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# THE ENERGY PERFORMANCE ASSESSMENT PROJECT AND SOME EARLY FINDINGS

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The Energy Performance Assessment project (EPA) of the Department of Energy has devised a methodology to assess and report on passive solar buildings. This paper describes the methodology which takes account of the energy, cost and amenity issues of occupied buildings. By 1991 the EPA project will have evaluated over 30 buildings. Some of the initial findings from the first few buildings are reported here.

## INTRODUCTION

In attempting to reduce the energy consumption of buildings, designers have evolved a range of design solutions which emphasise high levels of insulation, and maximum use of freely available solar energy.

Overall, solutions are required which give the best balance between energy performance, economics, environmental quality, user satisfaction, and controllability. If these are to be widely adopted then a detailed knowledge of their performance over time needs to be acquired and then transmitted to those who will shape the future built environment. Such an understanding will help key people, like developers and designers, to decide on today's "best buys" in buildings.

With this in mind, the Department of Energy (D.En.) initiated the development of a rapid, cost effective, multi-disciplinary form of building appraisal. Energy Performance Assessments (EPA), as these case studies are called, seek to determine to what extent individual buildings, representing particular design solutions, save energy, improve amenity, and incur additional costs. Furthermore, they assess the environmental consequences of the energy strategies by examining a number of physical and human parameters.

## PASSIVE SOLAR BUILDINGS

The building industry responded to the mid-70's energy crisis by reducing demand for energy in buildings. For new buildings this meant high levels of insulation, low air infiltration, and well controlled heating systems, etc. In existing buildings the economics are such that improved control of plant is more cost effective than changes to the fabric. These types of projects are well represented in the Energy Efficiency Demonstration Schemes (1).

Collective experience, coupled with the R&D programmes of the D.En. and other agencies, have greatly assisted the understanding of the thermal performance of buildings. Following a decade of energy efficient buildings, in which energy conservation was paramount, it has been realized that displacing energy supply has a complementary role. With the ensuing utilization of passive solar energy it is encouraging and exciting to see designers responding with the development of a new architectural vocabulary.

Reasons for the popularity of passive solar buildings are difficult to identify with certainty, but the admission of substantial amounts of daylight and sunlight into buildings is well liked by users often accustomed to buildings that reinforce their separation from the outside. Of course, not all buildings can be naturally lit or ventilated but most can be, and are.

Admitting solar energy into a building can save energy by two mechanisms:-

- solar displaced space heating - SDSH
- daylight displaced electric lighting - DDEL (2)

It is important to note that the design and operation of passive solar buildings is very different for houses and non-domestic cases. In houses the low internal gains, high surface to volume ratio and shallow spaces make SDSH the key factor. In the non-domestic buildings internal gains can be high, buildings may be deeper with a low surface to volume ratio so that the balance of DDEL and SDSH strategies will be different and DDEL may be the greatest opportunity (for example in a deep single storey well insulated building with much plant).

Furthermore, passive principles can be employed to introduce natural ventilation and daylight to buildings which otherwise might have to be mechanically conditioned. The high running costs associated with mechanical ventilation and cooling are often overlooked in the mistaken belief that more control will inevitably reduce consumption.

The controlled admission of ambient energy into buildings has been greatly assisted by the advent of new materials, equipment and techniques. For example:-

- low emissivity coatings that reduce heat losses from double glazing to less than that from conventional triple glazing;
- low cost heating and lighting controls which should allow better utilization of admitted energy;
- techniques such as light shelves to redistribute daylight;
- ventilation systems than can redistribute solar heat;
- atria that can provide exciting interior spaces and with careful design reduce the need for mechanical ventilation and cooling in deep buildings.

Although these techniques can be shown to be effective in theory and in laboratories, their performance in buildings also needs evaluating by field trials.

## ENERGY PERFORMANCE ASSESSMENTS

The Department of Energy's Renewable Energy Research, Development and Demonstration programme is managed by the Energy Technology Support Unit at the Atomic Energy Research Establishment at Harwell (3). The utilization of passive solar energy (heat and light) in buildings is a component of this programme which includes field trials of real buildings.

Since design, and designers, are informed by experience, field trials in occupied buildings have long been an accepted part of the D.En.'s R & D programmes. Early field trials were influenced by their research context. They tended to be lengthy and costly. More recently, as the building industry has rapidly expanded its application of the knowledge generated by early field trials and research programmes, the need for a new form of field trials has become apparent. These trials should be lower cost evaluations of a wide range of buildings with an emphasis on analysis, interpretation and presentation of data to the industry.

Such trials are especially needed in the increasingly popular area of passive solar buildings where developments are taking place rapidly, and where the detailed performance of the fabric and control systems is of paramount importance to the internal environment. Evaluations of such designs in their occupied state are required to provide both feed-back and feed-forward to those involved in building design. Additionally, field trials have an important role to inform and guide other forms of research.

