Low Energy Buildings and Low Carbon Strategies –Experience at the University of East Anglia

N.Keith. Tovey (杜伟贤): HSBC Director of Low Carbon Innovation: k.tovey@uea.ac.uk
Charlotte Turner: Postgraduate Student: charlotte.turner@uea.ac.uk
School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK

Abstract

For the last 15 years energy saving and conservation through technical means of low energy building design, good energy management, and awareness raising have been important aspects of policy and research at the University of East Anglia. Over this time the University campus has been expanding in size and this has resulted in the construction of many new buildings, the majority of which have been built to achieve energy standards far in excess of the prevailing Building Regulations. Furthermore the predicted heating and cooling requirements which will be better than all planned revisions of these regulations for many years to come.

This paper explores the successful energy management of new buildings on campus to ensure optimum performance. Such issues include not only the initial design concept and installed equipment, but also careful monitoring and analysis of energy use which has led to additional reductions in energy approaching 50%. The University also has a large scale building integrated photovoltaic array and on-site generation of heating, cooling and electricity via a 3 MW CHP plant and an adsorption chiller. Potential improvements in the buildings' utilisation of PV electricity will also be discussed as will future plans to install a biomass CHP unit and three large wind turbines.

In any move towards sustainability it is important not only to construct and effectively manage new low energy buildings with the use of renewables, but also to promote awareness in the large community. The last part of this paper focuses on CRed Programme (Community Carbon Reduction) established in 2003 and based at the University that takes up this challenge through innovative and integrated ways in promoting a low carbon economy.

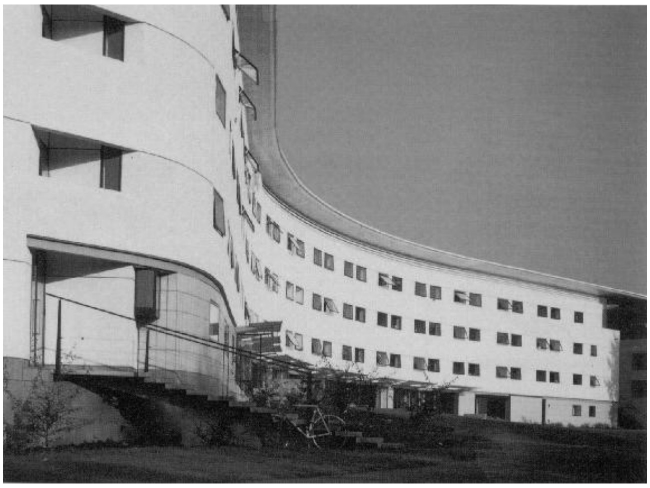
Introduction

The University of East Anglia was established in 1963 on a campus approximately 4km west of the city of Norwich. It currently has over 13000 students and over 2200 staff of whom 465 are academic staff. The initial phase of the development of the campus centred around buildings constructed in the mid to late1960s many of which represent the energy wasteful approaches to building design which were then prevalent. Many of these are now Grade 2 listed buildings and the scope for significant improvements in thermal performance is limited. Since 1990 the 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.

The University recognises the importance of a multi-pronged approach to a low energy and sustainable future consisting of:

1. the construction of low energy buildings paying particular attention to ventilation heat recovery
2. careful monitoring of building performance and adaptation of management regimes to ensure lowest possible energy consumption,
3. developing fuel efficient and alternative methods to provide energy on campus,
4. promoting awareness among occupants to complement savings achieved through management strategies,
5. addressing the issues of reducing energy in existing buildings which are Grade 2 listed and thus preventing the adoption of many low energy schemes.

The priority to date has been to tackle points 1 – 4 above and this paper discusses the experience gained and lessons learnt from these developments. Though important in overall University policy, the issues raised under item 5 are not discussed in this paper.



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

	U-Values ($Wm^{-2}K^{-1}$)			
	Walls	Windows	Roof	Floor
Actual	0.22	2.0	0.15	0.18
1990 standard	0.45	5*	0.25	0.45
1994	0.45	3	0.25	0.45
2002	0.35	2.2	0.16	0.25
2005	0.35	2.2	0.16	0.25
2050 (Boardman et al 2005)	0.1	0.8	0.1	0.1

* There was no specification for U-values for windows in 1990, the figure shown is illustrative.

Fig. 1. Constable Terrace built in 1993 and key parameters showing that the performance exceeds projected performance of new 2005 regulations.

With the exception of some of the newer and more remote buildings, all campus buildings are supplied with heat from a centralised boiler house which was constructed in the mid 1960s. Several significant improvements in the way heat is produced and distributed on campus have been made in the last 8 years such that substantial savings in carbon dioxide emissions have been achieved. More recently a large array of photo-voltaic cells has been installed on one of the buildings and experience gained during the operation suggests ways in which buildings might have an even low energy requirement in future.

Low Energy Student Residences

The first of the energy efficient buildings were two student residences completed in 1993 each housing around 390 students (Fig. 1). The fabric had particularly low U-values while pressure tests demonstrated that they were more air-tight than all other comparable buildings at the time. The performance can be judged from Fig. 1. It will not be until at least 2010 and probably much later that the standard will be exceeded and even then the significant use of ventilation heat recovery will make this building energy efficient for many years to come.

About 50% of the ventilation heat requirements are recovered by heat exchangers. Heating is provided in the incoming air duct after the heat exchanger to boost the temperature to comfort levels. Small individual resistive panels are also provided in each room to allow individual control, but these are rated at a maximum of 250W each. Unfortunately in the final stages of design, the favoured method of primary heat in the air ducts had to be changed to direct acting resistive heating on ground of cost. Nevertheless, the overall performance of the building was substantially better than the then current best practice buildings – Fig. 2. The estimated carbon emissions for this building are 770 tonnes per annum (BRECSU (1995), substantially lower than other similar buildings.

Low Energy Educational Buildings

The University of East Anglia (UEA) currently has four buildings built on the “Termodeck” principle which incorporates a highly efficient regenerative heat exchanger which is 87% efficient in recovering heat from the mechanical ventilation system. These four buildings, together with a fifth shortly to be built, gives the UEA Campus the highest concentration of such energy efficient buildings in a temperate climate. The construction uses lightweight hollow slabs for the floor through which both incoming and exhaust air can circulate (Fig. 3). The principle of operation is summarised in Fig. 4.

