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World Renewable Energy Congress VI (WREC2000)

Editor: A.A.M. Sayigh

LOW ENERGY ARCHITECTURE : A VISION FOR THE FUTURE

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FEILDEN CLEGG : THE EARLY YEARS

When I first started to investigate the impact of low energy design on architecture thirty years ago, global concerns were focused on fossil fuel depletion rather than climate change as the primary motivator behind both energy conservation and the use of renewables. As an architectural student, what excited me was the concept that new architectural form might emerge from environmental considerations, an architecture that was as responsive to sun and wind just as it was responsive to the dictates of site and brief.

In the late 60's at Cambridge University I was taught by Alex Pike who put together a team of researchers working on the concept of an autarkic house, free from connections to centralised service systems, reliant on wind power and solar collection. A few years later in the United States I worked with Everett Barber, one of the early pioneers in solar collector manufacture. At the time, it seemed as though the answer was to integrate all this new technology with our buildings, though we soon decided that a more cost effective route was to design the buildings themselves to act as solar collectors as well as increasing insulation so that energy requirements were reduced.

Back in England, having set up in practice during a recession, our main work for the first ten years was in the domestic sector, and we were able to explore these basic ideas in passive solar collection. We looked at every south facing surface of the building and turned it into a collector.

An early housing scheme in Bath in 1985 was novel at that time for its use of large areas of triple glazed windows, and where the windows were not required functionally such as in the upper floor bedrooms, we continued the glazing system over the masonry wall to which was adhered a selectively surfaced copper foil. This very simple version of a trombe wall, unvented except for a simple automatically actuated high level solar vent to reduce unwanted heat gain, worked in a fairly primitive fashion but it was never fully monitored. Now, our experience and thermal modelling tells us that reducing the insulation value of a wall such as this could never become cost effective.

Undeterred, we looked at ways of turning south facing roofs into collectors and, in the conversion of an agricultural barn, we produced a glazed roof space collector which sheeted the air in the attic which was then transferred to the insulated mass of the house below via a couple of small fans. This was extensively monitored and taught us that, although the solar energy was there for the

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collection, it wasn't necessarily needed except in the depths of winter. Since the house itself was so well insulated internal gains from people and lights could reduce the heating season to only a few months, - unfortunately those few months when in the UK at least there was a minimal amount of solar energy available.

We therefore looked to more northerly climates for inspiration and built some superinsulated houses at Milton Keynes in the late 80's. The developer insisted that they look like ordinary houses, so we imported an extremely high quality timber frame system from Finland which gave us U values approximately three times the effectiveness of the standard Building Regulations, and an extremely air tight house and then clad the frames in brick and tile. By reducing the overall heating requirement down to below 20kwh/m^2/yr, and introducing a whole house ventilation system, we found we could effectively dispense with the heating system in favour of a 1.5kw heater battery in the duct of the ventilation system. Extensive monitoring showed that the overall space heating load could be reduced to 1500kwh/yr for a fairly standard three bedroom house, yielding a total gas bill of around £6/yr. At the same time, the ventilation system ensured fresh air input and a simple cross flow heat exchanger meant that 65% of the energy normally lost through infiltration was transferred into the incoming air stream.

The space heating problem was therefore soluble but the architecture was, to say the least, dull. Exploiting both sunlight and daylight offered far more visual stimulation. We therefore went back to the very simple idea of direct passive solar gain and produced a design which maximised the south facing glazing in a 100m^2 house. The courtyard houses built at Energy World in Milton Keynes in 1988 had 54m^2 of quadruple glazing with a U value of 1.2, and a total solar transmission of 55%, which pushed to the limits the concept of house as collector. With these perameters, the design had obviously to consider severe potential overheating problems and a variety of internal diffusers, external shading systems and interpane Venetian blinds gave us the control we needed.

THE COMMERCIAL SECTOR : NATURAL COOLING AND DAYLIGHTING

The houses sold before they were completed on the basis of a show house that demonstrated the delights of glass in architecture and blurred the distinction between private courtyard and living room.