It was from such considerations that the Energy Performance Assessment project (EPA), and a complementary series of Design Studies (4), was formulated by ETSU. A feasibility study commissioned by ETSU (5) was followed by the appointment of Databuild and UWCOC to develop an EPA methodology. Some of the essential characteristics of EPA's soon emerged from an assessment of traditional field trials methods, for example EPA's:-

- should be credible to the building industry,
- should deal with typical (but 'good') buildings,
- will not be concerned with model validation,
- should be 'analysis-rich' and not simply 'data-rich',

- should be of short duration for valuable feedback,
- must not be solely concerned with energy issues but must also address economic and human factors.

Of particular note was the concern with human factors since passive solar buildings can require greater human intervention:-

- at their inception, when both client and designer need to be aware of the consequences of a passive solar building;
- in use, when both occupants and operators will interact necessarily with the building's environment.

The requirements of the above characteristics had many ramifications, e.g.:-

- Reliance would need to be placed on proven, available techniques.
- Measurement goals and methods would need clear definition.
- Standardization would be necessary to allow development costs to be spread over many buildings.

These rules guided the development of an EPA methodology which is intended to provide a robust body of physical measurement and human factors and of amenity.

The EPA methodology is regarded as a 'Template of Components' (a component is represented by a box in figure 1) each of which contains a 'Menu of Techniques'. Although the template is quite rigid in the way it defines the EPA method it also allows for a disciplined flexibility in the response to individual buildings.

In the Preliminaries Component each EPA is carefully defined using information from drawings, initial surveys, etc., and the subsequent components fall into three themes:-

- Measurement of the EPA Building.

  This measures energy and amenity issues in the occupied building. A range of human factors instruments had to be developed to parallel the more established tools for energy measurement.

- Modelling of the EPA Building.

  Standard QS techniques are used for costs, whilst mathematical models are used for energy issues.

- References.

  These are required to produce a baseline(s) for comparison of energy and cost data from the EPA building. They are drawn from a wide range of credible sources including:-

  - detailed modelling of a hypothetical reference building,
  - target design data as embodied in codes,
  - normalised data from real buildings.

Within the Conclusions component of each EPA, a holistic appraisal of the building is produced based on the analysis of the findings from the individual techniques. A full technical report and a shorter 8 page brochure are produced at this stage.

Thus the EPA development has created a simple but robust strategy for dealing with the following issues in both quantitative and qualitative terms:-

- a whole building evaluation,
- the energy performance of the building and its passive features,
- a capital cost analysis of the building,

- comparison of the energy and cost performance indices with a range of credible and appropriate references,
- the human aspects as embodied in the aspirations and experiences of those groups or individuals responsible for creating and using the building.

An EPA represents the result of a thorough development programme to produce a means of obtaining and presenting a wide range of information for the building industry. These issues and the related EPA methods are described in EPA reports (6, 7).

## SOME FINDINGS FROM EARLY EPA'S

At the time of writing this paper (November 1988) the EPA project is analyzing the results from the first 8 EPA's with a further 8 in progress. A selection of early results gives some idea of the information that the overall project will provide. Some of these findings related to the individual buildings are given in the summary sheets at the end of the paper. These summary sheets are a brief summary of the short technical report. This section reviews some of these.

### General Points

The EPA's (and related international studies to which the EPA project contributes (8)) suggest that passive solar buildings typically use about 25 to 50% less heating and lighting energy than similar conventional buildings. Of course not all the energy benefit is attributable to SDSH and DDEL. EPA's are only able to confidently quantify the solar contribution in houses, where it is of the order of 20 to 35% of the space heating demand. The energy saving is often frustrated by unresponsive heating and lighting systems. There is still considerable room for development of simple, cheap, effective control systems that are specifically designed to enhance SDSH and DDEL without interfering with user requirements.

This energy benefit is matched by very positive user reactions confirming that sunlight and daylight are appreciated for their quantitative and qualitative impact on the internal environment. The dynamic internal environment in passive solar buildings appears to be a positive attribute if extremes of discomfort can be avoided for most of the time. There are some risks to the use of large solar apertures but EPA's are helping to identify these for designers.

So what are the cost penalties for such design strategies? Here the evidence is, perhaps, surprising. In houses the additional cost has been only ±2%. Other studies (4) confirm that an on-cost of about 4% should be able to fund all or most passive solar strategies for houses. In non-domestic EPA buildings all had a cost per unit area in the typical range for similar buildings; they are about average cost.

Therefore, it appears that passive solar design strategies can be incorporated within buildings for little or no extra cost and can, with careful design, achieve significant amounts of SDSH and DDEL, making the strategy highly cost effective. However, the substantial amenity benefits as expressed through the users is perhaps the greatest benefit.

### Houses

For domestic buildings the dominant design strategy is to reduce the building's heat loss and to make maximum use of the thermal component of solar radiation to displace space heating (SDSH).

Findings from several houses indicate that the heating season is significantly shortened where good use is made of reduced heat loss and SDSH. Not all passive solar houses are insulated to much above building regulations, although it is true that most designers seeking to save energy by solar means do attempt to improve other aspects of the house's thermal performance.