Incoming air is first heated in the two channel regenerative heat exchanger before passing through a filter and a heater bank which might be supplied from any suitable source. The air passes through the hollow core sections and emerges through diffusers. 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 second intervals to provide a very high heat recovery rate. Since both the warm incoming air and stale air circulates through the building fabric the structure is close to the air temperature and this improves the perception of thermal comfort. The hollow core structure allows the full impact of the thermal mass of the building to be utilised in stabilising the temperature within the building even with quite large diurnal swings. 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. In hot climates this can be an important consideration as the peak cooling requirement can be substantially reduced.

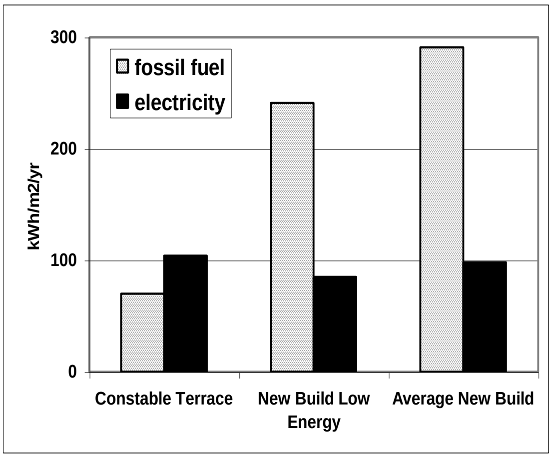


Fig. 2. Constable Terrace performs better than the then DOE Low and Average Buildings. Data derived from BRECSU (1995).

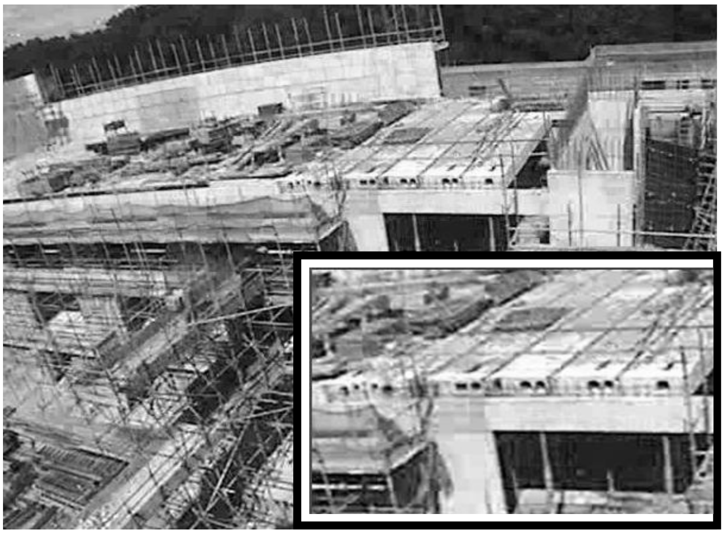


Fig. 3. Construction of a “Termodeck” Building showing hollow slabs in inset

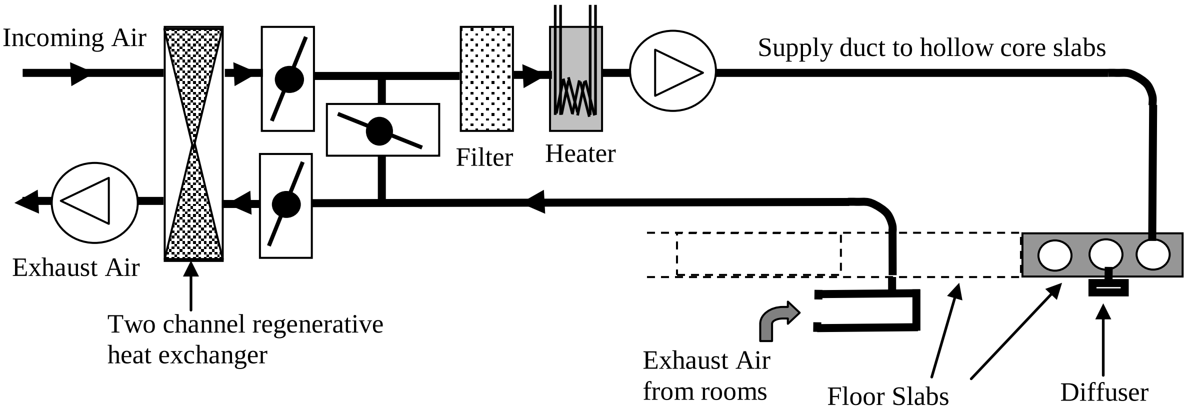


Fig. 4. Schematic diagram showing the principle of the "Termodeck" construction which results in a particularly low energy design.

The first building of this type on the UEA campus was the Elizabeth Fry Building (Fig.5) which was first occupied in early 1995. When constructed it was hailed as “the best building yet” by Probe 14 (1998) and despite costing less than 10% more achieves an impressive energy performance such that heating for the whole building is supplied by a single domestic heating boiler. 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. The U-values improve on those of Constable Terrace and indeed the windows have the equivalent of quadruple glazing.

The building initially performed well, but by careful fine-tuning over the first two years the space heating requirement was reduced by 50% to just 33 kWh/ m^2 / yr. This figure represents the temperature corrected value which when added to the 4 kWh/m^2/yr requirement for hot water produced an aggregate figure which was 20% of the standard for academic buildings (PROBE 14: 1998). 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 air-tightness of the building. In 2003 and 2004 there was a significant rise in hot water use association with the opening of a catering outlet in the building. Electricity consumption was initially static at 60 kWh/m^2/yr but has risen recently by 33% with the introduction of more computing and catering facilities.

