

# EFFECTIVE USE OF BUILDING INTEGRATED PHOTOVOLTAIC WASTE HEAT: THREE PROJECTS

## **David LLOYD JONES AA Dip RIBA FRSA**

Studio E Architects Ltd, Palace Wharf, Rainville Road, London W6 9HN  
Fax: +44 20 7381 4995, e-mail: david@studioe.co.uk

## **Bill WATTS MSc**

Max Fordham Associates, 42/43 Gloucester Crescent, London NW1 7PE  
Fax: +44 20 7482 0329, e-mail: watts.group@mfp.co.uk

**Abstract** - The emphasis in Building Integrated Photovoltaics (BIPV) projects has been to maximise electrical output. Around 75% of the energy generated in photo-electric conversion is produced as heat. Far less work has been carried out into harnessing this output for use in the building. Studio E Architects has been involved in three recent BIPV projects which investigate how the heat output can be used to reduce overall energy use.

## 1. INTRODUCTION

Three recent BIPV projects in the UK have sought to use the waste heat produced by photovoltaic power generation to reduce the building's energy consumption. The three projects are:

- i. The Solar Office at Doxford Internal Business Park, near Sunderland, where the heat is used to drive the natural ventilation of the office space;
- ii. The Solar Boarding House at Haileybury College, Hertfordshire, where the heat is taken from the back of the modules and transferred using a fluid medium via structural piles to a ground heat storage and then retrieved when needed in winter to heat the building; and
- iii. The Renewable Energy Systems Egg Farm Conversion where heat is used to dry willow coppicing for use as biomass energy supply.

### 1.1 SOLAR OFFICE DOXFORD (Project 1)

The Solar Office is an office building designed for Akeler PLC on a business park, Doxford International, located on the edge of Sunderland (Pearson, 1998). The building was completed in shell and core form in 1998 and will shortly be fitted out for its first tenant. The brief for the building and its procurement follow the robust fast-track pattern that is now commonplace in speculative office development

The building is designed to minimise the use of energy, while its external fabric, through the incorporation of a solar-electric array, has been developed to replace such energy that is used.

The energy consumption target for the building occupied by a tenant with conventional power requirements is 85 kWh/m<sup>2</sup>/year compared with a conventional air-conditioned office of over 400 kWh/m<sup>2</sup>/year. Electricity generation is provided by

a photovoltaic solar array integrated into the building envelope. The 73 kW<sub>p</sub> array (fig.1) is expected to provide 55,100 kWhrs of electrical power per annum which represents between one third and one quarter of the electricity expected to be used by the occupants during the period of a year. Surplus electricity is exported to the National Grid.

The low energy include:

- Limited depth floors (maximum 15m) with generous ceiling heights to encourage cross ventilation and good day lighting;
- Provision for secure night ventilation and the exploitation of building structure to provide thermal mass in order to provide night-time cooling in summer;
- Windows which facilitate good controllable ventilation, glare free daylight and solar control;
- A well insulated, impermeable building envelope to minimise heat loss in

**Fig. 1:** Doxford 73kW<sub>p</sub> façade, UK

- winter;
- Responsive controls; and
- Knowledgeable and sensitive building management.

The south facing, low mass, low insulation largely opaque façade posed a particular challenge.



**Fig. 2:** Internal translucent BIPV effect

The heat from the façade (the conversion of sunlight into electricity in itself generates heat) can be used in winter to assist in heating the building and, in summer to pull air through the office space. Lack of thermal mass is countered to some extent by specifying a concrete roof slab in place of the normal trussed and pitched roofs used elsewhere on the Park. The

insulating properties of the solar facade are good in the context of glazing (U value: 1.2 W/m<sup>2</sup>/oC for the PV modules), but relatively poor compared to solid wall construction (U value: 0.4.W/m<sup>2</sup>/oC). Heat loss, however, was minimised by ensuring exceptionally low leakage of air through the building envelope (3.7 m<sup>3</sup>/hr/m<sup>2</sup> at 50Pa).

