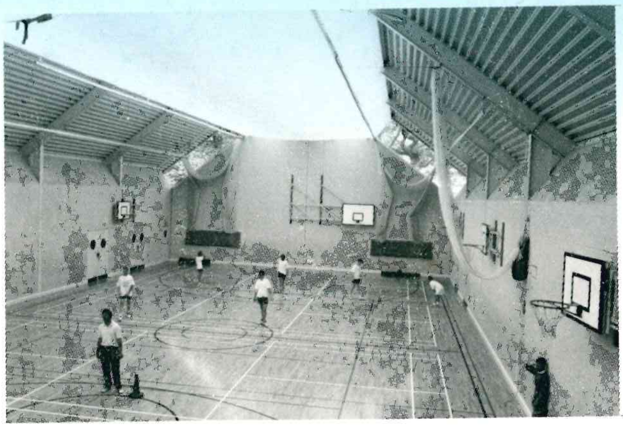
Watkins, Richard, Seager, A, Palmer, John and Shaw, P (1992) *Brune Park Sports Hall.* Technical report. Atomic Energy Research Establishment, Energy Technology Support Unit, UK

SOLAR ENERGY
A Renewable Energy

SOLAR BUILDING STUDY

Final Report



Brune Park Sports Hall

ETSU S 1160/18

dti
the department for Enterprise

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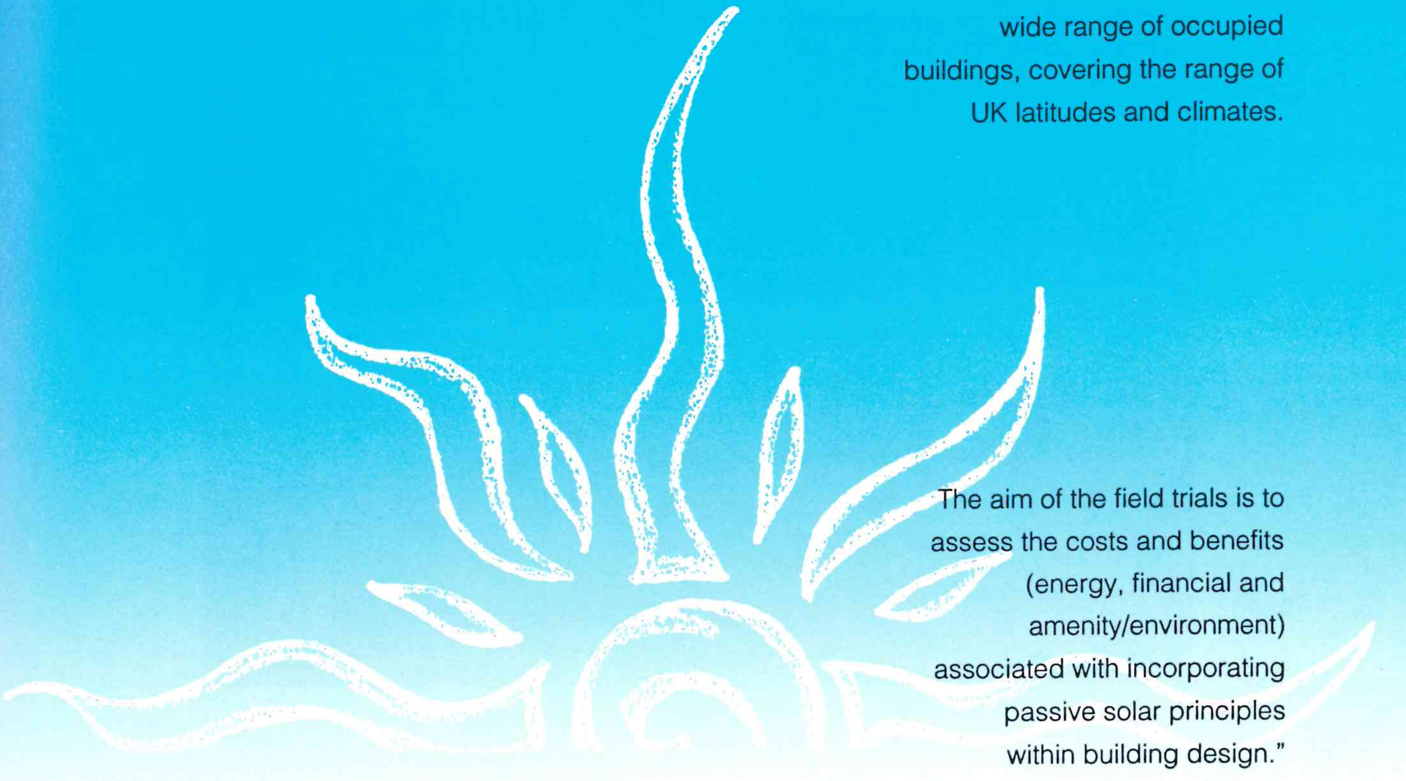
Energy Technology Support
Unit (ETSU) at Harwell. The
views and judgements
expressed in
the report are those of
the contractor and do not
necessarily reflect those
of ETSU or the
Department of Trade
and Industry.

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

ENERGY PERFORMANCE
ASSESSMENTS

THE BRUNE PARK SPORTS HALL

GOSPORT

EPA NON-DOMESTIC TECHNICAL REPORT
RESEARCH RESULTS

DATABUILD LTD
4, Venture Way, Aston Science Park, Birmingham

March 1992

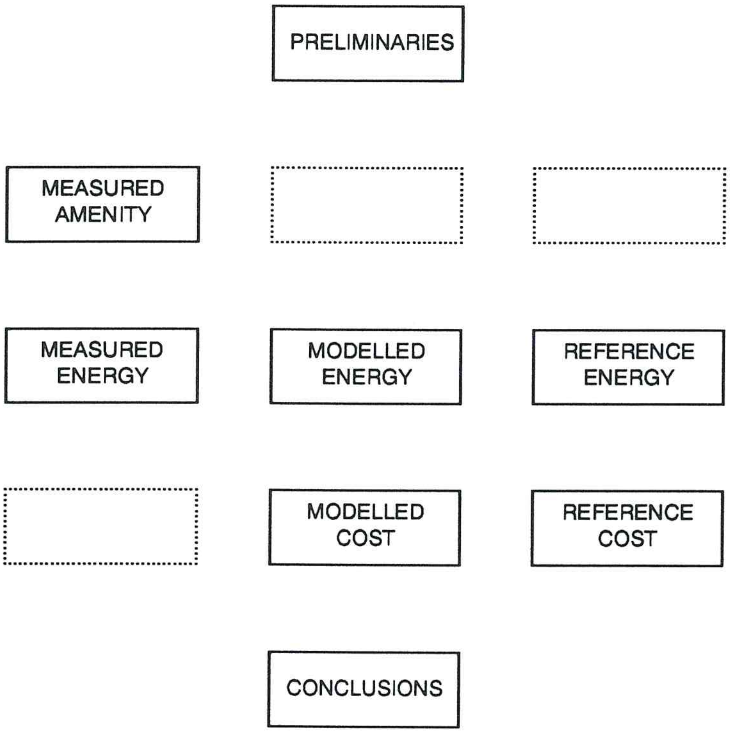
ETSU Report 1160/18

Main author: R.Watkins
Co-authors: A.Seager, J.Palmer, P.Shaw

PREFACE

This is the technical report on one of the buildings studied in the Energy Performance Assessment project. The project is sponsored by the Energy Technology Support Unit at Harwell on behalf of the Department of Energy. It aims to accelerate the uptake of designs of low energy passive solar buildings through field trials on occupied buildings. The field trials assess a number of issues as shown in the diagram below; this also indicates the sections of this report. The methodology implicit in the diagram was the result of the first phase of the EPA work.

The full technical report is summarized in the Solar Building Study which precedes the main text.



Databuild would like to thank all those who have helped with the EPA of the Brune Park Sports Hall. In particular, Keith Stephens and the other caretaking staff, the PE teachers and head teacher who have all been very helpful while their building has been under scrutiny.

Thanks also go to David Barnes and Neil Beasley, of Jackson Greenen Down & Partners, architects of the hall.

Professor D. Poole has offered very useful insights into the design for which we are grateful.

We would like to thank Hampshire County Council for their considerable help.

Phillip Michael, ETSU, has been responsible for directing the course of the EPA project. We are very grateful for the considerable effort he has devoted to reading each draft and final report. His comments have been instrumental in producing better EPAs.

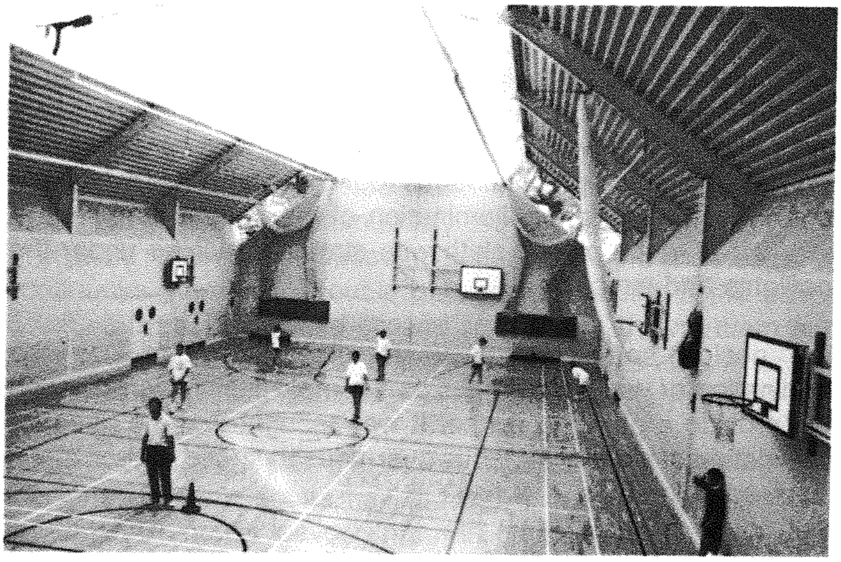
The evaluation of costs is largely done by Davis Langdon & Everest, ETSU's Cost Analysis Service. Support to ETSU in the appraisal of the reports has been provided by the Building Research Establishment.

SOLAR BUILDING STUDY

EPA SUMMARY REPORT
RESEARCH RESULTS

BRUNE PARK SPORTS HALL

ENERGY PERFORMANCE
ASSESSMENTS



Client:
Hampshire County Council

Architect:
Jackson Greenen Down & Partners

Building Type:
Sports Hall

Solar Features:
Roof-lights, Daylighting

Location:
Semi-urban, Gosport, Portsmouth

Date Occupied:
1987

Size:
Gross Floor Area 940m^2

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 delivered fuel, normalized for long term weather at the site, is moderately low at 195 kWh of delivered energy per m^2 gross floor area.

Daylight has displaced 40% of the annual electricity used for lighting.

The large saving in energy has been achieved without automatic lighting controls.

The building is too warm for most of the year; the heating system is set too high and there is no significant means of rejecting unwanted solar heat.

The poor air quality and lack of ventilation were complained of by users.

The overall cost of the building is average for sports and recreational centres. The passive solar features have been incorporated at no extra cost.

THE BUILDING

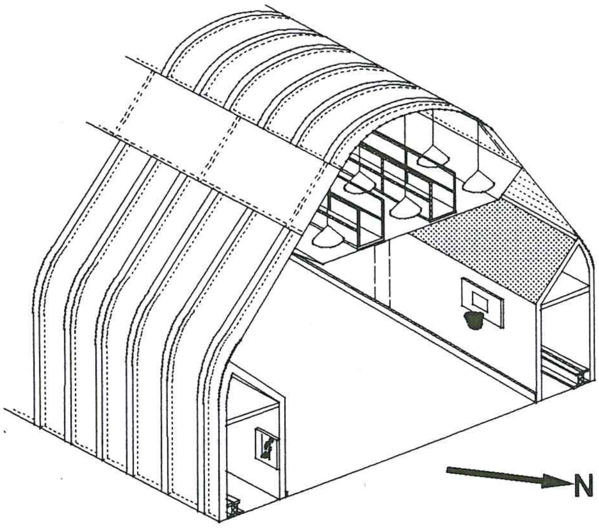
DESIGN

The requirements of Hampshire County Council were for a sports hall to be designed that would fulfil the sporting needs at Brune Park school and be within budget. There was also a requirement for the design to take advantage of natural light for illumination. The council have been incorporating daylighting in sports halls for a decade and this fitted well with the architects' preference for more open and airy buildings.

The architects based their design broadly on a previous sports hall at Fareham which had daylighting through a single roof-light and a diffuser below. With help from a daylighting consultant the hall was designed with continuous roof-lights on either side of the roof ridge. To make the illumination of the hall more uniform a velarium of white plastic cloth was stretched across under the rooflights and lamps.

The design sought to eliminate disability glare, use the illumination of vertical surfaces as the main illumination criterion and provide a pleasing space. It was thought that the need for illumination of vertical surfaces over-rides the need for horizontal illumination in any sports hall.

Automatic controls for the lighting were not used, because there had been mixed reactions to such systems in the past.



DESCRIPTION

FORM

The cross section of the hall is roughly "A" shaped with the horizontal link of the "A" at high level. The hall is rectangular with changing rooms, etc. along its longer sides. About half the northern end is glazed with the boiler house projecting outside and centrally placed. The southern end is glazed only next to the large eaves overhang. There are continuous roof-lights.

Site data

Latitude 50.8°N
Altitude 10m

Climate data

Annual:	
1989-90 degree days:	1962
20 year average degree days:	2273
External temperature:	10.7°C
October to April inc.:	
1989-90 degree days:	1582
20 year average d.days:	1896
External temperature:	7.3°C

Design details

Priority was given to the provision of daylighting. The building was designed to avoid a visitor feeling he was entering a box.

The angle of pitch of the roof was kept low (36½°) and the ridge rounded off to blend better with the surroundings.

The architect thought that it was important that there were views to the outside and that spectators could look in at more than one level. The glazing in the gable ends has this primary role, although it also allows some illumination from the north and south.

The architects did not use any computer models themselves.

Over-heating in the roof-space above the velarium was seen as a possible problem. An extract fan controlled by a thermostat was specified as a precaution.

THE BUILDING

Construction details:
Double glazing was used in the gable walls.

Roof-lights are PVC and double glazed with a third profiled layer, matching the roof cladding, that is bonded to them. This makes about one third of the roof-light area triple glazed. This construction transmits 57% of light.

The velarium is a made of a white plastic cloth which transmits 60% of light.

Overall about 34% of light is thus transmitted to the hall from outside.

U-values, W/m^2/°C:
Floor: 0.2
Wrap-over wall/roof: 0.5
Masonry walls: 0.5
Roof-lights: 2.7
Double glazed gable windows: 3.0

Envelope heat loss, kW/°C:
Fabric: 1.7
Infiltration & Ventilation: 1.2
(at ½ air change per hour)

Control of lights:
The 33 main lamps suspended above the velarium are activated by one key switch. Access to the key is restricted to the caretaker, his assistants and the cleaner. PE teachers and users are not allowed control. If the lights need to be switched on the caretaker must be contacted via internal telephone to the office, when the caretaker will be "bleeped". The caretaker attempts to foresee a need for the lights to be switched on.

Space heating
Installed capacity:
Gross floor area: 180 W/m^2

Design condition:
Internal temperature in hall: 16°C
(higher in changing rooms)

Lighting installed capacity:
Total, gross floor area: 19 W/m^2

CONSTRUCTION

The ground floor is made of a 95mm floor screed (which incorporates heating pipes) on a polythene membrane on 25mm insulation on a 150mm concrete slab. There is a wooden floating floor on top of this. The external walls of the longer sides of the building use a steel framework carrying a double skin of corrugated steel with 75mm insulation between. The insulation is divided (50mm + 25mm) by a damp-proof membrane. The gable external walls vary: either brick or block, with 40mm insulation, or in-fill panels on the steel frame.

The roof is a continuation of the corrugated walling. Either side of the ridge, 3m down, are 1.8m wide triple glazed plastic rooflights. These run continuously along the length of the roof. The gable walls include substantial glazing. At the southern end, continuous 1.5m wide double glazing runs beneath the eaves down as far as 3m above ground floor level. The northern end has the same glazing under the eaves, but this is augmented by two 4.5m widths of the gable wall being completely glazed.

PASSIVE FEATURES

It is unusual for a sports hall to have windows. The extensive glazing at Brune Park allows natural lighting of the sports hall. A prominant feature of the hall for users is the velarium formed by a white plastic sail-cloth stretched across over-head. This diffuses both daylight *and* artificial light; the lamps above it cannot easily be seen by players below.

SERVICES

Space heating to the building is zoned and provided by two 85 kW gas-fired condensing boilers. The main hall, weight-training room and perimeter changing rooms are heated by hot water from the boilers flowing through plastic pipes in the floor. Domestic hot water is provided from a separate 110kW gas boiler which has an integral storage tank. The flue gases from the three boilers are drawn into a manifold by a 1.1 kW flue dilution fan and led to an exit at high level.

At high level, above the velarium, there is a 0.14 kW extraction fan mounted in the north gable and designed to be switched on by a thermostat to avoid over-heating in the roofspace.

The main artificial lighting is provided by 33 x 400W high pressure mercury halide lamps. These are mounted in reflectors and suspended on chains 1.4 m above the velarium pointing downwards. Most other lighting is provided by fluorescent tubes.

The changing rooms and showers have no windows and receive ventilation air drawn from the sports hall. Forced ventilation is also provided in the weight training room.

PERFORMANCE

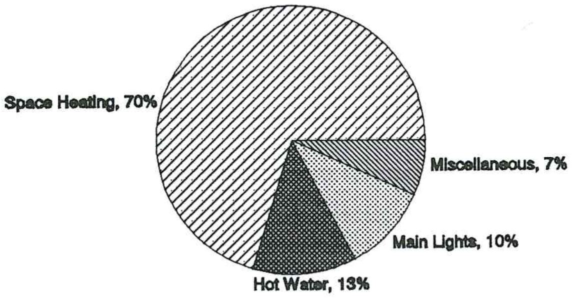
ENERGY AND ENVIRONMENT

All annual data come from monitoring in 1989-90. The pie diagram shows actual monitored data. The table shows the same data after the space-heating gas has been normalized to the long term degree-days for the site.

ENERGY

THE USE OF DELIVERED FUEL, %

(October 1989 to September 1990)



FUEL TYPE	USE	NORMALIZED DELIVERED FUEL, kWh/year	
		TOTAL	PER m² GROSS FLOOR AREA
GAS	SPACE HEATING	134218	142.8
	HOT WATER	20640	22.0
	TOTAL	154858	164.7
ELECTRICITY	HALL LIGHTING	17510	18.6†
	MISCELLANEOUS	10985	11.7
	TOTAL	28495	30.3
TOTAL ENERGY USE:		183353	195.1

†36 kWh/m² of *main hall area*

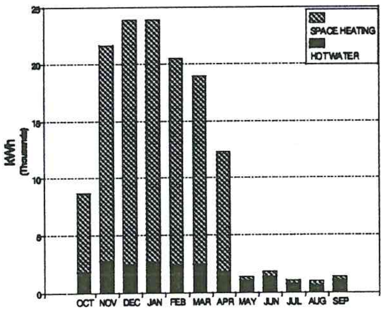
The total delivered fuel use of 195 kWh/m²/year, normalized for long term weather, is moderately low for a sports hall.

The Audit Commission have produced Normalized Performance Indicators of energy efficiency for sports halls. Their indicators adjust measured readings to allow for weather and hours of use. The NPI of good efficiency for sports halls is 220 kWh/m²/year: Brune Park's NPI is 260 kWh/m²/year. The NPI of poor efficiency is 410 kWh/m²/year.

Although only 18% of total fuel use is electricity, total primary energy use is about 50% greater than delivered fuel.

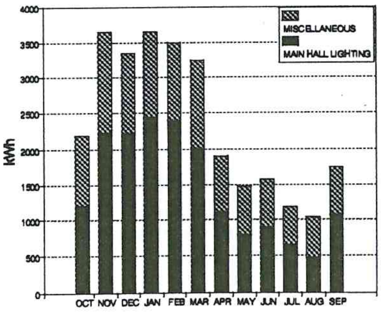
The heating season started on 13th October 1989 and finished on the 27th April 1990. Monthly gas use for space heating and hot water is shown below.

MONTHLY GAS USE, kWh
(Delivered Fuel)



The use of electricity is less in the summer largely because of reduced lighting consumption. Monthly electricity use for miscellaneous items and the main 33 lamps is shown below.

MONTHLY ELECTRICITY USE, kWh
(Delivered Fuel)



The extraction fan above the velarium appears to operate according to a timeclock rather than a thermostat. For instance it extracted air from the roof space for 14 hours on 8th February 1991 when the mean 24 hour temperature was -3.4 °C outside and 16.3 °C in the *roof-space.*

(The NPI shown on the left is substantially higher than the normalized delivered fuel use. This is mainly because the hours of use are different.)

PERFORMANCE

The gas pilot lights on the two space heating boilers together consume at a rate of 500W. They used 1956 kWh outside the heating season (1.7% of the annual space heating gas use).

The flue dilution fan for the space heating and hot water gas boilers is under time-clock control and is on from about 06.30 to 16.30. With a rated input of 1.1 kW, this fan consumes about 4000 kWh per year (14% of the annual electricity use).

The 33 main lamps in the hall take about ten to fifteen minutes to achieve full brightness. They are divided in to three banks and come on in sequence automatically once activated on with the key switch. The warm-up time militates against more frequent switching and they are generally put on some time before the hall has to be used.

Over the whole year, considering PE periods only in term-time, the main lights were *not* used for 76% of the time.

Horizontal illuminance was used in assessing the contribution that daylight could make, even though the design intention was to increase the illumination of vertical and sloping surfaces. This was done because there were no satisfactory guidelines available that recommended minimum vertical illuminances for sports halls. Because the sports hall might be used for school examinations there was also a design requirement for 300 lux on the standard horizontal working plane.

Vertical illuminance was measured: the lights gave an illuminance of 160 lux at the centre of the hall. (This is the mean of light coming from four directions and averaged along the axis of the hall.) This is low compared with the horizontal illuminance of about 390 lux measured in the same place, although it will be greater at increased heights.

SPACE HEATING

The space heating system seems to be responsible for much of the over-heating of the hall. Although solar gain can be high, this is not the case in the winter. The problem may simply be one of the set-points for controlling the heating being too high. (They are not designed to be adjustable by the caretaker.) The design temperatures are those suitable for active sport, i.e. 16°C for badminton. This temperature was exceeded for 90% of the time during the winter and 20°C was exceeded for 20% of the time.

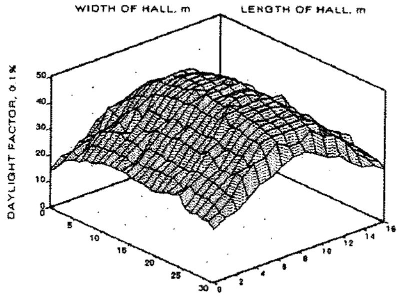
LIGHTING

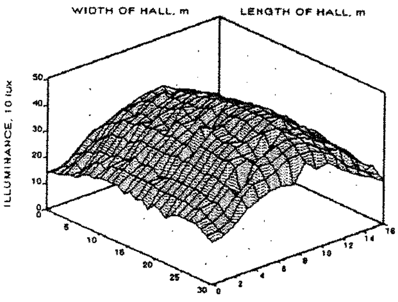
The main hall lights were used for about 40% of the time that would be expected in a conventional windowless design of sports hall. The use of sports halls varies, but a typical use is from 9am to 9pm every day. For this use the Brune Park design has the potential to save 48% of annual lighting electricity - assuming that lights are turned off when there is sufficient daylight. This is a substantial saving worth about £1900/year at 1990 prices.

This has been achieved entirely by manual switching of the lights. Access to the key-operated switch is restricted to the caretakers who are keen to ensure that the lights are not on unnecessarily when the sky is bright.

PASSIVE SOLAR FEATURE

Uniformity of lighting is desirable for most sports. The velarium diffuses both artificial lighting and daylight as can be seen from the two profiles below. The left hand one shows the fraction of external light received at any point in the hall, on an overcast day. The other shows the light from artificial lighting at night. Both profiles are exceptionally smooth with intensities on the horizontal plane varying a maximum of 3¼:1 - daylight and artificial light the same.





In order to test the performance of the passive solar feature the following questions were asked: what is an adequate level of lighting? What level of solar radiation would produce this? How does the requirement for lighting that follows from this compare with what was actually used?

As there were few complaints about the artificial lighting, adequate lighting was defined as the highest nightime horizontal illuminance measured - **360 lux** (the adequacy level).

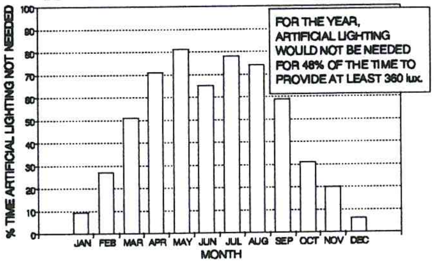
PERFORMANCE

The effectiveness of the sun in illuminating the hall varies according to sky type. The ratio of external solar intensity to internal horizontal illuminance was computed for each quarter of an hour when the lights were off from 12 months' data. The ratio varied from 2 to 3½ lux/W/m^2. A very *conservative* value of **2.1 lux/W/m^2** was chosen - 96% of the values were higher.

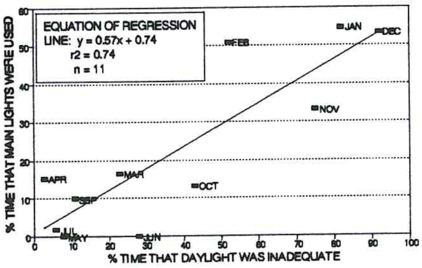
Dividing the adequacy level by this solar effectivness ratio gives a value for adequate solar radiation to avoid artificial lighting having to be used - **171 W/m^2**. For use of Brune Park hall from 9am to 9pm the sun exceeds this value for 48% of the year as shown on the right.

To confirm this saving in the use of lighting, the percentage of time that the lights were *used* during PE periods was plotted against the percentage of time that daylight was *adequate* (the sun greater than 171 W/m^2). This is shown on the right with the regression line through the monthly values. The correlation is very good.

THE SAVING IN ARTIFICIAL LIGHTING
THAT WOULD OCCUR FOR CONTINUOUS USE
BETWEEN 09.00 & 21.00 SEVEN DAYS A WEEK



THE NEED FOR LIGHTING v ITS USE
MONTHLY DATA FOR PE PERIODS



AMENITY

Users of the hall were satisfied with the level of lighting day or night. Many of those questioned preferred the artificial lighting on because it provided unvarying even light. They alluded to the problem of scudding clouds and it was sometimes a long-winded procedure to get the lights put on.

Users liked the internal appearance but found the hall far too hot to be comfortable playing badminton, netball, etc. They particularly complained about conditions in the summer, but many complained about winter over-heating as well. Air-quality was also criticized and fire-doors were opened in the summer to increase ventilation.

