SOLAR ENERGY
A Renewable Energy

SOLAR BUILDING STUDY

Summary Report

Gateway Two

ETSU S 1160/SBS/11

dti
the department for Enterprise

The work described in this report was funded by the Department of Trade and Industry 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 Trade and Industry.

In preparing this report we acknowledge the assistance of the Building Research Establishment, who provide technical consultancy services to the Department of Trade and Industry'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

GATEWAY TWO

ENERGY PERFORMANCE ASSESSMENTS

Client:
Wiggins Teape PLC

Architect
Ove Arup Associates

Building Type:
Office Block

Solar Features:
Atrium used for Natural Ventilation of the Offices

Location:
Semi-urban, Basingstoke, Hampshire

Date Occupied:
1983

Size:
Gross Floor Area incl. Atrium : 12,000m²
GFA excluding atrium : 11,000m²

EVALUATIONS

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

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

Total annual fuel use for the building, including the atrium, was satisfactory at 194 kWh/m^2 GFA. Reduction of an unnecessarily high nighttime electricity use would improve this.

Space heating of the offices at 81 kWh/m^2 was very good in comparison with performance indicators

Natural ventilation via the atrium provides an adequate fresh air exchange rate to the offices.

Summertime overheating is largely avoided by a combination of natural ventilation and high thermal mass.

The atrium is well liked both aesthetically and as an amenity, adding to the buildings overall appeal.

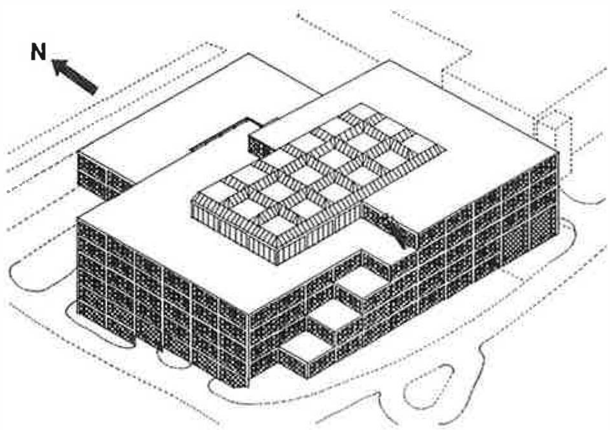
The building cost £584/m^2 which compares well with references. The incorporation of an atrium did not increase the overall building cost whilst removing the need for expensive HVAC.

ETSU-1160/SBS/11

THE BUILDING

DESIGN

The brief for the building called for a low budget development to complement the clients existing adjacent building. The provision of natural ventilation to the offices was a further requirement. These requirements and certain site constraints lead to the offices being planned around a central courtyard. The attractions of glazing over the courtyard to form an atrium soon become apparent, both for its amenity value and potential energy saving. It was thought that induced natural ventilation for the building would be improved by the presence of the atrium. The ventilation would be controllable by opening roof vents.



DESCRIPTION

FORM

Gateway Two is a seven storey development built around a 45m by 22.5m atrium. It is located on a sloping site and is designed such that the main entrance, which is at the top of the slope, is on the third floor level. This is also the atrium floor level.

For the purposes of this study only the naturally ventilated levels, three and above, are considered. The computer suite on level two is therefore excluded.

Above the atrium floor level, there are five levels to the west half of the building and four to the east, providing a clerestory level of glazing at the east end (as shown above). These floors, which contain the office accommodation, are wrapped around the rectangular central atrium. Each office is generally 13.5m deep from external wall to the atrium boundary wall.

Externally the building is of an imposing black appearance. It has a stepped garden terrace which provides a more pleasant external appearance to the building. Another external feature is provided by the 1.5m deep louvred sunscreen / walkways at each floor level around the entire perimeter of the building.