Bands of clear glazing were introduced into the façade to allow views out and ensure good internal light levels (figure 2). Reconciling between maximising power output (from the opaque solar cells) and that of daylight (a requirement for a daylight factor of at least 2 over 80% of the office floors) was arrived at by modelling glazing permutations using a 1:40 scale model under an artificial sky. The risk of glare is minimised by the introduction of semi-transparent modules immediately above the clear



modules immediately above the clear

glazed panels and by provision for the introduction of locally controlled roller blinds capable of covering both the clear and semi-transparent modules.

Monitoring is taking place over 2 years. It covers the performance of the photovoltaic installation, energy consumption and internal comfort.

### **1.2 Solar Boarding House (Project 2)**

The Solar Boarding House, with funding assistance from the EU and the UK government, starts on site in April 2000. It is described in detail below (section 2).

### **1.3 RES Egg Farm (Project 3)**

This project involves converting and extending the arts and crafts Ovaltine egg farm in Hertfordshire to provide new offices for Renewable Energy Systems, a company within the Sir Robert McAlpine Group, and a visitors centre. It is intended that all energy demand will be from renewable energy sources: one third wind turbine, one third photovoltaics and one third biomass. In this instance photovoltaic heat will be used to assist drying willow coppicing prior to be used for CPH combustion.

## **2. SOLAR BOARDING HOUSE, HAILEYBURY COLLEGE (PROJECT 2)**

### **2.1 Introduction**

Haileybury College is an independent coeducational school in the green belt of north of London. The school commissioned Studio E Architects to design and get planning permission for two girls boarding houses on a relatively tight site around a pond within the Grade Listed College grounds. Each house comprised a dormitory and study bedroom accommodation for 66 girls, a staff flat and a house for the house mistress.

Having gained permission on this sensitive site, the school built the first boarding house which was occupied in Autumn 1999. Based on the success of the first house, the school commissioned the second house for completion in Autumn 2001. As a parallel exercise the design team was funded by the UK Department of Trade and Industry (through an ETSU grant) to investigate the issues surrounding installing building integrated PV's (BIPV) on the second boarding house. The attraction of this was that, if built, the two buildings with identical briefs and occupancy could be compared in capital construction and energy running costs.

### **2.2 Design Considerations**

The school does not intend to occupy the building outside school term time. This, in conjunction with the fact that the building will be largely empty during the day as the pupils will be in classes, meant that the electricity from the PV array during the day and in the summer does not match the building load. However, generated PV electricity can be readily used elsewhere on the large school campus when available.

The buildings on the campus are fed by a number of separately metered supplies from several South East Electricity (SEE) Board owned transformers. The new

development has a new small (72 kVA) transformer, and metered supply intended to serve both boarding houses. Therefore, the simplest way of transferring electricity from the BIPV boarding house to the rest of the campus is via the SEE Board low voltage and high voltage network.

The alternative of running a separate LV cable around the site would be very expensive. Negotiations with SEE Board were very encouraging. In their role as network providers and electricity suppliers they offered to credit any electricity exported by the PV's against the electricity used by other buildings on the campus at any one time. This effectively meant that the value of the PV electricity to the school was always the on-peak rate it was paying to the utility.

The basis for this offer was:

- i. The electricity produced by the PV's would be small compared to consumption of the campus, so it would not be exported outside the campus.
- ii. To credit the electricity produced against that used elsewhere, the PV building had to have an import/export meter. Other meters on the site would need to be the type that communicated back to a central sorting system that monitors half-hourly electricity consumption in real time from each consumer.

The central sorting system would aggregate the net electricity consumption of all the meters on the site. SEE Board said that there would be a charge for setting this arrangement up and that they would expect to have a contract to supply the college with electricity over the next 3 years.