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

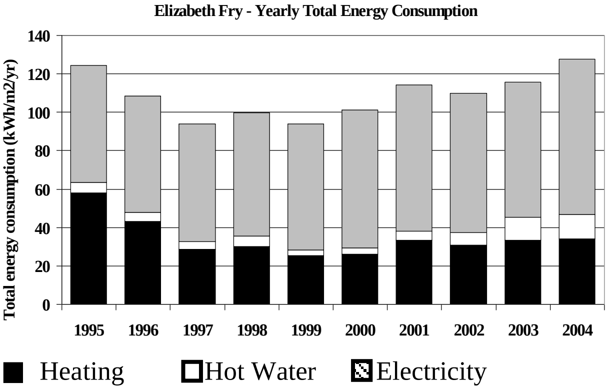


Fig. 6. Performance of Elizabeth Fry Building.

An even more innovative building on the campus is the Zuckerman Institute for Connective Environmental Research (ZICER) shown in 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 constructed as a "Termodeck" construction with an exhibition area on the top floor which was designed to demonstrate the use of photo-voltaic cells. The heating requirement of this building was expected to be around 90% of that of Elizabeth Fry. The early results of the performance of the new building were not encouraging (Fig. 8).

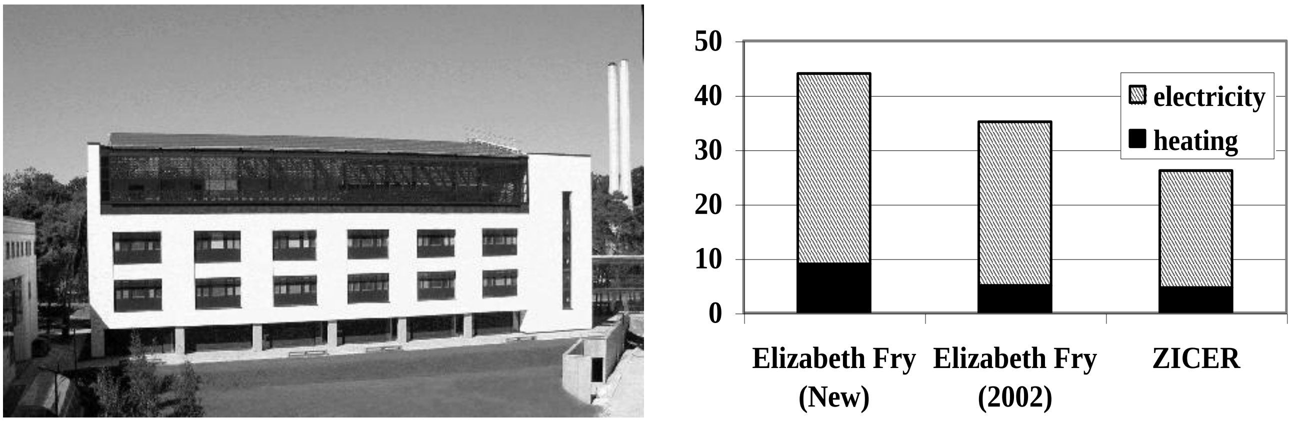


Fig. 7. The ZICER building showing the photovoltaic array on the top floor. On the right the projected performance of the "Termodeck" part of the building compared to the Elizabeth Fry Building.

Six months after completion, the heating requirement was double that of the Elizabeth Fry building when expressed in terms of heat requirement per unit area. Careful analysis of the data suggested that a different management regime using control of the temperature of the slabs might be appropriate and this was implemented in the summer of 2004. The consequence has been a dramatic improvement in performance with the ZICER building substantially outperforming the Elizabeth Fry building for most of the winter. This demonstrates that to achieve low energy sustainable buildings requires not only good initial design, but also careful management of heating strategies if the optimum performance is to be achieved. Fig. 9 illustrates the dynamic performance of the building during a “no-heating” period in summer. The three main slabs have almost identical temperatures and vary very little during the day despite the external temperature varying by over 12 ^{o}C. The basement slab temperature is slightly lower, partly because there is often little activity in that area and thus little opportunity for incidental gains.