Just as we were running out of ideas for low energy design in the domestic sector, we were asked to look at the conversion of a building in North London to become offices for approximately 120 people as the headquarters for Greenpeace UK. This presented a wholly different set of problems. Typical office energy usage is likely to be more than 50% electricity to cope with the demands of artificial lighting and summertime ventilation. In air conditioned offices, this is obviously much higher. At Greenpeace, we were presented with a four square building four storeys high and 24m deep. We developed a strategy of using light shelves on the south facade to bounce light deep into the plan of the building, in combination with a lightwell down the centre of the space that contained the suspended staircase. The latter also aided natural ventilation from the lower floors. The central spaces on each floor were serviced using a simple heat exchange ventilation system, and the entire building was served by a combined heat and power plant. The new interior architecture, and the suspended external light shelves gave the building an aesthetic which was derived from the environmental considerations of heat, light and air within the building.

THE BRE NEW ENVIRONMENTAL OFFICE

Three years later we were given the opportunity of applying the same low energy philosophy to a new building, in this case the New Environmental Office for the Building Research Establishment at Garston. The challenge of the brief here was to produce a landmark building but one that was also replicable, and to meet a low energy target which was around 30% lower than current "best practice" in office buildings. Again, the strategies are relatively simple. High insulation ensures minimal heat loss and benefit from inevitable internal gains from people and equipment. The real challenge is to avoid air conditioning, mechanical ventilation and to optimise natural lighting by careful use of glare-free daylight. The orientation of the site gave us the opportunities for using large areas of glazing to the north but requiring very careful attention to the south facing elevation.

The summertime peak temperatures are controlled by ventilating the building during the night and using the concrete floor structure to act as a coolth store. Cross ventilation is wind driven with high level BMS controlled vents at each side of the building. Additional air movement is provided by thermosiphoning within the external ducts on the south side of the building. These have a glass block facade and so are also able to admit diffuse light into the floor plate of the building through internal windows which open into the floor space. The sinusoidal floor slab contains ducts which provide for cross ventilation even when cellular offices impede the air flow from north to south, and also increase the surface area of concrete that is exposed to the cool night air. The rediscovery of the thermal mass in buildings in the last decade has been one of the most significant developments in low energy commercial buildings. The consequent demise of the suspended ceiling which insulated the concrete floor structure from the office space below has provided a welcome change to the interior architecture of the office environment.

The south facing elevation is protected from direct sunlight by both the "blinker" effect of the thermosiphoning stacks, and by adjustable horizontal white glass louvres which can close themselves against the midday sun or act as a series of light shelves to bounce light onto the ceiling of the internal space. The external layer of the facade can therefore change to suit the climatic conditions. The louvres are photo cell controlled but with manual override for the occupants inside. The building has thus developed an intelligent skin, enabling it to filter, absorb or reflect the energy striking it.

Further, a long facade is an area of photovoltaic panels which provide direct conversion of incident sunlight to electricity for use in the building. The building's south facing roof was angled at a more appropriate angle for optimising solar collection, but the facade of the building was chosen to enable the collectors to be more highly visible. There are amorphous crystalline photovoltaics with a relatively low efficiency, but also lower cost. The 25m^2 array provides approximately 3kw peak for around 10% of the electrical usage of the building.

The building is being extensively monitored and full results will be published shortly which show that its overall energy consumption is 37kwh/m^2 for electrical usage and 40kwh/m^2 for heating. One of the more impressive series of measurements was taken during its first year with record high temperatures during the summer of 1998. During this week, five days, temperatures rose above 30°C but the internal temperature without any form of cooling at all other than passing night-time air through the building, was maintained at 5°C below external ambient temperature (figure 00).

The BRE building allowed us to test a number of different ideas and technologies. Later, when asked to produce a new entrance building for the Open University at Milton Keynes, we used a stripped down version of the same ideas. In this case, the building had an east/west orientation solar control mechanisms on the outside of the building which varied accordingly. The interior

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space consisted of a simple 3.6m high x 14m wide floor plate with exposed concrete soffits and beams, and aerofoil shaped columns that also acted as shading to lower level solar radiation.

