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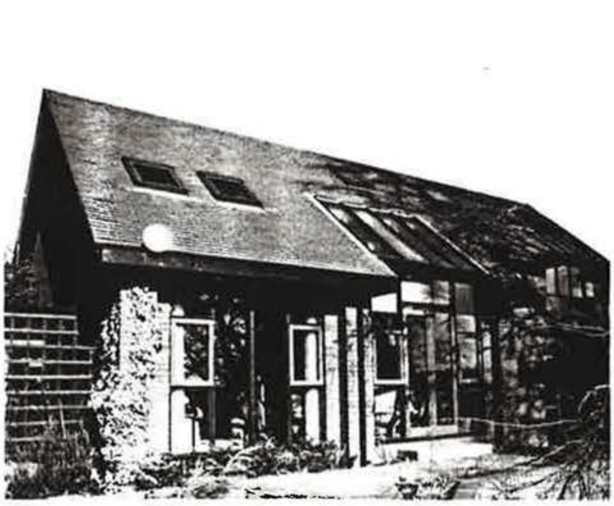
SOLAR ENERGY
A Renewable Energy

SOLAR BUILDING STUDY

Summary Report



Copper Beech House

ETSU S 1163/SBS/2

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this report was funded by
the Department of Energy
and managed by the
Energy Technology Support
Unit (ETSU) at Harwell. The
views and judgements
expressed in
the report are those of
the contractor and do not
necessarily reflect those
of ETSU or the
Department of Energy.

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of Energy's Passive
Solar Design Programme.

"This report is one product of the Energy Performance Assessments project, a programme of field trials in a wide range of occupied buildings, covering the range of UK latitudes and climates.

The aim of the field trials is to assess the costs and benefits (energy, financial and amenity/environment) associated with incorporating passive solar principles within building design."

ENERGY PERFORMANCE
ASSESSMENTS

SOLAR BUILDING STUDY

EPA SUMMARY REPORT
RESEARCH RESULTS

COPPER BEECH HOUSE

ENERGY PERFORMANCE ASSESSMENTS

Client :
Mr and Mrs Murray

Architect :
Mr Murray

Building Type :
Private domestic

Solar Features :
Direct Gain
Conservatory
Rooflights

Location :
Urban, Cardiff

Date Occupied :
1983

Size :
Gross Floor Area 153 m^2

The building was highly appreciated for the quality of daylight indoors and the contact with external surroundings that the extensive glazing induced.

Total annual fuel use of 25077 kWh compared favourably with that of a well insulated traditional design. Fuel use was effected by the occupants' choice of low room temperatures. Fuel used for space heating was 106 $kWh/m^2/year$.

The energy performance was substantially influenced by solar gains. Without such gains gas use for space heating would have been 31% higher.

The solar performance was not to the detriment of occupant comfort for there was little evidence of overheating, this being virtually eliminated by the presence of a large copper beech tree to the south of the conservatory.

At £463 m^2 GFA (2nd 1/4 1989) the house cost little more to build than a comparable traditional house.

EVALUATIONS

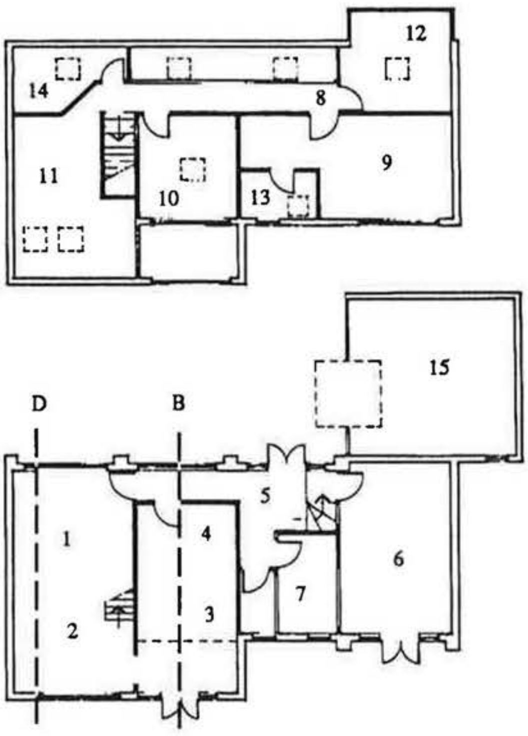
ENERGY	★★★
SOLAR DESIGN	★★★★
AMENITY	★★★★
COST	★★★★

The evaluations are based on 12 months monitoring, interviews, questionnaires, and modelling studies. For ease of comparison with other studies in this series, the performance of the building has been summarised under the four headings in the following way. Five stars indicate an excellent, three an average, and one a poor standard.