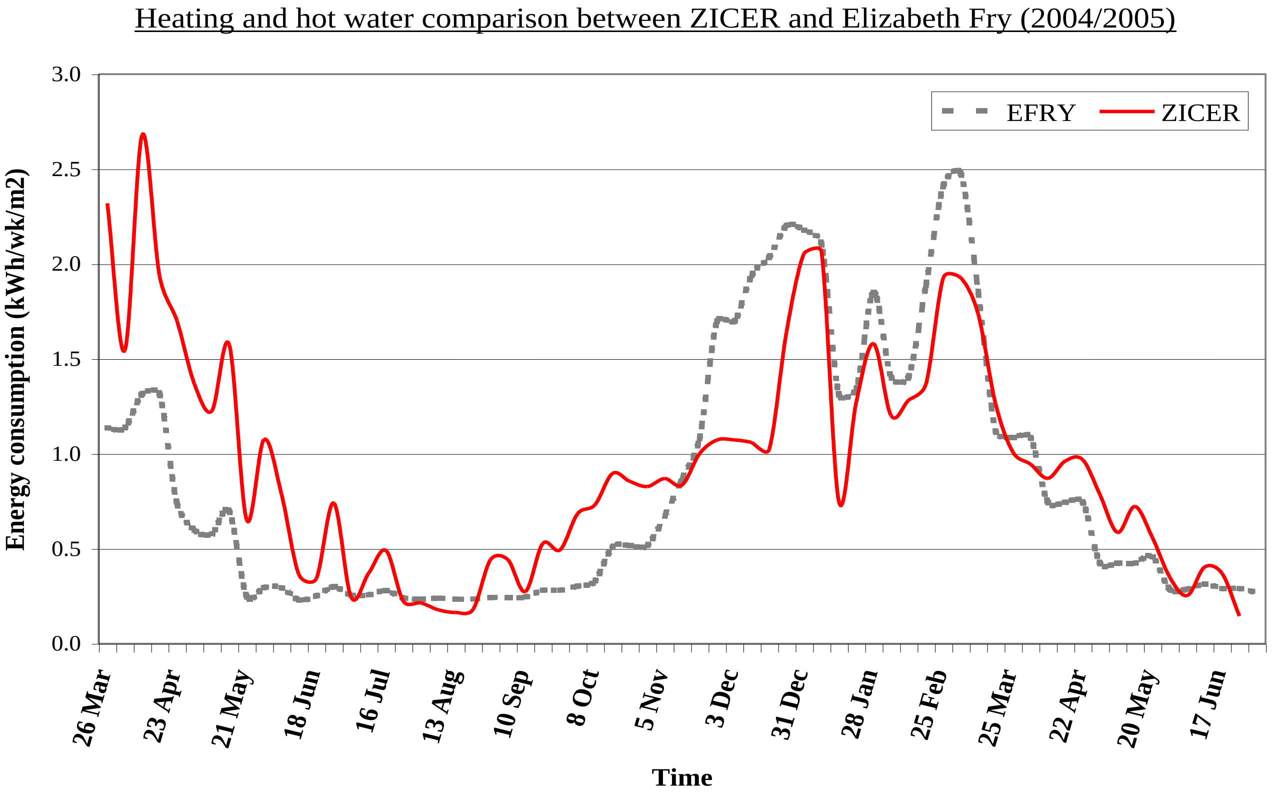


Fig. 8. The actual performance of the "Termodeck" section of the ZICER Building compared to the Elizabeth Fry Building.

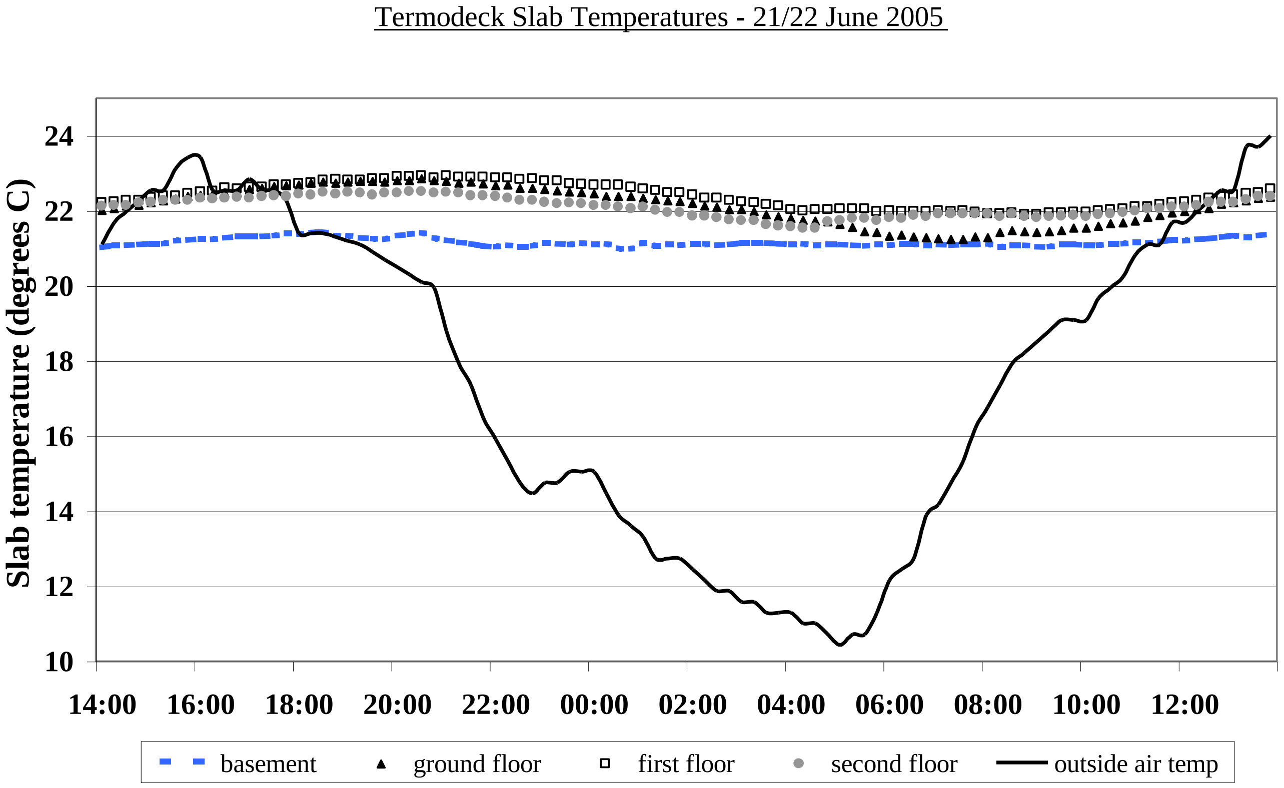


Fig. 9 Typical dynamic response of the slab temperatures in the ZICER building in summer.

All the “Termodeck” buildings are well sealed and rely for their performance on good air-tightness. There is provision for individuals to open the windows, although this facility is seldom used. However, it is important that such provision is available as acceptability of the working environment will become important as buildings of low energy standards are built. A survey of user satisfaction in the Elizabeth Fry Building demonstrated that in all the measured categories the perception of the building was above average as shown in Table 1.

Table 1. Perception of users of Elizabeth Fry Building

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

The low energy demands of the "Termodeck" buildings and the residences such as Constable Terrace have been achieved through careful consideration of ventilation heat recovery. As standards of insulation increase, ventilation becomes an increasingly important part of the total energy requirement. Research carried by Tovey and Nunn (2004) as part of a feasibility study to convert an office building constructed in the 1930s into luxury flats demonstrated that energy requirements for traditional natural ventilation of such buildings could be as high as 75% of the total energy requirement (Table 2). Tackling the issue of ventilation heat requirement is now becoming more important than simple measures to improve the thermal resistance of the fabric of the building.