Designers have noted that whereas energy efficiency measures such as increased insulation and high efficiency boilers have an identifiable additional cost they do not provide any additional amenity. Conversely attempts to utilize SDSH often cost little extra but can improve amenity.

The simplest and most widely used strategy is to redistribute glazing to give large south and small north windows. EPA's and other trials have observed that this can lead to north rooms with insufficient daylight where electric lighting is almost always required and where the occupants feel the room to be gloomy and unpleasant. Often this room is a kitchen and here the effect is particularly noticeable. In a development of this simple strategy one house employed an integral conservatory with large windows on the south elevation and large windows on the north. It was found that the heat loss from these north windows was more than compensated for by the daylight gains from those windows and the heating gains on the south side.

Much concern is expressed about overheating as a result of large south glazed areas. Generally speaking it appears to be straightforward to protect the house itself from overheating by the use of mass, modest shading and provision for natural ventilation. Monitoring shows that users rarely complain of overheating and that the houses behave well in summer. This is probably related to the UK tradition of high mass (solid floors, blockwork partitions, etc.). In one self-build case the high level vents to the conservatory were omitted as a cost saving for later insertion; although the conservatory did go higher than recommended the vents have never been installed. In another case the occupants go to considerable lengths to limit conservatory summer-time temperatures, but this is motivated by a concern for the plants not people!

In one house the whole house average internal temperature was lower in summer than winter! This raises another issue. It is often stated, and assumed, that we do not want our houses to be heated throughout to 21°C or above for all of the day. In passive solar and low energy houses where this is affordable the occupants often choose such a temperature regime. This suggests that assumptions about UK house temperatures, based on experience of conventional houses, may not be applicable to passive solar houses. In low energy passive solar houses, higher temperatures are consciously enjoyed. This is reinforced by other work which showed that once people had lived in such houses then they would actively seek to purchase another low energy passive solar house (9).

A difficulty with large south windows facing public spaces is that the need for privacy may lead to the use of blinds and net curtains which can severely reduce the SDSH. In one EPA the house used large south windows for direct gain and these worked reasonably well facing on to the rear garden. The developer, however, felt that other houses of the same design on the estate but which had their south elevation to the road were much less successful and many occupants used net curtains. This design was equipped with reflective roller blinds to reduce night-time radiation losses through the large windows. It was noted that the occupants often did not raise the blinds in the morning before going to work. This reduced SDSH by about 10 - 15%. The occupants were knowledgeable about the energy principles of the house and the consequence of their actions but certain lifestyles can cut across a designer's intended use of controls, even when motivation is high.

## Non Domestic Buildings

Generalization about non domestic buildings is difficult owing to the vast range in size, function and complexity. Passive solar strategies, however, are generally limited to displacing space heating (SDSH) and electric lighting (DDEL) in the perimeter zone of a building, and usually these zones are naturally ventilated in such buildings. Consequently, similarities do exist, not withstanding the diverse occupancy requirements and patterns.

Solar displaced space heating. Since these buildings are usually well insulated and have high internal gains, then the potential for SDSH is reduced and the risk of summer overheating is increased. Consequently, where experience with domestic design has been transferred directly to non-domestic buildings then difficulties have been observed. This applies to early pioneering designs where the SDSH has been disappointing and where some summertime overheating has been noted. These occurrences are not numerous nor serious and the buildings are still well regarded by owners and users. The lesson is simply that designers must take full account of the differing thermal inputs. With reasonable standards of insulation (opaque U values of 0.4 $W/m^2/K$, or less, window U values of 3 $W/m^2/K$, or less) then balance temperatures of close to winter ambient can easily be achieved. Field trials confirm that in such cases half, or more, of the buildings heat requirement occurs as morning pre-heating, therefore the potential for direct SDSH is limited. Several strategies adopted in an attempt to counteract this disadvantage have been monitored, e.g.:-

Thermal Capacity: Mass can be used to carry over thermal gains and limit summertime temperatures. Whilst this works well in sunny periods it also requires large amounts of preheating energy and time. The control of the heating system during preheating and occupied periods is then very different and quite complex if optimum use of SDSH is to be made.

Warm Air Heating: If forced ventilation systems, to provide rapid pre-heating, are coupled with an east of south orientation then SDSH has a greater potential. In these cases the automatic control of the air system can become quite complicated. For example, if maximum use of recirculated air in unoccupied periods is to be made, when available solar energy is sufficient to warrant running the fans, then those control requirements may conflict with requirements during occupied periods. In one case a shallow plan office with 80% glazed area had an apparently straightforward air heating system and, in theory, constituted the simplest and most direct use of SDSH. However, monitoring failed to detect any significant relationship between the heating system and the solar radiation. Undoubtedly, solar gain made a contribution to energy savings in this building but the design and control of the warm air heating system was such that SDSH was not optimised.

Air Redistribution: Forced ventilation systems can be used to redistribute solar heat away from a southerly perimeter zone, where it will often exceed demand, to other areas of the building where it can provide SDSH. Attractively simple in concept, the control strategy and equipment for this can become nightmarish if the ventilation system is also used to provide fresh air and heating (which it may have to do to be economically justifiable). Monitoring one such system confirmed that it failed to optimize energy savings due to competing controls in different parts of the complex system.