THE BUILDING

DESIGN

The house was designed by its present owner, an architect by profession, to meet his and his wife's requirements for : a building that was easy to build (in what was a self-build project), roof-space that was usable, privacy (in view of the proximity of other buildings), a conservatory. The design did not specifically develop from passive solar energy considerations, these being incorporated into the design at a later stage after site purchase and planning constraints had largely dictated the general form of the building. Those passive solar elements identifiable in the design appear either because the designer wished to make use of the amenity benefits of a building with a large southerly aspect, or because professional experience alerted him to the energy possibilities in the emerging form, or out of a desire to emulate some of the daylighting benefits he had noted in his professional work on hospitals.



Key to space numbers :-

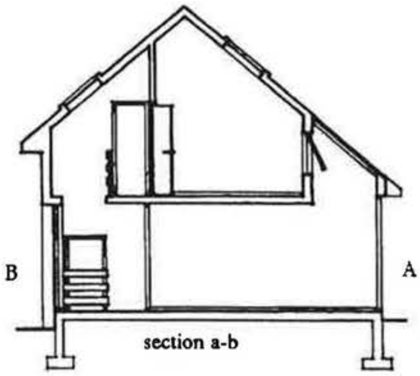
1. Kitchen
2. Sitting room
3. Dining room
4. Double height conservatory
5. Lounge
6. Hallway
7. Utility room
8. Landing
9. Master bedroom (Bed' 1)
10. Middle bedroom (Bed' 2)
11. West bedroom (Bed' 3)
12. North bedroom (Bed' 4)
13. Bathroom 1
14. Bathroom 2
15 Garage

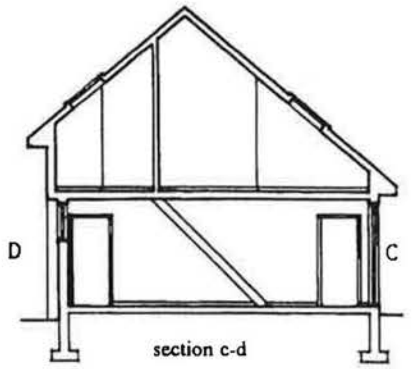
DESCRIPTION

Most of the living space is situated on the south side or extends across the width of the building whilst the circulation spaces are located on the north side. Circulation spaces on the two floors are open to each other to allow the uninterrupted flow of daylight and visual contact with outside. Whilst the house conforms to passive solar tradition by including considerable glazing on the south elevation the building is atypical in that it has extensive ground floor glazing on the north elevation as well. The roof extends to ground floor level. Four rooflights are set into the upper part of the north slope of the roof whilst three appear in the south slope. In place of a fourth rooflight on the south facing roof the master bedroom has its south facing window extend into the roof, mimicking, in smaller form, the integral conservatory.

Site Details :

Llanishen, Cardiff	51°32'N, 3°10' W
Altitude	55m
Annual Degree-Days	2078
Annual Sun-hours	1572
Met' Station	Cardiff, Rhoose
Obstruction	S-SE deciduous trees
Exposure	Sheltered terrain (3)
Winds	Westerly
Mean yearly speed	5.0 m/s





Design Aids Used :

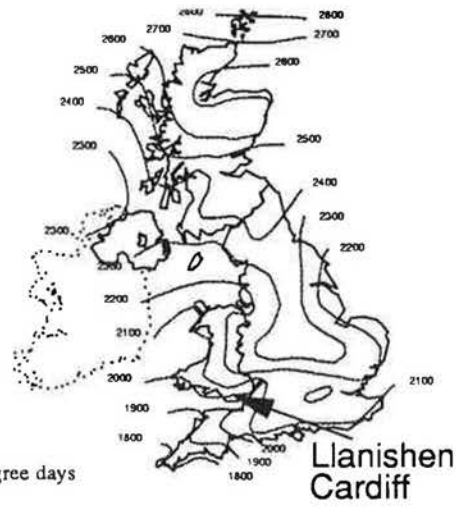
None specified

Consultants :

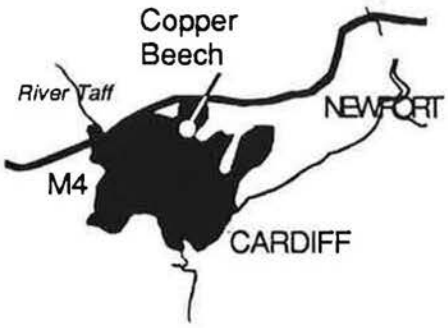
None

Dates :