Without the constraint of matching the PV output to the needs of the building, the study looked at various massing arrangements to see what would provide the greatest area of PV. This resulted in a range of arrays of between 450m<sup>2</sup> and 750m<sup>2</sup>. The planning conditions of the conventional scheme insisted, amongst other things, that the roof line was kept below an existing adjacent building and that the large trees were kept. It was decided to take one scheme forward to the planners that was one floor taller than the conventional scheme and cut down some tall trees. This change of massing made the building cheaper to construct as the footprint and retaining ground structures were reduced, and so released money for the PV installation. The more compact form also had a lower fabric heat loss. On the basis of being "green" in energy terms the building was granted planning consent. However, the planners reserved judgement on the felling of the tall trees until the deleterious effect of the overshadowing could be demonstrated.

### **2.3 Heat Recovery**

The use of the heat from the back of the PV's was considered. It was clear that most of the energy and heat was collected over the summer when there was little load - especially given that the school was empty through the holidays. It was decided to look at seasonally storing the thermal energy from the PV's in the ground. To do this heat needed to be collected by a fluid medium so it could be transported into the ground.

Shell Solar, in connection with the Dutch Research Organisation ECN were developing a PV and thermal solar hybrid panel. This comprises a mono-crystalline PV panel bonded to a liquid thermal collector, with a glazed cover to reduce heat loss. Conversations with Shell Solar suggested that the loss of electrical output, due to the glazing removing some of the light, could be regained if the cooling medium was

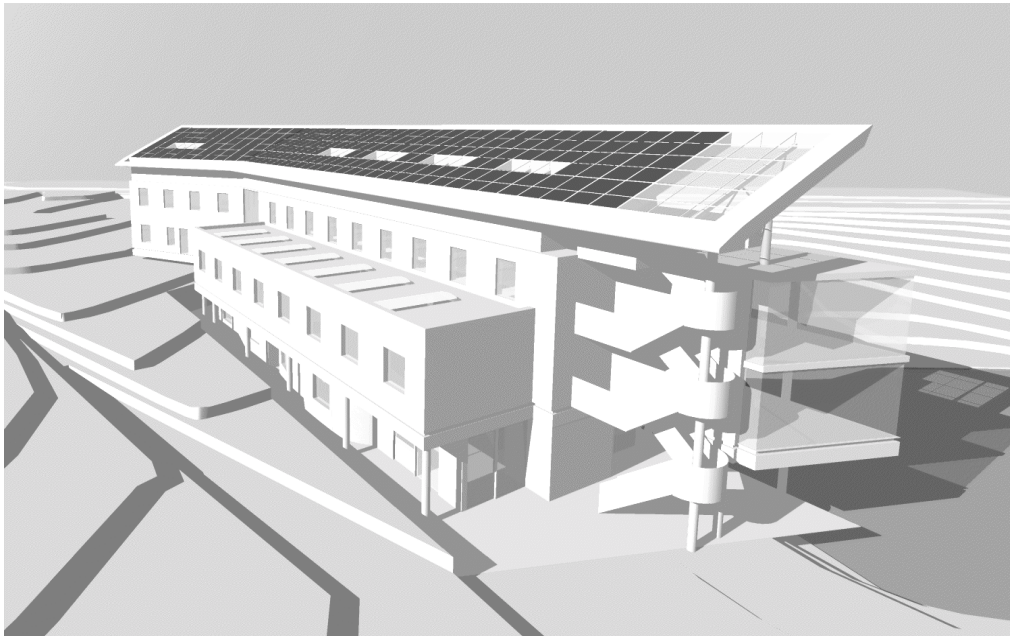
kept to 35°C to cool the panel. Losses of 10% over a 'standard' air cooled BIPV could be expected with water at 55°C.