Moveable Shading: Moveable shading devices are sometimes installed to allow large solar apertures to displace morning heating but restrict solar gains when internal loads are high. If these devices are manually controlled then it has been observed that they are often left permanently in the worst-case condition, thus excluding much useful solar heat at other times. If the shades are automatic then the control strategy and equipment need to be quite sophisticated to avoid inadvertently excluding solar displaced space heating. In one case automatic blinds have been observed in operation when solar radiation and heating demand were simultaneously high.

Concern about overheating in passive solar buildings with a thermal strategy is, rightfully, high. In two cases designers used deep cills at windows to provide some thermal mass, daylight reflection, and to keep desks out of the highly sunlit zone. Understandably, these cills/shelves are used for papers and when windows are open these are disturbed by air movement. An apparently minor point such as this can be very annoying to users and mitigate their enjoyment of their working environment.

Daylight displaced electric lighting: Despite a rich design and research background for daylight design (the UK led the world with its daylight R & D in the post war decades) interest had waned. Whilst the benefits of daylight in passive solar buildings have often been noted there have been few examples of buildings specifically designed to admit large amounts of daylight in a way which can displace electric lighting. Recently however this has changed with the realization that daylight has both energy and amenity benefits that can outweigh any commensurate thermal disadvantages.

Daylight cannot be redistributed as easily as solar heat, and penetration is limited to a perimeter zone (say 6 - 8m for side lighting, or one level for top lighting). Additionally, and unlike thermal gains once daylight falls below a certain level and electric lights are switched on the DDEL can fall to zero despite daylight availability. These factors all combine to make design for DDEL a more complex problem than design for SDSH. Hopefully a recent excellent review (2) and design guide (10) will assist.

In one case an office design incorporated high ceilings, for good daylight penetration, together with internal and external lightshelves to improve the uniformity of this penetration. The concept functioned well in terms of daylight, and the daylit environment was well liked by users. Several instances of glare were noted, particularly where VDU's were in use.

Although the electric lighting use was low it was not as low as could have been achieved since the control strategy proved to be too coarse and pessimistic, often providing electric lighting when and where it was not needed. Fortunately, better advice now exists about controls for electric lighting in daylit buildings (e.g. 11). However, this EPA emphasised the need for integrated design of electric and daylighting systems if DDEL is to be optimised.

An interesting side effect of large glazed areas is their effect on the electric lighting installation. Near to the windows the absence of any reflected electric light from the glazing means that uniformly spaced ceiling luminaires will give a substantially reduced lux level in that zone. However, lighting design guides make no mention of this effect which was particularly noticeable in one EPA where the internal light shelves exacerbated the 'window black-hole' effect.

In another study, still in progress, top lighting is used in sports halls. In one case the adequate daylighting does not displace electric lighting because a user retrofit of an occupant sensor switch, intended to switch lights off after vacation of the hall, switches lights on at the beginning of use, irrespective of available daylight! This is an example of a well intentioned but badly briefed operator frustrating an otherwise successful design intent. In a similar hall switching is manual, but key operated, and limited observations suggest that lights are only switched on when really necessary.

Controls. The most common practical obstacles to successful SDSH and DDEL and to user satisfaction have been related to control.

Often these controls are manual and reflect a design intent "to provide users with control over their own environment". However, manual controls such as shutters, blinds, vents, louvres, etc., are often not used as intended with a consequent reduction in energy savings and comfort.

EPA findings, supported by earlier US research, indicate that occupants are most likely to operate controls if their action:-

- will yield a noticeable benefit,
- is connected to consequences by an easily understandable logic,
- is required at easily recognizable times and circumstances,
- is not counter-intuitive,
- does not require an overly complex sequence,
- is within their physical capacity.

EPA's have observed several cases where one or more of these requirements are not met. For example:-

- an integrated manual and automatic lighting control strategy was not understood by the majority of users, with consequent dissatisfaction and misuse;
- deep cill height light shelves prevent some users from reaching opening windows;
- a natural ventilation strategy which requires openings to be operated by three separate sets of people.

Where controls are automated then EPA's have observed many instances where they do not function as intended, occasionally with a substantial energy wastage. The rules given above for manual controls also apply to automatic controls. However, we have observed control systems with, for example:-

- little benefit accruing from their action,
- overly complex logic,
- unknown and unidentifiable set-points,
- competing strategies leading to exclusion of potential SDSH and DDEL, and in one case the dumping to outside of collected solar heat whilst another control was calling for space heating.

## CONCLUSIONS

EPA's and other field trials in Europe (8) have confirmed that it is possible to build passive solar buildings that make good use of solar heat and daylight to reduce energy use. The evidence is that these buildings:-

- cost little or no extra relative to equivalent buildings of similar standards;
- save about 25% of the energy demand for space heating and lighting;
- produce environments with high amenity value and with few comfort problems.

The major widespread difficulty concerns controls, both manual and automatic, which need particular attention in terms of logic, reliability, and ergonomics.

