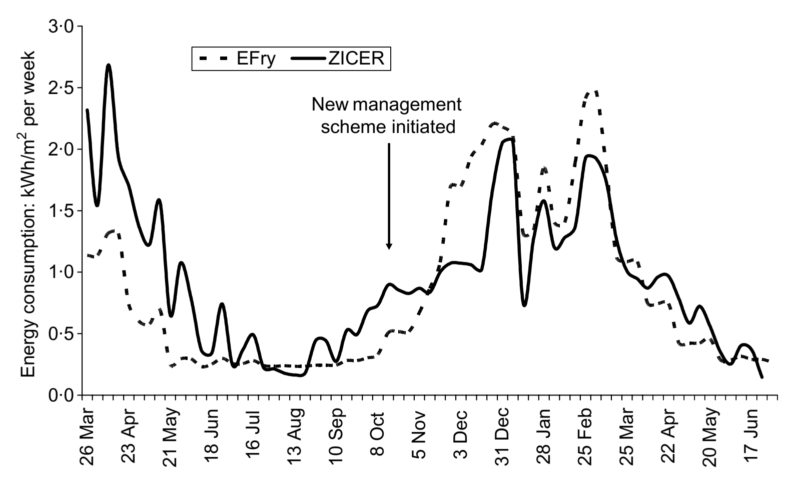

Fig. 8. The actual performance of the Termodeck section of the ZICER compared with the Elizabeth Fry Building

emission factors used were those relevant at the time and, in the case of electricity, also include the effect of transmission losses. Total carbon dioxide emission associated with UEA activities amounted to 15 699 t. As is evident, the boilers ran for the majority of the time using gas, and only for a short period using oil.

Table 5 shows comparable data for the first full year after installation of the CHP units. During the year, 6·2% of the electricity generated was exported. Despite a 2·7% increase in electricity demand, overall carbon dioxide emissions fell by 33·6% from 15 699 t to 10 422 t.

It became apparent that the load factor of CHP generation varied significantly over the year, as shown in Fig. 10 which covers the period 1 March 1999 to 31 July 2005 (excluding data for three months during a major overhaul). Overall, the load factor is 67% though there is a slight variation from year to year, particularly when there was a major overhaul. Each year the trend is the same with the lowest generation occurring in the summer months at around 40% compared with over 80% in winter. Paradoxically, this means that when the demand for electricity is least, the amount of electricity imported is sometimes at its highest. This arises because whenever electricity is generated by thermal means, there is a need to remove the waste heat in the generator and in summer the demand for heat is very low. The solid curve in Fig. 10 shows the average load factor for each month while the dashed curves show maximum and minimum load factors in each month.

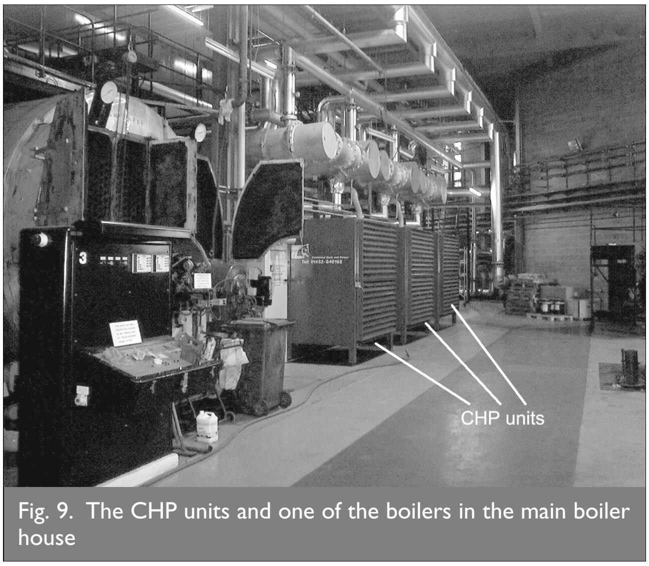

Fig. 9. The CHP units and one of the boilers in the main boiler house

As the size of the university has increased so has the demand for chilling. This is mostly associated with the cooling requirements of scientific equipment rather than air-conditioning (the latter is restricted to a few specialised locations only). Part of the rapid rise in electricity demand in recent years (see Table 3) is associated with this cooling. Adsorption chilling can utilise waste heat to provide cooling, and the combination with CHP (usually known as tri-generation) provides a truly win–win approach to low-energy design. In future all building complexes such as universities and hospitals should consider tri-generation at an early stage in design. Such a unit, which will provide 1 MW of cooling, has been installed at UEA and was undergoing commissioning in April 2006.