Plastic pipes will be cast into piles in the ground to transfer the heat into the clay. The ground is dense saturated clay. The impermeability meant that heat could be stored without being carried away by water flow. However there is a heat loss due to conduction that is minimised by decreasing the surface area to volume ratio. The current design employs plan area of 15m x 15m and 30m deep below the building. The building itself insulates the top of the store. The volume of about 15,000m<sup>3</sup> is intended to store 82,000 kWh with a 15°C temperature swing in the clay. Over the year we estimate from guidelines from Sweden that 50% of the heat will be lost through conduction at the temperatures we are intending to use.

The structural piles required for the scheme were 15m deep with spacings of 4-5m between pile clusters. Swedish work on the conductivity and diffusion of the clay suggested that we needed to tighten the spacings of the piles to 2m centres. Consequently additional non-structural piles were added to the design, making a total of 80 piped piles. All the piles were 30m long in the heat store area. Each pipe in the piles would be brought back to an above ground manifold so that any one pile could be isolated. Warming the ground will make it expand thermally. If the water is not constrained, the clay may dry out and shrink affecting the thermal conductivity and structural adhesion between the pile and the ground. Finally, the pile itself will expand thermally which will either be constrained from moving by the ground or move the building up/push pile down. These issues are yet to be fully resolved. It may be cost effective not use the structural piles and employ a separate smaller drilling rig to make the ground heat exchanger.

It is clear that the lower the temperature the heat is collected and stored at, the better. Lower solar panel temperatures increases the PV electrical output. It also increases the amount of solar heat collected by reducing the heat lost from the panel. Similarly, the heat loss from the thermal ground store is a function of how hot it is. It was decided to use the heat from the ground store and panels to warm the incoming outside air, rather than heat the spaces directly. With external air temperatures during the heat season being lower than the internal space, heat at or below room temperature can provide useful heat into the air. The ventilation scheme comprises an air handling unit with two heater batteries. The first can be connected directly to the thermal panels on the roof. With the external air at 0°C, any solar gain will be collected in the thermal panels increasing the fluid temperature to 8°C on a sunny day. This fluid will heat the incoming air from 0 to 5°C. The second heater battery connects to the ground store which will heat the air further. Again with this method it is possible to extract useful heat from the ground at below room temperature.

The temperatures of the systems are dynamic and vary through the year. The thermal ground store will be divided into two zones: a core and a perimeter. The two zones will be used to take full advantage of temperature gradients in the various systems. The central zone will be 'hot' and the outer one 'warm'. With maximum summer insolation, hot water at 52°C from the panels is first passed through the inner core giving up half its heat before going through the outer piles at 42°C and finally returning to panels at 32°C. The inner core warms to 35°C and the outer to 25°C. Through the year heat will be lost from the store but this is minimised by reducing the size of the high temperature part. At the beginning of the heat season, the temperature in the outer layer may be enough to heat the supply air. During the coldest part of the year, both zones will be used. The high temperature core is needed to provide more heating. Heat can be extracted from the outer zone to pre-heat the colder incoming air. In the spring the temperature of the outer zone is too low to heat the warmer external air and the heat remaining in the inner core is used. The pipework to the piles is arranged so the heat flow can be managed in this way.



### 3. CONCLUSIONS

Initial studies suggest that the 250m<sup>2</sup> of panels will collect about 110,000 kWh of heat. Of this, 30kWh will be collected during the heating season and used directly. 80 kWh will be collected through the summer and stored. Of this, 80 kWh, 40 kWh is estimated will be lost, leaving 40 kWh of available heat. The project will provide useful data to validate these predictions.

**Fig. 3:** View of the Solar Boarding House

### REFERENCES

- Vries, Douwe W. De (1998) Design of a Photovoltaic/Thermal Combi-Panel Eindhoven University Press.
- Pearson A. (1998) Doxford Solar Office Building Analysis Building Services Journal, Magazine of the CIBSE.
- Lloyd Jones D. (1998) Architecture and the Environment: Bioclimatic Design, Calmann and King London.