Designed	1983
Constructed	1983
Occupied	1983
EPA started	1987
EPA completed	1988



Degree days



Building Information :

Area	m²	U-value
Walls	123.4	0.5
Ground floorslab	73.1	0.7
Roof	94.2	0.3
Glazing (south)	30.0	2.9
Glazing (north)	15.0	2.9
Glazing (east)	1.0	2.9
Velux (area in glazing)	--	3.7

Gross floor area (incl. conservatory) (excluding garage) — 153 m²

Enclosed volume — 373.1 m³

Heating & DHW — 176.5 W/m² GFA
Valaint Combi gas fired boiler (rated output 27kW) serving 10 radiators and domestic hot water needs, gas fire in the lounge

Target ventilation rate — 1.0 AC/h

Heat Loss Coefficients

Fabric	1.88 W/°C/m² GFA
Ventilation	0.81 W/°C /m² GFA

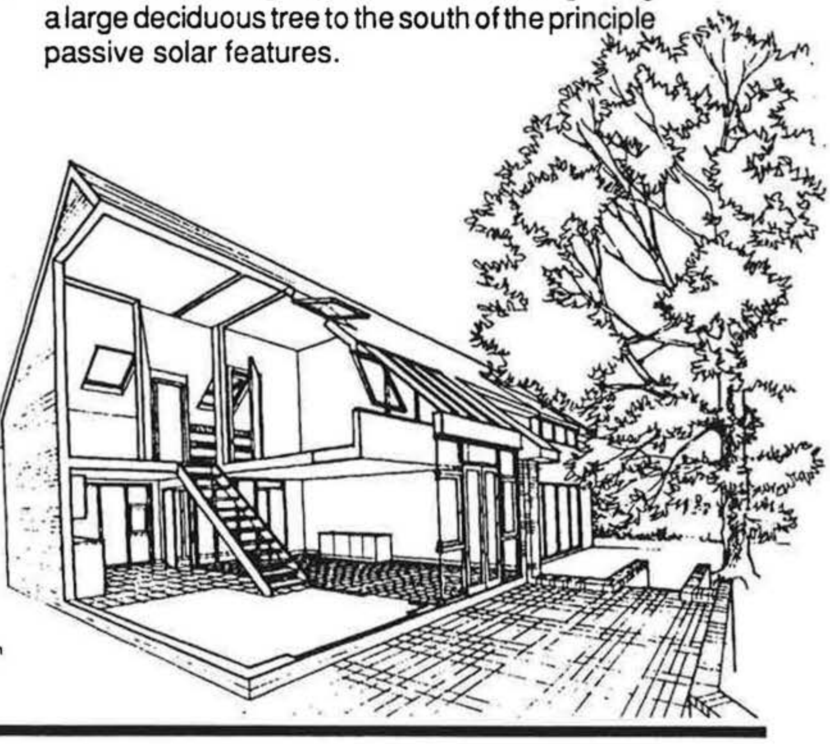
Design Day Heat Loss — 56.5 W/m² GFA

Andrew Murray

SOLAR STRATEGY

The design is a mixed direct and indirect gain system which seeks to utilise solar energy to displace space heating through direct gains to the main living areas and the circulation of warm air from an integral conservatory into adjacent upstairs living spaces. More specifically the main solar elements that can be identified in the design are :-

a. The maximisation of direct gains through the building's south-southeast orientation and highly glazed south elevation.
b. Solar warming of conservatory air before it passes to the adjacent bedroom.
c. Daylighting of north facing spaces such as the hall and upstairs landing for amenity.
d. Seasonal shading to prevent overheating using a large deciduous tree to the south of the principle passive solar features.



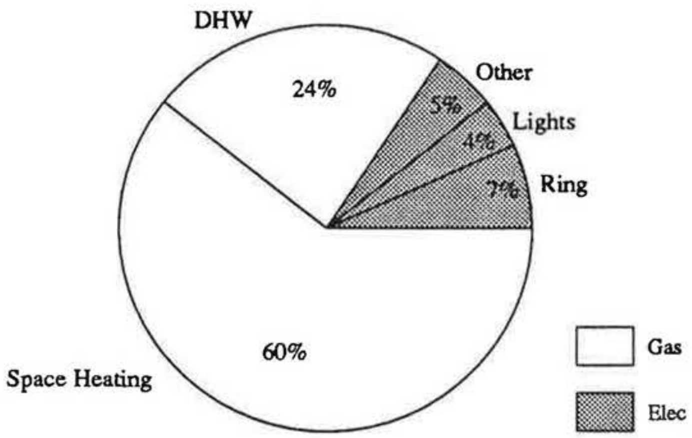
Paul Allen

PERFORMANCE

ENERGY AND ENVIRONMENT

Annual delivered fuel use during the monitored year was 25077 kWh. Of this some 16178 kWh was used for space heating. This compares favourably to average figures for the type and size of dwelling. However, given that Copper Beech was only partially heated, and, that it was heated to lower temperatures than is typical for the type of house the space heating performance must be viewed with some circumspection.