Table 2. Importance of ventilation in designing low energy buildings. The data refer to the conversion of an existing office block into luxury flats (from Tovey and Nunn, 2004). The fabric heat loss rate conforms to the current UK Building Regulations and also the proposed values. Without heat recovery, ventilation energy required for space heating becomes a significant proportion of the total energy requirement.

	current regulations			proposed regulations
	$W\ m^{-2}\ K^{-1}$	$W\ m^{-2}\ K^{-1}$	$W\ m^{-2}\ K^{-1}$	$W\ m^{-2}\ K^{-1}$
fabric heat loss rate	129	129	129	109
% heat recovery	0	50	85	0
ventilation heat loss rate	354	177	53	354
total heat loss rate	483	306	182	463
% of heat loss from ventilation	73%	58%	29%	77%

Low Energy Strategies for supplying Heat and Electricity to Campus Buildings

Of the three buildings discussed above, only one (ZICER) is supplied directly from the centralised heating main. The other two buildings are more remote and are heated by self contained systems (a standard domestic boiler in the case of Elizabeth Fry). The boiler house originally housed three 8 MW boilers running on residual fuel oil and installed in the early 1960s. While efficient under full load these boilers were very inefficient under low load and a more modern 4MW boiler was installed 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. This had attractive financial implications as relatively cheap interruptible gas tariffs could be used. By the late 1990s further changes took place such that one 8 MW boiler was removed and three 1MWe combined heat and power (CHP) units were installed. These have 16 cylinder gas engines as prime movers providing 1 MWe of electrical output per machine and up to 4.2 MW in total of heat. The primary supply of heat thus comes from this source while the boilers are used as top up as needed during the winter. The new configuration of the boiler house showing the three CHP and one of the 8 MW boilers may be seen in Fig. 10. After installation of the CHP units a saving of around £400 000 per annum in energy bills was achieved out of a total of £1 000 000. Table 3 shows the proportion of electricity generated by the CHP Units.

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. There are two reasons for this. The first arises from the increased total demand of electricity as the University has grown, the second arises from the New Electricity Trading Arrangements (NETA) which came into force on 27th March 2001. These arrangements were replaced by the British Electricity Transmission and Trading Arrangements (BETTA) which came into force on April 1st 2005. The consequence of both of these changes in electricity supply has had adverse effects on the financial viability of export prices and at the same time the raw fuel prices for gas have risen.

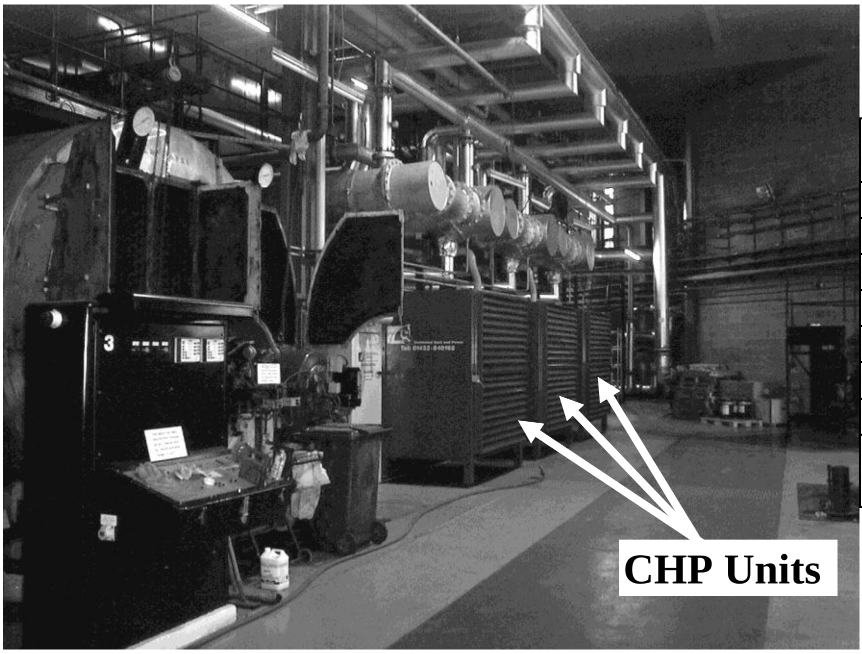


Fig. 10. The CHP units and one of the boilers in the main boiler house.

Table 3. Electricity generated on campus, total demand and percentage supplied by CHP

	CHP generated	Total Demand	Percent supplied
	MWh	MWh	
1999	16753	20432	82.0%
2000	15301	21410	71.5%
2001	18440	24756	74.5%
2002	15644	25611	61.1%
2003	15655	26277	59.6%
2004	17567	26961	65.2%
2005	01/01/2005 to 31/07/2005		
	11198	16422	68.2%

Notes:

i). values for 2000 were affected by a major overhaul of units

ii). after 2001 financial viability for export was affected by NETA.

Electricity generated in schemes such as these are particularly beneficial in promoting low energy communities as the electricity is used locally and avoids the normal losses of electricity associated with transmission. In the UK, despite the relatively short distances compared to many countries, these losses amount to 8.5%

To judge the environmental benefit of CHP, a comparison may be made between the energy consumption both before and after the installation. In 1997/98, the last full year of operation before installation, the consumption figures and the carbon dioxide emissions may be seen in Table 4. The emission factor of 0.46 kg/kWh electricity represent the figure prevailing at the time and allows for the transmission losses.

Table 4. Energy use and annual CO_2 emission at UEA Campus before installation of CHP.

1997/98		electricity	gas	oil	total
	MWh	19895	35148	33	
emission factor	kWh/kg	0.46	0.186	0.277	
carbon dioxide	tonnes	9152	6538	9	15699

Table 5 shows the comparable data for the first full year after completion. Despite an increase in electricity demand, the overall carbon dioxide emissions fell by 33.6% from 15699 tonnes to 10422 tonnes.

Table 5. Comparable data for first complete year after installation of CHP

		Electricity				Heat			
1999/ 2000		total site	CHP generation	export	import	boilers	CHP	oil	total
	MWh	20437	15630	977	5783	14510	28263	923	
emission factor	kWh/kg			-0.46	0.46	0.186	0.186	0.277	
carbon dioxide	tonnes			-449	2660	2699	5257	256	10422

Fig. 11 shows the utilisation of the CHP units over the period from installation in mid February 1999 to 31st July 2005. The solid line shows the average load factor for each month while the dashed lines show the maximum and minimum load factors in each month. Data for three months corresponding to major overhauls have been excluded. Nevertheless it can be seen that though the average load factor is 67%, it falls to below 40% during the summer months. The level of import of electricity is almost independent of the total demand and this highlights the critical issue with CHP that there must always be a heat sink for generation to take place. Since the space-heating load is low in summer this limits the total amount of electricity which can be generated during these months as clearly demonstrated by Fig. 11.