Services Engineer
Ove Arup Associates

Site Data
Latitude 51.3°N
Altitude 91m

Climate Data
Degree Days

Heating Season (Oct - April inclusive) :

1990/1	1899
20 year average	1915

Annual:

April 1990- March 91	2282
20 year average	2296

Techniques used to optimise benefits were:

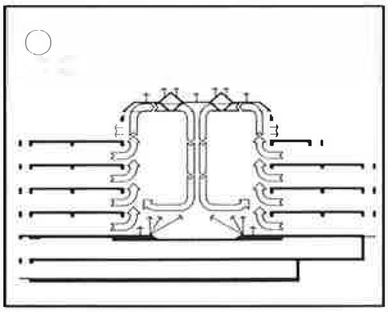
- Use of natural ventilation to avoid the high energy and monetary cost of air conditioning.
- Use of an atrium to encourage natural ventilation (by stack effect) on days of low wind speeds.
- Exposed, high mass, concrete ceilings to absorb heat gains and help reduce risks of summertime overheating.
- External and atrium permanent sunscreens, to reduce solar gains.
- Lights switched off automatically at preset times.

Dimensions:
Floor to ceiling height: 2.85m

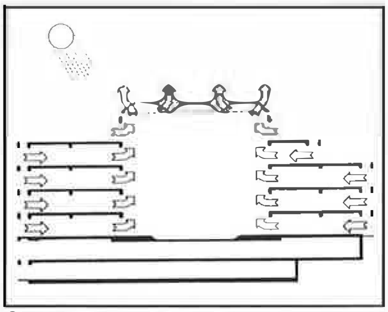
Floor Areas:	m^2
Atrium	- 1012
Level 3	- 2376
Level 4	- 2148
Level 5	- 2398
Level 6	- 2285
Level 7	- 1017

Volume:	m^3
Offices	- 21,600
Atrium	- 20,800

U - Values:	W/(m²K)
Ground Floor	- 0.19
External Wall	- 0.20
External Window (inc. clerestory)	- 5.80
Office Roof	- 0.14
Atrium Glazing	- 3.00
Atrium Roofdeck	- 0.28
Atrium to Offices	
Glazing	- 4.00
Panelling	- 2.00



WINTER Ventilation mode



SUMMER Ventilation mode

Space Heating
Installed Capacity:
Gross Floor Area - 150W/m^2

Design Condition:
Internal Temp - 21°C

Lighting
Installed Capacity:
Offices: Ceiling - 22W/m^2
Task negligible

Design Condition:
Offices - 500 lux

Ceiling Luminaires:
1200 mm, 40 W, fluorescent lamps.

CONSTRUCTION

The building has a concrete frame structure to the offices and uses steel columns in the atrium to support the walkways and roof structure. The external walls comprise curtain walling incorporating 100mm insulation in opaque areas with tinted single glazed opening windows. The wall between the office and atrium comprises an oak screen incorporating single glazing with manually adjustable glass louvres, together with acoustically absorbent panels. The roof to the atrium comprises double glazed rooflights and lightweight roofdeck incorporating 100mm insulation all on a steel frame. The office roof incorporates 75mm polystyrene insulation. The internal floors comprise precast concrete inverted troughs with exposed soffits incorporating light fittings and a timber suspended floor above.

PASSIVE FEATURES

The main passive solar feature of the building is the atrium. During the winter it provides a buffer space which reduces heat loss from the offices (compared to the originally envisaged OPEN courtyard) and a dilution volume for the stale air from the offices. The low temperature perimeter underfloor heating tempers the environment at ground floor level, reduces cold down draughts and induces ventilation from the offices.

During the summer the atrium assists with the natural ventilation and hence the cooling of the building. Solar gain through the atrium glazing warms the air in the atrium which induces a stack effect. When the rooflights are opened air is drawn into the atrium through the offices via the external and louvre windows. A computer model developed by the designers led to a number of refinements to assist the natural ventilation and cooling in the building. These included larger louvre windows to the top floor, the use of tinted glass in the external window, permanent sunshading on the external façade and the exposed concrete structure. By these means the use of HVAC was avoided.

SERVICES

Space heating : Three gas fired modular boilers feed a LPHW distribution system serving perimeter radiators, each of which has a thermostatic control. The atrium is heated throughout the winter by an underfloor coil system which runs from heat recovered from the computer suite air conditioning or directly from the boilers if necessary. The reclaimed heat is used to supplement the hot water supply during the summer.