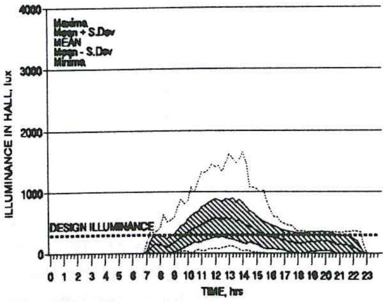
BUILDING COST

Designing for the sun did not significantly increase capital costs. The cost of the building was £519/m^2 (adjusted to 1990 prices) and this was average compared to a sample of 44 other sports or recreational buildings.

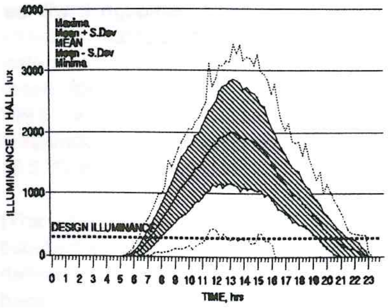
The velarium lighting diffuser cost £14,500, but this is a necessary part of the main lighting installation if glare is to be avoided.

Users of the hall often experienced much higher light levels than would be the case in a sports hall without daylighting. Two mean seasonal profiles of internal horizontal illuminance are shown below. One for winter: one for summer. They show the mean and the extreme values experienced through the day. The shaded regions show where about two thirds of the data lay.

WINTER



SUMMER



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 whole building. The total fuel demand is reasonably low when compared with other recreational buildings, but there is scope for the space heating fuel to be reduced by lowering temperatures. It is space heating which dominates the fuel demand at over 70% of total use and contributes to heating season over-heating.

SOLAR DESIGN ★★★★

The design provides excellent daylighting within the hall. The roof-lights and velarium diffuser project a smooth profile of illumination on to the floor. The availability of daylight has displaced a large amount of electricity. The design is responsible for over-heating in the summer, but this is a problem more because of the lack of any substantial extract fan; ventilation is poor.

AMENITY ★★

The internal appearance was well liked and there were no reports of glare being a problem when playing sport. Sufficient light was provided, but many users preferred the artificial lighting on because it did not vary. There was a general dissatisfaction with the high temperatures through the year and particularly in the summer. Many complained of the air being stuffy and that there was a lack of ventilation.

COST ★★★★

The cost of the sports hall was quite average. There was clearly no overall cost penalty for the passive solar design. A feature of the hall is the roof-lights which would not be required on a conventional sports hall. They cost no more per square metre than the opaque part of the roof and allow much higher light levels than could be afforded using artificial light. The energy saved by the design is worth about £1,900/year.

COMPOSITE ★★★★

Brune Park's design halves the annual need for using artificial lighting. The quality of the light is generally very good. It is unfortunate that there is insufficient ventilation and that the heating system is apparently set too high. There is considerable over-heating *for a sports hall* throughout the year. There are some simple measures that could be taken that will improve the environment it offers users.

ASSESSMENT

CONCLUSIONS

The design is highly recommended. At no overall extra cost a well lit sports hall has been produced which need only use the lights half the time compared to a traditional opaque design.

When the hall was assessed, the space-heating system appeared to be set several degrees too high. This is easily rectified and would solve much of the over-heating problem in the heating season.

New buildings are often tightly constructed to save energy, but then insufficiently ventilated to maintain air quality and allow cooling through air exchange with outside. There is perhaps a tendency to avoid using *bought* energy to reject any unwanted *free* energy from the sun. In fact in a passive solar building such as Brune Park the amount of electricity that would be required to vent excess solar gain in the summer would be substantially less than the amount the design saves in lighting energy in a year.

LESSONS & RECOMMENDATIONS

The comments below are extracted from the full technical report on the monitoring of the Brune Park sports hall:

1. The design allows a substantial entry of solar energy into it and needs to incorporate some method of equivalent heat rejection for when it is not needed.

2. Given sufficient conscientiousness and collective agreement, manual switching of lights in a highly daylit building can realize a large proportion of the potential saving in energy.

There are several things that can be done to improve conditions:

3. The space heating system should be investigated to help reduce over-heating. Either the set-points are simply too high, by three to five degrees, or the responsiveness of the heating system needs to be programmed into the heating controller.

4. The extract fan in the roof-space should be replaced with a much more powerful one. This should be controlled by a thermostat rather than by a timeclock. The fan should be used to cool the building over-night, when necessary, to take advantage of the cooler night-time air and prepare the hall for the following day.

5. There should be some larger apertures at low level to allow ingress of fresh air. This would help improve the air quality, reduce over-heating and avoid the fire-doors having to be propped open in hot weather.

FURTHER INFORMATION

EPA Technical Report No. 1160/18 on the Brune Park sports hall, available from ETSU.

The building's designers, Jackson Greenen Down & Partners, Winchester.

EPA Technical Report No. 1160/19 on the Mountbatten sports hall, available from ETSU.

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

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 was funded by the former Department of Energy through its Energy Technology Support Unit at Harwell. The R&D was carried out by Databuild (Birmingham) and UWCC (Cardiff). The views contained in this document are those of the authors.
EPA of the Brune Park sports hall 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.

THE BRUNE PARK SPORTS HALL, GOSPORT

EPA NON-DOMESTIC TECHNICAL REPORT

RESEARCH RESULTS

DATABUILD LTD
March 1992

Main author: R.Watkins

Co-authors: A.Seager, J.Palmer, P.Shaw

CONTENTS

WHOLE BUILDING

PASSIVE FEATURES

PRELIMINARIES

Energy Performance Assessments are preceded by a preliminary investigation of a prospective EPA building. There are two quite different objects of this EPA component.

A building is investigated using all available knowledge that can be gathered quickly so that a decision can be made on how worthwhile an EPA of the building would be. If the building passes this preliminary assessment then with the owner's permission a full EPA is set in train. The information gathered in deciding whether to proceed to an EPA is written up and extended as part of the assessment of the building. This includes a design statement which reports the views of the designer and the context within which the building was planned and a specification for the EPA. It is extremely useful in developing an understanding of the system at an early stage.

The findings of the Preliminaries' component of Brune Park Sports Hall are reported here. It should be remembered that conclusions reported in this section may be modified or rejected later on in the EPA proper.

BUILDING DESCRIPTION:

Summary

Hampshire County Council commissioned the building of a sports hall attached to Brune Park Secondary School near Gosport. In line with the council's strong interest in energy efficiency, the hall was required to be designed to exploit natural light for illumination. The roof includes continuous rooflights at the ridge which transmit light down through a diffusing cloth to the hall below.

The building was completed in 1987 at a cost of £500,000. It provides a sports hall 30m x 16m, with a viewing gallery, weight-training room and changing rooms etc. around it. The gross floor area is 940 m^2.

Project Description

For several years Hampshire County Council has experimented with the design of sports halls in an effort to provide good internal illumination. They have experimented with buildings relying solely on artificial lighting and in recent years have incorporated daylighting in several different designs.

This sports hall was commissioned to provide facilities for Brune Park secondary school and for the community outside school time. The council appointed Jackson Greenen Down & Partners as the architects and additionally considerable design advice was given by Mr. D. Poole at the council acting as daylighting consultant.

The hall provides 500 m^2 of playing area, with changing rooms, a weight lifting room, etc. around it. Above the playing area an awning of woven plastic cloth diffuses light from rooflights at the roof ridge. The rooflights coupled with the use of this velarium, or awning, were the main techniques used to provide uniformity of daylighting and artificial lighting. Artificial lighting is provided above the velarium.

Site and Location

Brune Park sports hall is situated adjacent to a main road in the grounds of Brune Park secondary school about 15 miles south east of Southampton. The location is urban with Fareham to the north and Gosport to the south. The hall has some mature trees towards its southern end.

The site is located on latitude 50.8° at 10m above sea level. Long term external temperature and degree days are shown in Table 1.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
External temperature	4.7	4.9	6.7	9.2	12.4	15.4	17.2	17.0	15.0	12.0	7.9	6.0	10.7
Degree days	343	318	296	230	144	72	38	44	79	153	252	304	2273

Table 1. The long term external temperature(for Southampton) and degree days (for the southern region).

The long axis of the building points 28° away from a north-south line.

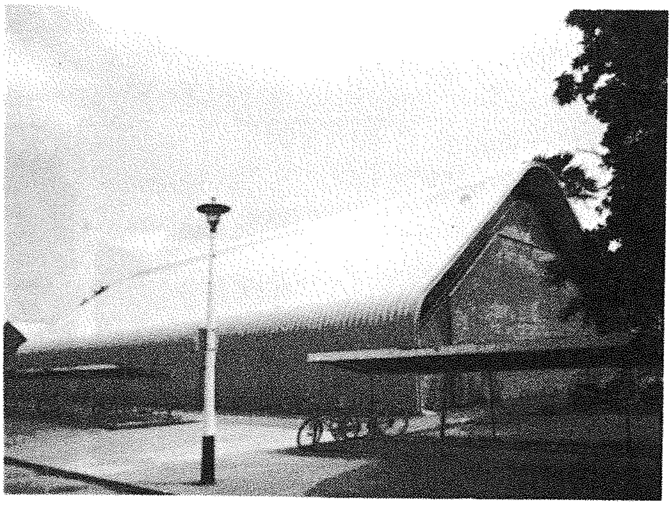
Building Form

The cross section of the hall is roughly "A" shaped with the horizontal link of the "A" formed at high level. The hall is rectangular with changing rooms, etc. along its longer sides; male and female opposite. About half the northern end is glazed with the boiler house projecting outside and centrally placed. The southern end is glazed only next to the large eaves overhang. The roof has glazing on either side of the ridge extending the length of the building.

There is an observation gallery inside at the northern end approached by spiral staircases. The covered link to the older sports building is here also.

At a height of about 8m above the floor level a plastic cloth is stretched across forming a velarium to diffuse the light from the roof and electric lighting. Access for cleaning etc. of the velarium is gained by ladder from the observation gallery up to a service catwalk above.

The space in the hall allows for up to four badminton courts to be used simultaneously.



Picture 1. Brune Park Sports Hall - the south west corner.

Plans of the building are shown in Figures 1 to 4.

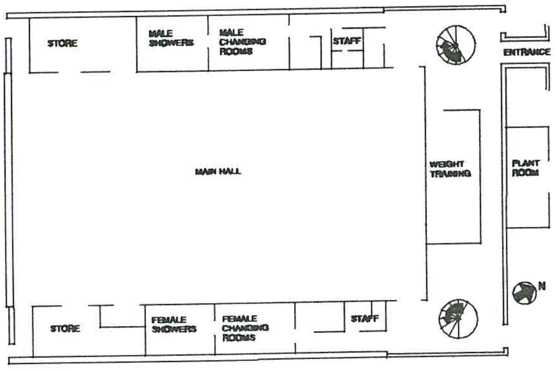


Figure 1. Ground floor plan.

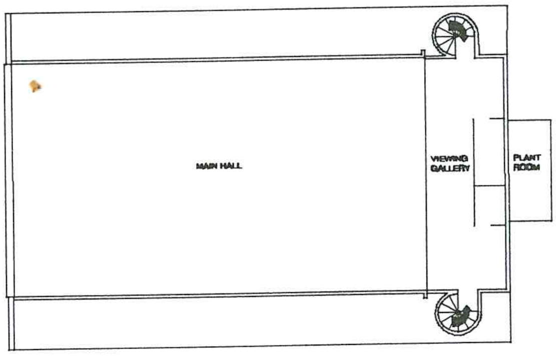


Figure 2. First floor plan (at observation gallery level).

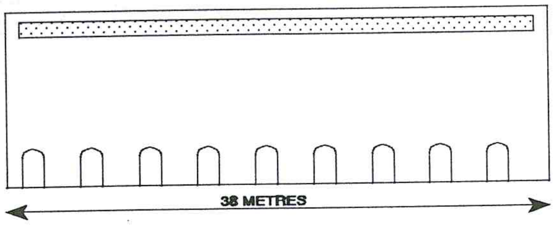


Figure 3. West facing elevation.

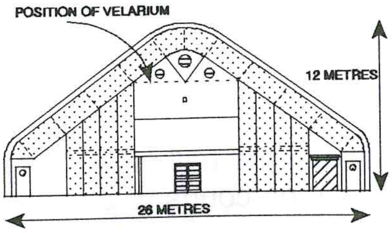
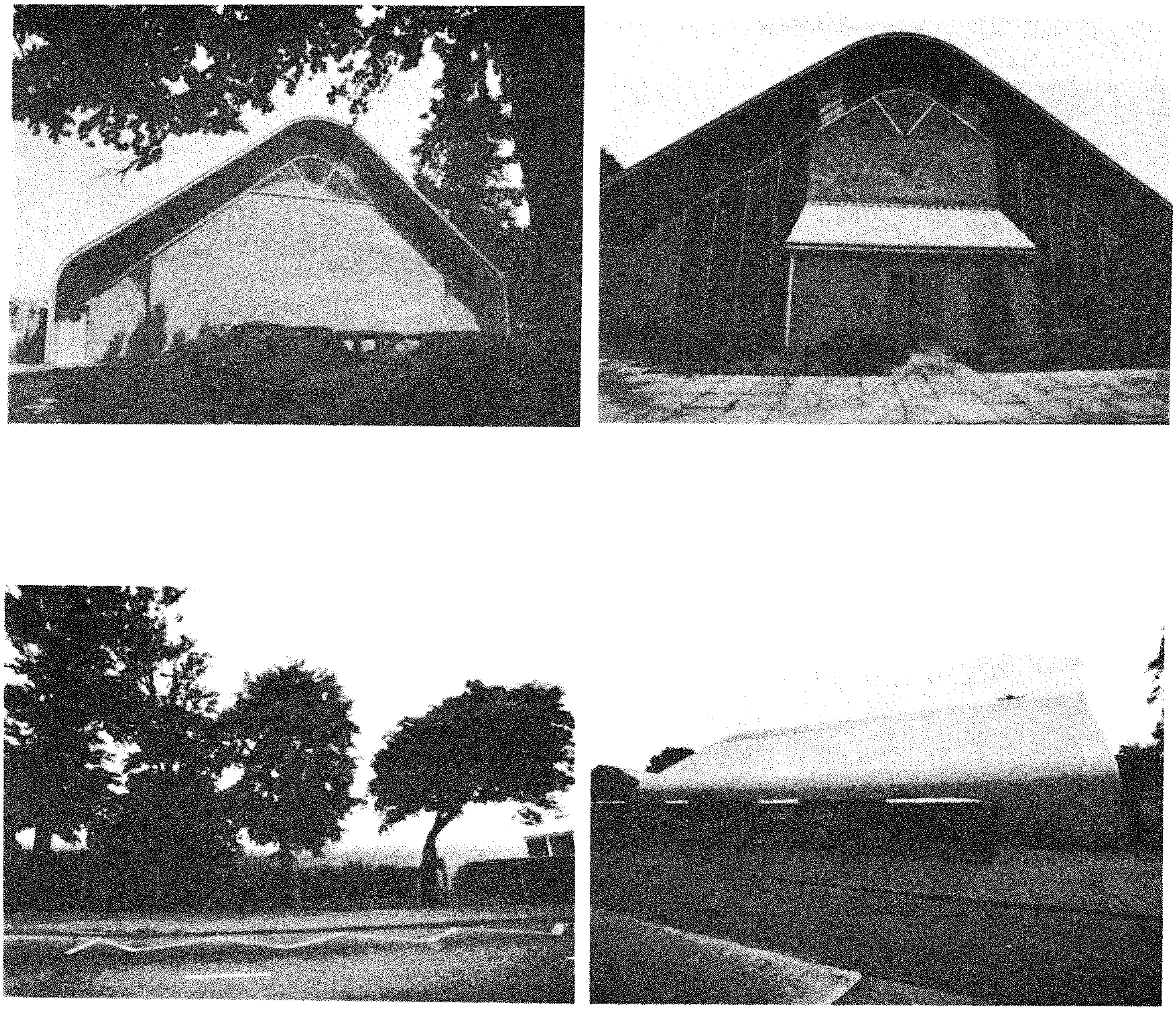
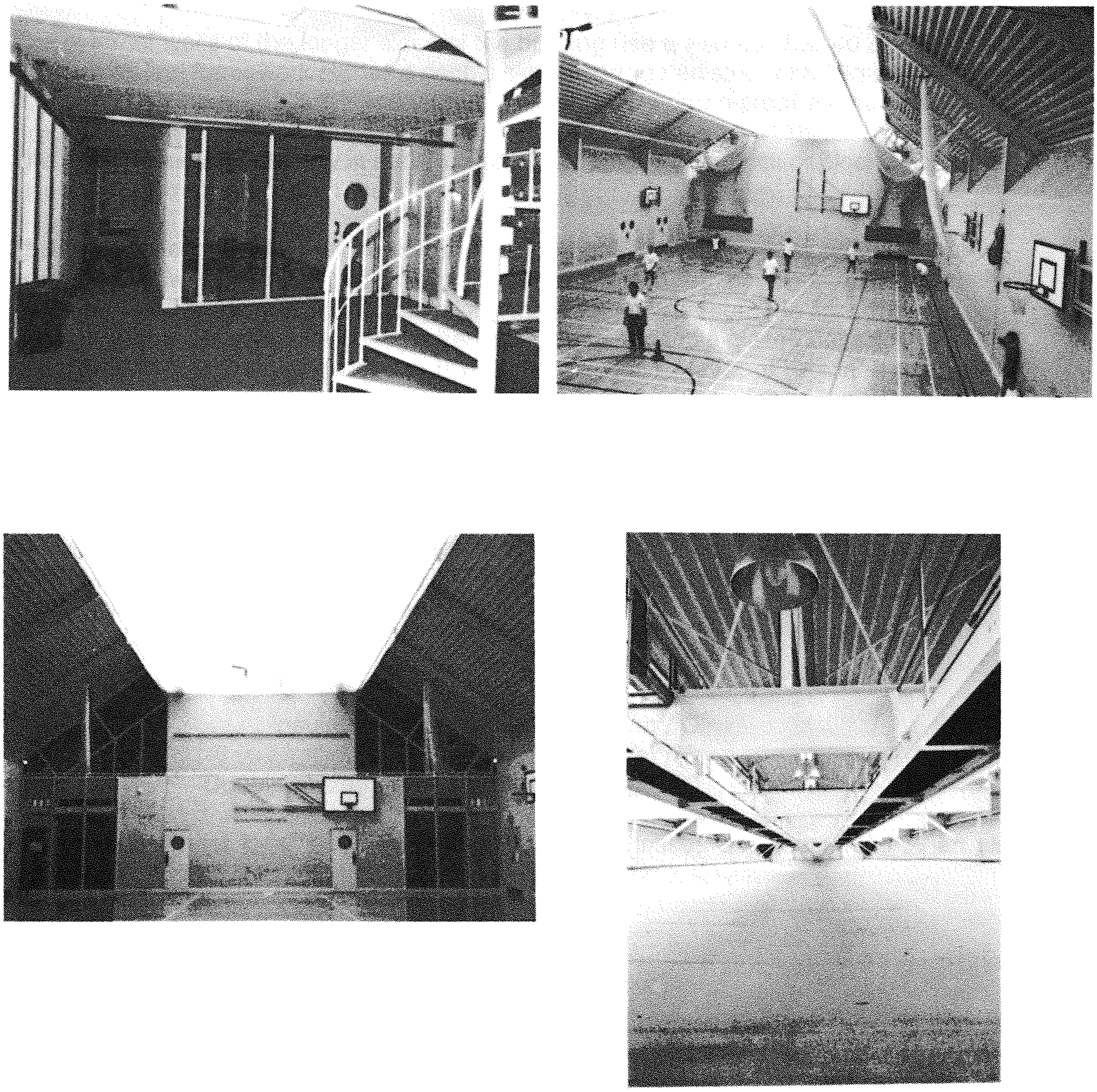


Figure 4. North facing elevation.

Picture 2. FOUR EXTERNAL VIEWS OF BRUNE PARK SPORTS HALL: (CLOCKWISE FROM TOP LEFT) N, S, E, W.



Picture 3. FOUR INTERNAL VIEWS OF BRUNE PARK SPORTS HALL: (CLOCKWISE FROM TOP LEFT) THE MAIN ENTRANCE LOBBY; VIEW LOOKING NORTH SHOWING VELARIUM; VIEW LOOKING SOUTH SHOWING THE VIEWING GALLERY; VIEW ABOVE VELARIUM SHOWING LAMPS AND ROOF LIGHTS.



Building Construction

The ground floor is made of a 95mm floor screed (which incorporates heating pipes) on a polythene membrane on 25mm insulation on a 150mm concrete slab. There is a wooden floating floor on top of this.

The external walls of the longer sides of the building use a *Plannja Top 40 Energy Roof System*; a steel framework carries a double skin of corrugated steel with 75mm insulation between. The insulation is divided (50mm + 25mm) by a damp-proof membrane.

The gable external walls vary in construction. They are of either brick or block with 40mm insulation, or in-fill panels on the steel frame.

The roof is a continuation of the corrugated walling. Either side of the ridge, 3m down, are 1.8m wide triple glazed plastic rooflights manufactured by *Brett Martin Roofing Products Ltd.* These run continuously along the length of the roof. The light transmission of each glazing sheet is 83% giving a transmission for the triple glazed units of 57%. The outer glazing layer is profiled and is bonded to the middle layer at regular intervals. In plan, the rooflights occupy 17% of the roof area of the playing area of the sports hall.

The gable walls include substantial glazing. At the southern end, continuous 1.5m wide double glazing runs beneath the eaves down as far as 3m above ground floor level. The northern end has the same glazing under the eaves, but this is augmented by two 4.5m widths of the gable wall being completely glazed.

The principal heat loss coefficients are as follows:

Floor: 0.2 $W/m^2/^\circ C$.
Wrap-over Wall/roof: 0.5 $W/m^2/^\circ C$.
Insulated masonry walls: 0.5 $W/m^2/^\circ C$.
Roof-lights: 2.7 $W/m^2/^\circ C$.
Double glazed gable windows: 3.0 $W/m^2/^\circ C$.

The envelope heat loss is 1.7 kW/°C for fabric heat losses and (assuming ½ an air change per hour) 1.2 kW/°C for infiltration and ventilation lossses.

Building Services

Space heating to the building is provided by two *Seagold* gas-fired condensing boilers each rated at 84.4 kW input. The main hall, weight-training room and perimeter changing rooms are heated by hot water from the boilers flowing through plastic pipes in the floor. The distribution of space heating is zoned.

Domestic hot water is provided from a *Beaumont Energy Master* gas boiler rated at 110 kW input and 87 kW output. This heats water in an integral storage tank.

The flue gases from the three gas boilers are drawn laterally into a manifold and led from the boiler house through the wall into a duct in the sports hall. This exits at high level. The path for the gases necessitates a flue dilution fan, rated at 1.1 kW.

At high level, above the velarium, there is a 0.14 kW extraction fan mounted in the north gable and designed to be switched on by a thermostat to avoid over-heating in the roofspace.

The main artificial lighting is provided by 33 high pressure mercury halide lamps rated at 400 W each. These are mounted in reflectors and suspended on chains 1.4 m above the velarium pointing downwards. Most other lighting, not in the main hall, is provided by fluorescent tubes though there are some spot-lights in the entrance lobby area.

The changing rooms and showers have no windows and receive ventilation air from the sports hall. About half way along the length of the hall at 3m height there are disguised special "dummy" breeze blocks (in the separating wall) which have a 12 mm annular gap. Forced ventilation is also provided in the weight training room.

The installed space heating capacity is 180 W/m^2 (whole building, gross floor area).

The installed lighting capacity is 19 W/m^2 (whole building, gross floor area).

Passive Systems

The building has been designed to allow daylight to enter the space. This is not typical of sports halls which are usually of opaque design. Light enters the Brune Park hall through the rooflights and from the partially glazed gable ends. The light is then diffused by the velarium that is stretched across the upper part of the hall. See Figure 5.

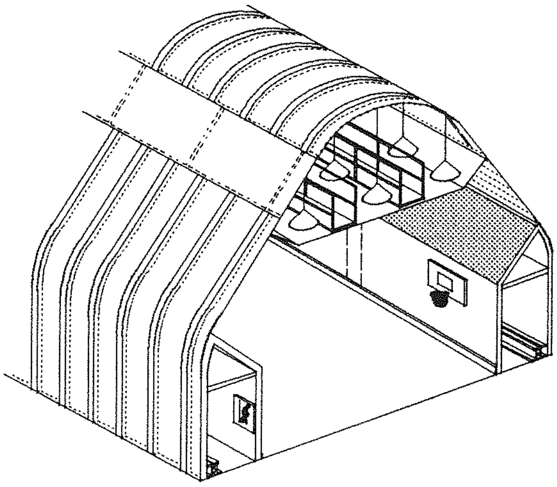


Figure 5. The main passive solar feature - continuous rooflights and diffuser.

This is the passive solar feature. There is no automatic control of the artificial lighting system; the exploitation of the availability of sunlight has been left to human control. The only control system that was thought necessary was for a thermostatically controlled extract fan to be fitted at the northern gable end of the roofspace.

The cloth which forms the velarium, about 8 to 9 metres above floor level, substantially reduces the light received in the hall (by about 40%), but simultaneously presents a more evenly lit surface to occupants below. The resultant effect will be explored in detail later.

DESIGN STATEMENT:

Aims and Intentions

The requirements of Hampshire County Council were for a sports hall to be designed that would fulfil the sporting needs at the school and be within budget. There was also a requirement for the design to exploit natural light for illumination. The council has long had an interest in energy efficiency and daylighting in sports halls. Considerable support in the daylighting part of the design was received from the council.

The architects drew upon their experience with a previous sports hall, at Fareham, which had daylighting and a diffuser. Because that was thought to work well, they wished to adopt a broadly similar design.

The daylighting consultant (Mr. D. Poole) sought to eliminate disability glare, use the illumination of vertical surfaces as the main illumination criterion and provide a pleasing space. Vertical illumination levels were chosen in gauging the effectiveness of daylighting at the design stage because it was thought that these over-ride the need for horizontal illumination in any sports hall. The consultant drew upon the experience of the first sports hall built in Hampshire that emphasized these criteria: the hall at Henry Cort School. This was similar to the final Brune Park design except that its axis runs east-west and it has a rooflight only on the north side.

Hampshire County Council have in fact been instrumental in building many sports halls which incorporate daylighting techniques. They are listed here in the chronological order of the development of the design, starting in 1981:

Henry Cort School*	Fareham
Romsey School*	Romsey
Fordingbridge School	Fordingbridge
Bridgemary School*	Gosport
Mountbatten School	Romsey
Brune Park School*	Gosport
Brighton Hill School	Hampshire

* The form of these sports hall is similar to that of Brune Park.

The daylighting consultant has expressed the following thoughts on the design of sports halls:

> *"Two factors that beset large surfaced volumes such as sports halls are lighting and acoustics. It has long been accepted practice to have a completely black box, electrically lit and to bear with long reverberation times, echoes and standing waves as a normal function of the space.*
>
> *This need not be so. Electric lighting systems are frequently poor whilst it is possible to provide a daylighting system that is good. Likewise the acoustics. Only a small section of the side walls needs to be vertical. Fareham sports hall demonstrates one solution to this; a lot of absorbent above the playing area and inclined surfaces that do a great deal to improve the acoustic*

> *quality. The north light, filtered through the large velarium provides a very large low brightness light source which with the light provided to the walls and floor produces both good background and task illumination."*

The architects' design of the shape of the roof was influenced partly by that of an ice rink (at Oxted). The buildings adjacent to the sports hall are all quite low and the rolled-over roofing system was a way of helping the building to blend in better with the site. The angle of the roof to the horizontal was kept low (36½°) and the apex was rounded off.