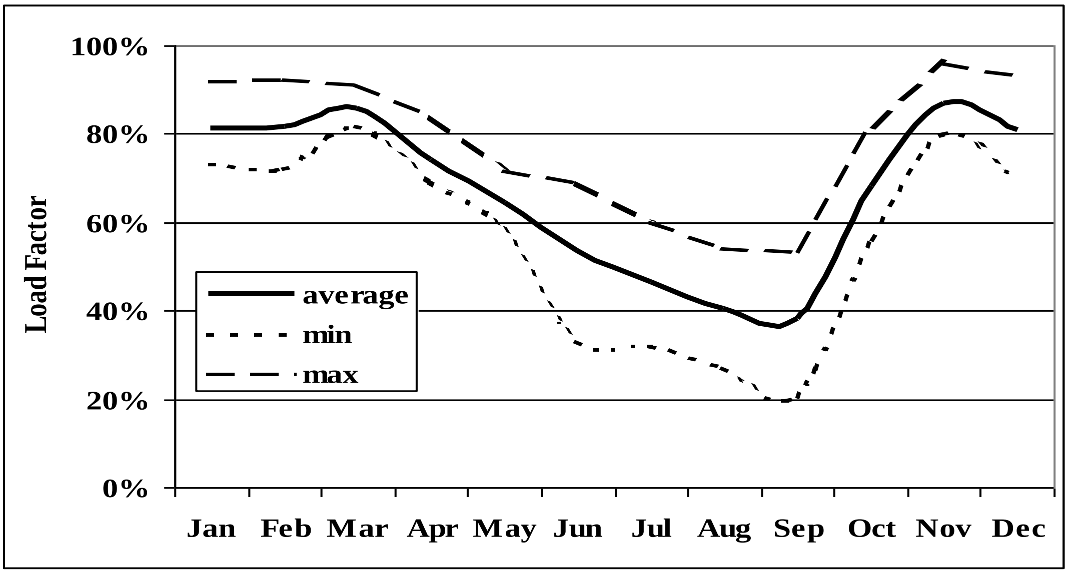


Fig. 11. Variation in load factor for electricity generation by the CHP units. The graph demonstrates the under utilisation of units in summer because there is limited demand for heat.

New Low Energy Strategies at the University of East Anglia

In the last 10 years the demand for chilling at the University has increased. This is mostly associated with the cooling requirements for scientific equipment rather than air-conditioning. The use of the latter is restricted to a few specialised locations only. Part of the rapid rise in electricity demand in recent years has been associated with this cooling. Adsorption chilling can utilise waste heat to provide this cooling, and the combination with CHP usually know as tri-generation provides a truly “win-win” approach to low energy design and in future all building complexes such as universities, hospitals etc., should consider such tri-generation at an early stage in design. Such a unit, which will provide 1MW of cooling, is being installed at the University of East Anglia and is due for commissioning in the last week of September 2005.

During the summer months waste heat from the generation of electricity from the CHP units will be used to provide the chilling, and thus the trough in utilisation of the CHP units as shown in Fig. 11 will be largely removed. In this way the financial viability of the CHP units will be improved. At the same time, the demand for electricity will fall as much of the chilling will now be provided from the adsorption chillers. The additional projected savings in carbon emissions will be between 350 and 400 tonnes, however the exact amount will depend on the length of time the chiller is run. While initially it would be expected that the chillers 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 short fall in heat with the existing boilers. Over the first year the situation will be carefully monitored to devise the optimum strategy. However, despite the fact that it reduces carbon emissions, the UK implementation of the European Union Emissions Trading System EU-ETS is such that the University will be penalised for such measures. This is because an increase in utility of equipment does not qualify for additional emission credits and must therefore be purchased. Thus low energy strategies are sometimes not helped by inappropriate legislation.

In addition to the adsorption chilling, the University is planning to start a feasibility study into the installation of a biomass CHP unit in late 2005. This unit will be larger than the existing units at 1.4 MW electrical and 2 MW heat. Biomass may be considered to be carbon neutral if it comes from sustainable growth. However, the growing, harvesting and transportation of such biomass will entail energy use, much of which will be as fossil fuel, and so there will still be some emissions of green house gases even though on a lower scale than normal fossil fuels. Initial estimates of such a scheme suggest that a further saving in carbon dioxide emissions of 3500 – 5000 tonnes per annum is possible.

Renewable Energy at the University of East Anglia

The ZICER building discussed above is not only a low energy building but it has two photovoltaic arrays which together can produce a peak output of 34 kW. Most of the south facing façade of the top floor has 3 separate arrays of poly-crystalline PV cells while the roof, which is tilted at 15^o, is covered with 10 arrays of mono-crystalline PV cells. Figs. 12 and 13 show the typical amount of electricity generated by the building. On a summer weekend when there is more than sufficient to satisfy the requirements of the building an export of surplus electricity to the grid occurs.