Lighting : Lighting in the offices is manually controlled. However an automatic override system turns off office lights near to the windows at predetermined times throughout the day (10.30, 12.30, 20.00 and 24.00). Lights can be turned back on immediately if desired. The atrium is largely daylit and benefits from light from the offices. Installed lighting in the atrium is principally low level lighting for walkways and display purposes.

PERFORMANCE

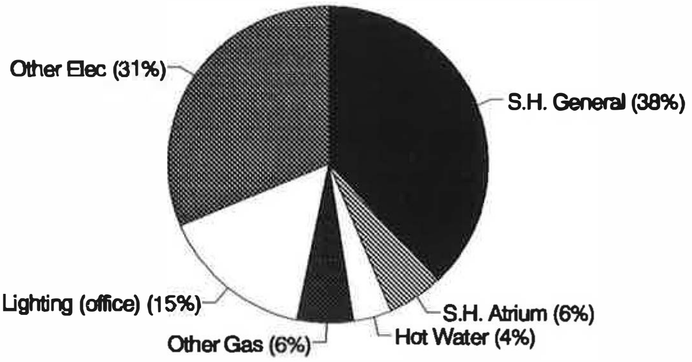
ENERGY AND ENVIRONMENT

All figures and observations are based on a monitoring period of 12 months from April 1990 to March 1991 inclusive. Space heating fuel use has been normalized to local 20 year average degree day data.

ENERGY

All heat to the atrium underfloor system is treated as a delivered energy. This is because the source of reclaim is outside of the monitored building.

DELIVERED FUEL USE : %



Normalized Delivered Fuel Use

FUEL TYPE	FUNCTION	NORMALIZED FUEL (kWh/year) Total	/m²	%
Gas	Space Heating General[1]	886 000	81	38
	Space Heating Atrium[2]	130 000	128	6
	Hot Water	90 000	8	4
	Other	133 000	11	6
Electricity	Lighting (offices)[3]	358 000	45	15
	Other Uses	731 000	61	31
Gas & Electricity Total		2328 000	194	100

The building has a reasonable total annual delivered fuel use of 194 kWh/m². This is outside of the "good" category of the PSA performance indicators, but is well within their "fair" category (between 175 and 215 kWh/m²pa). The result compares well with the figures from the Best Practice Programme (BPp).

Monitoring showed that almost half (46% or 90kWh/m²,) of the total fuel use is electricity, of which 30% can be attributed to unnecessary equipment loads used out of normal working hours and use in areas outside of our monitored area. The total energy use, in terms of primary energy, is 448 kWh/m². This is higher than the BPp references and the PSA good practice offices.

* A system efficiency of 65% was derived from the simple relationship between gas delivered to the boiler and the energy use of all of the functions serviced by it.

PSA Performance Indicators
Naturally Ventilated Offices > 10,000m²
Whole Building Delivered Fuel

	kWh/m² pa
Good	< 175
Fair	175 to 215
Poor	215 to 305
Very Poor	> 305
A/C Good	< 216

Best Practice Programme (BPp)
Delivered Fuel Use kWh/m² pa

Energy Consumption Guide :-

No. 19	A/C Good Practice	: 220
No. 19	Typical Offices	: 271
No. 19	Good Practice	: 148

Good Practice Case Studies :-

No. 14	Cornbrook House	: 141
No. 15	Hempstead House	: 165

1 Floor area used is Gross Floor Area minus the atrium (11,000 m²).

2 Floor area used is for the atrium alone (1012 m²).

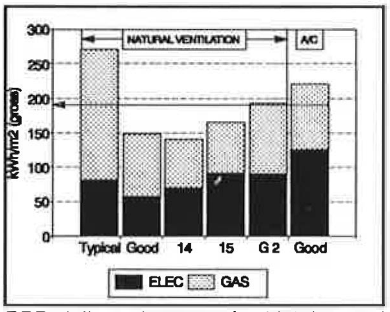
3 Lighting is for the office areas alone (8050 m²).