The space heating system was designed using a consultant from the council (Mr. A. Dowdell). The designers wished to avoid radiant heating strips and this led to the use of underfloor heating using plastic tubing embedded in the floor screed. Because lower temperature heat could be used, it was thought that this was an ideal application of condensing boilers. The underfloor heating was zoned with separate thermostatic temperature controls for each. The set point for the sports hall proper was designed to be between 16°C and 17°C with a higher setting for the changing rooms, showers, etc. To avoid tampering, all thermostats were enclosed in secure boxes; the system was not designed so that individual zone thermostats could be adjusted by the caretaker. However, a weather compensation control provided a means to raise or lower the temperature of the primary water pipes and thus maximum output.

Priorities

Priority was given to the provision of daylighting. The architects are keen to provide light and airy buildings. They wished to avoid a visitor feeling he was entering a box. It was important that there were views to outside and that spectators could look in at more than one level. The glazing in the gable ends has this primary role, although it also allows some illumination from the north and south.

> *"Daylighting was more important than energy efficiency as far as we were concerned."*
>
> *"As a practice we like to have "airy" buildings and well lit buildings and big over-hangs if we can, particularly with schools, and that all goes along with the pattern of solar heating."*
>
> *"We tried to open up the whole feeling that sports halls should be a box - we don't think they should be."*
>
> -Architect

It was thought very important to get the colour of the inside surfaces of the hall right. A particular shade of green was chosen.

Difficulties in Realizing Intentions

The design went over budget and cost savings were sought. A perforated version of the *Plannja* roofing system had been specified to reduce echoing, but this was changed to the standard one.

The architects did not use any computer models themselves in designing the hall. They modified their design for daylighting according to advice from the consultant. For instance, they had intended the rooflights to be twice as wide as finally built, but were advised that this would have been excessive.

Over-heating in the roofspace above the velarium was seen as a possible problem. An extract fan controlled by a thermostat was put in as a precaution. Originally two fans - one at either end of the roofspace - were specified, but this was reduced to one to lower the cost.

> *"We knew it was going to get hot up there* [above the velarium] *and it* [the extract fan] *was more of a precaution."* *-Architect*

EPA SPECIFICATION:

Goals

There are two main goals: an assessment of the overall performance of the building and an assessment of the passive solar component of the building. Overall performance attempts to show in basic fuel-bill terms what the energy requirements are and how they compare with other buildings. It also checks that the building's environment is amenable to its occupants.

The second goal attempts to find a demonstrable connection between reduced energy use and the sun. This seeks to avoid the erroneous replication of a passive solar design feature when the energy savings may in fact be coming from extra insulation, better management of heating and lighting or more efficient boilers, etc.

Two testable hypotheses have been defined for Brune Park sports hall's energy performance assessment.

H1. The design allows natural daylight alone, when available, to provide adequate illumination.

H2. Artificial lighting is used less as the availability of daylight illumination increases.

A further goal was for some appropriate data to have been collected so that in the event that the hypothesis should be rejected some light might be shed on the reasons for rejection. There can, for instance, be institutional or management reasons why the apparent potential for energy savings is not realized in practice.

Measurement of Energy

The boundary of interest for the hypotheses is the sports hall itself, neglecting the equipment rooms, changing rooms, etc.

H1 and H2 require that the sun, and internal illuminance be measured together with the use of the main lights.

As part of the overall reporting of the building's energy use, the gas used for space heating and hot water is required, as well as the electricity used in the sports hall.

The building is not designed to selectively receive daylight from a particular direction and this dictates that the total radiation on a horizontal surface needs to be monitored. Total solar radiation is a sufficient indicator of the available sunlight impinging on the building.

To aid the assessment of the space heating needs of the building some internal temperatures are needed together with the external temperature.

Measurement of Amenity

A fundamental part of the EPA is to assess the degree to which the building offers an attractive comfortable environment for its users and how well they find it works for them. This amenity value is measured in several ways in this sports hall.

Questionnaires need to be filled in by the adult users of the hall to test to what extent they are satisfied with the hall in general and its lighting in particular.

Temperature measurements are needed to assess over- or under-heating within the main space.

The amount of light that is available in the hall needs to be measured to allow correlation with users' comments. For a multi-purpose sports hall there is probably no ideal single measurement of lighting that can be used, but for the purpose of the energy performance assessment the light can be sufficiently characterized by measurements of the light falling on the floor and a wall.

The actual light falling from all angles on to the floor, or just above it, cannot practically be measured directly because of the nature of the use of the space. This is unlike, for example, the measurement of light falling on to a desk - the working plane -in an office. To circumvent the problem, the light reflected upwards from the floor needs to be measured, most easily with sensors hanging from the ceiling and pointing directly down.

The light falling on to a vertical plane can only really be measured at the walls and a sensor needs to be sited to avoid direct sun.

The above data requirements (for Measured Energy and Amenity) led to an instrumentation and logging schedule that is detailed in an appendix. Results and discussion are presented later in the main text.

Modelling of Energy

Modelling of non-domestic buildings allows the evaluation of a building under prescribed conditions. In EPAs both steady state and simulation models may be used. The former can allow EPA buildings to be compared with others and the latter may be used to test individual features of a building and the effects of alteration to the design. However, for this sports hall, whose EPA emphasizes the lighting rather than heating energy used, useful modelling has been considered to be beyond the scope of this study.

The resources available do not allow for extensive simulation modelling with daylight computer programmes - nor are these thought to be required for a proper assessment of this building.

Modelling of Cost

Costs are not strictly modelled. The term is used to reflect a need to make the costing of a particular building comparable with others, in the mind of the reader. The break-down of costs is based on actual costs, but with these adjusted to 1990 prices by ETSU's Cost Advisory Service, performed by Davies, Langden and Everest.

The CAS need to report any cost implications specific to the passive solar design of the building. These should cover both capital and maintenance aspects of the design.

Reference Energy

An important part of the EPA is the comparison of the building's energy consumption with that of others. Though no other building will have exactly the same use, reasonable parity in type of use can be sought. The ideal comparisons are other conventional buildings used for similar sports purposes. Additionally, various bodies have produced energy targets or indicators to help designers and energy managers. These may be a recommended target consumption based on running a building in a very definite way. (A model may be used to predict this consumption.) They can also be indicators derived from studies of real buildings.

The main requirement is to provide interested parties with appropriate points of reference when judging Brune Park sports hall.

The Energy Efficiency Office produces tables as a guide to energy consumption in different economic sectors.

There are many other sports halls and these may provided comparison data. However, the normal design of a sports hall has essentially excluded windows and so a good estimate can be made of the savings on lighting energy by comparing the running cost with that for the lights being on more or less continuously for the same period of use.

Reference Costs

The costs of the buildings used for comparing energy consumptions need to be obtained for comparison with Brune Park. This may prove difficult and general published guidelines for different sector's costs may have to be used. ETSU's Cost Advisory Service provides these data.

MEASURED AMENITY AND ENVIRONMENT

Environment and an occupant's response to it have no less importance than the energy consumption used within the building. Energy profligate paradises and low energy nightmares need identifying. Buildings provide amenities whose value is assessed in an EPA. Their value at Brune Park Sports Hall has been assessed in four ways.

Introduction

The sports hall is in some ways used by two distinct groups. It is used by children in the secondary school in PE classes, etc., and it is used (predominantly by adults) by the local community for a variety of activities. The external group generally use the hall at a different time, most frequently in the evening, from the internal users with the consequence that ambient light levels are generally less. The external group also pay directly for the use of the hall. Additionally, an important variable -the actual use of the sports hall - is known for the external group, but with less precision for the internal one. It is convenient, therefore, to sometimes treat the two groups separately. The two uses will be referred to as **school use** and **non-school use**. The methods and data used for assessment are introduced briefly below.

140 questionnaires with attached reply-paid envelopes were distributed by the caretakers on Databuild's behalf to various adults using the sports hall; children's views were not directly collected. The PE teachers' views were included in the distribution and some of them were also interviewed. Fifty six questionnaires were received back. The questionnaires were filled in during May and June 1991. (The questionnaire itself appears as an appendix.) Most respondents played either badminton or netball. An abbreviated profile of the sample appears below. A complete listing of all data appears as an appendix.

Respondents' main use of the hall:

Badminton : 37
Netball : 10
Keep-fit : 1
Basket ball : 1
Rhythmic gym : 1
PE teachers : 4
Unrecorded : 2

All but one respondent used the hall at least once a week. About 80% of respondents used the hall in the evening (at 18.00 or later). The median age of the respondents was 31; age ranged from 16 to 64. 43% of the sample were male: 57% female. 20% of respondents were in charge of an activity.

Reactions from key operators of the building have also been accumulated during the monitoring exercise.

Temperatures in the hall have been analysed to assess the incidence of departures from recognized temperature boundaries.

Two detailed tests were carried out measuring the illumination levels both in the daytime on an overcast day and at night using artificial lighting. These measured the level and uniformity of the illumination.

WHOLE BUILDING:

Occupants

General Reactions to the Building

Table 2 below shows the replies given to some general questions about the inside of the sports hall. Median responses are shown shaded, as they are throughout this section. Where a median response falls between two categories, both are shaded. The replies to certain questions, e.g. relating to thermal comfort, are discussed later in separate sections; the replies to all the questions are shown here as this is how the questions were asked.

On a scale of 1 (very dissatisfied) to 7 (very satisfied) 75% of the sample rated the internal visual appearance 5 or above. There was a similar or better satisfaction with the colours of surfaces in the hall.

Respondents were mostly satisfied with the type of floor (64% of the sample rating it 5 or above).

When asked to give their general view in terms of satisfaction with the inside of the hall, 62% gave a rating of 5 or above. 17% gave a rating of 3 or below.

	Very dissatisfied						Very satisfied	
	1	2	3	4	5	6	7	n
Its visual appearance	0	2	5	7	16	8	7	55
Its temperature in summer	29	19	2	3	0	3	0	56
Its temperature in winter	6	4	8	8	10	15	5	56
Its air quality	16	8	13	11	2	4	2	56
Its lighting	1	2	6	11	8	15	13	56
The colour of its floor	2	1	0	7	13	16	16	55
The colour of its walls	0	4	2	8	12	17	13	56
The colour of its ceiling	0	1	4	6	13	17	13	54
The type of floor	4	4	2	10	10	15	10	55
What is your general view?	1	4	4	11	14	12	6	52

Table 2. Respondents' replies when asked to rate their satisfaction with various aspects of the inside of the hall. Median responses are shown shaded.

Users of the hall were asked to state what activities they engaged in when in the hall and to identify their *main* activity. They were then asked how suitable they considered the hall for their main activity. See Table 3 below. Most people reported that the hall was suitable for their main activity (68% of the sample rated the hall at 5 or above).

	Not suitable at all						Thoroughly suitable	
	1	2	3	4	5	6	7	n
How suitable is the hall for your main activity?	0	2	6	10	13	14	11	56

Table 3. Respondents' replies when asked to rate how suitable the hall was for their main activity. The median response is shown shaded.

The median ratings for badminton players and netball players were identical, at 5.

Thermal Environment

Users of the hall were asked to rate their satisfaction with the internal temperature in summer and winter. See Table 4 below. There was great dissatisfaction with the temperature in summer. 48 out of 56 respondents gave it the poorest or next poorest rating and the median rating was 1.

The respondents had more mixed views on the winter time temperature, though satisfaction ratings were higher. 54% of the sample gave a rating of 5 or higher. However, a substantial number were quite dissatisfied as can be seen from the table.

	Very dissatisfied						Very satisfied	
	1	2	3	4	5	6	7	n
Its temperature in summer	29	19	2	3	0	3	0	56
Its temperature in winter	6	4	8	8	10	15	5	56

Table 4. Respondents' replies when asked to rate their satisfaction with the temperature in the hall. The median responses are shown shaded.

Most respondents said that the space was too warm and there were many comments on this; none said it was ever too cool.

"The air-conditioning seems to be non-existent. It is too hot in the winter and unbearable in the summer." -Badminton player
"Far too hot in summer..." -Netball player
"The heating seems set a little too high; we never feel cold in there, nearly always it's too hot." -Netball player
"Its worst aspect is temperature in the summer, which can make it unusable."
"Generally for any aerobic sport the temperature is too high." -Netball player
"Air conditioning ineffective in summer." -PE teacher

Several people said that air-conditioning was *required* and others suggested air-conditioning would be beneficial.

Internal temperatures were measured continuously in three places during the monitoring: at either end of the sports hall at low level (3m) and just above the sailcloth at high level. To support the comments from respondents on temperature, the year's quarter hourly data have been processed to generate seasonal daily profiles. See Figures 6 to 9 in which the mean of the two low level temperatures has been used. The figures show the mean temperature through the day together with the extremes recorded during each season. To indicate the distribution of the temperatures a band of one standard deviation width either side of the mean has been shaded in. (The temperature lay within this band for roughly two thirds of the time.)

The four seasons were defined as three monthly periods starting with Winter as December, January and February.

The profiles show the broadening of the distribution of temperatures towards the summer and the increasing incidence of (for a sports hall) very high temperatures.

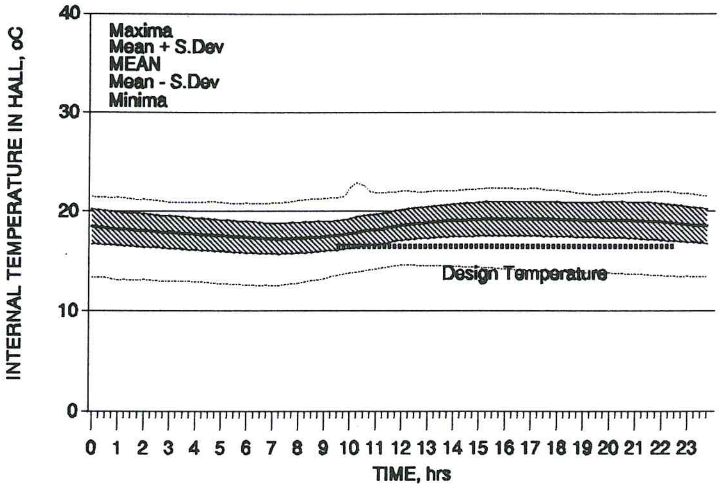


Figure 6. Mean Seasonal Profile of Internal Temperature: **WINTER**

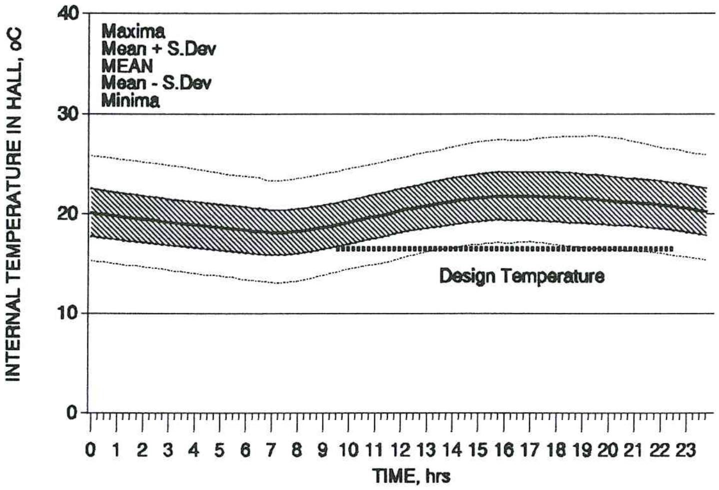


Figure 7. Mean Seasonal Profile of Internal Temperature: **SPRING**

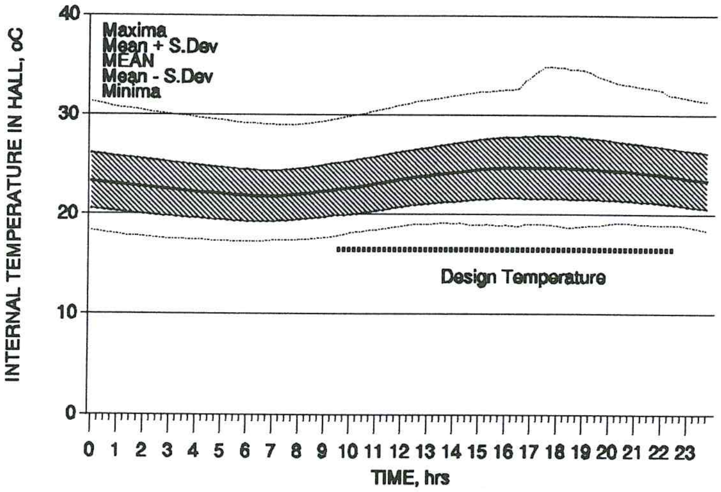


Figure 8. Mean Seasonal Profile of Internal Temperature: **SUMMER**

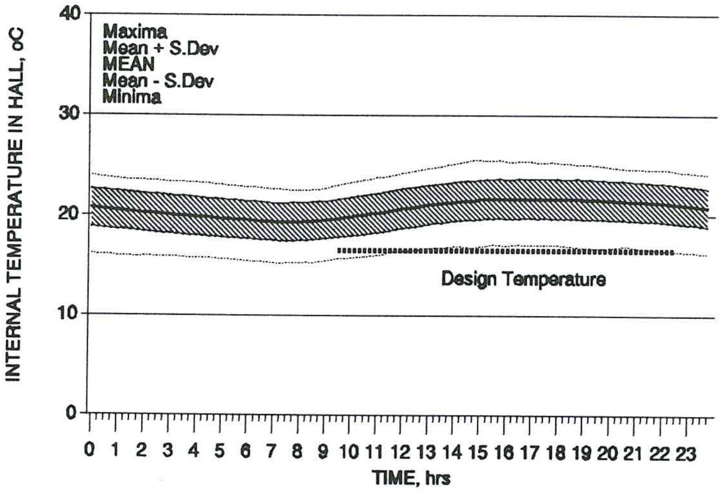
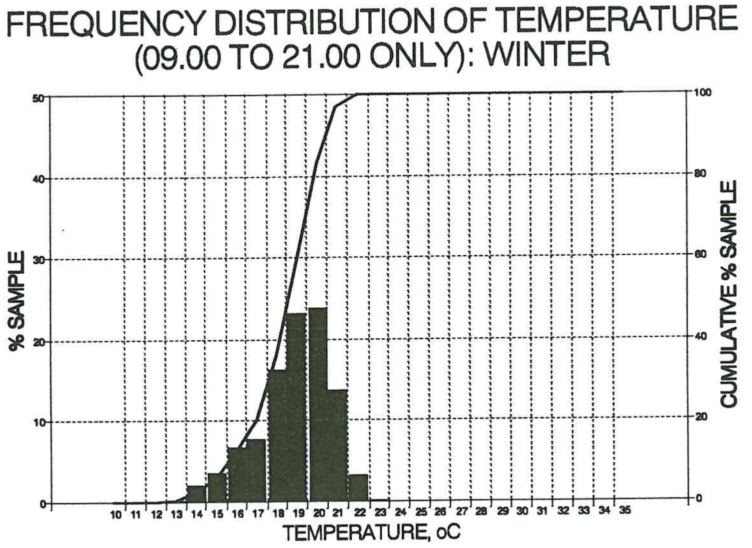
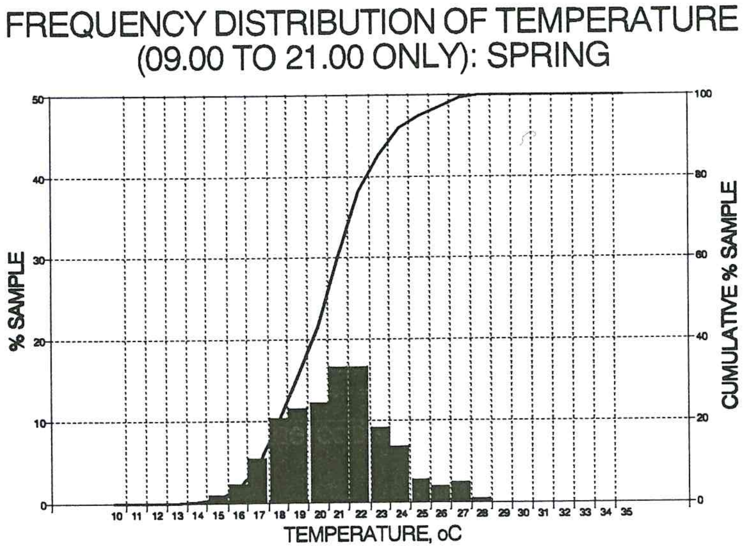


Figure 9. Mean Seasonal Profile of Internal Temperature: **AUTUMN**



FREQUENCY DISTRIBUTION OF TEMPERATURE
(09.00 TO 21.00 ONLY): WINTER

Figure 10. Frequency Distribution of Internal Temperature: **WINTER**



FREQUENCY DISTRIBUTION OF TEMPERATURE
(09.00 TO 21.00 ONLY): SPRING

Figure 11. Frequency Distribution of Internal Temperature: **SPRING**

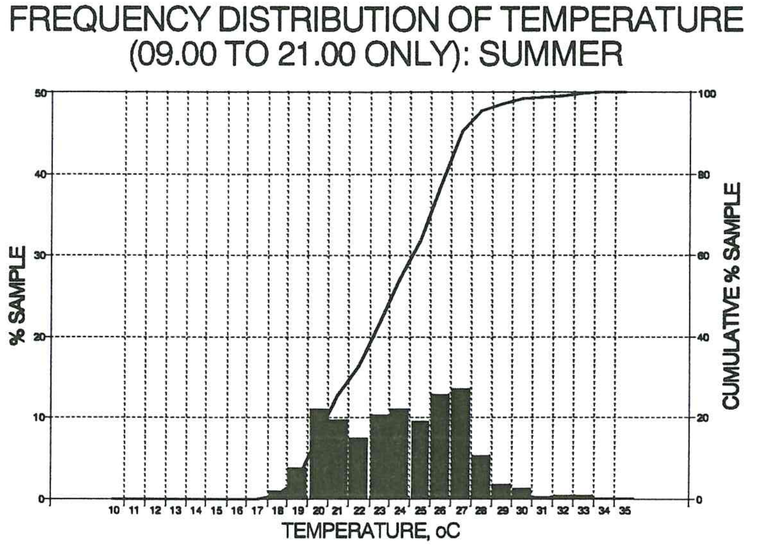


Figure 12. Frequency Distribution of Internal Temperature: **SUMMER**

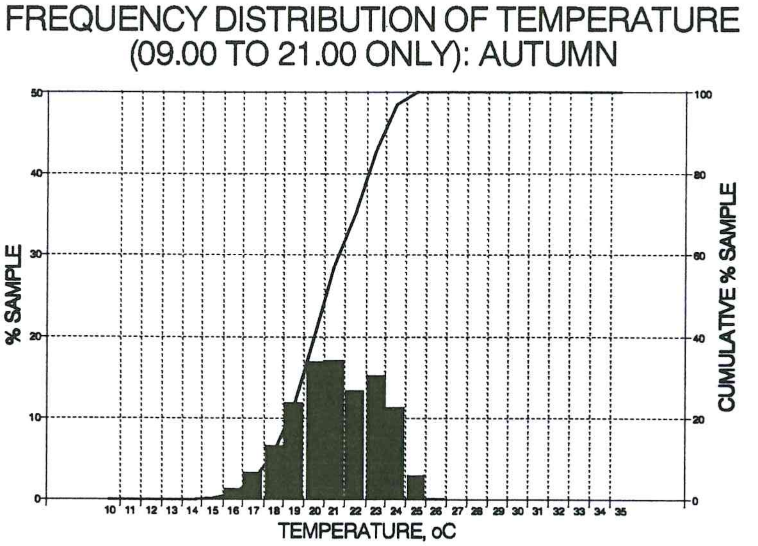


Figure 13. Frequency Distribution of Internal Temperature: **AUTUMN**

The frequency distributions of temperature for each season are shown above in Figures 10 to 13. Night-time data are excluded here.

The measured distribution of temperatures should be considered in relation to some comfort level or band. Comfortable temperatures decrease as a person's activity increases and this hall is used for a variety of purposes - and activity levels. The sports council recommend a range of temperatures (12°C to 20°C) for different activities. However, two temperatures are particularly worth considering: 16°C as the general recommended temperature for badminton and 20°C as the maximum recommended for a sports hall (for gentle keep-fit activity).

The design intent was that the space heating system be set to maintain a temperature comfortable for the *more active* users and it therefore assumed that the desired temperature was no higher than 16°C to 17°C. (See the *Design Statement* in the *Preliminaries.*) This is consistent with sports council advice.

Table 5 shows the percentage of time that the internal temperature exceeded the recommended temperature for badminton and the maximum advised for a sports hall for each season. (16.5°C and 20.5°C have actually been used as this was more convenient.) The measured internal temperatures support the comments from the respondents on over-heating.

	%Time that INTERNAL temperature was above 16.5°C	%Time that INTERNAL temperature was above 20.5°C	%Time that EXTERNAL temperature was above 16.5°C	%Time that EXTERNAL temperature was above 20.5°C
WINTER	88	17	0	0
SPRING	97	57	14	7
SUMMER	100	84	84	46
AUTUMN	99	60	47	8

Table 5. The proportion of the time that the temperature in the hall exceeded recommended temperatures for badminton and gentle activity. All data between 09.00 and 21.00 hours have been used. (For comparison, the same statistics are given for the external temperature during the same periods.)

In winter, the hall is above the recommended badminton temperature for about 90% of the time, although it is not often (17% of the time) above the maximum recommended for sports halls. In spring, summer and autumn these comfort conditions are exceeded for much longer periods. It can be seen from Table 5 above that in this particular summer (which was exceptionally hot in July and August), the *external* temperature exceeded the recommended badminton temperature for most of the time. This indicates the limitations for maintaining comfort without recourse to refrigeration plant. However, the frequency profiles earlier show that internal temperatures were often very much higher than external ambient.

It is important to realize that the energy to generate over-heating may come from several sources: the heating system; the sun; the use of electricity within the hall; and people. It is not within the remit of this EPA to assess the heating system in detail, but it is necessary to know whether the provision of daylight has incurred a significant thermal penalty. We now estimate the contribution of the passive solar design to over-heating.

The over-heating is worst in the summertime when external temperatures are also at their highest. It can be assumed that the contribution of solar gain to over-heating will also be at its highest in the summertime, because of the higher altitude of the sun and longer daylength. For this analysis we first exclude all data in the heating season so as to avoid any over-heating resulting from the heating system. Out of this period (28th April to 7th October) we examine just the months of June, July and August, starting, because of missing data from 9th June 1990 to 31st August 1990.

The contribution of the artificial lighting to heating *at low level* would be expected to be low. The lights are rated at 13.2kW, are at high level, and have a sail-cloth beneath them. During the period chosen for analysis their use was, in any case, quite low. The internal gains (i.e. excluding solar gain) to the hall were therefore very low during this time.

The hall was in use for most of this period, but metabolic contributions have been ignored.

To indicate the impact of the sun on internal temperature the analysis has taken the rise in internal temperature above the dawn internal temperature and compared this with the daily insolation. These differences between the daily maximum and dawn temperature have been plotted against the total daily insolation for 83 days of the summer. See Figure 14.