## ACKNOWLEDGEMENTS

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Finally, we must acknowledge the contribution to EPA's of the building owners, designers, and occupants. Without their willingness to have their buildings closely scrutinised, building science and design would be impoverished.

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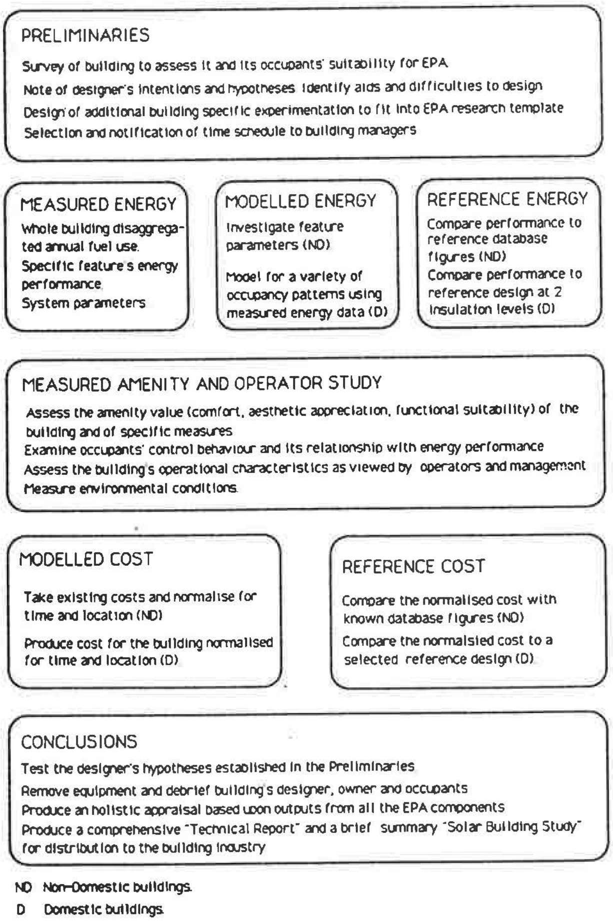


PRELIMINARIES
Survey of building to assess it and its occupants' suitability for EPA
Note of designer's intentions and hypotheses Identify aids and difficulties to design
Design of additional building specific experimentation to fit into EPA research template
Selection and notification of time schedule to building managers

MEASURED ENERGY
Whole building disaggregated annual fuel use.
Specific feature's energy performance.
System parameters

MODELLED ENERGY
Investigate feature parameters (ND)

Model for a variety of occupancy patterns using measured energy data (D)

REFERENCE ENERGY
Compare performance to reference database figures (ND)
Compare performance to reference design at 2 insulation levels (D)

MEASURED AMENITY AND OPERATOR STUDY
Assess the amenity value (comfort, aesthetic appreciation, functional suitability) of the building and of specific measures
Examine occupants' control behaviour and its relationship with energy performance
Assess the building's operational characteristics as viewed by operators and management
Measure environmental conditions.

MODELLED COST
Take existing costs and normalise for time and location (ND)

Produce cost for the building normalised for time and location (D)

REFERENCE COST
Compare the normalised cost with known database figures (ND)

Compare the normalsied cost to a selected reference design (D)

CONCLUSIONS
Test the designer's hypotheses established in the Preliminaries
Remove equipment and debrief building's designer, owner and occupants
Produce an holistic appraisal based upon outputs from all the EPA components
Produce a comprehensive "Technical Report" and a brief summary "Solar Building Study" for distribution to the building industry

ND Non-Domestic buildings.
D Domestic buildings.

Figure 1 - The Components of an EPA

## SOUTH STAFFORDSHIRE WATER COMPANY

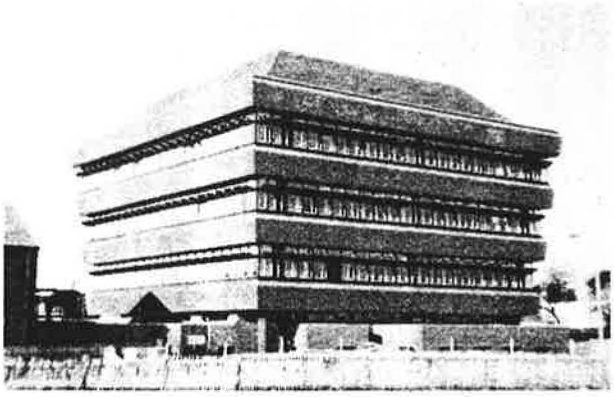
The building is a four storey 3800m$^2$ office building incorporating a 7 x 7m services and circulation core. The form of the building is such that each floor overhangs the one below it. Floors 1, 2 and 3 contain open plan office spaces wrapped around the central core. Each floor has a continuous band of fenestration using low emmisivity glass to reduce solar gains and heat losses. The fenestration incorporates light shelves which, along with the overhangs, provide summertime shading to perimeter areas. The building was principally new build and at a cost of £467/m$^2$, compares well with typical costs for offices of similar size.