All other figures are over the Gross Floor Area (12,000 m²).

PERFORMANCE

Space Heating and DHW
PSA Performance Indicators
Naturally Ventilated Offices > 10,000m²

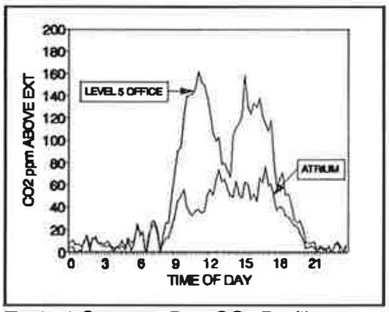
	kWh/m² pa
Good	< 145
Fair	145 to 180
Poor	180 to 260
Very Poor	> 260



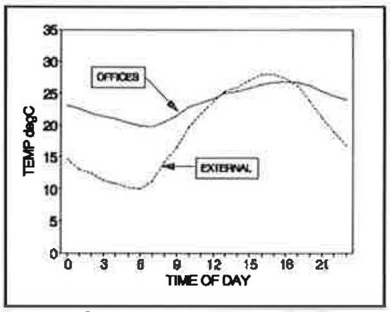
BPP delivered energy for Lighting and Space Heating and DHW

Electricity (for uses other space heating, mainly lighting)
EEO Performance Indicators

	kWh/m² pa
Good	< 23.9
Satisfactory	23.9 to 29.0
Fair	29.0 to 44.4
Poor	44.4 to 68.3
Very Poor	> 68.3



Typical Summer Day CO_2 Profile



Typical Summer Day Temp. Profile

SPACE HEATING

The space heating use for the offices alone was 81 kWh/m² p.a. which compares very favourably with the PSA indicators. The space heating requirement of the atrium is considerably higher at 128 kWh/m² p.a., reflecting the much larger volume of air being heated. However the heat input to the atrium is predominantly reclaimed from the computer suite and is therefore a low cost heat supply. The combined heating and domestic hot water use is calculated at 92 kWh/m² p.a. which is well within the "Good" category of the PSA performance indicators and compares well with the results from the Energy Efficiency Offices Best Practice Programme.

Although not designed to utilise solar radiation for space heating, the building space heating use was found to be quite responsive to the recorded solar radiation.

LIGHTING

Office electric lighting at 45kWh/m² p.a. is rated as poor in the EEO performance indicators (shown in the narrow column) and is higher than the Good Practice figure from the BPp. It is however, equivalent to results from the BPp case studies used.

The building design was not intended to utilise daylighting for displacing electric lighting despite the large window areas. Indeed the measures which were taken to reduce the solar gain to avoid overheating, would necessarily also reduce the level of daylight into the office spaces. The electric lighting energy saving strategy, in which lights are switched off automatically, was largely unsuccessful in reducing the lighting load, with lights being turned back on soon after being automatically switched off.

PASSIVE SOLAR FEATURE

The passive solar feature was found to satisfy the design intentions by providing an adequate summertime ventilation and thermal buffering in winter. The ventilation was found to be driven by both prevailing wind conditions and by the stack effect induced by the atrium. The stack effect was more important during days of very low wind speeds.

During the summer the general flow of air was from outside, through the offices and out through the atrium as designed for. The average air change rate during the working day of 4.6ach, was effective in keeping the average CO_2 level in the office at around 475ppm which is within the ASHRAE comfort criteria level of 1000ppm and well below the U.K. limit of 5000ppm.

Office temperatures were always below external throughout the hotter than normal summer months. This was not entirely due to the ventilation but was also a result of the high thermal mass of the building. Overnight ventilation was used to cool the building and was effective in keeping the daytime conditions comfortable.