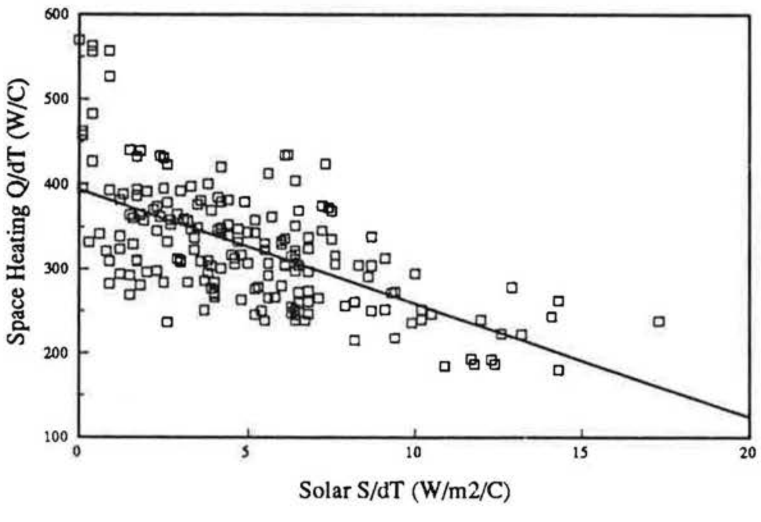
Annual Delivered Fuel (Total) 25077 kWh



Annual Delivered Fuel

As the regression chart below shows there was a strong positive relationship between solar energy and space heating use. This use of solar gains is further demonstrated by the finding that some 30.9% of the building's space heating requirements were provided by solar gains (SDSH).

Annual 4 Day Rolling Regression



Heat Loss Coefficient	393.5 W/K
Effective Solar Aperture	13.5 m^2
Solar Displaced Space Heating	30.9 %
Solar Contribution	20.2 %

Monitoring took place between March 1987 - July 1988. During this period occupancy was typical for a professional couple who do not travel away as part of their work . Weather conditions were unexceptional for the area.

Annual Delivered Fuel :

GAS	kWh
Space Heating (central)	10041
Space Heating (fire)	2385
Domestic hot water	4967
Losses (flue, casing)	3752
Total	21145
ELECTRICITY	**kWh**
Ring	1691
Light	983
Other	1258
Total	3932
TOTAL	25077

Space Heating Fuel Use 106 kWh/m²/year

Average Vertical Solar Radiation

Month	w/m²/day
January '88	33.9
February	63.3
March	45.1
April	69.9
May	64.9
June	59.6
July	55.9
August	56.4
September	51.9
October	41.8
November	32.2
December	18.7
Year Average	49.5

SDSH

Solar Displaced Space Heating

The amount of space heating displaced by solar gains. Expressed as :-

(SG/SH) * 100 %

SCON

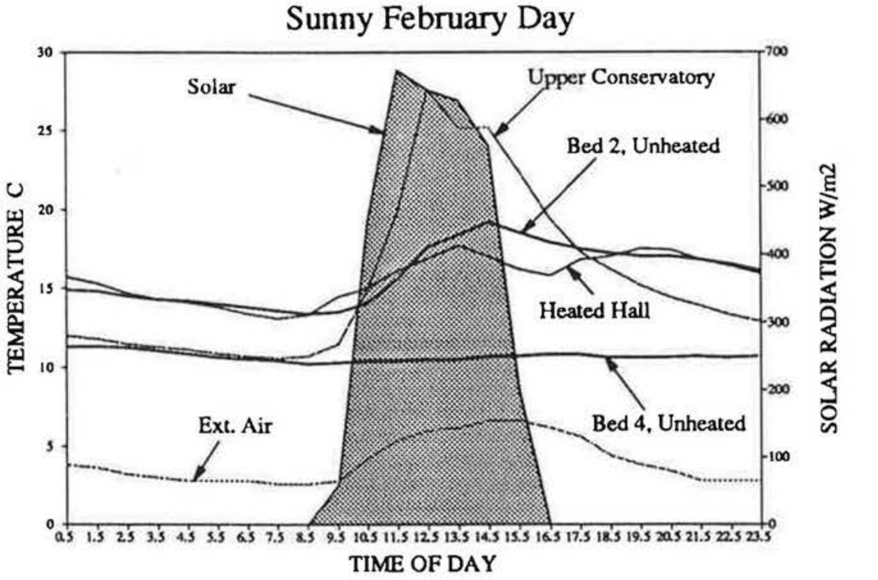
Solar Contribution

The relative contribution of solar gains to the overall heat input to the building. Expressed as :-