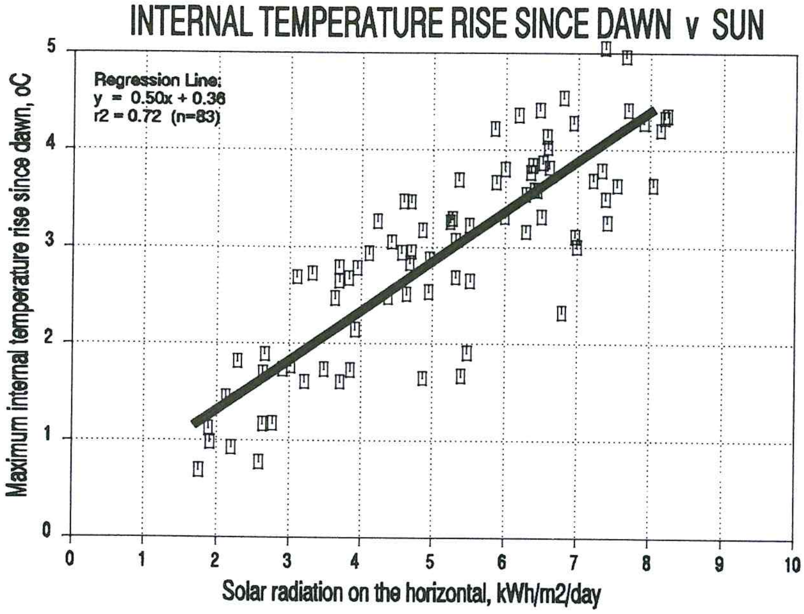


Figure 14. The maximum rise in temperature since dawn plotted against the daily insolation.

Figure 14 shows that there is a strong daily relationship between incident solar energy and internal temperature rise at low level inside the hall. It also shows that the maximum rise above the dawn temperature in any one day is unlikely to exceed 5°C. Part of this rise will be due to a rise in external temperature; the effect of allowing direct solar gain into the building will not *exceed* 5°C. Extrapolating to a day with no sun shows that internal gains apparently contributed 0.36°C ± 0.75, i.e. it was reasonable to ignore internal gain during this period.

The maximum daily rise of 5°C applies to the summer period only and will be less at other times of the year. The effect of the building being warmer at the start of a day following solar energy received the previous day has not been explored. However, other data show that over-night cooling using external air could always be used to advantage in order to prepare the hall for the next day. The extract fan is turned off automatically at 16.00 hours and never used for more than 10 hours a day. (A much more substantial fan would be required to effectively cool the building - during the night and daytime. The fan was not powerful enough to avoid the air temperature in the roof-space at velarium floor level reaching 35°C on occasion, and a recorded maximum of 45°C - both ten degrees above external ambient.)

Air Quality and Ventilation

Respondents were asked to rate their satisfaction with the air quality inside the hall on a scale of 1 (very dissatisfied) to 7 (very satisfied). Respondents were mostly dissatisfied with air quality; 66% of the sample rated it at 3 or less with a median of 3. See Table 6 below.

	Very dissatisfied						Very satisfied	
	1	2	3	4	5	6	7	n
How satisified are you with the air quality?	16	8	▨ 13	11	2	4	2	56

Table 6. Respondents' replies when asked to rate their satisfaction with the air quality inside the hall. The median response is shown shaded.

There were many comments offered on this subject.

> *"For some reason during the summer month the hall gets very warm with a lack of circulating air stream."* -Badminton player
>
> *"Poor air quality in winter - air conditioning needed."* -Badminton player
>
> *"After a short period of exercise I find the air very stuffy and it is difficult for me to breath properly."* -Netball player (16 years old)
>
> *"Air becomes too humid and warm in summer."* -Badminton player
>
> *"Lack of windows means it is rather airless and becomes like a greenhouse all year round. More windows at low level would mean more air/ventilation and mean a cooler hall in winter."* -Badminton player

> *"I feel the ventilation of the hall could be improved by automatic venting in the summer season. All groups using the hall tend to wedge doors open to the outside to allow some ventilation."* -Badminton player
>
> *"Ventilation is very poor, even in Winter, the lack of air and the heat can be awful."* -unspecified
>
> *"Ventilation only by opening fire doors."* -Badminton player
>
> *"In the summer the hall is a bit airless. We have to prop the doors open but it doesn't help much."* -Badminton player
>
> *"There doesn't seem to be any 'AIR FLOW' - it's always very hot - especially in summer - almost unbearable."* -Badminton player
>
> *"There should be doors that can be opened direct from the sports hall to the outside or a window or fan in the ceiling thus enabling fresh air in."* -Badminton player
>
> *"Lack of ventilation makes the hall extremely uncomfortable and stuffy in the hotter months. The ventilation needs to be re-assessed. The sports hall is first class in design."* -Badminton player
>
> *"No ventilation. Atmosphere "stuffy" and "oppressive".* -PE teacher

Most comments seemed to be linked to over-heating (and the need for ventilation) rather than the desire for fresh air *per se*. The reported actions of the users - in opening fire-doors etc. for ventilation - suggest that the monitored internal temperatures would have been higher still but for their intervention.

Control over the Environment

The users of the hall were not asked in the questionnaires about their ability to control the environment. They are not expected to have any and no-one commented directly on their inability to control the heating or lighting. A discussion on control of the artificial lighting appears in the following section *Passive Features*.

Acoustic Environment

The acoustic environment was not investigated, but there were no reports of echoing, etc. being a problem. The designers had hoped to use perforated wall panelling with better sound absorption, but cost prevented this. The existence of a sail-cloth probably helps to absorb sound considerably.

General Problems

Users volunteered information on some general problems, though how important these were was not tested. The comments are summarized here.

The floor being too slippery: 10 people
A need for new badminton nets: 3 people
Poor markings for netball: 2 people
Injury caused by netball post having to be positioned unconventionally: 2 people
Hall being slightly too short for netball: 5 people
Sail-cloth showing dirt: 2 people
The observation area being a waste of potential teaching space: 1 person
The lack of anywhere to sit and have a drink: 1 person

Comparison with Other Sports Halls

Users were asked to rate various aspects of the hall in comparison with other sports halls they may have used. The usefulness of this question is doubtful as, to keep the questionnaire simple and short, no information was requested on the sports halls people had used elsewhere - or their type. However, it is interesting to note how respondents reacted when asked this question. See Table 7.

	Very much worse						Very much better	
	1	2	3	4	5	6	7	n
Its temperature in summer	19	13	7	8	5	0	0	52
Its temperature in winter	6	4	4	16	9	7	6	52
Its air quality	15	10	7	12	3	2	3	52
The colour of its floor	2	1	2	13	9	14	10	51
The colour of its walls	2	2	3	12	11	12	10	51
The colour of its ceiling	2	0	4	14	9	12	10	51

Table 7. Respondents' replies when asked to rate their satisfaction with various aspects of the inside of the Brune Park hall in comparison with other halls they may have used. Median responses are shown shaded.

Operators

The operators of the hall are the caretaker and his assistants. Information gathered from them on the whole building is reported here. (The PE teachers are very much users of the hall.)

It has been found that the plastic glazing material for the rooflights can be cracked by stones thrown from outside the hall. This has led to a rooflight having its outer pane (only) breached and thus, because it is triple skinned, allowing rain to fill up the glazing cavity to the point of collapse of the window. This sent about ten litres of water down through the sail-cloth on to the wooden floor below. The hall was not able to be used for two weeks, while waiting for the floor to dry out. *(Alternative, but more expensive, versions of the roof-light are available from the same manufacturer. These allow drainage of such water to outside.)*

The velarium requires brushing periodically to remove dust that accumulates.

The caretaker has reported that he has no control over the temperature settings for the space heating system. He does have access to the *programmer* for setting the on:off times for each day of the week. The space heating and hot water boilers can have separate settings, however both systems have been set to be enabled between 06.00 and 16.30 (Monday to Friday) and 08.00 to 12.00 on Saturday. (There is no Sunday programme.) A two and a half hour extension of heating can be activated using a simple switch. This is most often used in the evening for the hot water boiler. It is the caretaker's practice to check the temperature of the hot water storage tank to see if extra heating is required for evening use of the showers etc.

PASSIVE FEATURES:

The passive solar feature of the hall is the provision of glazing to allow daylight illumination. The effectiveness of this and, for comparison, the artificial lighting in the sports hall have been characterized and assessed in a number of ways: the spacial variation of daylight factors; night-time measurements of artificial lighting and finally the results of the questionnaire survey.

The Variable Intensity of Light through the Space

It is desirable for a degree of uniformity of illuminance in a sports hall. Visual acuity is related to light intensity and in competitive activities it is clearly only fair to aim at providing a uniform illuminated environment.

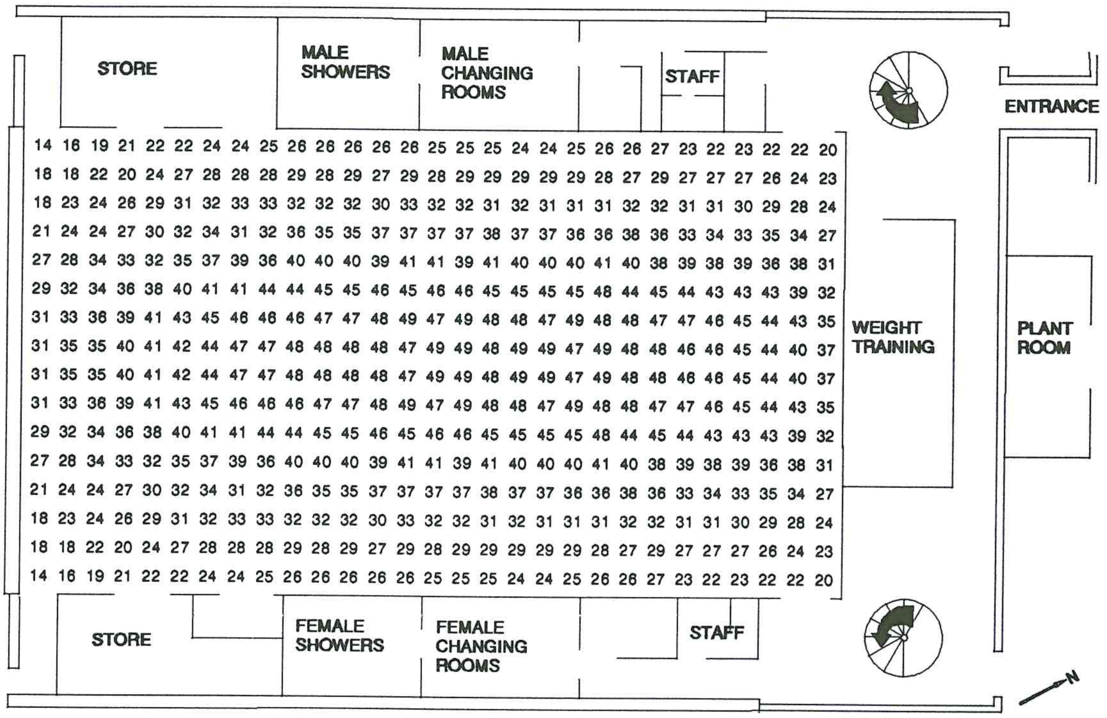
To assess the hall's ability to be naturally illuminated, ratios of various internal to external illuminances were measured in the hall. These *daylight factors* were measured at every square metre of the hall on a completely overcast day.

The horizontal daylight factor was measured using a light sensor placed horizontally two metres above floor level facing upwards with an external sensor placed similarly some 50 metres from the building. A vertical daylight factor was also measured at two metres above the floor, using four light sensors placed orthogonally and facing the four walls of the hall normally. The four vertical sensors gave four daylight factors; the average of these has been used throughout this section (This represents a quasi-cylindrical daylight factor.). Figures 15 to 18 show the variation of the values of the daylight factors measured in these tests. Note that the units in all four graphs are tenths of percentage points. (This aids clarity in the figures by reducing the bulk of numbers to be printed.)

Good data were obtained for only half of the hall owing to equipment failure. It has been assumed that the physical symmetry of the hall gives rise to a daylight factor symmetry along the length of the hall; the measured data for the eastern half of the hall have been mirrored (about the long axis) in the western half.

	DAYLIGHT FACTOR, %	
	Horizontal	Vertical
Mean:	3.5	1.7
Maximum:	4.9	2.1
Minimum:	1.4	1.0
Ratio of Maximum to Minimum:	3.5	2.1
Standard Deviation:	0.9	0.2

Table 8. A summary of the results from the daylight factors' test. The mean vertical daylight factor is half the horizontal one, but is less variable through the space.



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14	16	19	21	22	22	24	24	25	26	26	26	26	26	25	25	25	24	24	25	26	26	27	23	22	23	22	22	20

Figure 15. Horizontal daylight factors as measured on an overcast day on a one metre grid. Units are tenths of percentage points.

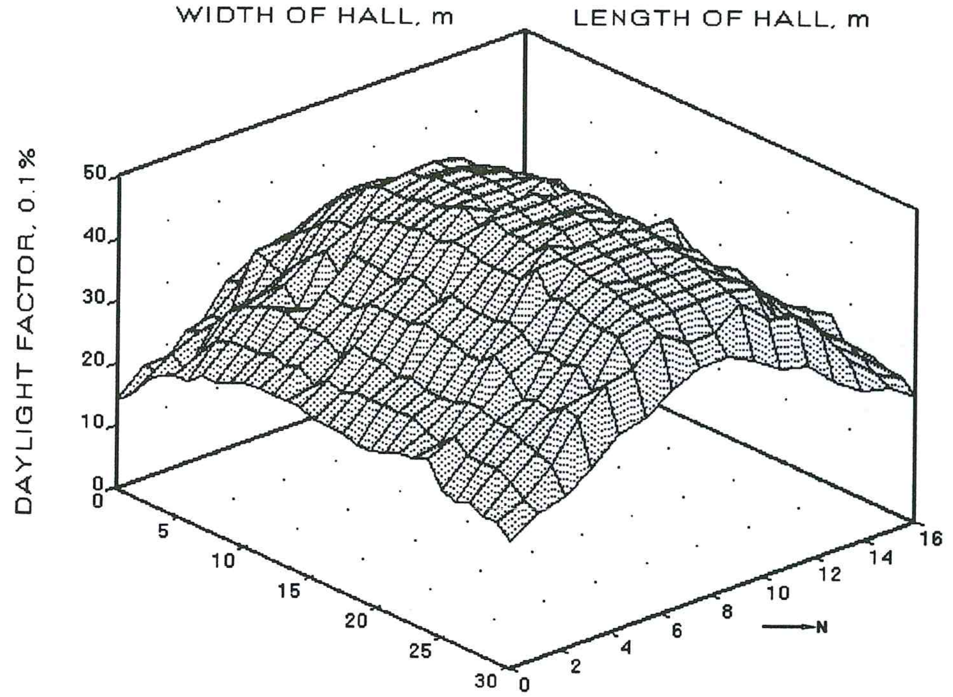
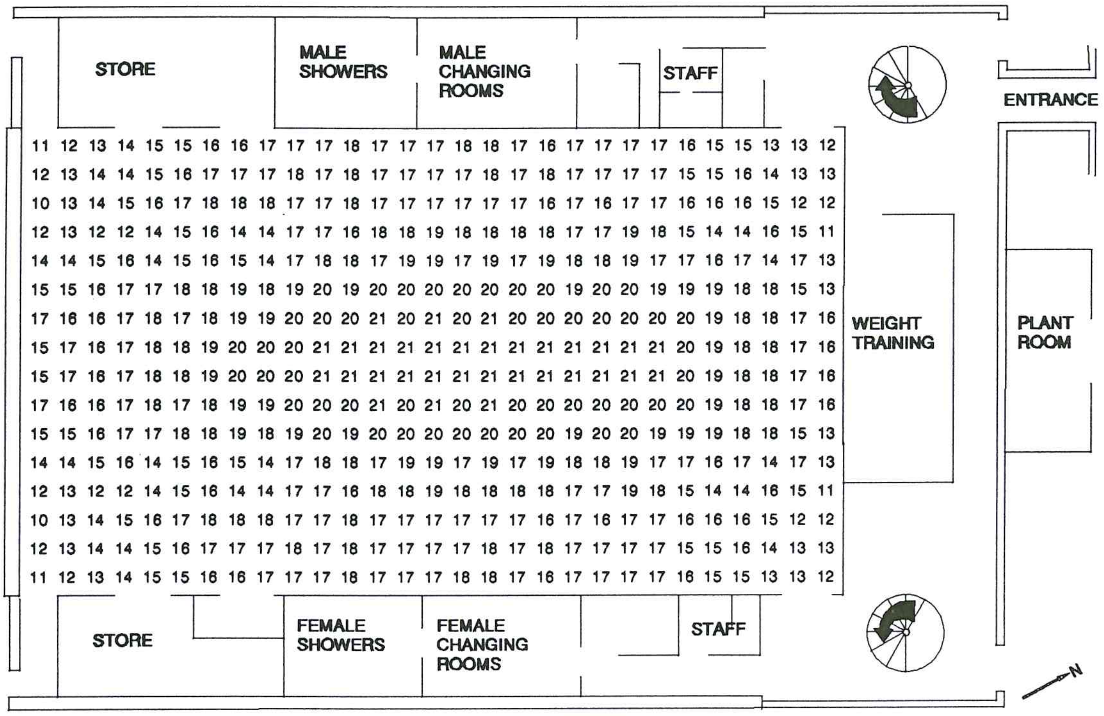


Figure 16. Horizontal daylight factors. A three dimensional profile as viewed from the northern end of the hall. Units are tenths of percentage points.



11	12	13	14	15	15	16	16	17	17	17	18	17	17	17	18	18	17	16	17	17	17	17	16	15	15	13	13	12
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Figure 17. Vertical daylight factors as measured on an overcast day on a one metre grid. The data represent the means of measurements taken in four orthogonal directions in the vertical plane. Units are tenths of percentage points.

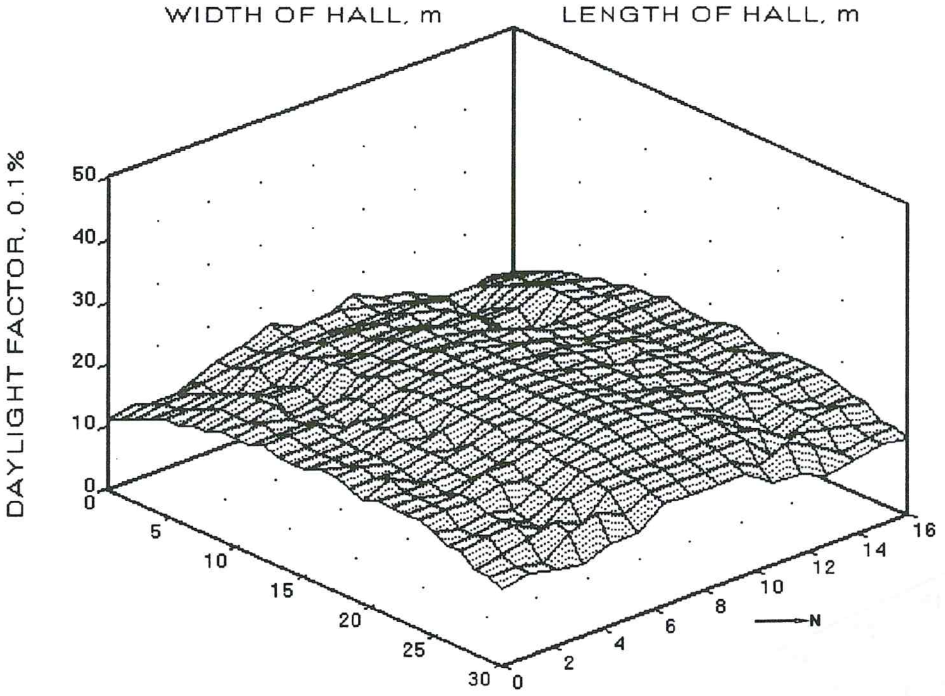


Figure 18. Vertical daylight factors. A three dimensional profile as viewed from the northern end of the hall. Units are tenths of percentage points.

Table 8 above summarizes the results from the daylight factors' test. Several things are clear from the data. The horizontal illuminance of the hall is not uniform, but does change very evenly from about 2½% of external at the edges of the hall to 4 to 5% towards the centre of the hall. A daylight factor of 5% is very good and is achieved despite the sail-cloth which reduces light transmission downwards by 40%. (Were the sail-cloth not there, the *mean* horizontal daylight factor would increase to about 6% from 3.5% - but, this would be at the expense of evenness of lighting and might cause glare.)

Side, or vertical, lighting is important in a sports environment because the object of gaze is usually some way in front of the viewer, rather than below as in an office context. This has been characterized at Brune Park hall by measuring an average vertical daylight factor. This varies much less than the horizontal daylight factor, rising from about 1½% at the edges of the hall to about 2% in the middle. This shows excellent uniformity, but its value is generally low.

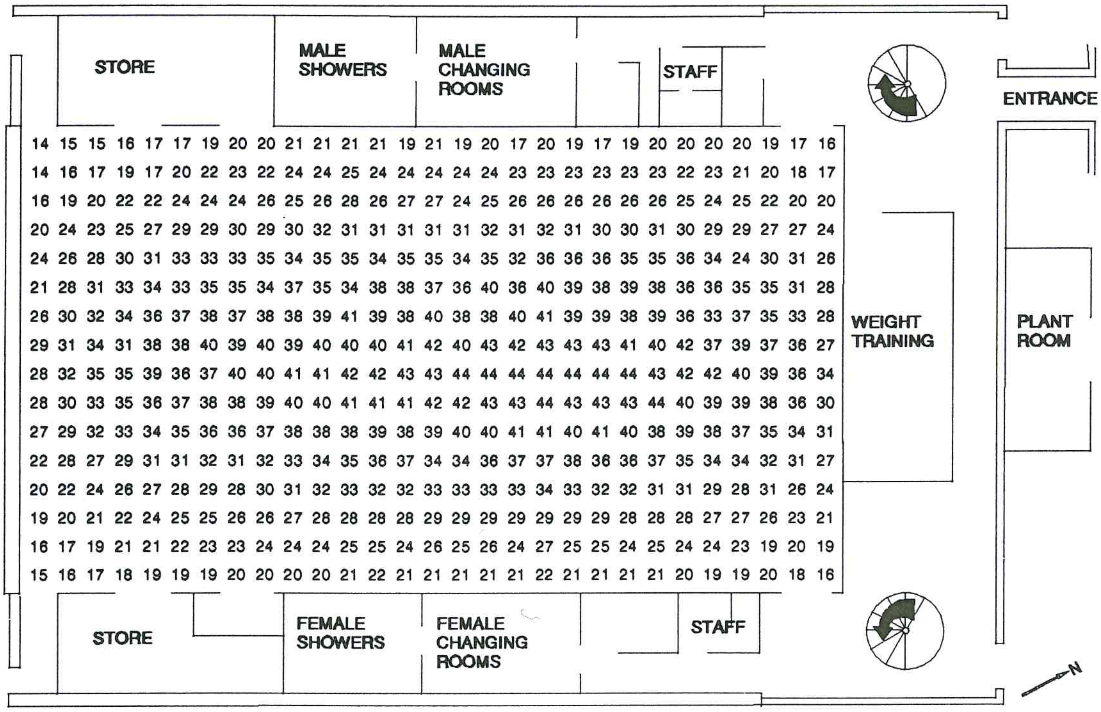
To give the daylight factors a direct context, the uniformity of artificial illuminance was measured at night-time. The results are presented in a similar format in Figures 19 to 22. Note that the illuminance scales are in tens of lux.

	ILLUMINANCE FROM ARTIFICIAL LIGHTING, lux	
	Horizontal	Vertical
Mean:	301	153
Maximum:	440	190
Minimum:	140	90
Ratio of Maximum to Minimum:	3.1	2.1
Standard Deviation:	78	18

Table 9. A summary of the results from the night-time illuminance test. The mean vertical illuminance is half the horizontal one, but is less variable through the space.

The night-time results are summarized in Table 9. They show that the artificial lighting provides a mean horizontal illuminance of 300 lux ranging from about 200 lux at the edges of the hall to about 400 in the centre. This is consistent with recommendations of 300-400 lux for multi-purpose sports halls (IES Code, 1977 & The Sports Council, Energy Data Sheet No. 15). The profile of uniformity of the artificial lighting is very similar to that charted in the daylight factors' test. It is slightly more even.

The artificial vertical illuminance is almost even ranging from about 150 lux at the edges of the hall to about 175 lux in the centre. This is rather low, though as design



14	15	15	16	17	17	19	20	20	21	21	21	21	19	21	19	20	17	20	19	17	19	20	20	20	20	19	17	16
14	16	17	19	17	20	22	23	22	24	24	25	24	24	24	24	24	23	23	23	23	23	23	22	23	21	20	18	17
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15	16	17	18	19	19	19	20	20	20	20	21	22	21	21	21	21	21	22	21	21	21	21	20	19	19	20	18	16

Figure 19. Horizontal illuminance from artificial lighting alone as measured at night on a one metre grid. Units are tens of lux.