The building uses a lphw gas-fired compensated temperature circuit for heating the office spaces. A constant temperature circuit is used for central core heating, computer suite air conditioning and domestic hot water. The office spaces with the exception of the computer suite are naturally ventilated by means of openable windows. An automatic lighting control system uses time of day and exterior light levels to judge when to make available, or to turn off, light in the perimeter offices.

The building was monitored for 12 months from March 1987 to February 1988 to determine the disaggregated annual fuel use. Short term monitoring was used along with a Daylight Performance Evaluation Methodology to predict savings in electric lighting use due to the daylighting strategy.

Monitoring shows that the annual fuel use for the compensated circuit was 62 kWh/m$^2$; whereas the constant circuit uses 199 kWh/m$^2$. This excessive consumption was due to the constant circuit being on 24 hours a day all year round, in order to meet the potential requirement of the A/C and DHW.

Electricity for lighting was 16 kWh/m$^2$ measured for the whole building which includes the central core. The second floor south-facing office was modelled for electric lighting usage and a figure of 9.3 kWh/m$^2$ was predicted. Analysis showed that electric lighting usage could be reduced by modifications to the lighting control strategy, which maintained an unnecessarily high base (or safety) level of electric lighting throughout the working day. Initial feedback indicates that occupants are pleased with daylight features. There is some dissatisfaction with the automatic lighting controls.



Photograph 1 - SSWC, South Facing Aspect

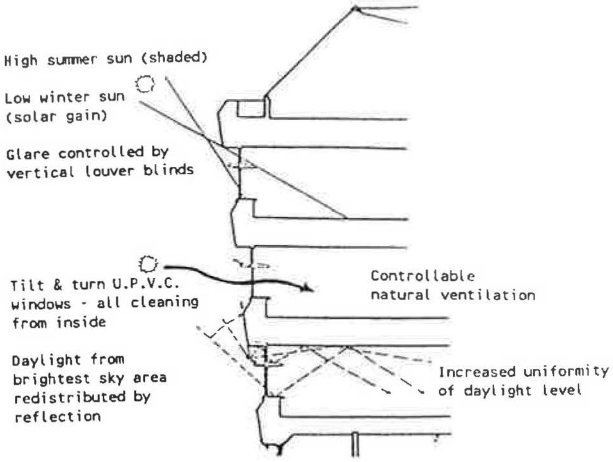


Figure 2 - Illustration of Lighting Strategy

## SOLAR COTTAGE

This passive solar house was one of the first EPA's to be undertaken, and it served as a test bed for the methodology. The house was a detached three bedroom house, with 135m$^2$ of usable floor area, situated in a village to the north of Birmingham, see photograph 2. The passive solar and energy efficiency measures included: a south facing conservatory, large south facing glazing, a well insulated envelope (average U value = 0.28 W/m$^2$/k), and a high volume to surface area design. The unheated conservatory was linked to the landing of the house with sliding glass panels which the occupant opened when the conservatory air temperature was higher than the house temperature.

The house had a solid fuel fired boiler feeding a wet control heating system and domestic hot water cylinder. High efficiency room convectors with TRV's were fitted in all occupied spaces.

The cost of the house was only 2% greater than an equivalent non-solar house and for this provided the extra space and amenity of the conservatory.

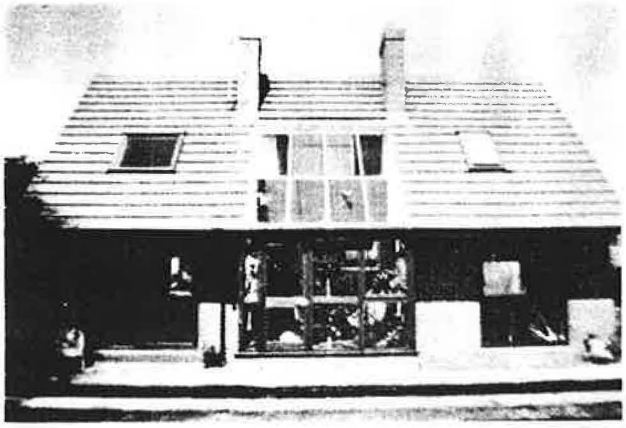
Monitoring took place from November 1985 to January 1987, providing hourly data on internal and external temperatures, and daily meter readings of the fuel and electricity consumptions, heat flow to radiators and hot water cylinder, and the solar radiation.

To allow for the vagaries of the weather the data were normalized to average conditions for the location. This indicated that in a typical year the passive solar gains to Solar Cottage would result in approximately a 35% displacement of space heating fuel.

Modelling of a non-solar references house to the same conditions as Solar Cottage (using BREDEM) showed that the passive solar design used only 60% of the fuel of a conventional house.

Analysis of the data for the year of 1986 indicates that the house consumed 2000 kWH (148 kWH/m$^2$) of fuel for space heating to provide a whole house average internal temperature of approximately 22.5°C.

The daily data allows for the estimation of the contribution of solar gain and this shows a solar heat gain of 2600 kWh for the year. If this is considered to displace space heating energy provided at the efficiency of the boiler, then it is equivalent to a saving of approximately 5000 kWh, or 20% of the boiler fuel.