(SG/(SG+SH+IG)) * 100 %

Average Temperatures :

Month	External C°	Internal C°
January '88	6.3	15.4
February	5.9	15.8
March	8.1	16.9
April	9.4	15.9
May	13.6	18.5
June '88	16.7	19.5
July '87	17.7	20.4
August	16.8	19.9
September	15.5	18.8
October	10.4	17.0
November	7.5	15.9
December '87	6.4	15.0
Heating Season	7.7	16.0
Year Average	11.2	17.4



SPECIFIC MEASURES AND FEATURES

In respect of the designer's intention to use solar heated air from the conservatory to warm upstairs areas the effect of the strategy was typified by a single day in February where the lagged relationship of solar irradiation to upper conservatory and bedroom 2 temperatures is noticeable. In contrast the hall, on the "sheltered" north side of the house, shows no such response. The benefit from indirect gains was limited by the lack of independent ventilation pathways between upstairs rooms; doors having to be kept shut to exclude animals from rooms.

The building is unusual of its type in that it has an extensive area of window on the north facade. Where it might have been expected that this glazing would lead to a net heat loss the contrary was found to occur in that the total glazing in the building contributed 25kWh/day to house heating during the heating season whereas the mean heat loss through that glazing over the same period was only 22kWh/day.

TEMPERATURES

Despite the large areas of south facing glazing recorded temperatures over the course of the year indicated very little overheating. The presence of the large deciduous tree, just to the south of the house, had a very beneficial effect on reducing the influence of the sun on conservatory temperatures at those times of the year when it was not required to enhance temperatures or displace space heating. Hence, this natural feature can be regarded as a very successful seasonal solar shading device.

In contrast to the absence of overheating, when judged against average room temperatures recorded in a national survey of 1000 centrally heated homes in the UK, temperatures in Copper Beech house during the heating season might be regarded by many people as being too low.

PERFORMANCE

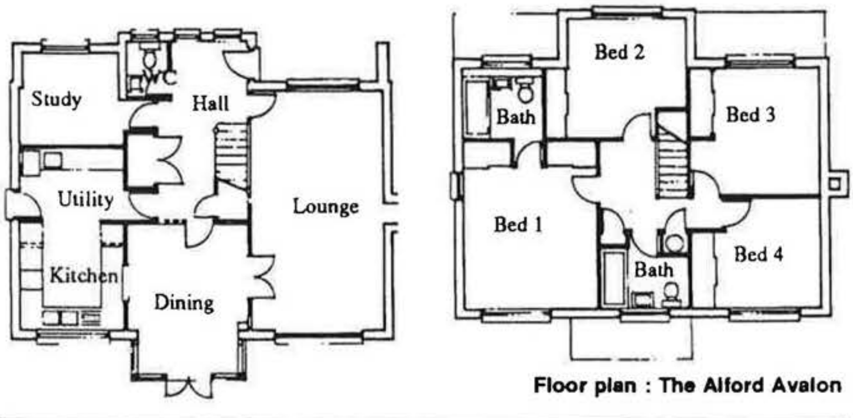
Reference house : The Alford Avalon

BUILDING COST

The EPA house and a comparable reference house were costed by Davis, Langdon and Everest using a standard elemental method which does not take account of the actual costs of the constructed building. The reference house, the "Alford Avalon" by Alford brothers, was chosen by D,L&E to provide a comparison in terms of what a purchaser might have bought as an alternative to Copper Beech. The costings were developed using a base date of the second quarter 1989, an Outer London location, and included an adjustment for any differences in Gross Floor Area between the two buildings.

Copper Beech house was found to cost £70,900 (£463 m²) in contrast to the Avalon which costed out at £68,600 (£448 m²). Despite its costing more than the Avalon, at £70,000 the cost of Copper Beech house was still within the normal range of costs for the category of house.

Cost differences were found in eight elements : the substructure, stairs, roof, external walls, windows and external doors, internal doors and mechanical services. The greatest difference in costs between the two houses came in the roof. The additional cost in this element was attributable to the greater area of roof in the Copper Beech house and the integrated glazing. Mechanical services cost considerably less in the Copper Beech house.