PERFORMANCE

Air movement from the offices, during winter, was very low with no distinct flow pattern. Air movement in the atrium was observed to flow clockwise, when looking north, this was found to be driven by a cold down draught created by the single glazed clerestory on the eastern half of the atrium. Measurements showed that air often flowed from the atrium into the offices and vice-versa, indicating that the atrium was acting as a buffer in providing a large volume of air for dilution of the stale office air. In using the warmer air from the atrium as a fresh air source, the heating load of the building was reduced. Additionally the atrium acts as a thermal buffer in reducing heat-losses from the offices.

The average working day ventilation rate out of the offices, during winter, was found to be 0.6ach, which is above the CIBSE guide's figure for fresh air requirement of 0.3ach. The average level of CO_2 measured in offices during the working day was 900ppm which is again within the comfort criteria. However peak values were recorded in excess of 1700ppm.

AMENITY

Questionnaires completed by the buildings occupants reveal that the air quality and thermal conditions were generally satisfactory during both winter and summer. There was however a fairly high level of dissatisfaction with the amount of control they had over the heating.

The level of daylighting in the workspaces was rated as satisfactory by most respondents. Despite this, the majority of people frequently switched lights on and rarely turned them off.

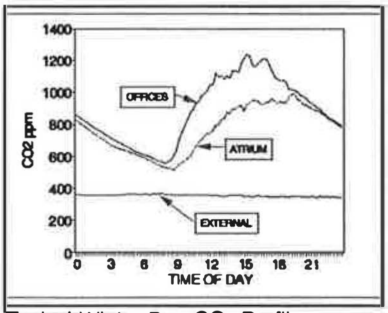
The occupants rated the aesthetics of the building as successful, particularly the atrium for which there was a high level of satisfaction. The added amenity provided by the atrium was well appreciated.

BUILDING COST

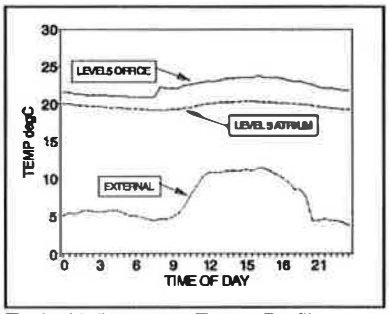
At £584/m² gross, the modelled building cost (adjusted to December 1990) is well within the BCIS band of average costs for comparable buildings. Gateway Two is slightly higher than the average for non-air conditioned buildings, this can be accounted for by the high quality finishes throughout.

The atrium roof structure, external wall cladding and sunscreens are more expensive than typical ranges. These are however offset by the low cost of mechanical and electrical services.

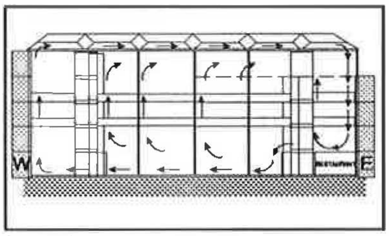
Modelled costs showed that if Gateway Two had been built as a fully air conditioned building around a central courtyard, it would have cost £720/m², almost 25% more expensive. In addition to this, the running costs (estimated at about £4 to £5/m² treated area[1]) and maintenance costs associated with air conditioning have also been avoided.



Typical Winter Day CO_2 Profile



Typical Winter Day Temp. Profile


Typical Winter Day Air Movement

Design Occupancy
490, giving 14m² office space/person

Functions
Senior Management, Administrative, Accounting, Computing

Building Cost (1990):

Gateway Two	£584/m² gross

Modelled with Air Conditioning

Gateway Two	£720/m² gross

BCIS Average Building Costs (1990):

Generally	£598/m² gross
Steel Framed	£585/m² gross
Concrete Framed	£665/m² gross
Air Conditioned	£677/m² gross
Non-Air Conditioned	£520/m² gross
3 - 5 Storeys	£607/m² gross
6 + Storeys	£783/m² gross

1. Based on ETSU and BRE estimates of between 90 and 100kWh/m² treated floor area, for air conditioning of typical offices and 55 to 70kWh/m² for good practice offices.