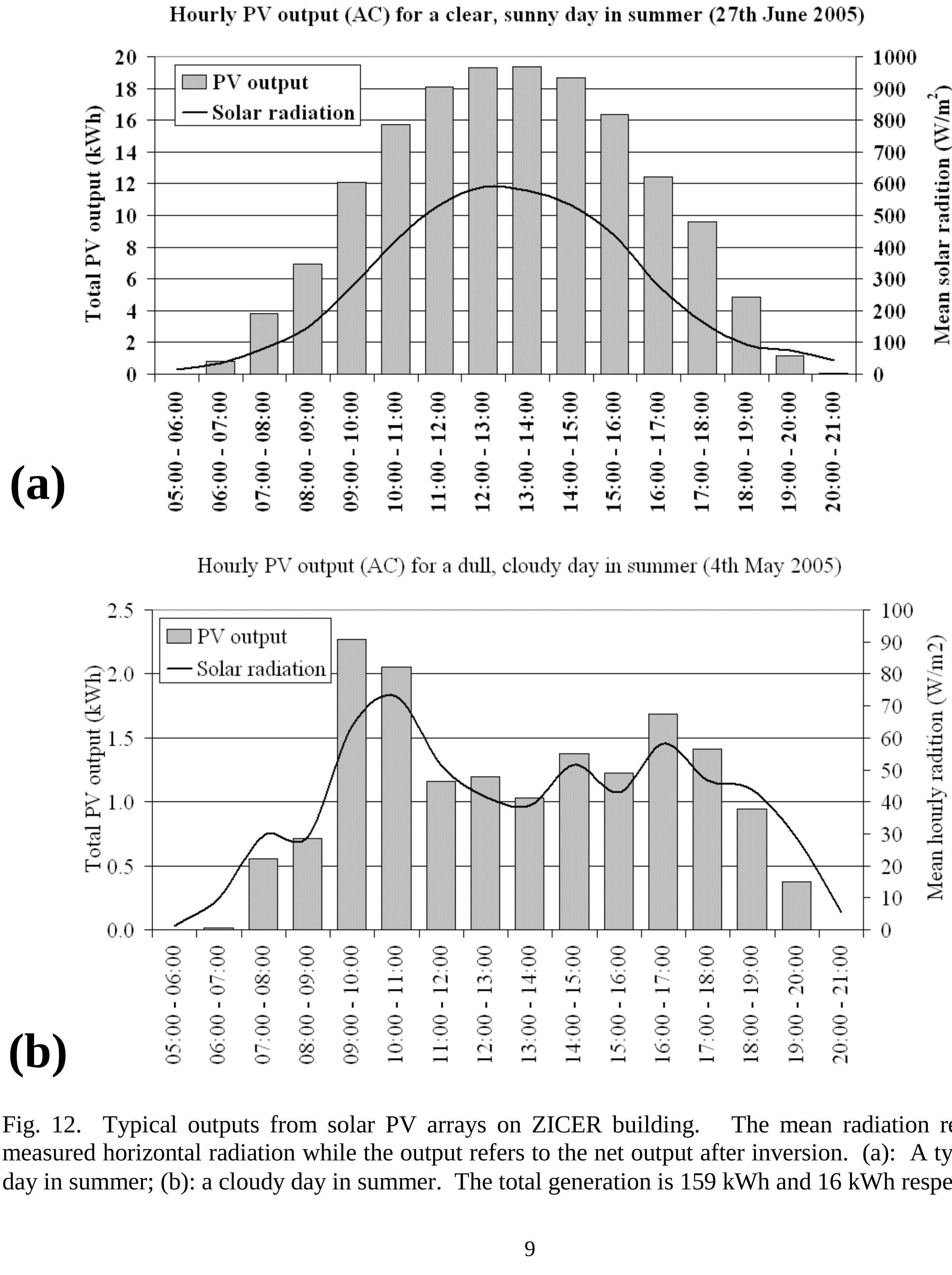


Fig. 12. Typical outputs from solar PV arrays on ZICER building. The mean radiation refers to the measured horizontal radiation while the output refers to the net output after inversion. (a): A typical sunny day in summer; (b): a cloudy day in summer. The total generation is 159 kWh and 16 kWh respectively.

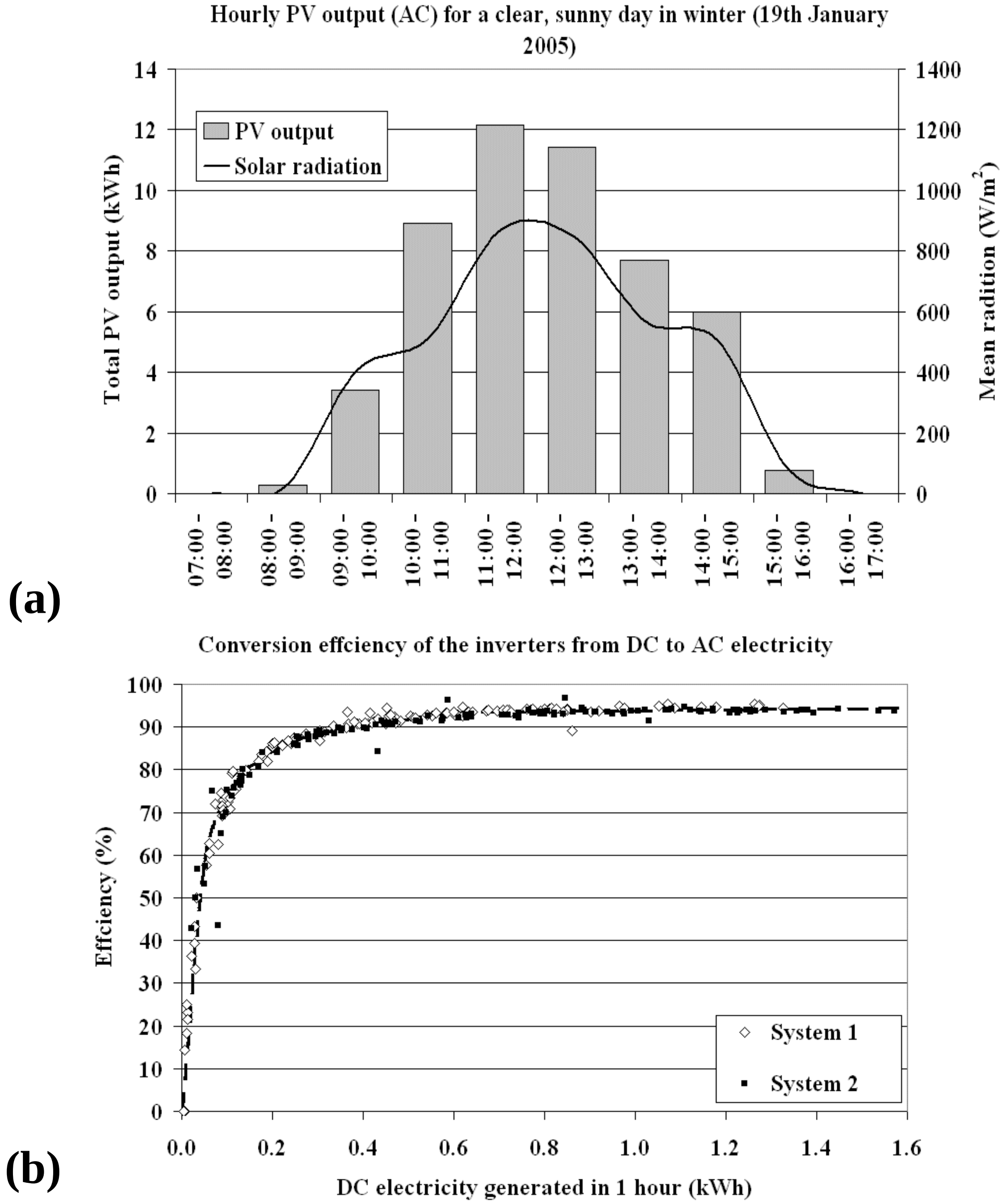


Fig.13. (a) Typical output on a clear sunny day in January; (b) Inverter efficiency for conversion of DC generated electricity to AC is at best 92% efficient.