Floor plan : The Alford Avalon

Occupants' ratings of their home :-

FEATURES	SCORE (Female)
Its thermal comfort	4
The effort needed to keep the home warm or cool	4
The adequacy of heat distribution throughout the home	4
The quality of the air indoors	4
Its soundproofness from outside noises	4
The amount of daylight entering north facing rooms	5
The amount of daylight entering south facing rooms	4
The extent of the view of outside from indoors	5
Its privacy from outside viewers	4
Its standard of construction	5
Its general character and 'atmosphere'	5
Its external appearance from the south	5
Its external appearance from the north	4
Its internal appearance	5
Its internal layout and design	5
Its resaleability	3
Its heating costs	4
OVERALL irrespective of individual characteristics	4

1988

FEATURES	SCORE (Male)
Its thermal comfort	5
The effort needed to keep the home warm or cool	5
The adequacy of heat distribution throughout the h	5
The quality of the air indoors	4
Its soundproofness from outside noises	5
The amount of daylight entering north facing room	5
The amount of daylight entering south facing room	4
The extent of the view of outside from indoors	5
Its privacy from outside viewers	4
Its standard of construction	5
Its general character and 'atmosphere'	5
Its external appearance from the south	5
Its external appearance from the north	3
Its internal appearance	5
Its internal layout and design	5
Its resaleability	4
Its heating costs	4
OVERALL irrespective of individual characteristics	5

Scoring : (1) Very dissatisfied through to (5) Very satisfied

AMENITY

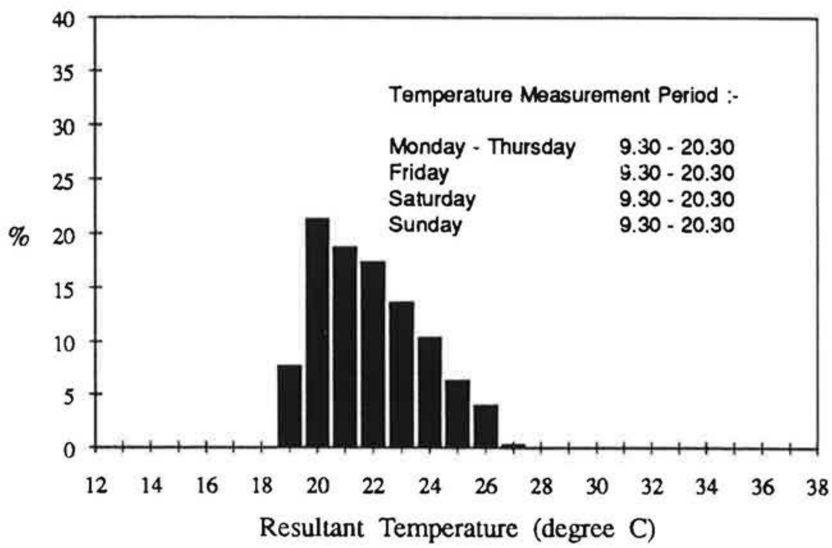
The occupants, one of whom was the building's designer, liked the house and had no major criticisms of it.

> *"I am very happy with the house. It's large and spacious, bright and airy. ...... It goes back to all the glass. I mean the outside comes in. It's all around you, the trees, the garden, the green. We are just aware of it around us all the time, as we walk about the house."*

The quality of the daylight in the house and the degree of visual contact with outdoors was, for the occupants, the building's most appealing feature. The house was felt to be very attractive from outside generally, although the south elevation was preferred to the north. A difference that the designer attributed to planning restrictions placed on the north elevation. The conservatory was regarded as an aesthetically attractive, "intermediate zone" between the house and garden which enabled the occupants to enjoy the benefits of their garden at times when it was uncomfortable outdoors.

In response to the occupants' chosen heating regime room temperatures were often low, falling below the national average for centrally heated homes. Limited underheating was reported, by the occupants, in several areas of the house including the lounge (in late summer when the beech tree continued to provide the shade which it had been valued for only a month or so earlier), the downstairs hall (November-December), and the kitchen (January-February). Significant summertime overheating did not occur in any part of the house, demonstrating the effectiveness of the copper beech tree as a shading device.

Histogram of conservatory temperatures in July



The house was not built for resale but rather to meet the occupants' long term requirements for a home. Acknowledging that its slightly unusual looks might mean that it would be less favourably viewed by purchasers with traditional houses in mind, the occupants, nonetheless, felt that the house had fairly good resale potential.