From summer 2006, waste heat from electricity generation from the CHP units was used in the adsorption chiller to provide the necessary cooling for scientific equipment. The reduction in load factor in summer will largely be removed and the financial

	CHP generated: MWh	Total demand: MWh	Per cent supplied by CHP
1999	16 753	20 432	82·0
2000	15 301	21 410	71·5
2001	18 440	24 756	74·5
2002	15 644	25 611	61·1
2003	15 655	26 277	59·6
2004	17 567	26 961	65·2
1 Jan–31 July 2005	11 198	16 422	68·2

Table 3. Electricity generated on the UEA campus, total demand and percentage supplied by CHP units (Note that values for 2000 were affected by a major overhaul of units and, after 2001, financial viability for export was affected by NETA/BETTA)

	Electricity	Gas	Oil	Total carbon dioxide emission: t
Energy: MWh	19 895	35 148	33	
Emission factor: kWh/kg	0·46	0·186	0·277	
Carbon dioxide: t	9152	6538	9	15 699

Table 4. Energy use and annual CO_2 emission on the UEA campus before installation of CHP units (1997/98)

	Electricity				Heat			Total carbon dioxide emission: t
	Total site	CHP generation	Export	Import	Boilers	CHP	Oil	
Energy: MWh	20 437	15 630	977	5783	14 510	28 263	923	
Emission factor: kWh/kg	—	—	−0·46	0·46	0·186	0·186	0·277	
Carbon dioxide: t	—	—	−449	2660	2699	5257	256	10 422

Table 5. Comparable (to Table 4) data for first complete year after installation of CHP (1999/2000)

viability of the CHP units will be improved. At the same time, the demand for electricity will fall as, in the future, much of the chilling will be provided from the adsorption chillers rather than at present from electricity. The additional projected savings in carbon emissions will be between 350 and 400 t per annum and may be more; however, the exact amount will depend on the duration of use of the chiller.

While initially it would be expected that the chiller would not be operated in winter when the demand for heat is high, there may be both environmental and financial benefits in running the chillers for extended periods and topping up any shortfall in heat with the existing boilers. The issues involved in the decision making for such a strategy are complex and require careful consideration once actual performance (i.e. efficiency) data are available. The emission factor for centralised electricity generation electricity is currently 0·52 kg/kWh compared to gas (allowing for boiler efficiency for providing heat) at 0·22 kg/kWh. Local on-site generation of electricity avoids the 8·5% transmission loss associated with imported electricity. Extended seasonal use of the adsorption chiller would reduce winter electricity demand, but additional gas would have to be burnt for space heating to compensate. In financial terms, it is the relative prices of imported gas and electricity that will be important, as will the total energy bill. Furthermore, since the UEA is a large site it comes within the European Union Emissions Trading System (EU-ETS) and any excess emission of carbon dioxide requires the purchase of additional credits, while any saving in emissions would attract income from the sale of credits.

The situation will be carefully monitored to devise the optimum strategy: there are many parameters to consider, including the overall reduction in carbon emissions and the relative prices of gas and electricity. However, despite the fact that the scheme will reduce carbon emissions, the UK implementation of EU-ETS in 2005 is such that the university will be penalised for such measures. This is because an increase in utility of the CHP plant will not qualify for additional emission credits under the UK National Allocation Plan for Credits. Though there will be a net reduction in carbon emissions as a whole, there will be an increase in locally emitted carbon and thus the University of East Anglia will have to purchase extra carbon credits at an expected cost of several thousand pounds.