The inverters which convert the output from the DC photovoltaic cells on the building into traditional AC electricity are at best 92% efficient (Fig. 13b). 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 building is for computing requirements: each computer hich has its own power pack to convert AC electricity back into DC. Aebischer and Huser (2003) suggest that these power packs convert no more than 50 – 60% of the AC electricity available into useful DC 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 DC source) is actually useful. Further more, the energy lost in the power packs will result in waste heat and in climates where air-conditioning is required will result in increased energy requirements.

It would seem sensible in low energy buildings to provide electricity services that are compatible with the main system of use. Thus provision of a DC network at suitable voltage should be provided in all low energy buildings where renewable energy systems are an integral part of design.

The University of East Anglia currently is exploring the possibility of erecting three 1.5 MW turbines to reduce carbon emissions from the complex further. Some critical issues have arisen in public acceptability of such a scheme and the CRed (Community Carbon Reduction Programme) team, which is promoting low carbon strategies, has successfully swayed public opinion from a general antagonist feeling towards the turbines to a significantly positive one. It is hoped that progress can be made on this aspect in the next 12 months.

Optimising Low Energy Communities through awareness raising.

Low energy strategies require the multi-pronged approached outlined in the introduction. The University of East Anglia 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 time spent in improving the management of the thermal environment has been particularly important in reducing energy demand in already low energy buildings. In addition, the CRed team are exploring ways to capitalize on this and further reduce energy demand 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 mid April 2005 was targeted and data for one building was carefully recorded both before and after the specified day. The results are shown in Fig. 14.

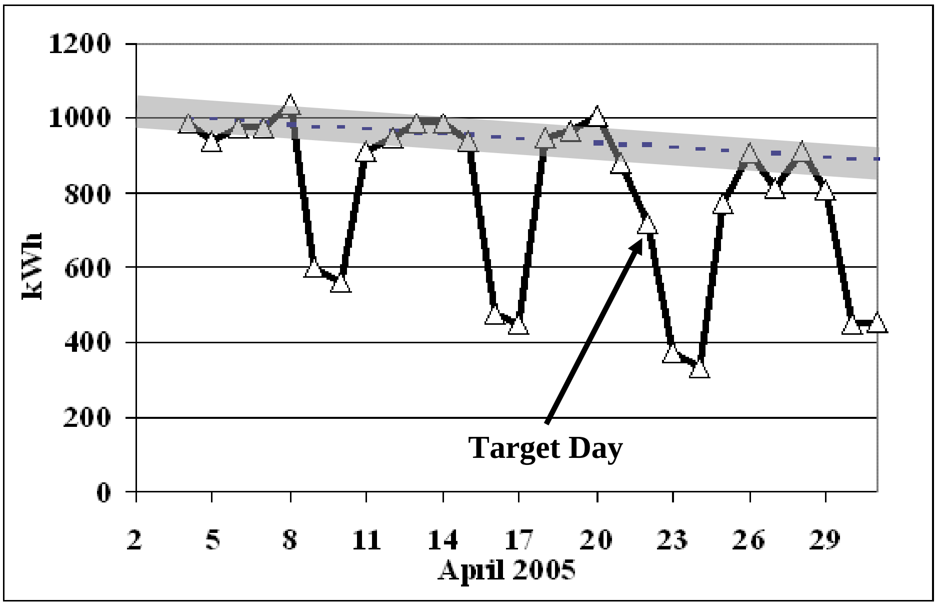


Fig. 14. Daily electricity demand in the Registry at UEA.

The reduced weekend demand is clearly visible while the dotted line and shaded band represent the change in demand as summer approached when there is a reduced less lighting load. The width of the band represents one standard deviation from the trend line. The target day (Friday 22nd) shows a substantial fall in demand (nearly 4 standard deviations from the trend line) demonstrating that with concerted effort low energy strategies can be significantly enhanced by promoting awareness of building users. There is evidence that the awareness continued, albeit at a lower level on the following Monday, but thereafter old habits appeared to be returning. The University is now examining ways in which such improvements can be made more long lasting.

Conclusions

The University of East Anglia has been proactive in promoting low energy strategies and several important issues have arisen from the experience gained. The following are key issues in low energy strategies:

1. Effective design of low energy buildings will cost little more than conventional buildings, typically in the range of 5- 10%, but this is recouped through long term energy savings.

2. 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%.

3. Effective record keeping, analysis, and management is essential if the full potential of low energy building is to be realised.

4. Combined Heat and Power can be effective in reducing carbon emissions, but the requirement for heat disposal when electricity is generated creates problems in the summer when the heat demand is low.

5. Inclusion of adsorption chilling with a combined heat and power scheme (tri-generation) should always be considered where there are significant summer time chilling requirements either for air-conditioning or for cooling of scientific equipment.

6. Incorporation of renewable energy systems into buildings is attractive. However the trend is to provide AC electricity. Inversion of DC electricity is only 91% efficient and losses in the power packs of many appliances result in poor utility of the generated electricity. A holistic approach to building design including the appliances to be used in the building is required.

7. Promoting effective awareness can reduce energy consumption in low energy buildings dramatically, but ways to prevent “back-sliding” must be researched.

8. Some Regional, National, and International legislation in the UK and some other countries is not conducive to promoting the most energy efficient strategies in communities. Pressure must be brought to bear make sustainability and low energy strategies the key aspect in new legislation.

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