PERFORMANCE

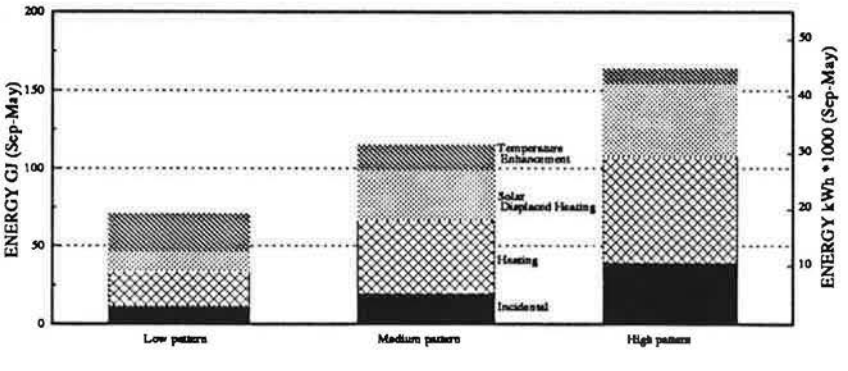
DESIGN STUDY

In order to assess the energy performance of Copper Beech the building was compared to a more traditional, less explicitly passive solar reference designs using the well established model BREDEM. The reference design was modelled for the same occupancy, insulation, internal temperatures, orientation, degree days and solar radiation as Copper Beech.

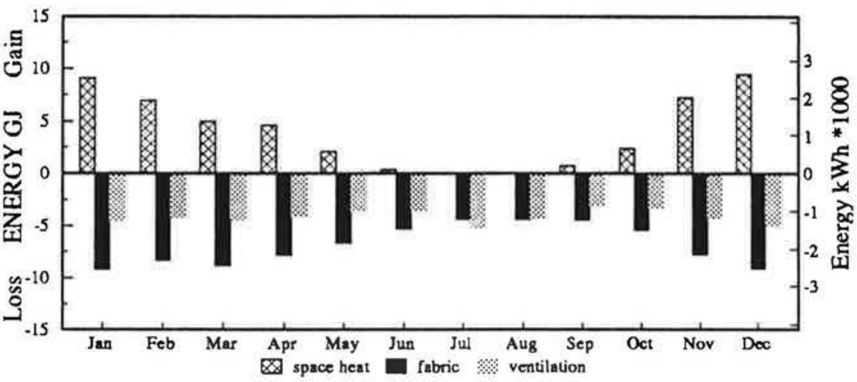
The simulation showed that Copper Beech performed as well as a well insulated example of a traditional home for the same occupancy conditions and thermal environment.

Using a more advanced computer model (HTB2) a series of simulations were performed to test the sensitivity of the Copper Beech house design to different types of occupancy and to investigate the performance characteristics of specific design measures.

These simulations demonstrated that the design had considerable potential to displace space heating through the use of solar gains and that this potential was robust to different occupancy patterns although a problem might occur with underheating in the low occupancy case. But for the presence of the copper beech tree or similar shading devices overheating would occur due to the large expanse of south facing glazing. Hence, any repetition of the design would require special attention to the provision of shading.



HTB2 : solar energy balance estimated by regression technique



HTB2 : predicted monthly fabric energy balance for the medium occupancy

	Avalon - Regs. (BREDEM)	Avalon - Hi insulation (BREDEM)	Copper Beech (Monitored)
Average internal temperature °C	16.6	16.8	16.7
Space Heating Output kWh/year	17057	13390	11711
Space Heating Fuel kWh/year	22724 *	17863 *	14836
Total Fuel kWh/year	32836	27975	25077

* assuming a long term efficiency of 75%

BREDEM Analysis

HTB2 Modelling results for 3 different occupancies

Space heating	Useful Solar heating GJ (kWh)	Aperture, m²	Aperture, r²	Useful Solar Gains GJ (kWh)	Temperature Enhancement C	Temperature Enhancement GJ (kWh)	Total GJ (kWh)
LOW	22.3 (6195)	12.6	.4	13.1 (3639)	2.2	23.6 (6556)	36.7 (10195)
MEDIUM	47.5 (13195)	15.5	.7	27.6 (7667)	1.7	16.0 (4445)	43.6 (12111)
HIGH	68.5 (19028)	23.6	.8	42.0 (11667)	0.8	9.1 (2528)	51.7 (14361)

EVALUATIONS

The evaluations are based on 12 months monitoring, interviews, questionnaires, and modelling studies. For ease of comparison with other studies in this series, the performance of the building has been summarised under the five headings in the following way. Five stars indicate an excellent, three an average, and one a poor standard.