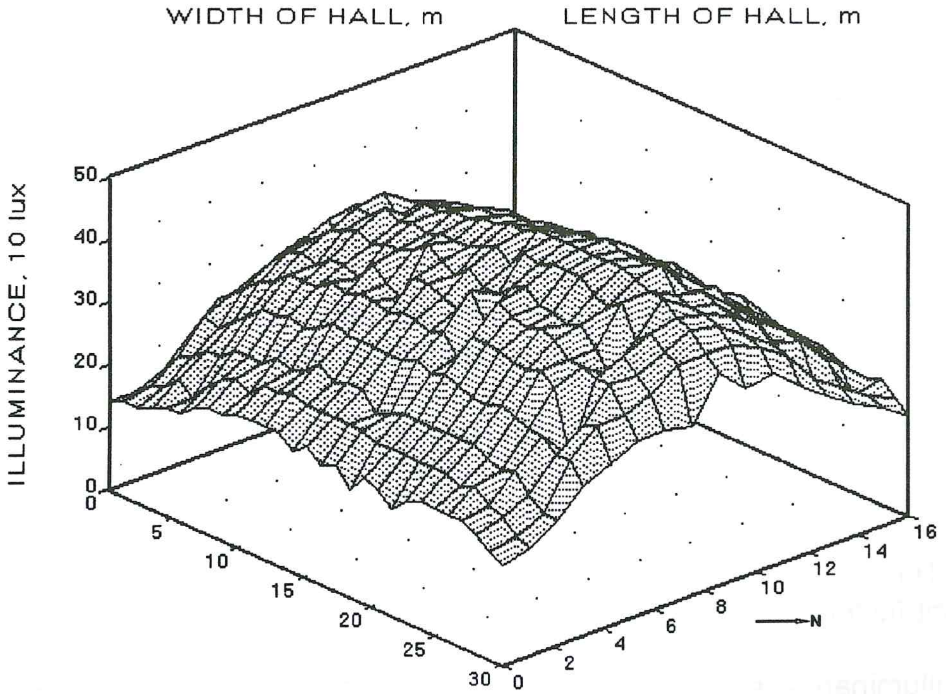
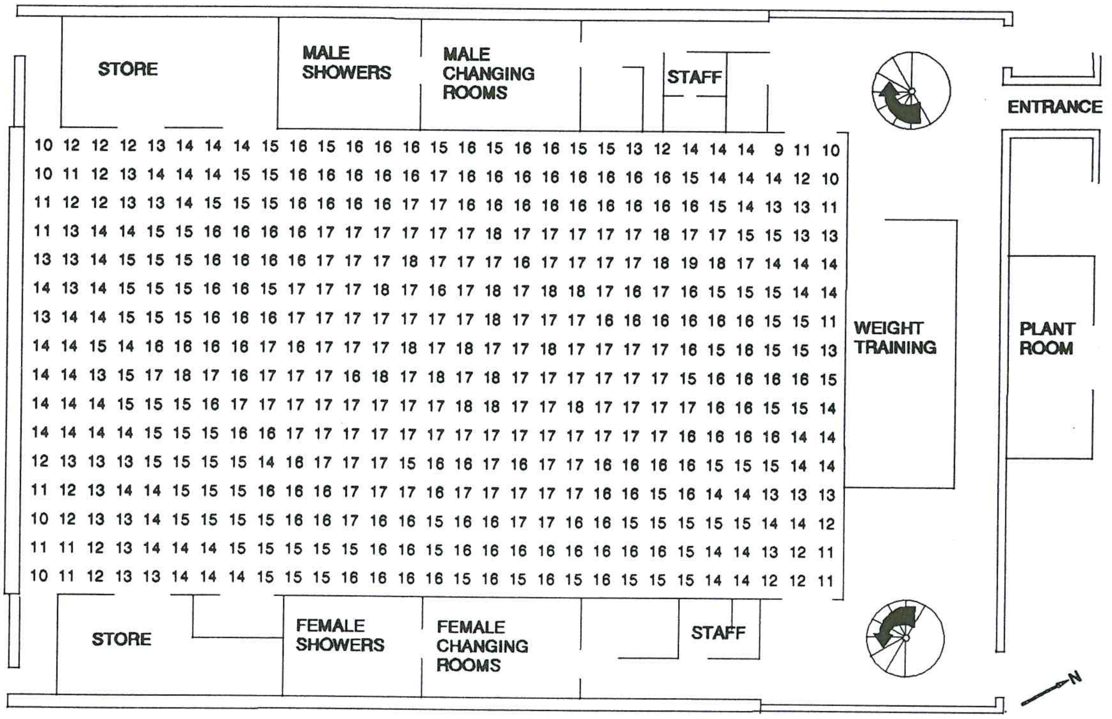


Figure 20. Horizontal illuminance. A three dimensional profile as viewed from the northern end of the hall. Units are tens of lux.



10	12	12	12	13	14	14	14	15	16	15	16	16	16	15	16	15	16	16	15	15	13	12	14	14	14	9	11	10
10	11	12	13	14	14	14	15	15	16	16	16	16	16	17	16	16	16	16	16	16	16	16	15	14	14	14	12	10
11	12	12	13	13	14	15	15	15	16	16	16	16	17	17	16	16	16	16	16	16	16	16	16	15	14	13	13	11
11	13	14	14	15	15	16	16	16	16	17	17	17	17	17	17	18	17	17	17	17	17	18	17	17	15	15	13	13
13	13	14	15	15	15	16	16	16	16	17	17	17	18	17	17	17	16	17	17	17	17	18	19	18	17	14	14	14
14	13	14	15	15	15	16	16	15	17	17	17	18	17	16	17	18	17	18	18	17	16	17	16	15	15	15	14	14
13	14	14	15	15	15	16	16	16	17	17	17	17	17	17	17	18	17	17	17	16	16	16	16	16	16	15	15	11
14	14	15	14	16	16	16	16	17	16	17	17	17	18	17	18	17	17	18	17	17	17	17	16	15	16	15	15	13
14	14	13	15	17	18	17	16	17	17	17	16	18	17	18	17	18	17	17	17	17	17	17	15	16	16	16	16	15
14	14	14	15	15	15	16	17	17	17	17	17	17	17	17	18	18	17	17	18	17	17	17	17	16	16	15	15	14
14	14	14	14	15	15	15	16	16	17	17	17	17	17	17	17	17	17	17	17	17	17	17	16	16	16	16	14	14
12	13	13	13	15	15	15	15	14	16	17	17	17	15	16	16	17	16	17	17	16	16	16	16	15	15	15	14	14
11	12	13	14	14	15	15	15	16	16	16	17	17	17	16	17	17	17	17	17	16	16	15	16	14	14	13	13	13
10	12	13	13	14	15	15	15	15	16	16	17	16	16	15	16	16	17	17	16	16	15	15	15	15	15	14	14	12
11	11	12	13	14	14	14	15	15	15	15	15	16	16	15	16	16	16	16	16	16	16	16	15	14	14	13	12	11
10	11	12	13	13	14	14	14	15	15	15	16	16	16	16	15	16	15	16	15	16	15	15	15	14	14	12	12	11

Figure 21. Vertical illuminance from artificial lighting alone as measured at night on a one metre grid. The data represent the means of measurements taken in four orthogonal directions in the vertical plane. Units are tens of lux.

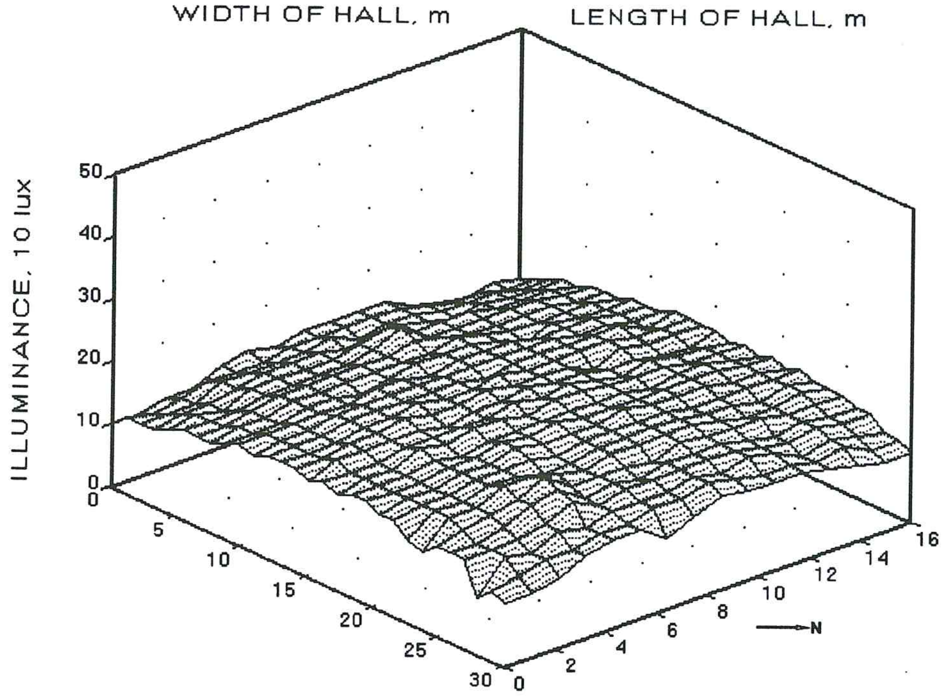


Figure 22. Vertical illuminance. A three dimensional profile as viewed from the northern end of the hall. Units are tens of lux.

guidance is often given in terms of horizontal illuminance, the recommendations for the latter may implicitly allow for the lower vertical illuminances that will attend them.

The two lighting tests show that both natural and artificial horizontal illuminances change evenly across the hall and show much the same variation - about two to one for most of the hall. Artificial vertical illuminances are more uniform than those from daylight, but both show excellent uniformity and evenness.

Before considering the views of the users, seasonal profiles of mean internal horizontal illuminance are presented as an objective description of the light levels experienced - whether from artificial or natural lighting, or a combination. See Figures 23 to 26. The data have been processed in local time and cover all days for a year. These figures represent the *mean* horizontal illuminance over the whole floor area rather than at the specific point of measurement.

There were two hanging light sensors in the hall: one towards the southern end and one towards the northern end. Both were positioned the same amount off the main central axis of the hall, but to the east and west respectively. The light levels from these two sensors were often different and this is because of the path traced by the sun in the sky in relation to the building. An analysis of the two sets of data has shown that the difference in light levels was usually no more than 10% during the main part of the school day. Early in the morning the north western sensor could be 20% higher and in the evening the south eastern sensor could be 20% higher. *Exceptionally* differences of 30% could occur. These differences in illuminance in the hall are not thought to significantly reduce the quality of the lighting. A straight average of these two sensors has been used in most of the analysis.

The use of artificial lighting in the evening and the level of illuminance from it is clearly visible in the four profiles. They also show that the illuminance available from daylight is often very much greater than that experienced by evening players. For example, in summer the mean light level in the hall is above 1000 lux between 09.00 and 18.00. The maximum mean horizontal illuminance was 3400 lux at one o'clock on 6th July 1990.

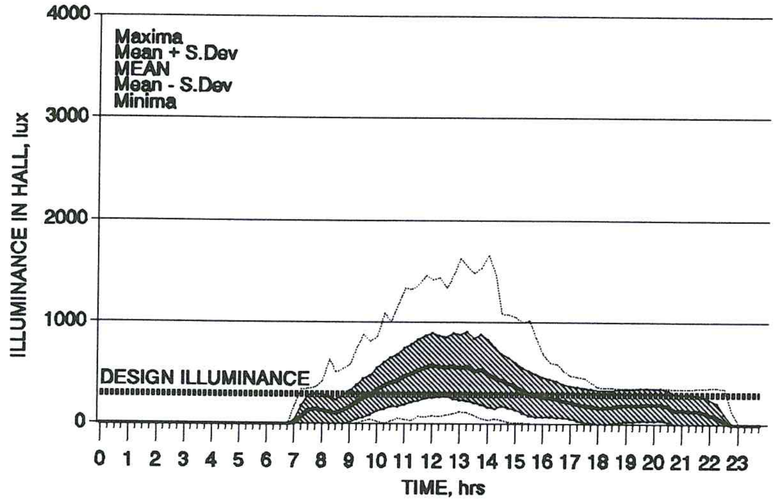


Figure 23. Mean Seasonal Profile of Horizontal Illuminance; mean for the whole hall: **WINTER**

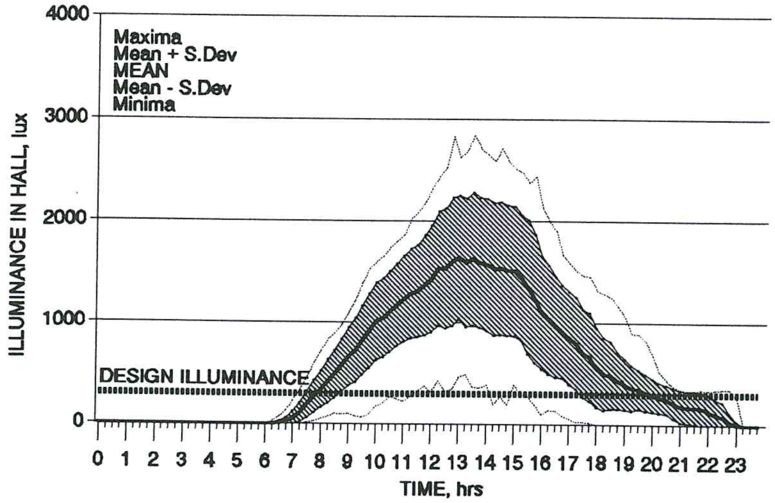


Figure 24. Mean Seasonal Profile of Horizontal Illuminance; mean for the whole hall: **SPRING**

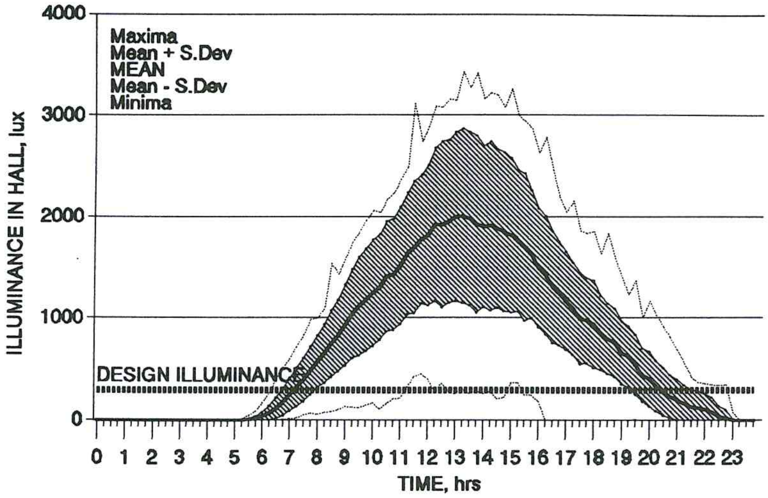


Figure 25. Mean Seasonal Profile of Horizontal Illuminance; mean for the whole hall: **SUMMER**

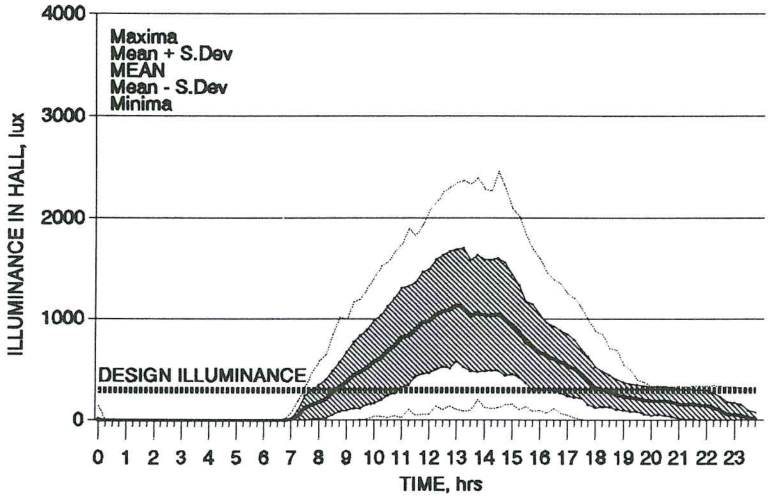


Figure 26. Mean Seasonal Profile of Horizontal Illuminance; mean for the whole hall: **AUTUMN**

Occupants

We now consider the results of the questionnaire survey with respect to lighting.

Satisfaction with Lighting

Users were first asked to indicate their satisfaction with lighting, i.e. no distinction was made between artificial and natural light. See Table 10 below. Most respondents were reasonably satified with the lighting in general; only 16% of the sample rated the lighting three or less on the seven point scale.

	Very dissatisfied						Very satisfied	
	1	2	3	4	5	6	7	n
How satisfied are you with the lighting?	1	2	6	11	8	15	13	56

Table 10. Respondents' replies when asked to rate their satisfaction with the lighting inside the hall. The median response (between 5 & 6) is shown shaded.

Satisfaction with level of light in daylight hours and outside daylight hours

Users were then asked to rate separately their satisfaction with the level of light, when they were engaged in their activity, during and outside daylight hours. Most respondents indicated they were quite satisified. 63% of the sample rated the lighting 5 or greater in daylight hours with slightly more (71%) outside daylight hours.

	Very dissatisfied						Very satisfied	
	1	2	3	4	5	6	7	n
During daylight hours:	2	3	6	7	5	12	14	49
Outside daylight hours:	3	3	2	7	10	14	12	51

Table 11. Respondents' replies when asked to rate their satisfaction with the level of light during and outside daylight hours. The median response is shown shaded.

Five of the sample recorded that they used the hall around midday (probably Saturday morning) and would not be expected to have experienced artificial lighting alone. All but one of this group returned a rating of 6 or 7 for the light levels during daylight hours. The median for this group (7) is rather higher than that (5) for those using the hall after 18.00 hours.

Of the four PE teachers, two gave ratings of 7 (very satisified) for both during and outside daylight hours. The other two gave ratings of 3 and 4 (for light levels during daylight hours) and 1 and 7 (for outside daylights hours).

There were no significant differences between the responses for players of different levels of competitiveness.

Preference for lights on during daylight hours

Users were also asked to record their preference for using the hall with or without the artificial lighting on - during daylight hours. 63% of the sample indicated that they preferred the lights on and 33% had no preference. Only two people preferred the lights off. See Table 12.

As reported above, most respondents used the hall in the evening when daylight would be less. The median response for the five morning users and the four PE teachers was "have no preference". Of the evening users 55% of the netball players and 76% of the badminton players preferred the lights on. However, this does not imply a greater lighting need for the latter as all the netball players started at 18.00 hours whilst the majority of badminton players started one to two hours later when it would be darker.

The four PE teachers were divided equally between preferring the lights on and having no preference.

	Prefer lights OFF	Have no preference	Prefer lights ON	n
Do you prefer the lights to be on or off when using the hall in daylight hours?	2	17	33	52

Table 12. Respondents' replies when asked to indicate their preference for using the hall with or without the artificial lighting on during daylight hours. The median response is shown shaded.

Respondents were invited to give a reason for their preferences - and did. The comments are reported here according to their indicated preference. (The replies of several respondents suggested that they were unaware that there were any rooflights.)

For those preferring the lights off:

"Because the hall is bright enough with the lights off." -afternoon basketball player
"Light is bright enough anyway." -(County match level) evening badminton player

For those having no preference:

"Whether on or off there is no difference!!!" -Late evening badminton player
"Not known lights to be off at all." -Netball player
"I can't say I've noticed." -Evening badminton player
"Seems to me to make no real difference." -Late evening badminton player
"Depends on outside light quality." -PE teacher

For those preferring the lights on:

-because of lack of alternative:

"Hall has no real natural lighting." -Netball player
"Even during daytime, the small number of windows admit inadequate light." -Late evening badminton player
"Lack of windows." -Late evening badminton player
"Limited windows." -Late evening badminton player
"Still quite dull without lights - not enough natural light comes in." -Netball player
(Five other people said that it was too dark without the lights on.)

-because they avoid variable lighting:

"On cloudy days the variation is too noticeable." -Evening rhythmic gym participant
"During dull weather light in hall bad and can change." -Badminton player
"Adequate lighting, even under cloud cover." -PE teacher

-because they provide more even lighting:

"Visibility even." -Late evening badminton player
"Leaving lights on gives more even light for sighting shuttlecocks in flight." -Late evening badminton player

-for some other reason:

"Need as much light as possible to see." -Evening badminton player
"Brightness gives the hall a more airy feeling." -Netball player
"Enhances aesthetic appearance." -PE teacher

The comments from several people suggested that they are often unaware, or it is difficult to tell, whether the lights are on or off in daylight hours. (During an interview, this was true of a PE teacher.)

It is unfortunate that, because of the nature of the hall's use, it would not have been easy to survey a large number of daytime users. The comments from late evening users on the unavailabilty of any alternative to artificial lighting are understandable and should not therefore be regarded as a criticism of the hall. However, many respondents gave other reasons instead for wanting the lights on: to provide and maintain a fixed even light level and to make the hall more attractive.

There were no significant differences between the responses for players of different levels of competitiveness.

Comparison with other buildings

Users were asked to rate the lighting of the hall in comparison with other sports halls they may have used. See Table 13. As before, the usefulness of this question is doubtful except as a record of this group's response.

	Very much worse						Very much better	
	1	2	3	4	5	6	7	n
Its lighting (natural)	2	5	7	17	5	2	9	47
Its lighting (artificial)	2	3	3	8	9	12	14	51

Table 13. Respondents' replies when asked to rate their satisfaction with the lighting at Brune Park hall in comparison with other halls they may have used. Median responses are shown shaded.

It is worth reiterating that not everyone was aware that the hall had roof-lights, and thus they may often have assumed that the lights were switched on when in fact they were off.

Operators

A variety of information on the lighting has also been gathered from the caretaker. Of particular note is the way in which the lights are controlled.

Control of lights

The lights at Brune Park are controlled manually by a key switch. There is only one key (this has recently been rectified) and this is kept in a locked cupboard. Only the caretaker and his two assistants and the cleaner have access to the key. The caretaker has reported the following typical routine in the hall:

06.50 The cleaner will come in and may turn the lights on depending on the time of year. She needs to be able to see to clean.

07.30 The cleaner will turn the lights off, unless it is obviously dark and they will be needed later.

For rest of school day:
If it is obviously too dark, a caretaker will take it on himself to turn the lights on in readiness for the first PE period at 09.30, otherwise he won't.

If a PE person thinks it's too dim they will contact the school office, who will "bleep" the caretaker who will then go and put the lights on.

At any time during the day that the caretaker realizes that it is sunny and knows therefore that it will be bright in the hall, he will go and turn the lights off if they are on. He will do this even if the hall is actually being used. "They will not notice. The lights can't be seen."

17.00 The lights may be turned on for cleaning. If there is evening use of the hall scheduled for 18.00 hours, the lights will be put on in readiness as they take some 10 to 15 minutes to achieve full brightness.

18.00 Evening use of the hall starts (if scheduled).

22.30 Activities do not usually extend beyond this time, when the lights will be turned off.

The caretakers basically wait to be contacted, before turning lights on, but take it upon themselves to turn them off. They *will* turn lights on when it is obviously too dark.

In interviews with the PE teachers, it was apparent that they would like to have control of the lights, but understood and respected the school's desire to save money. The system (of contacting the office by telephone to get the lights put on) worked least well at lunchtime. The hall is usually in use at lunchtime.

Other aspects of the lighting

The caretaker reported that the only complaints on the lighting that he was aware of were from some badminton players in the morning when shafts of bright sunlight could appear in the hall.

The caretaker considered that any automatic control system for the lights would have to take into account their relatively long warm-up time.

The three banks of lights (33 lamps in all) are always switched on or off together at the key switch. This initiates an automatic starting sequenced in which the lamps are energized in groups over a few minutes. (*This suggests that this kind of lamp would be less amenable to a control environment dependent on fluctuating daylight levels.)*

CONCLUSIONS

Respondents to the questionnaire were generally happy with the inside of the hall. Their main criticism was that it was too hot.

There was general dissatisfaction with temperature in summer: most found the winter temperature satisfactory, although about a third of the sample still reported dissatisfaction. The internal temperature exceeded the recommended temperature for badminton (16°C) for 88% of the winter and 100% of the summer. The maximum temperature recommended for sports halls (20°C) was exceeded for 17% in the winter and 84% of the time in the summer.

The sun contributed a *maximum* of a 5°C rise in temperature above the dawn internal temperature on any one day in the summer. This suggests that for much of the rest of the year, users would benefit from the heating system being adjusted to a lower setting. Over-night cooling by ventilation was not used. The power of the extract fan is in any case much too low for the size of the hall, nor are there good sized routes for fresh air to enter the hall at low level.

There was general dissatisfaction with air quality, through lack of ventilation. Much of the criticism was associated with the over-heating.

Measurements on an overcast day showed that the horizontal daylight factor varied very evenly from 2½% at the edges of the hall to 4 to 5% towards the centre, and averaging 3½%. A quasi-cylindrical daylight factor was measured and this was more uniform, but generally had an apparently low value (1½ to 2%).

Measurements at night showed that the artificial lighting is slightly more even than daylight from an overcast sky. Horizontal illuminance averaged 300 lux (the minimum recommended level for this type of sports hall), varying from 200 lux at the edges of the hall to about 400 lux in the centre. The vertical illuminance was quite low (150 to 175 lux).

Continuous monitoring showed that the internal horizontal illuminance was often much higher in the day-time than at night. For example, during the spring season it was above 500 lux in school hours for at least two thirds of the time. Artificial lighting was used for no more than 17% of these hours, so this was predominantly due to daylight. Despite these high levels, most respondents to the questionnaire survey said that they preferred the artificial lighting to be on during daylight hours. However, not all respondents were aware that the ceiling illumination could come from anything other than artificial lighting. Additionally, most of those replying used the hall in the evening, when conditions would be less favourable. Respondents *were* generally satisfied with the artificial lighting level. It would thus seem probable that were these evening players to experience daytime light levels they would often find daylight alone sufficient. The variability of daylight - the scudding cloud problem - might still cause concern, but the seasonal profiles show that daylight levels were generally superior to the light levels at night in all seasons except winter.

The lights are key-operated and switched on and off only by the caretaker - not teachers or players. This method of controlling the lights is accepted as practical and necessary, but less than ideal. If the caretaker has not anticipated a need for the lights to be switched on in the day-time, he has to be contacted through a third party. This can be irksome to players if daylight levels suddenly drop during a game.

Example measured data:

> ***Two weeks of measured data are given at the end of this section of the report to illustrate most variables that were monitored. See Figures 27 & 28.***

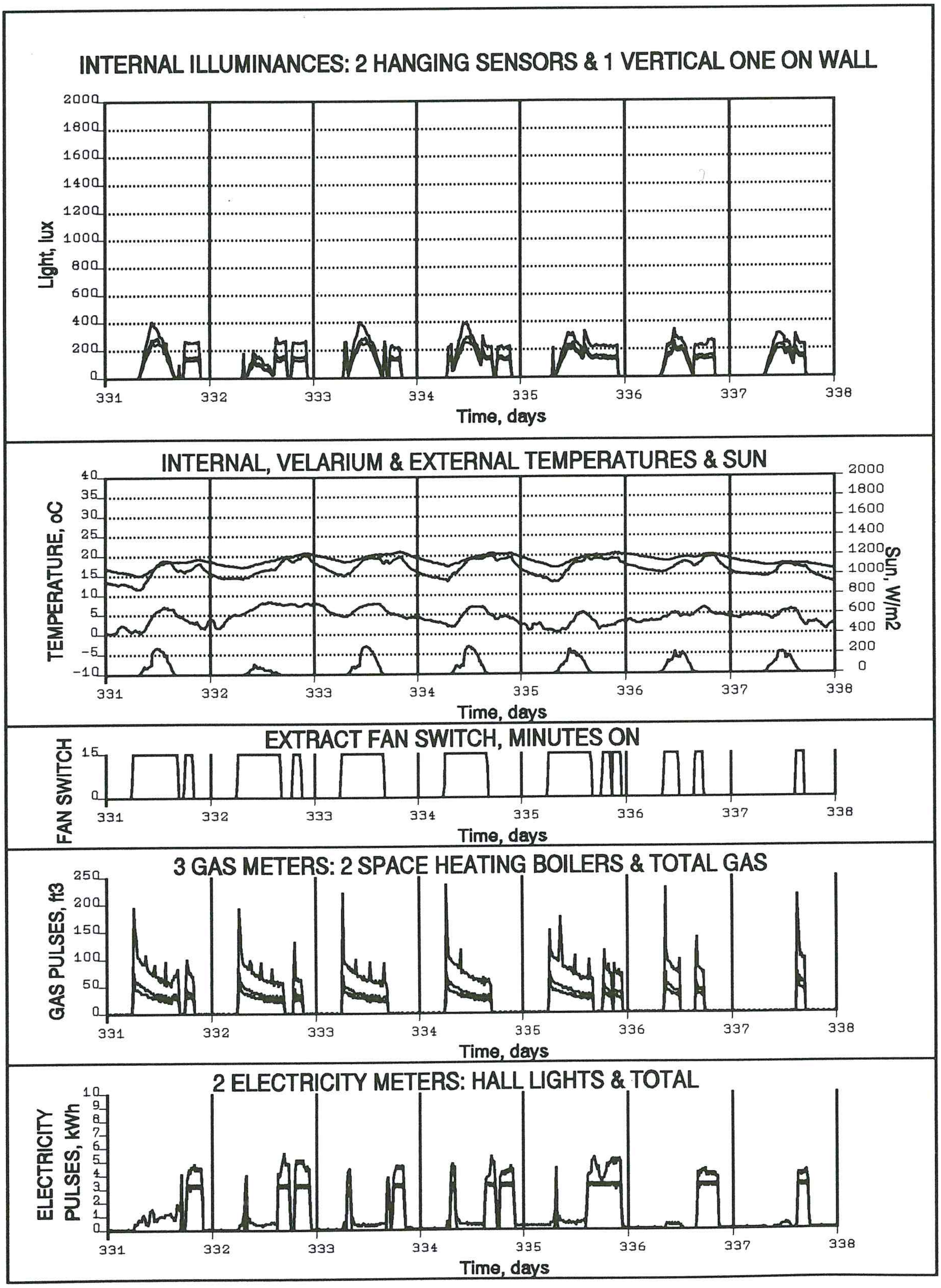


Figure 27. Example monitored data for seven days in the **WINTER** starting on Monday, 27th November 1989. Note that the data are as recorded; the hanging light sensors measured *reflected* light.