Photograph 2
Solar Cottage, South Facing Aspect

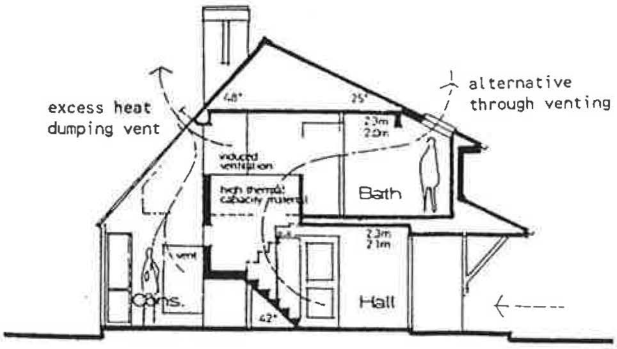


Figure 3 - Section Through Solar Cottage

## OAK FARM ROAD

The monitored test house was built during 1984 and occupied in May 1985. It was a two-storey three bedroom semi-detached house with 77m$^2$ gross floor area. This building was costed as being 2% less expensive than an equivalent non-solar dwelling.

The primary design requirement was for the building to be constructed with a high thermal envelope (U value 0.3 W/m K)). It was double-glazed throughout with large south glazing windows and minimal glazing on the other sides. In order to avoid excessive heat gain during the summer and to retain stored heat at night time, energy saver blinds were incorporated.

The building services included a combination boiler and cylinder for gas-fired wet central heating and DHW; an associated room thermostat in the hall for controlling the temperature (no TRV's on the radiators), and mechanical extract fans and humidity control in kitchen and bathroom.

Monitoring of the building continued for twelve consecutive months from March 1987 to February 1988 and provided hourly data for internal and external temperatures; electricity and gas usage; heat to space heating, and solar radiation.

The results showed a fairly low annual fuel use (1235 kWh) which was influenced by the low occupancy pattern. Of this, the gas for space heating was about 8000 kWh (104 kWh/m$^2$) and this produced an average Whole House Average Temperature of 18.1° for the heating season. An effective heat loss co-efficient of 129 W/C indicated a successful standard of building and tests for air tightness confirmed a basically 'tight' structure with a Q 50 value of 8.6 ach/hour.

An annual displacement of 816 kWh of space heating energy by solar gains was determined (17%) and this would have been equivalent to a gas fuel use of 1255 kWh. When normalised for 20 year average weather conditions, this value became 21%. An increase in this figure could be anticipated with lower incidence of drawn curtains and blinds in the lounge (south facing), higher level of occupancy, and a longer period of heating. This assumption was verified by the SERI RES modelling of the house.

Photograph 3
Oak Farm Road - South Face

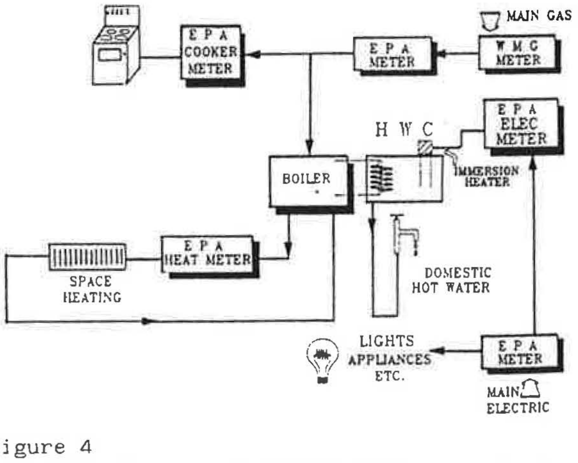


Figure 4
Schematic Diagram of Energy Monitoring System

## JEL HEADQUARTERS, STOCKPORT

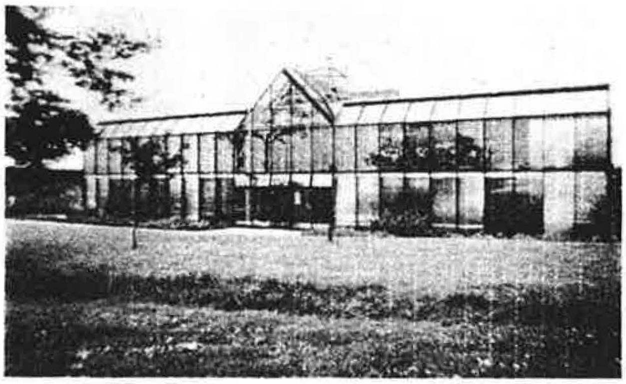
This is a two storey rectangular building, 45 metres by 30 metres, containing both office and electronic assembly areas. The centre is a double height production area which is flanked by two storeys of offices and other 'cellular' accommodation. The plan is organised so that the management and sales areas are on the south. R&D, training and other support functions are on the east and west perimeters. The centre of the building is devoted to production with stores and access through a north entrance. The south facade is 100% glazed with offices on either side of a central double height atrium which is, in fact, the plant room. Glazing on other facades is restricted. South facing rooflights are used to provide daylight in the production space.