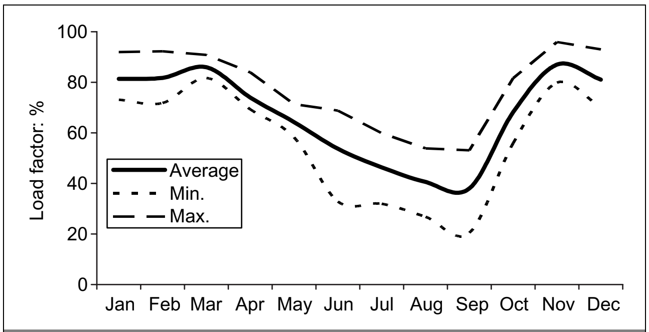

Fig. 10. Variation in load factor for electricity generation by the CHP units. The graph demonstrates the under-utilisation of units in summer because there is limited demand for heat

5. RENEWABLE ENERGY AT THE UEA

The ZICER discussed above is not only a low-energy building but it also has two building-integrated PV arrays that together can produce a peak output of 34 kW. Most of the south-facing façade of the top floor has three separate arrays of poly-crystalline PV cells while the roof, which is tilted at 15°, is covered with ten arrays of mono-crystalline PV cells. Fig. 11 shows typical amounts of electricity generated by the building on clear and cloudy summer days. On a summer weekend when there is more than sufficient electricity generated from the PV cells to satisfy the requirements of the building, surplus electricity is exported to the grid. The maximum export in any week in 2005 was 63 kWh (Fig. 12(c)). However, the overall demand in a month significantly exceeds the total PV production as shown in Fig. 12(a). The annual production of electricity has amounted to around 22 MWh, implying an overall load factor of 7·4%. When compared with other installations, the output performance of the ZICER array is one of the better ones in the UK.

The inverters that convert the output from the d.c. PV cells on the building into traditional a.c. electricity are at best 94% efficient (Fig. 13). Overall, the annual average inverter efficiency is 91·1% for the roof-mounted cells and 89·6% for those on the façade. A large percentage of the electricity use in the ZICER is for computing requirements. Each computer has its own power pack to convert a.c. electricity back into d.c. Aebischer and Huser[8] suggest that these power packs convert no more than 50–60% of the a.c. electricity available into useful d.c. voltages for computer use. This suggests that only around 50% at best of the electricity produced by the PV cells (or for that matter any d.c. source) is actually useful. There is therefore the potential for significant improvement by utilising d.c. electricity directly by integrating a d.c. network into such buildings in the future. To deal with those occasions when demand exceeds supply, a single (and more efficient) transformer rectifier could supply such a network. This system offers an additional benefit as the energy lost in the power packs will result in waste heat and, where air-conditioning is required, this will result in increased energy available for cooling. While it is true that the additional heat will reduce heating demand from other sources in cold winter climates, there is still an advantage for such a strategy. Using any heating system other than direct-acting electric resistive heating to provide the extra