Energy ★★★

The building's energy performance was good. However, energy consumption may have been considerably higher were more of the house to be heated, and, if higher temperatures were maintained in heated areas. Furthermore, there were indications that the performance may have partly been a function of the particular occupant's atypical ability to make good use of solar gains through his operation of the heating system.

Solar Design ★★★★

The building had a good solar aperture. The design incorporated both direct and indirect gain strategies and whilst the former was clearly successful the latter, because of the lack of unobstructed ventilation pathways between the conservatory and upstairs spaces was less influential. Solar tempering, through the use of the large copper beech to the south of the building, was successful when judged by the small amount of summertime overheating and the level of solar gains in winter. In view of the Solar Displaced Space Heating achieved and the relative absence of overheating the solar performance was rated as four. This rating would have been higher if better management of the indirect gains had been apparent and less glazing used on the north facade.

Amenity ★★★★

The building was highly valued for the aesthetic quality of its spaces and the degree of contact the design facilitated with the surrounding mature trees and garden. The building was found to be visually attractive from both indoors and outdoors although the occupants acknowledged that the slightly unusual looks might discourage future purchasers who were seeking a more traditional home. Only minor instances of over- and under-heating were reported.

Cost ★★★★

As the building cost only some 3% more than the reference building, that the cost difference was principally due to the "chalet" style of building rather than the passive solar features, and that the solar related amenity benefits have been enjoyed at little additional cost means that a four star rating is given.

Composite ★★★★

The building was well liked and comfortable, comparable in cost to its non-solar reference and performed well in passive solar terms. The high rating that these characteristics suggest is only reduced by the energy performance which would have been poorer if higher internal temperatures had been maintained.

ASSESSMENT

LESSONS and RECOMMENDATIONS

1. The intermittent heating profile generally adopted by the occupants was particularly appropriate for a direct gain design because the heating system was generally turned off whilst the solar gains were occurring. Thus, the system was not required to respond to solar gains, and, therefore any control inefficiencies were not a problem. The solar gains acted as a preheat for evening use without conflicting with the operation of the system.

2. Site factors such as trees can be advantageously used to allow the use of solar gains without detriment to amenity. In this example a deciduous tree was used as an effective summertime shading device without severely limiting the building's use of solar gains for heating displacement.

3. In designing a passive solar building to make use of indirect gains, it is important to ensure that any ventilation pathway which is intended to transfer solar gains from one space to another be independent of potentially conflicting occupant requirements such as keeping doors closed to exclude animals or children from rooms.

4. The energy performance of the house was to a good standard. Further improvement could be achieved by reducing the glazing on the north facade, possibly at the cost of amenity in terms of reduced daylighting. The resulting balance between amenity and energy performance was considered by the designer, who in this case erred towards amenity, perhaps because he was also the occupant.

5. In view of the absence of overheating and glare and Copper Beech's reasonable energy performance, it can be said that it is possible to successfully design a house to meet both occupant requirements for daylight/sunlight derived amenity and make use of solar gains to displace space heating.

CONCLUSIONS

Despite being constrained by site factors in developing the design of Copper Beech house the architect has responded very effectively to the site in producing a house that draws energy and considerable amenity benefit from the sun. Whilst Copper Beech cost slightly more than its comparator, the Alford Avalon, the costs are still within the acceptable range for the category of house. The slight additional costs have to be set within the context of Copper Beech's amenity and energy benefits.

A combination of useful solar gains and skilled use of the building by the occupant during the heating season resulted in a good energy performance in comparison to an equivalent traditional design. The copper beech tree was a major determinant in eliminating the problem of summertime overheating without effecting the solar performance in winter.

In many ways Copper Beech is a good representation of state of the art passive solar design in the UK through its careful use of aspect ratio, orientation, south facing glazing and natural shading. The only departure from this lies in what might be considered excessive glazing on the north facade which detracts from the building's overall insulation value.

FURTHER INFORMATION

EPA Technical Report : Copper Beech House 1990. ETSU Report - 1163/2

Solar Building Studies are summary reports of the Energy Performance Assessment project. This is funded by the Department of Energy through its Energy Technology Support Unit at Harwell. The R&D is carried out by Databuild (Birmingham) and UWCC (Cardiff). The views contained in this document are those of the authors. The EPA of Copper Beech was carried out by UWCC (Cardiff).

The co-operation and assistance of all those concerned with the building reported here is gratefully acknowledged : owners, operators, designers and occupants.

"This report is one in a series of
30 buildings being studied. For
further information on this and
the other buildings,
please write to: "

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