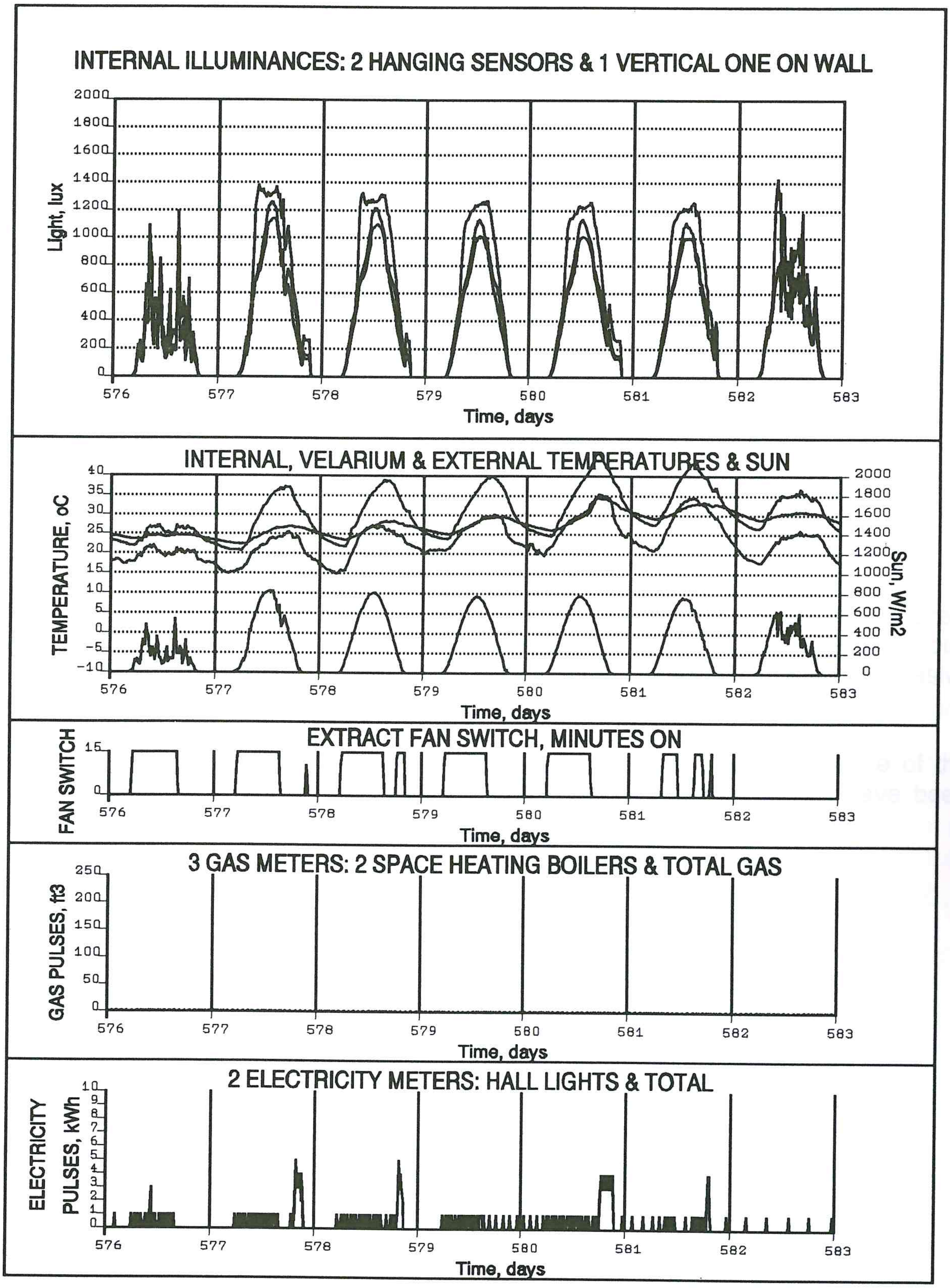


Figure 28. Example monitored data for seven days in the **SUMMER** starting on Monday, 30th July 1990. Note that the data are as recorded; the hanging light sensors measured *reflected* light.

MEASURED ENERGY

Fuel use is central to the appraisal. The whole building's consumption allows direct comparison with other buildings. The performance of the system for collecting solar energy in the form of daylight and distributing it decides the efficacy of this kind of passive solar design.

The fuel use of the whole building is reported first and then the performance of the passive solar feature is analysed. Two testable hypotheses (H1 and H2) have been defined for the EPA of Brune Park sports hall (See earlier.)

WHOLE BUILDING:

The Requirements for Data

There is a general requirement in an EPA to measure the fuel use in the whole building under study and to split this according to use. At Brune Park the total gas use was measured and separate meters were put on the two space heating boilers. The difference between the total and the space heating use gave the hot water boiler's consumption. Total electricity use was measured together with that used for the sports hall lighting; the difference including miscellaneous lighting and power needs. All these consumptions were recorded every quarter hour.

Weather information including degree days has been obtained for the southern region from the Meteorological Office so that the conditions during monitoring can be compared to the long term weather for the site.

The times of use of the sports hall have been provided by the caretaker of Brune Park secondary school. These allow certain periods to be excluded from the analysis, e.g. Christmas and other periods when the hall was closed to adults and children alike.

(A listing of daily data appears in the Appendix. The appendix also includes a complete description of the data aquisition system.)

The Fuel Use

Table 15 summarizes the monthly monitoring of energy related variables from October 1989 to September 1990. The use of delivered fuel in this year of monitoring is also shown in Figure 29 and Table 14 below. From this it can be seen that over 80% of the total delivered fuel needs are met by gas, the remainder by electricity. 60% of electricity is used for the main hall lights above the velarium.

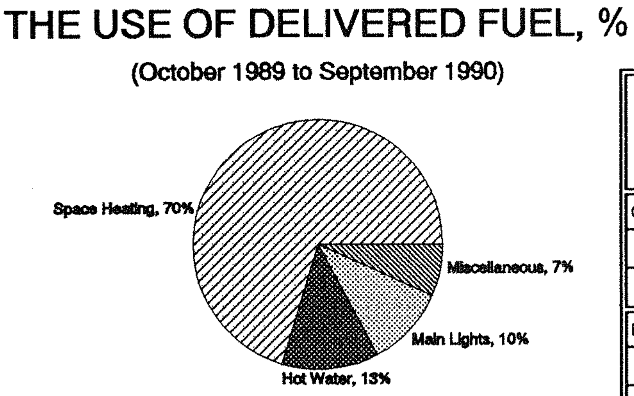


Figure 29. Delivered fuel use 1989-90, %

FUEL TYPE	USE	DELIVERED FUEL USE 1989-90, kWh	
		TOTAL	PER m² GROSS FLOOR AREA
GAS	SPACE HEATING	115854	123.2
	HOT WATER	20640	22.0
	TOTAL	136494	145.2
ELECTRICITY	MAIN HALL LIGHTING	17510	18.6[†]
	MISCELLANEOUS	10985	11.7
	TOTAL	28495	30.3
TOTAL FUEL USE		164989	175.5

[†] 36 kWh/m² of *main hall area*

Table 14. Delivered fuel for 1989-90, kWh.

Table 15. Monthly Data.

		1989	1989	1989	1990	1990	1990	1990	1990	1990	1990	1990	1990	
Quantity	Units	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
Gas Space Heating	[kWh]	6937	18913	21463	21317	18250	16499	10584	370	380	384	388	369	115854
Gas Hot Water	[kWh]	1735	2701	2457	2597	2319	2421	1742	1000	1393	691	519	1065	20640
Gas Total	[kWh]	8672	21614	23920	23914	20570	18920	12326	1370	1773	1075	908	1434	136494
Electricity Main Lighting	[kWh]	1199	2237	2218	2432	2400	2008	1101	800	905	663	476	1071	17510
Electricity Miscellaneous	[kWh]	989	1418	1132	1222	1100	1231	799	677	663	521	567	667	10985
Electricity Total	[kWh]	2187	3655	3350	3654	3500	3239	1899	1477	1568	1184	1043	1738	28495
Total Fuel	[kWh]	10859	25269	27270	27568	24070	22159	14225	2847	3341	2259	1951	3172	164989
External Temperature	[oC]	14.3	9.1	8.1	8.7	9.1	9.4	9.6	16.7	15.3	18.2	20.5	15.9	12.9
Degree Days(base15.5)	[oCdays]	111	251	301	254	201	238	226	118	80	47	33	102	1962
Internal Temperature	[oC]	19.5	19.2	18.6	18.0	18.7	19.7	19.4	20.5	24.0	23.5	25.3	21.1	20.6
Solar Irradiation	[kWh/m^2]	49	31	17	21	45	93	144	200	134	180	147	105	1166

Notes on the monthly data above:

May and June data contain estimated data. Monitoring problems lead to about 22 days' data being lost in May and 8 days in June.

> For gas consumption these estimates are probably quite accurate because the space heating was off and the main gas meter therefore read gas use for hot water. (Gas meter readings have been used.)
>
> For electricity consumption, there was no (electricity board) separate meter and consumptions have been estimated *pro rata* from the data that were collected. Other parameters have been treated similarly for these 30 days.
>
> Degree day data are for the southern region and are from the Meteorological Office.

No historical fuel bill data were available because the sports hall is not metered separately from the school.

Figures 30 and 31 profile the monthly measured fuel data. The heating season started on 13th October 1989 and finished on 27th April 1990.

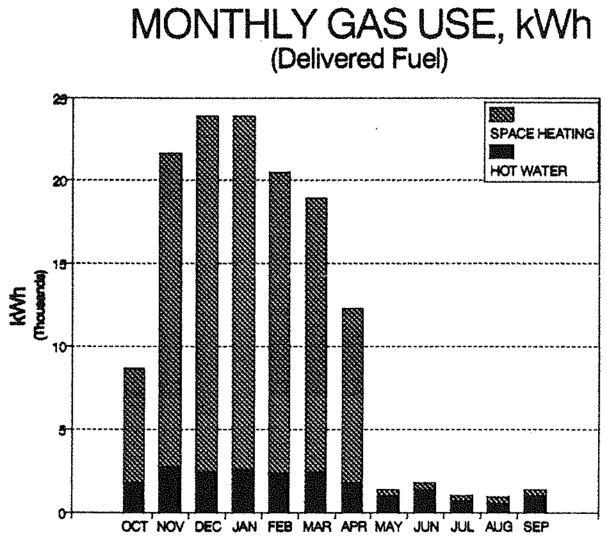


Figure 30. Monthly gas use.

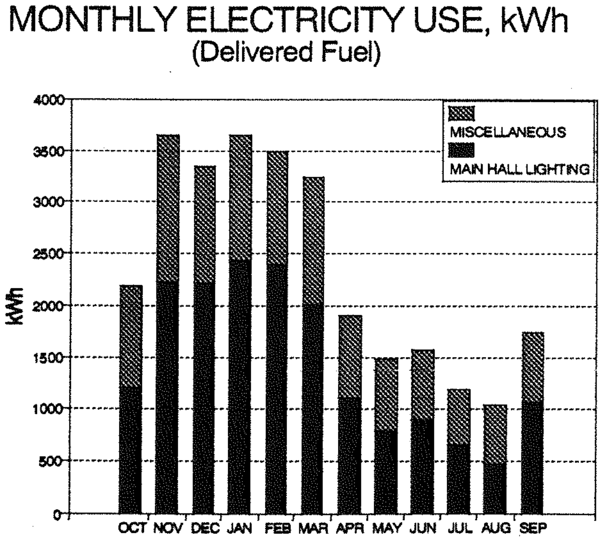


Figure 31. Monthly electricity use.

These data are shown exactly as monitored. To allow for the external temperature perhaps not being typical in the year of monitoring the gas data for space heating need to be adjusted. The ratio of the long term degree days for the site and those experienced during monitoring has been appplied to the annual data. These normalized data are shown in Table 16, together with the use of fuel per unit floor area.

FUEL TYPE	USE	ANNUAL DELIVERED FUEL, kWh	
		TOTAL	PER m^2 GROSS FLOOR AREA
GAS	SPACE HEATING	134218	142.8
	HOT WATER	20640	22.0
	TOTAL	154858	164.7
ELECTRICITY	MAIN HALL LIGHTING	17510	18.6
	MISCELLANEOUS	10985	11.7
	TOTAL	28495	30.3
TOTAL FUEL USE		183353	195.1

Table 16. ANNUAL NORMALIZED DELIVERED FUEL USE SUMMARY.

Primary Fuel Use

The reporting of the measured results is incomplete without assessing the impact of the use of delivered fuel upon supply consumption, rather than simply stating the delivered fuel. The boundaries for the energy analysis do not include all fuel use in providing the delivered fuels (in particular, extraction energy is ignored). However, the fuel factors used (1.07 for gas and 3.82 for electricity) to represent the ratios of primary to delivered fuel give a much more realistic view of real fuel use. The annual primary fuel use is shown in Table 17.

Although only about 18% of delivered fuel is in the form of electricity the primary fuel picture is rather different. Total primary fuel use at Brune Park sports hall is some 50%

greater than delivered fuel at 292 kWh/m^2/year.

DELIVERED FUEL TYPE	ANNUAL PRIMARY FUEL USE, kWh	
	TOTAL	PER m^2 GROSS FLOOR AREA
GAS	165698	176
ELECTRICITY	108851	116
TOTAL	274549	292

Table 17. Annual normalized primary fuel use summary for October 1989 to September 1990.

Other Whole Building Data

The annual hours of full load equivalent for space heating are given by dividing the total gas used for the monitoring period (115,854 kWh) by the full rated input of the gas boilers (84.4 kW). This gives 1373 hours of full load equivalent use.

The annual hours of full load equivalent for lighting (for the main hall lighting only) is calculated similarly. Dividing the lighting electricity (17510 kWh) by the full rated input of the 33 x 400W lamps (13.2 kW) gives 1327 hours.

Some comments on specific fuel uses are given below:

The flue dilution fan for the space heating and hot water gas boilers is under time-clock control and is on from about 06.30 to 16.30. With a rated input of 1.1 kW, this fan consumes about 4000 kWh per year (14% of the annual electricity use; 5½% total annual primary energy use).

The extraction fan above the velarium was designed to avoid over-heating of the roofspace and be under the control of a thermostat. The fan is rated at 0.14 kW. In the year of monitoring it was used for 1275 hours. This represents 178 kWh. Though designed to operate according to a thermostat in the roof space, it appeared to operate according to the timeclock for the space heating. This led to a regular use of about 250 hours a month regardless of the temperature. This would have led to about 3000 hours of use, but the fan was out of action for some other reason from 30th December 1989 to 28th July 1990 when it was replaced. The new fan still operates for about 250 hours per month. It also still appears to operate regardless of temperature. For instance it extracted air from the roof space for 14 hours on 8th February 1991 when the mean 24 hour temperature was -3.4 °C outside and 16.3 °C in the roof space. The fan control is probably in need of adjustment.

The gas pilot lights on the two space heating boilers were not turned off in 1990 outside the heating season, though they were found to be off during October 1989 before the start of the heating season. Each pilot light burnt gas at a rate of 250W for the 163 days between heating seasons; the two pilot lights together consumed 1956 kWh (1.7% of the annual space heating gas use; 0.75% total annual primary energy use). Annually the pilot lights consume 3¼% (4,400 kWh) of the total gas for space heating.

PASSIVE FEATURES:

The passive solar feature of the hall is the glazing that was designed to provide an opportunity for daylight to be exploited insead of artificial lighting.

Hypothesis 1

H1. The design allows natural daylight alone, when available, to provide adequate illumination.

The route for testing H1

To test H1 we need to: determine what was adequate illumination inside the sports hall;

determine the internal illuminance from *daylight alone* inside the sports hall;

determine to what extent the data show that daylight alone could have provided adequate illumination.

The method of tackling each of these is now discussed.

The determination of adequate illumination

We first need an indicator of adequate illumination. There are three approaches that could be used: a value of illuminance taken from design guidelines; a value given by an analysis of the light levels when lights were switched on or off; or the actual value available from artificial lighting alone (at night).

Taking a design value of adequacy does not necessarily represent what was achieved in practice; it would also ignore the monitoring. An analysis of switching levels has been done (see later), but this suffers from a paucity of switching events - particularly off events - in the main part of the day. The approach adopted has therefore been to use the measured values of illuminance at night-time from the artificial lighting. As was shown in the Amenity section, there are few complaints of the intensity of this light level.

Figure 32 shows the distribution of horizontal illuminance[1] experienced in the hall at night when the main lights were on. Spread in the distribution of the values is caused by the inclusion of quarter hourly periods when the lights were switched on. The characteristics of the lamps also introduce scatter; they take at least 10 minutes to achieve full

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[1] *Note that illuminance on the floor is inferred from the light reflected from it to sensors about 8m overhead. These measured values have been converted into the horizontal illuminance by dividing by the reflectivity of the floor. A few spot measurements using a* Hagner *meter gave a value of 0.45. A subsequent night-time test of lux levels measured the horizontal illuminance directly 2m above each square metre of the hall; the mean of these values divided into the hanging sensor's reading gave a conversion factor of 0.42).*

brightness. The apparent zero illuminance experienced when the lights were on is an artefact of data-logging. (These zero data-points were collected at times when the lights had *just* been turned on. The logging sequence measured light levels first, then energy used by the lights via a pulse counter.) From this graph it can be seen that all the values lie below **360 lux**. To err on the side of caution this value has been selected as indicating an adequate light level. (This might be thought to be a little pessimistic, but it does allow for the variation in light level across the hall; lower at the edges and higher at the centre.)

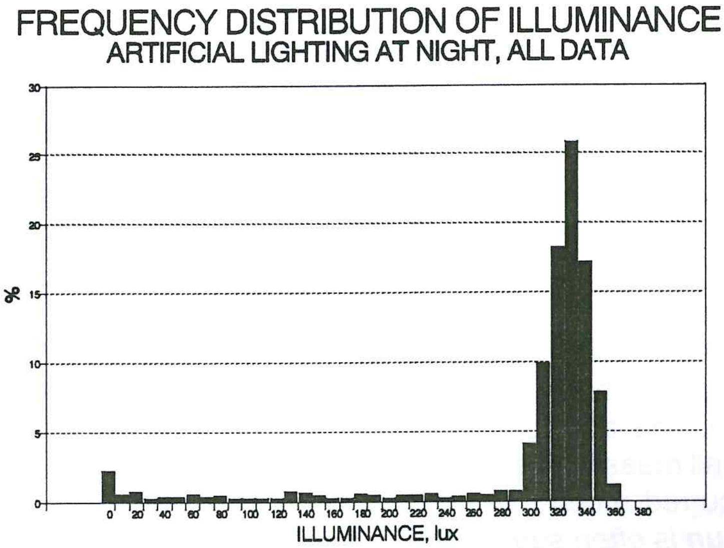

Figure 32. The distribution of horizontal illuminance experienced at night and when the main lights were on.

The determination of internal illuminance from daylight alone

Having established a criterion for an adequate level of lighting we next require the internal light level from daylight alone. This may be approached by making a *fixed* deduction from the measured data for when the lights are on, but considerable scatter is introduced, with horizontal illuminance often becoming negative. Some allowance can be made for the switching-on periods - a variable deduction dependent on fuel used - but this still gave unacceptable scatter. It was decided therefore to deduce the light level inside from the solar radiation outside.

The relationship between incident solar energy and internal light levels is complex. The building is subject to a variety of sky types which illuminate the hall with varying efficiency. To illustrate the relationship, we plot the frequency distribution of the ratio of the internal horizontal illuminance to the solar radiation on the horizontal. Figure 33 shows the result.

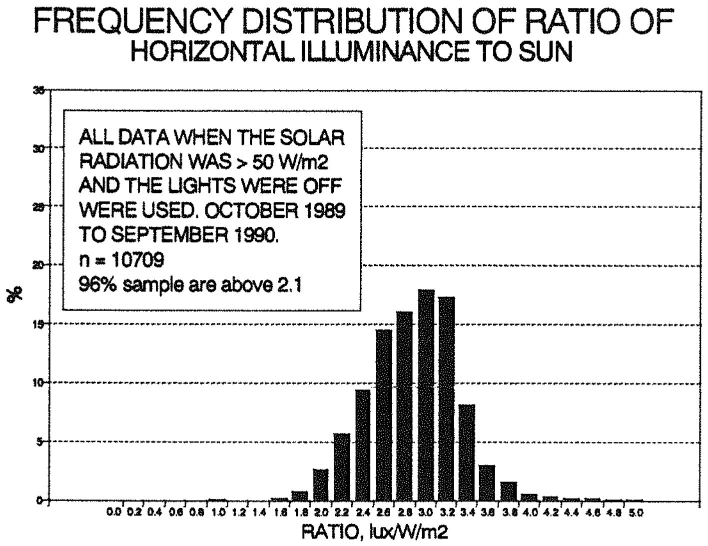

Figure 33. The variation of the ratio of internal horizontal illuminance to external solar radiation on the horizontal.

In Figure 33 only data when the solar radiation level was above 50 W/m^2, and the internal lights off were used. This avoided the magnification of errors resulting from the effect of taking a ratio of small measurements with small absolute offsets. It was also the case that light switching occurred much more below these solar radiation levels. *(Note that for brevity, the word* ***sun*** *is often substituted for what is actually the* ***global solar irradiance on the horizontal.****)*

Figure 33 shows that there was considerable variation in the effectiveness of solar radiation in illuminating the hall. Most values lay between about 2.0 and 3.5 lux/W/m^2. For this analysis of the availability of internal daylight a very conservative value of **2.1 lux/W/m^2** was chosen. 96% of the sample were above this value.

Before proceeding it is worth comparing this distribution of the effectiveness of solar illumination with information obtained from the daylight factors test. The daylight factors varied from 2.5% to 5% with the mean of all values being 3.5%. Assuming a luminous efficacy of 120 lumens/watt the mean ratio becomes equivalent to 4.2 lux/W/m^2, which may be compared with the distribution in Figure 33 above. This value implies a better provision of daylight than the year's monitoring data support. There are several reasons for this.

The whole of the daylight factors test was conducted when the sky was completely overcast - as is required. This is just one sky type of many; Figure 33 covers all sky types using a year's data. There is also some over-shadowing from mature trees at the southern end of the building. To illustrate the way in which the effectiveness of illumination varies we may plot the effectiveness ratio for two days - one cloudy and one sunny. See Figure 34. This shows two consecutive days in late February 1990. The ratio is shown for levels of sun greater than 50 W/m^2 and the sun is plotted for the whole day.

It is assumed that the first day was overcast. The ratio of effectiveness can be seen to vary considerably, being generally higher on the cloudy day.

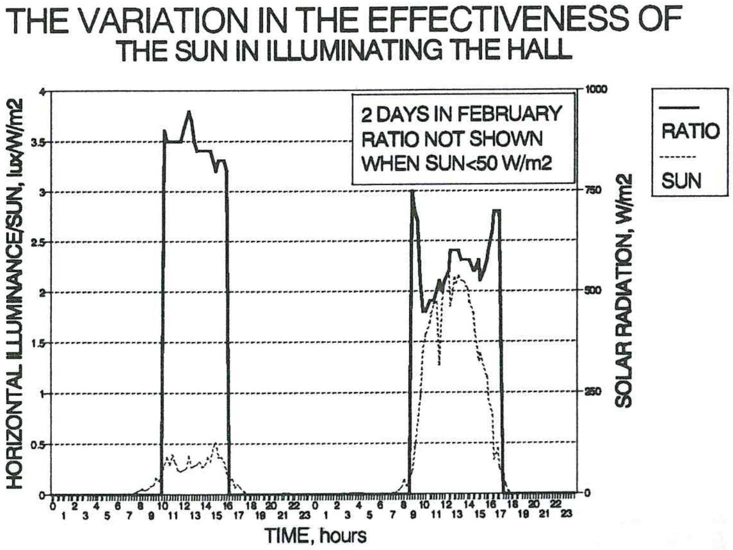

Figure 34. The variation of the effectiveness of the sun in illuminating the hall; two consecutive days - one cloudy, one sunny - in late February 1990.

The determination of the availability of adequate illumination from daylight alone

We now proceed and divide the adequacy level of horizontal illuminance (360 lux) by the lux to solar radiation ratio (2.1) to give **171 W/m²**. This is therefore the conservative estimate of the level of solar radiation that will provide adequate illumination, i.e. a horizontal illuminance matching that enjoyed at night-time from the artificial lighting.

The 12 months of solar radiation data can now be tested against this adequacy level to generate the percentage of time in the year when this level was exceeded. This percentage is shown for each quarter hourly period of the day in Figure 35. All 12 months' data were used for this distribution, though there are four weeks missing between May and June, mostly in May. (No allowance has been made for this gap, which were it possible to close, would probably have the effect of raising all values slightly.)

Figure 35 shows that daylight alone was capable of providing adequate lighting for much of the year. For the

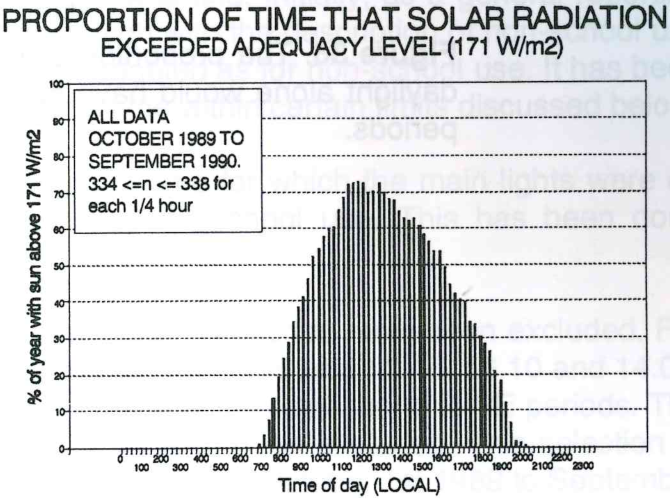

Figure 35. The proportion of the time in the year that total solar radiation on the horizontal exceeded 171 W/m² and thus the internal horizontal illuminance being adequate (at least 360 lux) from daylight alone.