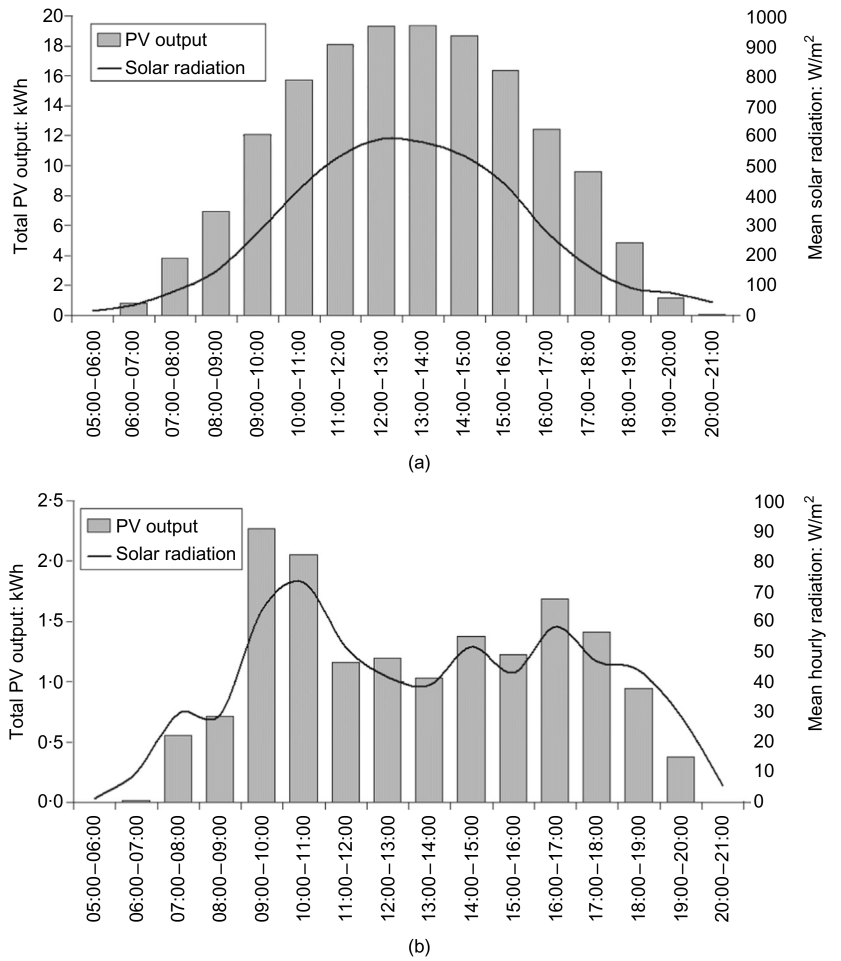

Fig. 11. Typical outputs from solar PV arrays on the ZICER for (a) a typical sunny day in summer and (b) a cloudy summer day. The mean hourly radiation refers to the measured horizontal radiation while the output refers to the net output after inversion. The total generation on the two days is (a) 159 kWh and (b) 16 kWh

heat will be beneficial both environmentally (less net emissions) and, in most cases, financially.

It would seem sensible in the design of low-energy buildings to provide electricity services that are compatible with the main system of use. Thus, d.c. networks at suitable voltages should be provided in all low-energy buildings where renewable energy systems are an integral part of design and where computing is a major use of electricity.

6. FUTURE RENEWABLE ENERGY AT THE UEA

The university has recently commissioned a feasibility study into the installation of a biomass CHP unit. This unit will be larger than the existing units (1·4 MW electrical energy and 2 MW heat) and will involve pyrolysis and gasification of wood chips to drive a CHP plant powered by the gas produced. Biomass may be considered to be carbon neutral if it comes from sustainable growth. However, the growing, harvesting and transportation of biomass will entail energy use, much of which will be as fossil fuels, and so there will still be some emissions of greenhouse gases. Initial estimates of such a scheme suggest that a further saving in carbon dioxide emissions of 3500–5000 t per annum on the campus is possible.

The UEA is also currently exploring the possibility of erecting three 1·5 MW wind turbines to further reduce carbon emissions. Some critical issues have arisen regarding public acceptability of such a scheme and the CRed (Community Carbon Reduction Programme) team, active in promoting low carbon strategies, has successfully swayed public opinion from a generally antagonistic feeling towards turbines to a significantly positive one. It is hoped that progress can be made on this aspect over the coming year.

7. OPTIMISING LOW-ENERGY COMMUNITIES THROUGH AWARENESS

Low-energy strategies require the multi-pronged approach as outlined in the introduction to this paper. The UEA has been successful in designing particularly low-energy buildings and moving forward to ensure the most efficient forms of energy (including renewable energy) are used to provide both heat and electricity on campus. In addition, the CRed team, established in 2003, is exploring ways to capitalise on this and reduce energy demand further by appropriate awareness, not only in the university but also in the community at large. As an example, the university targeted a particular day in which all students and staff were encouraged to think about the energy they were using and 'switch off' whenever possible. A Friday in April 2005 was selected and data for one building were carefully recorded both before and after the specified day. The results are shown in Fig. 14.