Additional shading was provided by access walkways (used for maintaining and cleaning the windows) together with fixed vertical "blinkers" on the eastern elevation, and adjustable external roller blinds on the more problematical westerly elevation. The final layer of glare control is provided by internal blinds. Cross ventilation is ensured by both high and low level opening windows, the upper layers being operated by a BMS system and the lower ones having manual controls.

The most recent commercial development that we have completed is a new headquarters for a computer software company where the design was driven by the requirement for each workstation to be adjacent to a window with a view of the countryside and landscape gardens into which the buildings fitted. The same strategic ideas produced a different aesthetic. The exposed vaulted concrete floor structure adds thermal mass to lower level, whereas the upper level space benefits from additional height and high level cross ventilation. Daylight is very carefully controlled by a combination of external sliding shutters and internal blinds, the additional heat from high powered computer equipment required that we needed a cooling system which is fed by borehole water drawn from 30m underground at a relatively constant temperature of 10°C. This is supplied to fan coil units adjacent to each workstation. The water was also used to feed water features within the landscape before returning to the aquifer below.

EXPERIMENTS IN REMOTE THERMAL STORAGE

Thermal storage in the office buildings described above is contained within the floor structures of the buildings, but it does not have to be linked to the spaces it serves. I will conclude with two examples of remote thermal storage where we have built each capacity, - or more significantly coolth storage into underfloor spaces beneath buildings in order to make a night-time cooling strategy work. Both buildings also had a wider green agenda looking at the sustainability of materials used in their construction.

Bedales School in Hampshire has a tradition of oak framed buildings. Born out of the Arts & Crafts movement, the school believes that the pupils' learning activities should be based on an in depth involvement in Arts and Crafts, including the craft of building. The library at the schools is a 1926 Listed building, designed by Ernest Gimson and Edward Barnsley as an essay in traditional oak frame construction. Our challenge was to emulate this and construct a theatre space for the school providing space for teaching, rehearsal and performance. We built a building with a green oak frame and cladding using English douglas fir and larch. The children helped to build it and the building uses not only traditional framing techniques but also introduces more sophistication into the structural detailing by adding stainless steel bracing and tension supports. From an energy point of view, the challenge of constructing a theatre is dealing with the summertime conditions where the outside temperature on a matinee afternoon can be 30°C and the building filled with an audience of 300 actors on stage and a heavy load from artificial lighting can generate 20kw of heating load. In a timber frame building with relatively low thermal mass, we had to look elsewhere for coolth storage. We found space beneath the tiered seating where the timber building sits on a concrete base with a maze of blockwork walls supporting the timber floors. This provides us with thermal storage which can be cooled during summer nights by flushing air naturally through the building, drawing it in underneath the covered walkways at ground floor level and out through the vents at the top of the central tower. By opening the vents again during the performance, air is drawn through the cooler basement area and into the space below the seats, and unwanted heat from lights is ventilated through the top of the building. Again, a very simple natural ventilation strategy ensures protection against overheating.

We used the same system in a more complex form at The Earth Centre which is a visitor attraction based around the concept of education and entertainment focussed on environmental issues.

The brief was to design exhibition spaces, a cafeteria and a shop as well as wc's and an information point, all of which would provide an entrance to the Earth Centre site. The strategy was to integrate a low energy building with a highly visible solar generator which would be the first component in a strategy for the site to be self-sufficient in terms of power generation, - the remainder ultimately to be provided by a wind generator located on an adjacent hillside and bio-mass fuel generated using material grown on site.

The buildings are located at the edge of a limestone escarpment and a number of the major spaces, particularly those which do not require daylight such as the main exhibition hall, are buried into the existing hillside. The limestone of the escarpment quarried less than half a mile away forms the retaining wall to the new buried buildings. These buried structures, founded as they are on poor quality ground, required a very strong raft foundation. This led to the concept of a basement "labyrinth" two concrete slabs separated by a maze of 1.5meter high walls, which is used to store heat from internal gains in winter and benefit from night-time cooling in summer. A building with high internal heat gains is therefore able to operate without the use of air conditioning.