A boiler plant provides space heating to three perimeter zones (south, east and west) with radiators and a heater battery for supplying warm air to the central production area. Air circulation fans in the production zone prevent air stratification. Shading to prevent summertime overheating is provided by external roller blinds and internal louvre blinds. A comprehensive BEMS controls room temperatures, shading and heat redistribution. The glazed south wall and south facing rooflights maximise daylighting in the offices and production area. High efficiency fluorescent lights are used in the offices and high pressure sodium lights in the production area. Task lighting is provided throughout the production area. Ventilation is provided by roof vents, openable windows and internal louvre windows. The warm air heating system to the production area can take in external air.

Monitoring to determine the disagregated fuel use began in March 1988 and is scheduled to be completed by January 1989. The principal aims are to determine the solar displaced space heating and the effectiveness of the shading devices in preventing overheating. Questionnaires are to be circulated in order to ascertain the occupants responses to building performance.

Initial results from the monitoring data reveal that overheating was a problem on days when the external temperature was high. Temperatures as high as 31°C have been recorded in the production area.

Historical fuel data shows that gas used for space heating was 86 kWh/$m^2$. Electricity usage was broken down as 6.7 kWh/$m^2$ for hot water, and other uses accounted for 35.6 kWh/$m^2$.



Photograph 4 - JEL South Facing

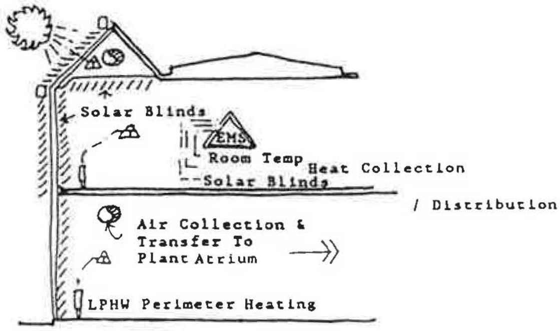


Figure 5 - Passive Hybrid Systems

## LOOE SCHOOL

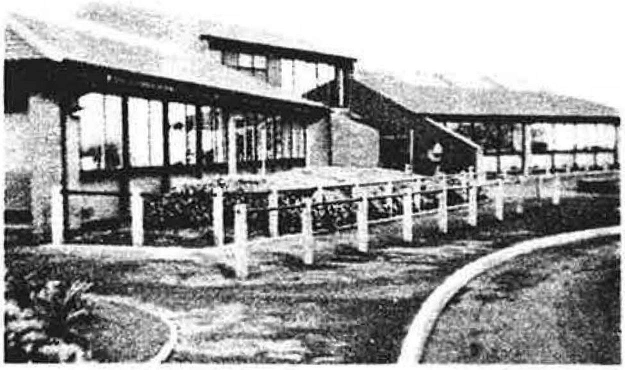
Cornwall County Architects Department designed a low energy passive solar school for Looe Junior and Infants School. The single storey building provided 1400m$^2$ of gross floor area for 300 pupils, see photograph 5. The Cruciform plan allowed all the teaching rooms to be largely south facing, with entrances on the north facade. The services were located centrally, see figure 6.

The fabric was well insulated with walls to a U value of 0.38 W/m$^2$/k, and all windows double glazed in high performance aluminium frames. Each classroom had 100% glazing on the south facing windows which incorporated a mini 'Trombe' wall. A thermally massive bench was provided internally to restrict the temperature swings caused by the solar gain. Clerestores and light wells took light to the rear of the rooms.

The space heating was provided by three 50 kW modular boilers supplying individually controlled convector emitters in each classroom, where there was also local thermostatic control. Natural ventilation was provided in the classrooms by opening windows. The lighting was provided by manually switched fluorescent lamps.

For the monitored year the preliminary results show a gas consumption of 777,400 MJ and electricity for lighting and small power of 65,000 MJ. Both of these figures compare very favourably with other low energy UK primary schools and were better than the current standards. The temperatures recorded throughout the monitoring were in range of 18 - 23°C for most of the occupied period, with little indication of severe over or under heating.

Detailed monitoring of the mini Trombe wall showed that under conditions of high solar radiation it would be inhibited from working by cold down draughts from the windows above. In low solar radiation conditions reverse flow of the air could inject cold air at floor level.



Photograph 5
Looe School - South Facing

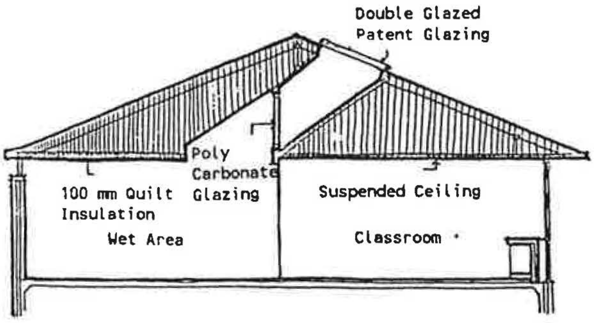


Figure 6
Cross Section Through the Infants Classroom