Throughout April the reduced weekend demand is clearly visible. The dotted line shows the trend of weekday consumption with the shaded band representing one standard deviation both above and below this line. The line and band slope downwards represent the change in demand as summer approached with a reduced lighting load. The target day (22 April) shows a substantial fall in demand (nearly four standard deviations below the trend line) demonstrating that, with concerted effort, low-energy strategies can be significantly enhanced by promoting awareness in building users. There is evidence that the awareness continued, albeit at a lower level, on the following Monday but thereafter old habits appeared to return. The university is now examining ways in which such improvements can be made more long-lasting. It is apparent that for such strategies to have a long-term effect, some form of incentive is required at a local level. Two

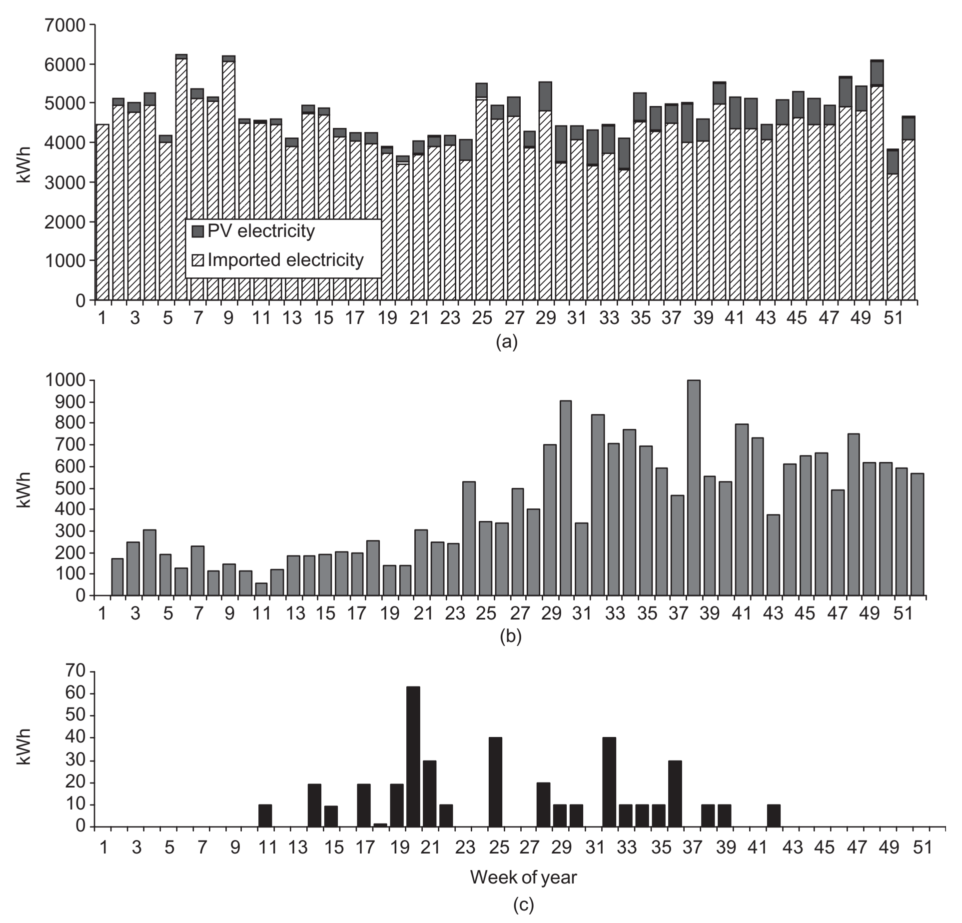

Fig. 12. The performance of the PV cells during 2005: (a) total electricity requirement and proportion generated by PV cells; (b) amount of electricity generated by the PV array; (c) the export of electricity from ZICER

buildings are shortly to be constructed with significant sub-area metering so that specific performance can be monitored with the possible ultimate aim of making each spending authority within the university responsible for the costs of its electricity consumption rather than having the costs centrally payable.

8. CONCLUSIONS

Tackling climate change requires a concerted effort on several different fronts. It is not sufficient to consider single issues such as the provision of renewable energy or the construction of low-energy buildings. Instead, an integrated approach involving not only these aspects but also effective management and the promotion of awareness is required. The UEA has been proactive in promoting low-energy strategies and several important issues have arisen from the experience gained thus far. The following are key issues in such low-energy strategies.

(*a*) The construction of low-energy buildings often costs a little more than conventional buildings, but this is recouped through long-term energy savings. With ever-rising energy costs, the payback times are reducing all the time.

(*b*) Ventilation heating requirements are becoming the dominant issue in low-energy buildings and ventilation heat recovery should be normally incorporated as standard. Many of the newer UEA buildings achieve a heat recovery rate as high as 87% through the use of regenerative heat exchangers.