The bulk of the buildings are therefore buried into the earth. One simple rectilinear building, however, floats free from the hillside and helps to enclose a funnel shaped arena which forms the entrance to the site. The canopy stretches across this trapezoidal shaped space and shelters both the ticket booth and main entrance area. The canopy is a distorted timber space frame constructed using roundwood poles of indigenous softwood with galvanised steel connectors. The elaborate geometry created by the trapezoidal frame and the almost random supporting posts creates a dynamic contrast with the purity and simplicity of the adjacent buildings. The canopy is roofed with photovoltaic cells embedded in glass. The cells are spaced 4mm apart with a 60mm space around the edge of each module so that approximately 20% of the daylight striking the canopy will penetrate through it. This dappled light will provide some welcome shading in mid summer and the semi-transparency, combined with the complex geometry of the timber structure, creates an abstract representation of a living forest: processed timber forms the trunks and branches of the trees with photovoltaic cells capturing and transforming sunlight as do the leaves of a tree.

In its materials and energy usage, the Earth Centre buildings are intended as an exemplar of sustainable design.

CONCLUSIONS

So what have we learned about energy use in buildings over the last quarter of a Century, and where will this lead us? Firstly, the emphasis has shifted from concern over heating to cooling, particularly in temperate climates such as the UK and particularly in non domestic buildings. We are aware of the usefulness but also the limitations of passive solar design and, significantly, the demands of VDUs have led us to produce buildings where natural light has to be very carefully controlled. There is a bright future for shading technologies however, in whatever form they may take. Polychromatic glass or electrochromic glass would revolutionise the cladding of buildings if they could be made cost effective. We are already using double glazed units which have a U value of 1.1 and a visible light transmission of 60%, considerably better figures than were obtainable

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twenty years ago, and I have no doubt that the development of glass technology will continue to enable us to enjoy natural light in our architecture.

As water heating begins to form a larger part of the overall energy budget of domestic buildings, we may see improvements in the cost effectiveness of active solar water heaters, but it is doubtful whether these will be successful in climates such as the UK with three virtually sunless months per year.

On the other hand photovoltaic technology, which has been waiting in the sidelines for thirty years, is eventually joining the mainstream. The fact that it is now heavily promoted by some of the major oil companies means that the long sought after savings from mass production may soon become a reality and transform the economics of PV installations. This does not mean that we will start covering every potential southerly facing surface of our buildings in photovoltaics just as we tried to cover them with active solar collectors in the early 70's. Only when it becomes cost effective to farm solar energy by covering our unwanted agricultural land in mono-crystalline silicone will we find PV modules appearing regularly as a cladding material on our buildings. Before then, we will see discreet direct current installations operating specific elements of the building service systems such as ventilation equipment but at present there are major obstacles to PV installations, not only due to the capital cost of the cells but also the attitude of the supply authorities who are only prepared to buy back excess electricity at summertime prices, and often make an excessive charge to the customer for the privilege of doing so.

Other renewable energy sources also need to stand alone before they can be accommodated into buildings. The wind generator on top of the autarkic house slide that I showed at the beginning of this lecture was a tremendous symbol of self-sufficiency, but few people would seriously consider living in such close proximity to the noise and vibration of a turbine if it could be more conveniently located fifty or a hundred yards away. There is no point in amalgamating buildings and generators if there is no real benefit. What we will see is further development of better insulated and more air-tight buildings. We are only just beginning to understand air movement in buildings as fabric heat losses reduce, infiltration losses become a greater proportion of the total heat load and, whether these are dealt with by efficient mechanical systems in sealed buildings or controllable systems in naturally ventilated buildings, there are plenty of further improvements to be made. At the same time, more efficient lighting appliances and mechanical systems will also help reduce energy consumption.

The outlook is positive. There are plenty of examples of technological advances over the last quarter of a Century that have produced what Amory Lovins would call a "factor 4" effect. In new buildings we have managed to dramatically improve comfort conditions whilst reducing energy consumption and, with the use of renewables combined with sound conservation technology, we ought to be able to achieve factor 8. What is required is a holistic approach : an architecture that in its form, details and materials can utilise or filter the natural forces of sun and wind that are available to it. We are now seeing a new generation of buildings that can genuinely be characterised as climate-responsive architecture.