School
60,8%
visual
Extend
[illegible]

extremes of times when the hall is used regularly (from 06.45 for cleaning to 22.30 for sport) daylight would have provided adequate light for 37% of the time. For various school uses of the hall (from about 09.30 to 17.00) daylight would have been adequate for 61% of the year.

To conclude this section we show how the proportion of time daylighting alone would have sufficed varied through the year. For convenience, the data chosen are the school PE periods for the whole year, inside term-time. There are four of these that take place between 09.30 and 15.20. The proportions are shown in Figure 36. They demonstrate how for much of the year there were many times when daylight would have been sufficient for PE activities. For about eight months of the year daylight alone would have been sufficient for at least half the PE periods. **This is good evidence for H1 that the building's design provides substantial daylight in the hall.**

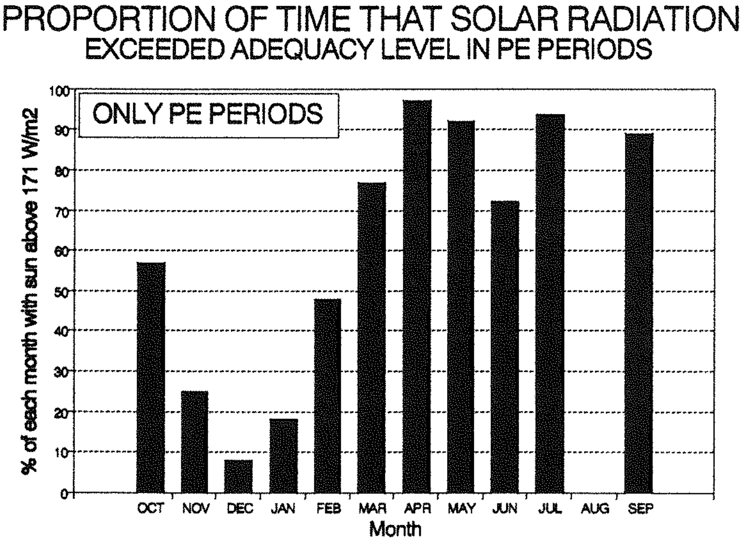

Figure 36. The proportion of time each month when daylight alone would have been adequate during PE periods.

Hypothesis 2

H2. Artificial lighting is used less as the availability of daylight illumination increases.

The route for testing H2

To test H2 we need to: determine when the sports hall was in use;

determine the proportion of this time for which the lights were on;

determine to what extent this proportion correlates with the mean solar flux during the same periods of analysis.

Having established that the design is successful in providing a basic opportunity to use daylight in preference to artificial lighting, we now see if the availability of daylight did indeed displace electric lighting use. Use of the hall by the school (during PE periods only and termed ***school use***) and for extra-school activities (***non-school use***) is looked at separately. Note that the hall is also used by children outside PE periods - at lunch-time and after school. This use is less regular and has been excluded from the analysis. Non-school use refers to mainly adult users of the hall.

SCHOOL USE

Information on when PE classes were actually using the hall is not obtainable from timetables because nearly all activities, except for example volley ball, may take place either in the sports hall or outside if the weather is fine. Initially, as a general reporting of lighting use in the hall and to allow comparison with the description of non-school use later, the same analysis procedure has been adopted as for non-school use. It has been assumed for this that the hall was used all the time within certain limits discussed below.

The analysis has simply looked at the length of time for which the main lights were on compared to the total time the hall was used for school use. This has been done separately for each of 12 months.

The analysis has been confined to term time data. Weekends have been excluded. For each school day only data between 09.30 and 10.20, 10.55 and 11.45, 13.10 and 14.00, 14.00 and 15.20 local time have been used. These times correspond to PE periods. The period of missing data in May to June 1990 has also been excluded. This selection of data then covers 625 hours of school use of the hall from October 1st 1989 to September 30th 1990.

Figure 37 shows how the proportion of time that the artificial lights were used in these school hours varied considerably through the year (from about 55% in January to 0% in May and June). The figure also shows the total hours of assumed use of the hall per month. This varies because of the holidays for the children; there are 12 weeks of holidays in the year - all of which have been excluded from the analysis.

To see if the reduction of the use of artificial lighting is related to the ambient solar radiation the same data have been plotted against the mean level of solar radiation during the same periods of time. The data are grouped into monthly values. The result is shown in Figure 38 and the data in Table 18.

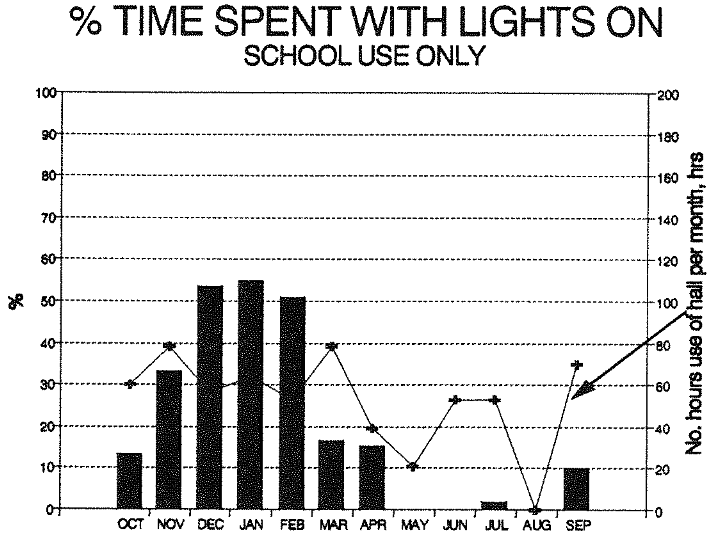

Figure 37. The variation in the use of artificial lighting for school use through the year.

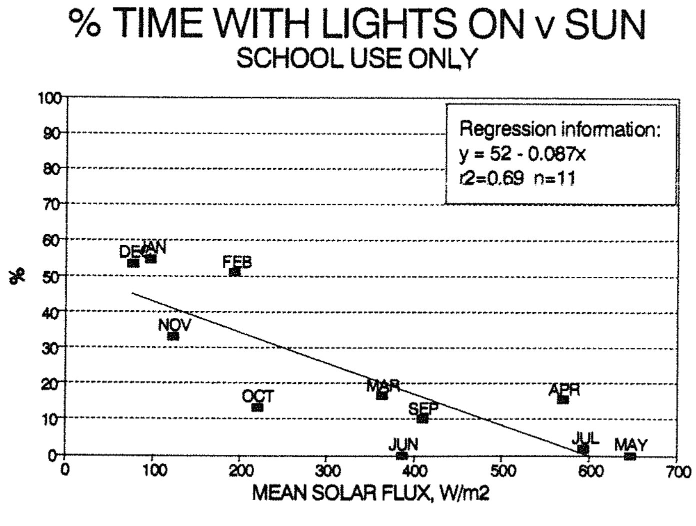

Figure 38. The variation in the use of artificial lighting for school use and the incident solar radiation.

		1989	1989	1989	1990	1990	1990	1990	1990	1990	1990	1990	1990	
Quantity	Units	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
Time with lights off	[hours]	52	52	26	29	26	65	33	21	53	52	0	63	472
Time with lights on	[hours]	8	26	30	35	27	13	6	0	0	1	0	7	153
Total time hall used	[hours]	60	78	56	64	53	78	39	21	53	53	0	70	625
% time with lights on	[%]	13	33	54	55	51	17	15	0	0	2	-	10	24
Mean solar flux	[W/m2]	220	124	78	98	194	363	571	647	387	594	-	410	335

Table 18. The time that lights were switched on in the main sports hall as a proportion of the total time that the hall was available for use by school users. (Only PE periods between 09.30 and 15.20 in term time are considered.)

Figure 38 shows that when the data are ordered according to increasing ambient solar radiation the use of electric lighting decreases. The data-points are rather scattered, but there is a clear difference between the winter months of December and January and March and April in the spring. The disparity in the use of the lights in February and October (53% and 13%), which have almost the same amount of sun, may be seasonal hysteresis in user reaction.

Over the whole year (PE periods only, in term-time) lights were not used for 76% of the time considered.

The above represents an accurate description of the measured school use of artificial lighting. However, because of the unknown reliability of the underlying assumption - that the hall was *in use* during these PE periods - it is not possible, and incorrect, to assume that the low use of lighting in months around the summer represents a fuel saving brought about by the design of the hall. Rather, it is often the case that away from the winter months and when the weather is fine, PE periods may be taken outside. Increased ambient solar radiation could be more directly associated with decreased use of artificial lighting, because the hall is not used. To address this uncertainty in the actual use of the hall only part of the year is assessed for estimating savings in electricity. We use only the months from November to March inclusive. This selects a cooler and duller part of the year (mean external temperature less than 10°C) when it is more likely that the hall was normally being used in PE periods.

It should be noted that in the regime operating at the school, pupils are involved in a much wider range of sporting activities for PE than hitherto. Some of these are only played inside the hall, e.g. badminton, indoor hockey (not played outside in summer) and *volley ball (there are no facilities to play it outside). It is the view of the head of PE that from November to March inclusive the hall is in use virtually all the time.*

It is, therefore, possible to calculate the saving in electricity with confidence if this period of time is taken. The time-tabled use of the hall in these months sums to 329 hours (52.6% of the annual time-tabled PE time).

Rate of consumption of main hall lights = 33 x 400 W = 13.2 kW

Total expected consumption had Brune Park sports hall been constructed with an opaque box design[2]
= 329 hours x 13.2 = 4343 kWh.

Actual consumption = 131 hours x 13.2 = 1729 kWh

Ignoring all use of the hall for the months of April to October inclusive:

The annual saving on electricity would therefore be 2614 kWh (60%) of delivered fuel for school use during the five months November to March.

NON-SCHOOL USE

A similar exercise may be performed on those data collected during non-school use of the hall. This use of the hall is variable, but booked in advance - there are no casual users. The times of use of the hall for each day were available from the booking sheets and these have been used to select only data that correspond to these times. As before, the analysis simply considers the length of time each month for which the main lights were on compared to the total time the hall was used for non-school use. The time spent on is shown as a percentage of the booked periods for each month in Figure 39. *(Booking data were only available for 11 months. Additionally, the main data for May and June were incomplete (9 and 22 days respectively were available. See earlier.), but these months have still been included.)*

Figure 39 shows that through the year the hall was in use for a considerable time with the lights off. (In considering the significance of the lights being off it should be remembered that a conventional hall would need lights on 100% of the time.) The proportion of time for which the lights were on varied from almost 100% in January to about 50%. nearer the summer. This variation is less than that for school use. The maximum use of almost 100% is also much more than the 55% maximum use by school users.

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[2] It is very common for sports halls to be designed with daylight excluded from the playing area of the hall. Following a competition organized by the sports council a Standardized Approach to Sports Hall design (SASH) was formalized. This design, since replicated many times, allowed daylight to be admitted into ancillary areas, but excluded it from the main hall.

The same monthly data are plotted again against the ambient solar radiation to reveal the degree of linkage. See Figure 40 and Table 19 for the supporting data.

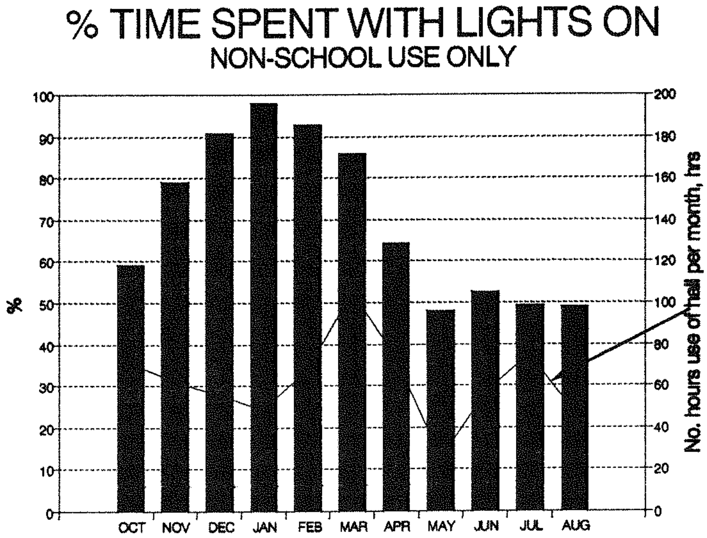


Figure 39. The variation in the use of artificial lighting through the year for non-school use.

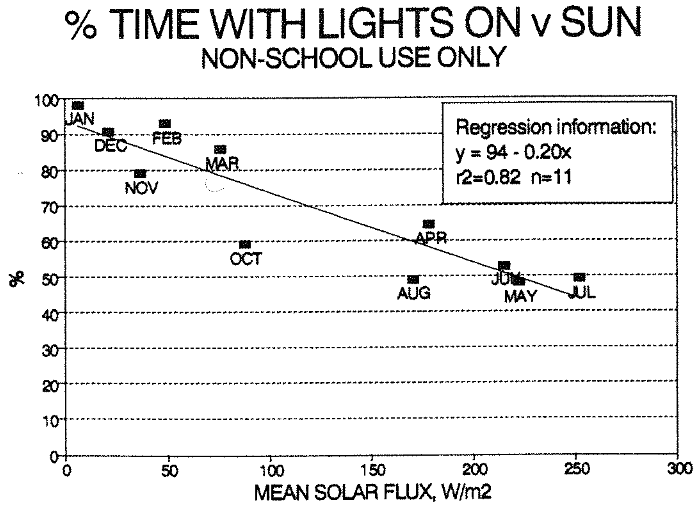


Figure 40. The variation in the use of artificial lighting for non-school use and the incident solar radiation.

		1989	1989	1989	1990	1990	1990	1990	1990	1990	1990	1990	
Quantity	Units	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	PERIOD
Time with lights off	[hours]	29	13	5	1	5	15	26	13	27	38	24	196
Time with lights on	[hours]	42	49	50	47	63	91	47	12	30	37	23	491
Total time hall used	[hours]	71	62	55	48	68	106	73	25	57	75	47	687
% time with lights on	[%]	59	79	91	98	93	86	64	48	53	49	49	71
Mean solar flux	[W/m2]	88	37	22	7	49	76	179	223	216	253	171	120

Table 19. The time that lights were switched on in the main sports hall as a proportion of the total time that the hall was booked for use by non-school users.

Figure 40 shows that there is a clear relationship between the average solar radiation level during use of the hall by non-school users and whether the main hall lights are on. The scatter is rather less than for school use. Over the 11 months considered lights were not used for 29% of the time the hall was booked for use. This may be construed as a definite saving of electricity when compared to the requirements of a traditional opaque sports hall such as the SASH design. Considering just these 11 months' data, the savings may be quantified as before:

Rate of consumption of main hall lights = 33 x 400 W = 13.2 kW

Total expected consumption had Brune Park sports hall been constructed with an opaque box design
= 687 hours x 13.2 = 9068 kWh.

Actual consumption = 491 hours x 13.2 = 6481 kWh

The saving on electricity is therefore 2587 kWh of delivered fuel.

For the 12 months October to September this would be somewhat larger because of the loss of data incurred during May and June and because September has not been included. By increasing the contributions from May and June *pro rata* and assuming that use of the hall in September 1990 was the same as in October 1989 a rough annual estimate can be made. This gives an annual use of the hall of 840 hours, 573 hours with the lights on.

The annual saving on electricity is therefore estimated at about 3500 kWh (32%) for the non-school use of the hall.

Both school and non-school use of the hall's lighting have shown reductions at higher solar radiation levels. Taking both uses together this is an annual saving on electricity of about 6,100 kWh/year. **There is good evidence that H2 is correct; the sun is displacing the use of artificial lighting.**

CONTINUOUS (09.00 to 21.00) HYPOTHETICAL USE

As this design of sports hall might well be considered in a different context, with higher use, it is worth considering what the fuel savings would be. We consider a situation where the Brune Park sports hall is used to provide a community sports hall required to have sufficient light for activities between 09.00 and 21.00, seven days a week, closed only at Christmas. Though we have termed it hypothetical use, this regime is common. The annual hours of use would then be 4356. Using the monitored solar data, daylight would provide adequate lighting for 48% of the year.

The extent to which potential saving in lighting energy can be realized in practice varies. If lights are left switched on regardless of available daylight there is obviously no saving at all. The method of controlling the use of the lights is paramount. At Brune Park, lights are clearly not switched off as soon as outside light levels become sufficient - nor are they switched on as soon as it becomes too dim. In the first case occupants experience brighter than necessary conditions and in the second it is dimmer. When conditions are dimmer than the adequacy level - the lights have not been turned on yet - light levels may still in fact be adequate for the occupants. The adequacy level chosen earlier was certainly generous.

The full potential saving of the design could of course be much higher than the 48% quoted above. If the three banks of lamps could be controlled individually then a stepped response to the use of artificial lighting could be achieved. This would have a dramatic effect on the potential for saving electricity. This would, however, require the use of automatic controls and these would need to operate at least as well as the caretaker. He will take into account the nature of the sky - changeable or steady, clear or cloudy - and the long warm-up time of the lights.

For this analysis it does not therefore seem unreasonable to suppose that lights can be switched on or off according to available daylight levels. As discussed above there will be over-estimation and under-estimation implicit in this assumption. There is moreover no suitable switching algorithm that could be used instead. Savings are therefore calculated on the assumption that lights will on average be switched on when daylight alone is insufficient and switched off when daylight is sufficient.

The percentage savings over an opaque hall are shown for each month in Figure 41. (The months have been re-ordered from January to December, but the data are the same.)

For 09.00 to 21.00 use every day:

Total expected consumption had Brune Park sports hall been constructed with an opaque box design
= 4356 hours x 13.2 = 57500 kWh.

Total expected consumption using the design for daylight
= 2265 hours x 13.2 = 29900 kWh

The annual saving on electricity would therefore be 27600 kWh (48%) of delivered fuel for this level of use.

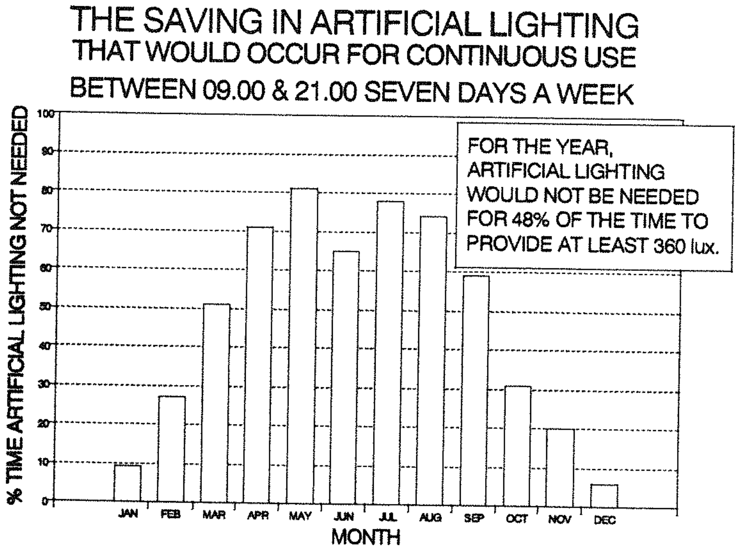


Figure 41. The monthly saving on lighting energy - compared to an opaque sports hall - were the Brune Park design to be used from 09.00 to 21.00 every day.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
% time sunlight adequate	9	27	51	71	81	65	78	74	59	31	20	6	48

Table 20. The monthly percentage saving on the use of artificial lighting were Brune Park to be used from 09.00 to 21.00 every day.

DETERMINED NEED FOR ARTIFICIAL LIGHTING COMPARED WITH MEASURED ACTUAL USE

We conclude this analysis by combining data from the testing of H1 and H2. Using the monthly data on the need for artificial lighting in Figure 36 with the actual use of lighting in Figure 37 we illustrate the strength of the link between the two. See Figure 42.

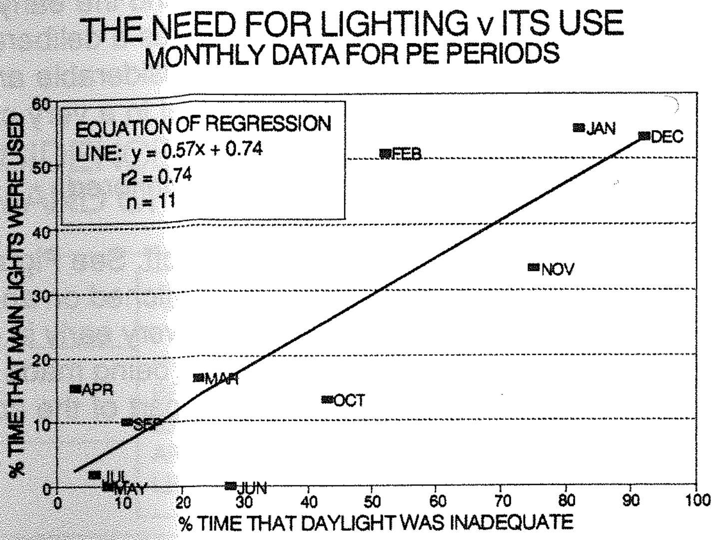


Figure 42. The relationship between the need for lights and the use of lights. Monthly data for PE periods only.

Figure 42 shows quite a good correlation between the need for artificial lighting - when solar radiation on the horizontal was below 171 W/m^2 - and the actual percentage of the time each month when the lights were used. The coefficient of determination (r^2) is 0.74 - slightly higher than the correlation of use with mean solar flux (See Figure 38).

This concludes the main energy analysis of the passive solar feature. The next section describes the control of the lighting; when the main lights were switched on and off.

THE CONTROL OF THE MAIN LIGHTS

There is no automatic control system for the main hall lights. (There is a control system for the exterior lighting using a photocell and a timeswitch in series.) The control of the lights is in the hands of the caretaker and assistant caretakers. The switches for the lights are at the entrance to the hall, but can only be operated with a key. During the period of monitoring there was only one key and this was therefore kept in a locked cupboard. Access to this cupboard was restricted to the caretakers and the early morning cleaner. This denial of access to the key for the users of the hall was a deliberate policy to avoid lights being put on and left on unnecessarily. There is considerable anecdotal evidence to suggest that the caretaker viewed his role in saving fuel in a very conscientious way.

In this section we describe the switching behaviour as monitored.

We first show when the main lights were switched on and off. See Figure 43. This shows the actual number of times in the year when lights were switched on and off for each time period in the day. There are a large number of switchings very early in the day (when the cleaner puts on the lights) and after 17.45 when the hall is being made ready for evening use. There are relatively few switchings during the main part of the school day.

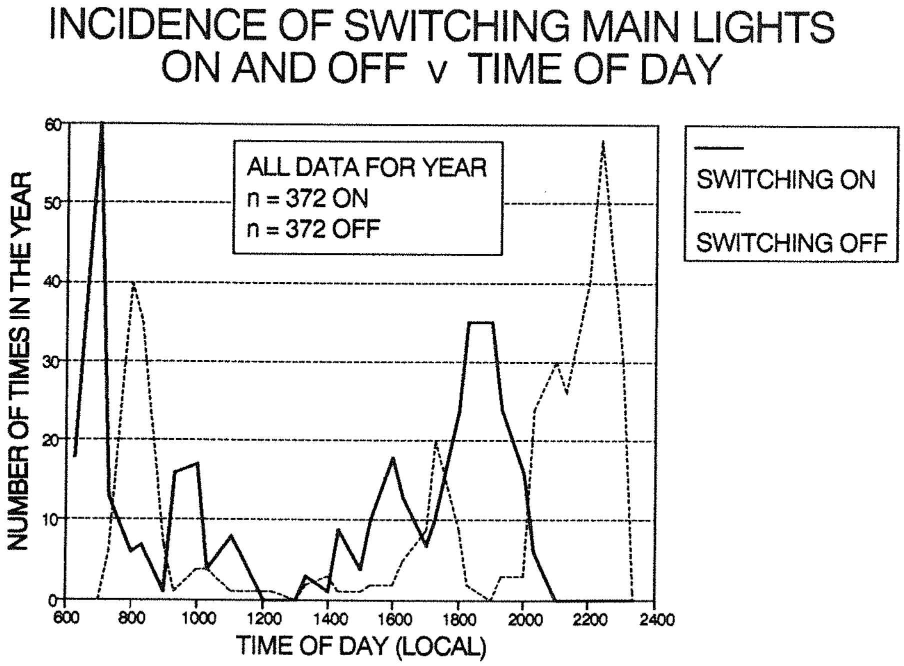
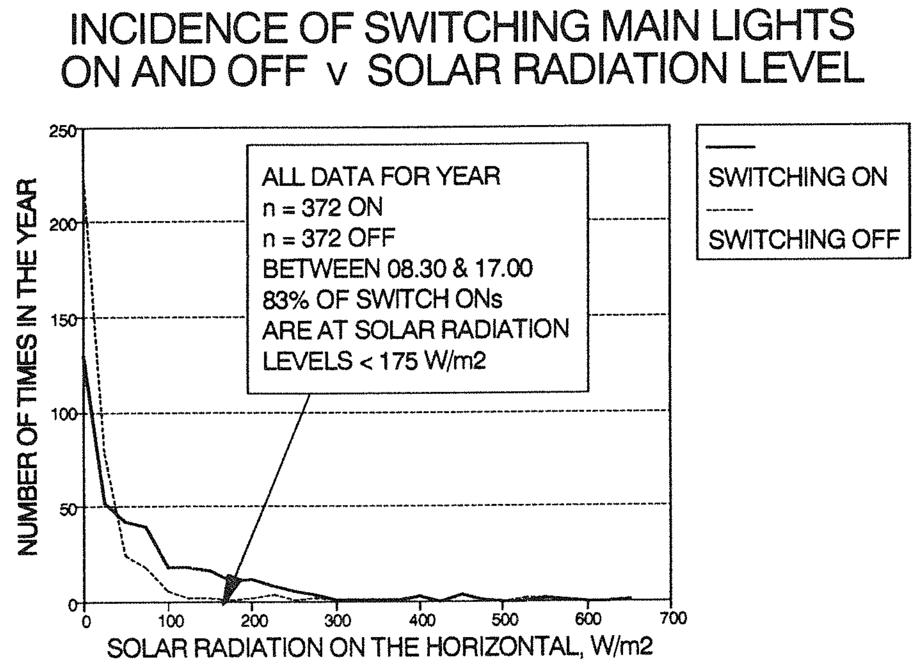


Figure 43. The number of times that lights were switched on and off at different times of the day. The data cover the whole year.

We now illustrate the level of solar radiation that existed when lights were switched. See Figure 44. As would be expected, the lights were switched on many times when the solar radiation was zero - for evening activities and early morning cleaning. There is generally a clear falling away of switching activity with increasing solar radiation. There is practically no switching above 300 W/m2. This graph is pertinent to the adequacy level chosen earlier for H1. If the solar radiation level at switching ON events is considered only within the school's day time period (08.30 to 17.00) then it is found that 83% of them occur below 175 W/m^2. This should be compared with the chosen adequacy level of 171 W/m^2. The monitored data are reasonably commensurate with this value being taken as an indicator of adequate light being available from daylight alone.