(*c*) Some organisations require the construction of low-energy buildings, but after occupation do little to improve their performance. Evidence at the UEA indicates that energy consumption can be reduced by as much as a further 50% in low-energy buildings through effective record keeping and analysis backed up with effective management strategies to optimise the operation of the buildings. Experience suggests that up to 18–24 months may be needed before a building is operating at its full potential.

(*d*) Localised CHP systems can be effective in reducing carbon emissions, but the requirement for heat disposal whenever electricity is generated creates problems in the summer when

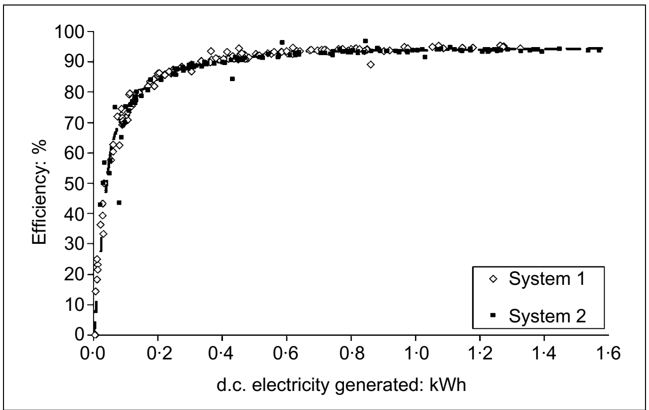

Fig. 13. Inverter efficiency for conversion of electricity generated by PV array from d.c. to a.c. is at best 94% efficient

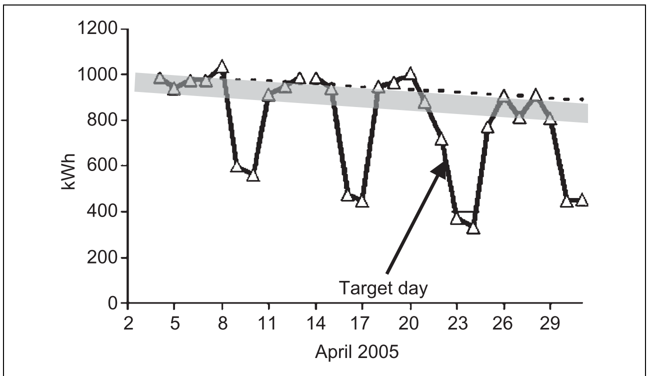

Fig. 14. Daily electricity demand in the Registry at UEA during April 2005

heat demand is low. The utility of CHP units in summer is often low but the inclusion of adsorption chilling into such schemes (as tri-generation) should always be considered where there are significant summertime chilling requirements whether for air-conditioning or for equipment cooling. As CHP generation is embedded in a local network, it avoids the not inconsiderable transmission losses from normal generation, thereby further reducing carbon emissions.

(*e*) Incorporation of renewable energy systems (e.g. solar photovoltaics or micro wind turbines) into buildings is attractive. However, the trend to date has been to use such devices to provide a.c. electricity. Inversion of d.c. electricity as produced to a.c. for distribution is only 91% efficient. In many offices, computing and IT requirements are a major use of electricity and losses in the power packs of such appliances, which may be as high as 50%, result in poor utility of the generated electricity. A holistic approach to building design *and* the appliances to be used in the building is required.

(*f*) Promoting effective awareness can reduce energy consumption in buildings dramatically, but ways to prevent 'backsliding' must be researched.

(*g*) The UEA has seen a reduction in carbon dioxide emissions of over 5000 t (or 33%) following installation of the CHP scheme in 2000, and further reductions have been realised through the construction of low-energy buildings. There has subsequently been a substantial (~40%) increase in activity at the university, causing emissions to rise again. New avenues for further reduction, such as the installation of wind turbines and biomass CHP systems, are now being explored.

(*h*) The implementation of regional, national and international legislation in the UK and some other countries is not always conducive to promoting the most energy-efficient strategies in communities. Pressure must be brought to bear to make sustainability and low-energy strategies the key aspect in new legislation and to avoid situations where organisations are effectively penalised for adopting the most effective measures in combating the adverse effects of climate change.

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