EVALUATIONS

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

ENERGY ★★★

This rating is given for the normalized total delivered energy use of 194 kWh/m^2 pa which compares reasonably well with published PSA performance indicators. The monitored result includes a high nighttime usage which if reduced would improve the building performance. The monitored lighting and space heating, particularly space heating for offices alone, compare favourably to the equivalent values from the reference buildings. This indicates that the building design is successful. The use of natural ventilation avoided the necessity for air conditioning, which would have added between 55 and 100kWh/m^2 to the total delivered fuel requirement[1].

SOLAR DESIGN ★★★★

The summer ventilation strategy has been successful in providing adequate fresh air and this combined with the building mass, has largely prevented overheating. The fresh air supply to the offices in winter was far lower than in summer, however it was double the CIBSE guide for fresh air requirements. The occupants were found to be generally more satisfied with the air quality in winter. The winter ventilation strategy appears to be successful.

AMENITY ★★★★

The environment appears to be well liked by the occupants. The solar feature helps to provide an acceptable air quality in the offices. However occasional problems of overheating in summer and stuffiness throughout the year were reported. The atrium was well liked aesthetically and as an amenity, adding to the attraction of the building overall.

COST ★★★★

The cost of the building, which has a high quality finish throughout, compares well with BCIS averages for comparable buildings. The higher cost of the atrium roof structure and external sunscreens, is offset by the reduced mechanical and electrical services. The actual building is 25% cheaper than an equivalent air conditioned building.

COMPOSITE ★★★★

Despite the high nighttime electrical use Gateway Two performs reasonably well in energy terms and its total cost is low. The natural ventilation strategy has succeeded in providing a suitable level of air quality and the building is well liked by the occupants.

ASSESSMENT

CONCLUSIONS

By successfully using natural ventilation throughout the building, the designers have avoided the requirement for air conditioning and its inherent costs in terms of initial capital expenditure and running and maintenance costs.

The atrium was successfully incorporated into the design and was found to assist the ventilation particularly on days when it could not be wind driven. The atrium has also allowed a degree of control over the ventilation, enabling ventilation heat loss to be reduced during the winter. This improves the effectiveness of the atrium as a buffer space, which in turn leads to it being a comfortable and well used area throughout the year.

LESSONS & RECOMMENDATIONS

The comments below are extracted from the full technical report on the monitoring of Gateway Two, available from ETSU.

1. The reliance upon occupants to open both windows and louvres, in order for the ventilation strategy to work, was largely successful in the summer. However the ventilation in winter was restricted because fewer windows were opened. This could be largely overcome by improved window design, the use of trickle vents or other sources of permanent low flow ventilation. This indicates that there is a greater potential for ventilation than was actually realized.

2. Night time ventilation during what was a very hot summer, was found to be important in providing comfortable conditions for the following day.

3. A high level of electricity was used out of normal working hours, throughout the year. By reducing this load, not only is there a potential for large energy and cost savings, but also for reducing the incidental gains and consequently the chances of overheating in summer.

4. Switching lights off automatically is largely ineffective in terms of energy savings in this building and is a source of considerable annoyance to the occupants. This could be improved by making the switching responsive to available daylight, and/or using continuous dimming, which would probably prove to be more acceptable to the occupants. Alternatively it could be restricted to switching off out of normal working hours.

5. Poor understanding or access to controls led to a degree of dissatisfaction, which may affect how the occupants perceive the relevant environmental condition.

6. The large areas of glazing between offices and the atrium failed to provide adequate daylight into the workspaces.

FURTHER INFORMATION

EPA Technical Report on Gateway Two, available from ETSU. ETSU Report 1160/11

ETSU Renewable Energy Enquiries Bureau: Telephone: 0235-432450.

The Arup Journal, Vol 19, No. 2, June 1984.

Architects Journal, 14th November 1984, Number 46, Volume 180

"Ventilation Strategies and Measurement Techniques" - M.J.Holmes, AIC Conference, September 16-19 1985, Netherlands.

"Gateway Two - Air Flow Modelling" - available from ETSU. ETSU Report 1323

For information on the Best Practice Programme of the Energy Efficiency Office, contact BRECSU: Telephone: 0923 664258

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 Gateway Two was carried out by Databuild (Birmingham).

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