INCIDENCE OF SWITCHING MAIN LIGHTS ON AND OFF v SOLAR RADIATION LEVEL

ALL DATA FOR YEAR
n = 372 ON
n = 372 OFF
BETWEEN 08.30 & 17.00
83% OF SWITCH ONs
ARE AT SOLAR RADIATION
LEVELS < 175 W/m2

Figure 44. The incidence of switching at various solar radiation levels.

CONCLUSIONS

There is good evidence that the building's design provides adequate light for much of the year. During the year of monitoring (October 1989 to September 1990) light from the sun alone would have been adequate for at least half the time for every month apart from November, December and January.

There is also good evidence that the use of artifical lighting dropped substantially when the monthly solar radiation levels were higher. It has been estimated that over the monitored year there was a total fuel saving on artificial lighting of about 6,100 kWh. This is 40% less than the 15,400 kWh (school & non-school use) that would have been consumed had the building been designed as an opaque box.

Were the Brune Park design to be used to provide a community sports hall required to have sufficient light for activities between 09.00 and 21.00, seven days a week, daylight would provide 48% of the lighting needs over the year. This would mean the design would save 27,600 kWh of electricity per year. This assumes that lights would be switched off when daylight was sufficient.

REFERENCE ENERGY

Data are provided to allow the measured fuel use to be compared with either other buildings, or semi-empirical targets. Energy use is given in units appropriate to the particular source of information.

DATA:

In 1985, the Audit Commission defined a Normalized Performance Indicator for buildings. This is simply the number of kWh/m^2 of delivered energy used by a building adjusted according to exposure, degree days, and the number of hours of use of the building relative to an appropriate national average. The Audit Commission's work covered 3,200 buildings in 19 categories in 30 local authorities in England and Wales. The NPIs for each category were assumed to be normally distributed and were used to give pairs of NPIs: a "target" NPI below which 25% of the sample lay and a "poor" NPI above which 25% lay. These are shown below for the most relevant category of "sports centre - no pool" , together with Brune Park's NPI[3] (normalized from the 1989-90 data).

Yardstick NPI of efficiency:	220 kWh/m^2/year of delivered energy
NPI of poor efficiency:	410 kWh/m^2/year of delivered energy
Brune Park's NPI (1989-90):	260 kWh/m^2/year of delivered energy

An alternative point of reference *for lighting energy only* can be obtained by considering Brune Park operating solely with artificial lighting. Its lighting energy use would then be equivalent to that of the common opaque box design of sports hall. A suitable analysis has been done in the *Measured Energy* section when the use of the Brune Park design to provide a community sports hall was considered. This reference (an "opaque Brune Park") would use 57,500 kWh/year for lighting (61 kWh/m^2/year). Using the measured solar data for 12 months it was computed that Brune Park would actually consume 52% of this, or 29,900 kWh/year (32 kWh/m^2/year). In both cases the use of the hall was set to be 09.00 to 21.00 hours, seven days a week.

As part of the Non-domestic Design Studies work managed by ETSU, the Standardized Approach to Sports Hall (SASH) design was modelled using the energy simulation model SERIRES. This design excludes daylight from the sports hall itself, but allows it in ancillary areas. The simulation assumed occupancy everyday of the year between 09.00 and 23.00 hours. Manually switched fluorescent lighting is used in the SASH design for the main hall. The modelling predicted the following fuel use:

All lighting: 69,000 kWh/year (53 kWh/m^2/year, gross floor area)

All space heating: 129,000 kWh/year (98 kWh/m^2/year, gross floor area)

All lighting energy was not measured for Brune Park, but a rough estimate can be made by adding miscellaneous use of electricity (after subtracting the known non-lighting use of the flue dilution fan) to the figure of 29,900 kWh above. We may also increase the consumption to allow for use between 21.00 and 23.00 by adding on (363 days x 2 hours x 13.4 kWh =) 9728 kWh. This gives (referring to Table 14 and page 57):

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[3] See Appendix for more detailed information on the calculation of Brune Park's NPI.

$$29{,}900 + (10985-4000) + 9728 = 45{,}713 \text{ kWh/year } (48.6 \text{ kWh/m}^2\text{/year})$$

This is 66% of the predicted total lighting energy consumption of the SASH design. Use per square metre is 92% of the SASH design.

All space heating delivered energy used at Brune Park was measured and normalized for degree days at 134,218 kWh (142.8 kWh/m^2/year). (Refer to Table 16.) This is 5% higher than the SASH design or 46% higher per square metre.

Space heating at Brune Park uses more energy than the SASH design, despite being well insulated. This is almost certainly due to the high temperatures maintained at Brune Park. The temperature in the hall exceeded 20.5°C for 17% of the *winter* season - more in the other seasons. The design temperature for Brune Park was 16 to 17°C and that for the SASH design 14°C.

CONCLUSIONS:

The normalized performance indicators given by the Audit commission's survey of sports centres show that Brune Park is near the yardstick NPI of good energy efficiency.

If Brune Park operated with the lights on using a common regime (09.00 to 21.00, every day), it would consume 61 kWh/m^2/year of delivered lighting energy. Under the same regime, but making use of daylight when available, Brune Park would consume only *half* of this.

Compared to the SASH design Brune Park saves 34% of the electricity for all lighting; this is a 8% saving of use per square metre. This comparison with the SASH design is a litle unfair as a substantial area of the SASH design includes a large ancillary area illuminated to lower levels than in the sports hall proper. (The savings would be greater if this were taken into account.) Space heating use is 5% higher and 46% higher per square metre. More space heating energy is used because temperatures are several degrees higher than in the modelled SASH design.

REFERENCE COSTS

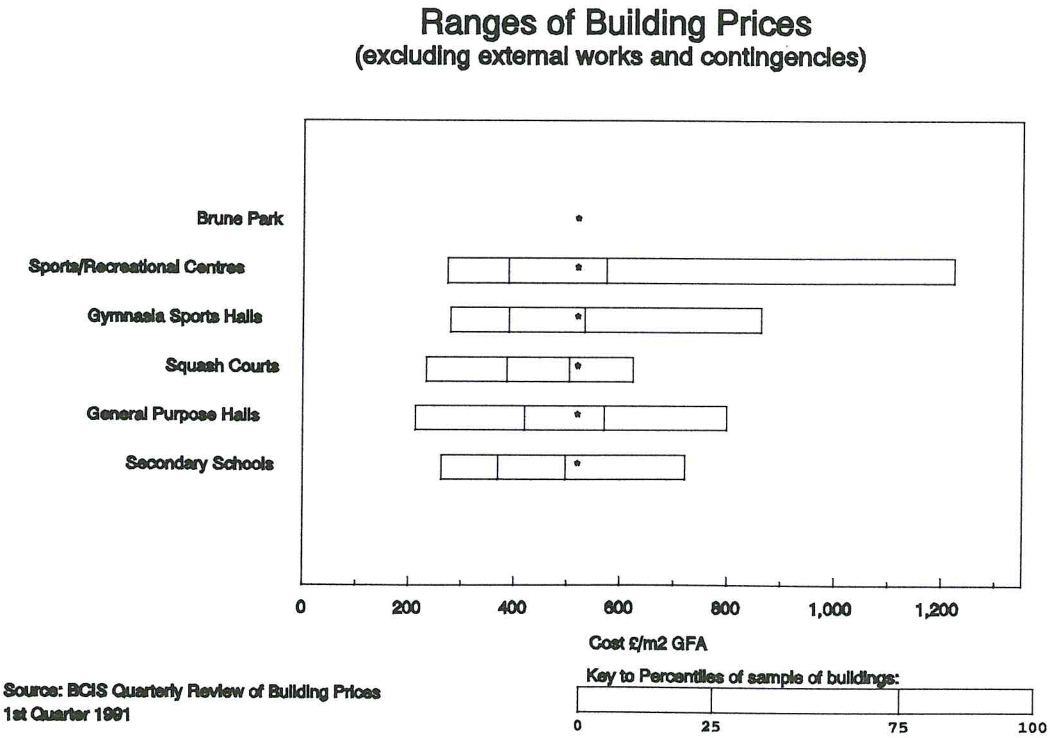
Some guide to the average costs of building different kinds of sports halls is given in this section. It is important to see if the overall cost of a putative low energy building differs significantly from standard buildings. If cost might prove an impediment to the widespread adoption of the Brune Park design, then that will become clear here.

COSTS:

Samples of appropriate building types have been investigated by the ETSU's Cost Advisory Service in order to provided a reference for comparison with Brune Park. The results are shown below in Tables 21 and Figure 45.

	BCIS AVERAGE BUILDING PRICES ADJUSTED TO DECEMBER 1990, £/m2 gross floor area			
	Mean	Range	Standard deviation	Sample size
Sports or Recreational Centres	521	272 to 1223	174	44
Gymnasia Sports Halls	476	278 to 862	115	78
Squash Courts	466	333 to 624	-	5
General Purpose Halls	498	213 to 799	136	28
Secondary Schools	446	261 to 721	103	79

Table 21. Average building prices for a range of building types. Brune Park cost £519/m^2.

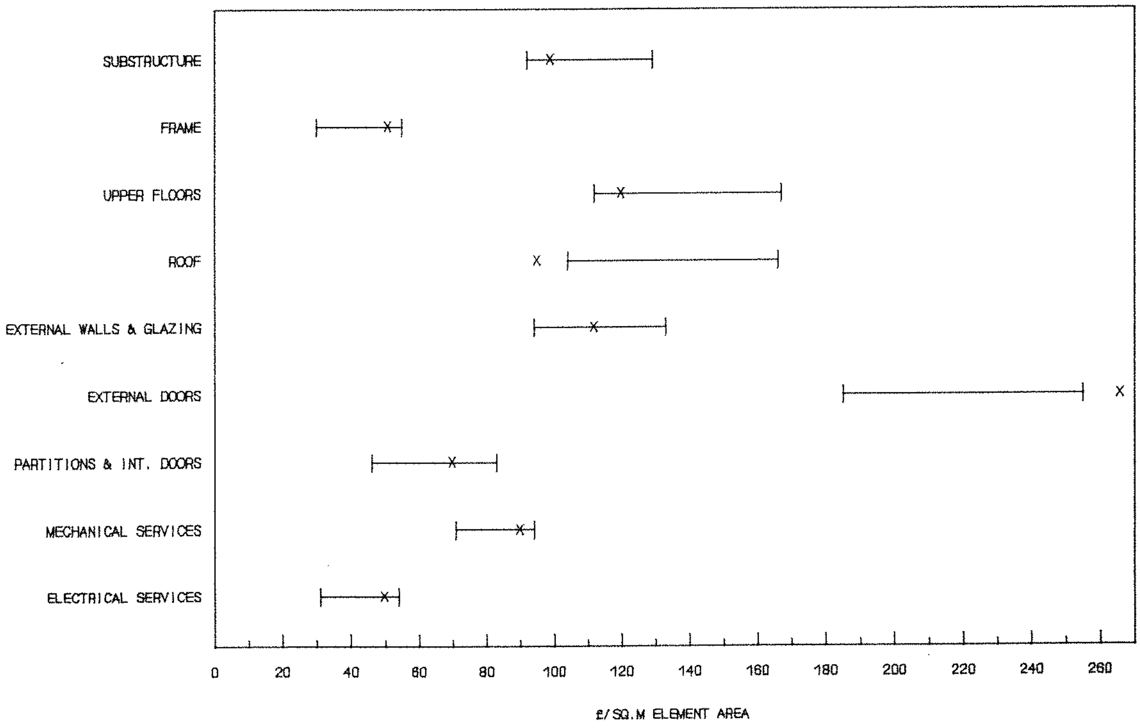


Source: BCIS Quarterly Review of Building Prices
1st Quarter 1991

Figure 45. Reference costs for a range of buildings.

The middle band for each building type in Figure 45 gives the range of costs/m^2 into which 50% of the sample fell. The data show that costs/m^2 vary greatly for the same building type - the extremes varying by three to one, or more.

Figure 46 shows the range of the costs/m^2 of the elements of leisure buildings as estimated by the CAS. Brune Park's costs are marked with an "X" and can be seen to be fairly typical.



NOTE: Costs include allowance for prelims. 12%
SOURCE: Development Economics -Leisure Buildings
Initial Cost Estimating DL&E AJ 14-12-88

X = Tender rate for Brune Park

Figure 46. Reference costs of the elements of construction for leisure buildings.

CONCLUSIONS:

Reference costs show that the cost of Brune Park, reported in detail in the next section, is similar to the mean costs for other sports and recreational centres, gymnasia and sports halls.

MODELLED COSTS

Costs for non-domestic EPA buildings are not actually modelled, but tender information is normalized for consistency. They have additionally been updated in time (to December 1990). The data are provided by ETSU's Cost Advisory Service.

COSTS:

Table 23 opposite shows the use of space in the whole building. The actual sports hall occupies about half the total gross floor area.

Figure 47 details the contributions to the total cost of the hall of £495,300 (£519/m^2 gross floor area). The addition of the sports hall to the school required a link to be built and some other associated work - all of which have been excluded from the cost analysis.

It is usually difficult and contentious to identify costs borne specifically because of passive solar design. Nevertheless, an example is given here for the reader to judge.

At Brune Park an obvious candidate for cost saving would be the roof-lights and velarium which are unusual, but not unique, features in sports halls. The roof-lights cost about the same as the roof per square metre. There is therefore no capital cost penalty associated with them. Maintenance costs of the roof-lights have not been measured but are not thought to be significant. Were the roof opaque, necessitating the continuous use of artificial lighting, re-lamping costs would be higher.

The CAS estimate that the velarium cost about £14,500 to provide, support and fit. However, because it acts as an effective diffuser for the artificial lighting as well as for daylight, it has not been pursued as a possible cost of the passive solar design. It is true that sports halls are commonly constructed without diffusers, but the resulting lighting conditions are poor; they cannot reasonably be used as a bench-mark for good design.

In *Measured Energy* the saving on lighting energy was estimated at 48% of a non-passive solar (opaque) design for a common, but hypothetical use of such a hall from 09.00 to 21.00 hours each day. This gave a saving of 27,600 kWh of electricity per year. This gives an annual saving of £1900 at December 1990 on-peak electricity prices.

The roof-lights and the other glazing bring other benefits - of openness and variety - as well as saving energy. In the *Design Statement* it was clear that the architect wished more to incorporate daylighting to improve the ambience of the building rather than to meet an energy efficiency target.

Using the data in Table 16 in *Measured Energy* normalized fuel costs have been estimated. (See Table 22 below.) The costs are only indicative as tariffs usually vary according to fuel use, maximum demand, etc., and the sports hall did not receive fuel bills separately from the school. Electricity use is considered to be on-peak.

	£/m^2/year	£/year
GAS	2.4	2,260
ELECTRICITY	2.1	1,960
TOTAL	4.5	4,220

Table 22. Annual normalized fuel costs of the Brune Park sports hall.

PART OF BUILDING	AREA, m2	AREA, %
Main hall	496	52.0
Weight training room	35	3.7
Exhibition area	53	5.6
Showers & Changing	74	7.8
Staff	10	1.0
Viewing Gallery	72	7.6
Toilets	24	2.5
Stores	58	6.1
Plant	22	2.3
Circulation	76	8.0
Partitions	33	3.5
Total Gross Floor Area	953	100.0

Table 23. Area analysis of Brune Park Sports Hall.

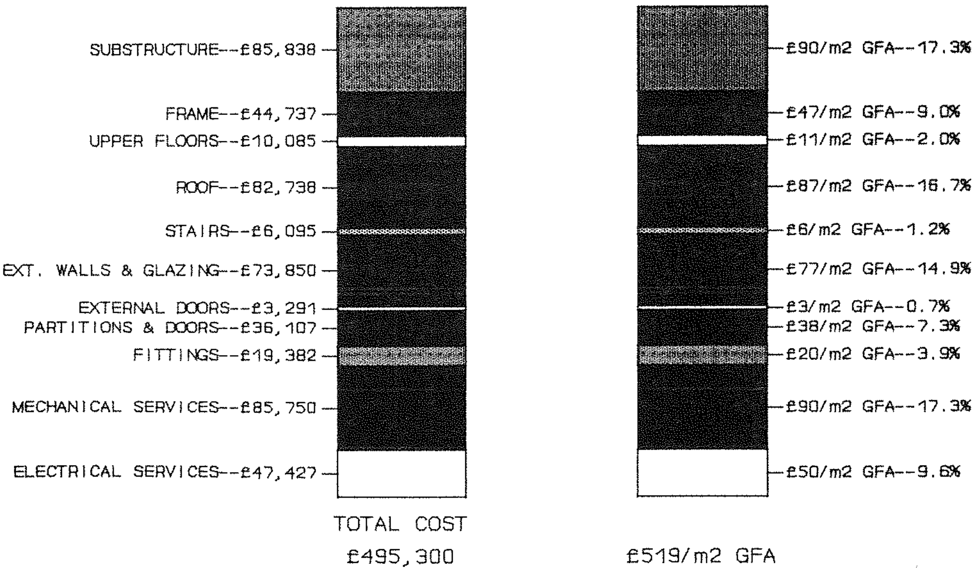


Figure 47. Elemental cost analysis of Brune Park Sports Hall.

CONCLUSIONS:

The previous section has shown that the cost of building Brune Park was very near the average for sports or recreational centres.

Incorporating roof-lights cost no more than having an opaque roof. They make possible an annual saving of about £1900 worth of electricity for lighting when the design is compared to an opaque sports hall in use 09.00 to 21.00 hours each day.

The velarium cost £14,500, but acts as an essential diffuser for the lighting.

The total annual fuel cost of the hall is about £4,200, or £4.50/m^2.

There is no evidence that there are any significant cost penalties associated with the passive solar design.

HOLISTIC APPRAISAL

A concise assessment of the building follows here, together with a rating on a five point scale for each aspect studied. To allow proper interpretation of the ratings, the guiding definitions for the extreme and middle ratings are also given.

Energy: ***

Using the 12 months' measured data, total fuel consumption per year has been computed using a space heating contribution normalized to long term average degree days. Total delivered fuel use is 183,353 kWh/year or 195 kWh/m^2/year (gross floor area). 73% is used for space heating, 11% for domestic hot water, 10% for the main hall lighting and 6% for miscellaneous power.

Brune Park's total energy use has been shown as a normalized performance indicator of 260 kWh/m^2/year (gross floor area). This is near the Audit Commission's NPI of efficiency for sports centres without swimming pools (220 kWh/m^2/year). The NPI for poor efficiency is 410 kWh/m^2/year. This is a reasonable consumption, though the higher than necessary internal temperatures suggest that the NPI could be reduced.

The gas space heating and domestic hot water boilers consume 14% (4,000 kWh) of the total annual electricity use through the use of a flue dilution fan. The pilot lights on the space heating boilers consume 3¼% (4,400 kWh) of the annual space heating gas use. About 2000 kWh of this are used outside the heating season.

Assessment Definitions:

*	***	*****
This indicates a high heat loss building with a passive solar feature that may be having a detrimental effect by causing problems with air infiltration, cold radiation, or cold bridging, for example. the building probably has a high fuel usage as high as chosen references. The services do not perform well.	This indicates a satisfactory heat loss building showing savings of fuel use. It is quite tightly constructed and is well insulated. Appliances and services have reasonable efficiency.	This indicates a much better performance than the general standard of low energy buildings. It is tightly constructed and well insulated. Appliances and services are efficient. The passive solar feature has not caused any problems with energy use.

Amenity & Environment: **

In the questionnaire survey, users of the hall reported that they were well satisfied with the *level* of lighting either in the day-time or at night. They were generally satisfied with the lighting as a whole.

Most people preferred the artificial lighting to be on, but a third had no preference. However, most of the respondents used the hall in the evening when daylight would be less. Only two people preferred the lights off, an afternoon player and an evening player, although interestingly the latter played badminton at up to county match level.

The survey showed that the users' views on lighting varied a great deal. Some are very particular about evenness and constancy of light and alluded to the scudding cloud problem. Others seemed unaware whether the lights were on or off. Indeed, perhaps because of the sail-cloth, some seemed not to know that there were any roof-lights at all.

Users thought the visual appearance inside quite satisfactory.

Users were very dissatisified with the hall being too hot. The monitored internal temperatures amply supported this. The recommended temperature for badminton (16°C) was exceeded for 88% of the time in the winter and more so in other seasons. 20°C was exceeded for 17% of the time in the winter and at least 55% of the time in the other seasons. There were many comments on how hot it was in the summer.

Many users commented on the poor air quality and thought there should be more ventilation.

Assessment Definitions:

*

This indicates a building which was not rated as having any positive advantages or amenity. There may be over and under-heating of working spaces at times, glare, etc.

***

This indicates that most occupants liked most of the passive solar features. There may be one or two areas of weakness, e.g. over-heating in summer. In general it is a well tempered and aesthetically pleasing environment.

*****

This indicates a successful building with negligible problems and very good amenity. Positive advantages are evident from the users' ratings and they would probably not move out, or only to another similar building.

Solar Performance: ****

The use of lighting energy is low through the reliance on daylight alone for much of the time. In *Measured Energy* it was shown that the annual savings on electricity were at least 60% (for timetabled use of the hall during PE periods) and were 32% (for definite use of the hall outside school hours). For continuous use of the hall, 09.00 to 21.00 every day, it has been estimated that savings would be 48%. This is excellent and provides the potential for saving 27,600 kWh/year of electricity for this level of use. (These are typical opening hours for a community sports hall; the actual level of use at Brune Park hall was rather lower.) All these savings are with respect to the same hall used for the same time, but with the lights *always* on when the hall is in use. (All potential savings would accrue only if the lights were turned off when there was sufficient daylight.)

Tests have shown that, at least in overcast conditions, the roof-lights and sail-cloth allow good uniformity of daylighting in the hall. The degree of uniformity matches that provided by the artificial lighting. Continuous measurements have shown that light levels enjoyed in the daytime are much higher than can be provided by the artificial lighting alone. In the spring season the horizontal illuminance averaged over the whole hall was above 500 lux in school hours for at least two thirds of the time and this was predominantly due to daylight. The artificial lighting provided only about 300 lux.

The sun contributes to a rise in internal temperature at low level. A *maximum* of a 5°C rise above the dawn temperature in any one day was observed during the summer. Much of the over-heating must be due to the heating system.

Part of the solar design was the provision of an extract fan at high level. This was provided to reduce over-heating *in the roof-space* to some extent. It was probably not envisaged that it would ventilate the hall, for which it would be very undersized. In any case, at 140W the fan is not very powerful and the temperature at velarium *floor* level to reach over 35°C (ten degrees above external ambient) and reach 45°C on one occasion (ten degrees above external ambient). It does not operate after 16.00 hours - thus precluding over-night cooling - and does not appear to operate according to a thermostat as designed, but to a time-clock. It does not operate on Sundays. There is not much in the way of an entry path for fresh air at low level and air will preferentially be drawn across the top of the sail-cloth from the inlet grilles in the opposite gable wall.

Assessment Definitions:

*

This indicates that little benefit is provided by the passive solar feature in terms of the estimated displacement of space heating or lighting energy. The design or use of the building is probably wrong, or it is not easily used by the occupants or it is overshadowed.

***

This indicates that the estimated displacement of heating or lighting energy by the passive feature is satisfactory. The system is easy to operate and produces heat at the appropriate times and is easily accessible to the occupants.

*****

This indicates a paragon; the estimated displacement of energy is large and operation and maintenance of the system is straightforward. It probably produces a shortening of the heating season that is noticeable to the users. It is easily controlled and responds well to solar radiation.

Cost Indicator ****

The cost of building Brune Park sports hall was £495,000 (£519/m^2 gross floor area) at 1990 prices. This was very near the average of 44 other sports or recreational buildings.

The roof-lights added no extra cost to having a completely opaque roof and enabled substantial savings on lighting energy. The velarium lighting diffuser cost £14,500, but should be seen as necessary part of the main lighting installation. For a common level of use of this kind of hall (09.00 to 21.00 each day) the energy saved on lighting would be 27,600 kWh (48%) of electricity per year. This gives an annual saving of £1,900 at December on-peak electricity prices.

Assessment Definitions:

*

This indicates a building in which the high cost of a passive solar feature would be unlikely to be recovered by displaced energy costs.

***

This indicates that the cost of the displaced energy is likely to pay for the costs of the moderately priced passive feature in a reasonable time.

*****

This indicates a passive solar feature which should provide large energy savings.

Composite ****

Drawing up an overall judgement is always difficult if it has to represent the distillation of quite different factors.

Brune Park's total fuel use is reasonably low. Its lighting use is about half that of an opaque sports hall design. Space heating fuel use, which has not been considered in detail in this EPA, could be substantially reduced because internal temperatures are generally too high.

The passive solar design has succeeded in reducing lighting energy use by about half, which is excellent. However, the hall as it stands produces much discomfort to its users. Over-heating is common, largely because of the space-heating system, and ventilation insufficient. In considering an overall assessment, weight must be given to the responses of the users of the hall; the hall was built for them - not as an energy conservation exercise.

The design admits substantial heat from the sun and there is no effective provision for exhausting or redirecting this when it is not required. The extract fan is of little use. The hall therefore suffers very high temperatures (for a sports hall) in the summer months. At other times of the year the hall also exhibits high temperatures and the heating system must be responsible for this much of the time. (It may be that set-points are too high or that the feed-back to the control of the underfloor heating is too sluggish.)

Brune Park's construction cost was average; there was no overall penalty for the passive solar design. The roof-lights cost no more than having an opaque roof, and they allow annual fuel savings of about £1,900. The velarium cost £14,500 and provides diffusion of artificial and natural lighting. This elimination of glare from above is a basic requirement for *good* lighting in sports halls. It is not an optional extra, nor is the velarium a *fundamental* part of the passive solar design; its cost should be seen as one way of providing appropriate lighting from artificial and natural sources.

A number of improvements can be made to improve the environment for users. The composite rating given above assumes that none of them is implemented. A list of recommendations follows this section.

Assessment Definitions:

*

This indicates a poor example of the use of passive solar technology. The passive solar feature of the building is not well liked, doesn't save energy either by means of its construction or passive solar gains, and costs more than it is worth. There may well be environmental problems. The building should not be followed as an example as it stands.

***

This indicates a satisfactory building in which most things are performing as expected with reasonably low energy use and a moderate displacement of auxiliary energy by the passive solar feature. The amenity is good and there are few if any environmental problems. Operation of the building is within the occupants' grasp. The costs are not too high and are repaid in good time. The design is probably suitable for replicating because there are few problems.

*****

This indicates a paragon. Both the building and passive solar feature are well liked with initial costs that are reasonable and quickly recovered by the high savings in fuel costs as indicated by references. There are no environmental problems and the overall energy performances of the building and passive solar feature are very good. This is a design which can be followed with confidence.

LESSONS AND RECOMMENDATIONS

1. The design makes good use of natural daylighting and this works well in displacing electric lighting energy. However, any design that allows a substantial entry of solar energy into the building should incorporate some method of equivalent heat rejection or storage, should this energy not always be needed.

2. Given sufficient conscientiousness and collective agreement, manual switching of lights in a highly daylit building can realize a large proportion of the potential saving in energy. Access to the control of the lights needs to be in the hands of a very few people.

There are several things that can be done to improve conditions:

3. The space heating system should be investigated to help reduce over-heating. Either the set-points are simply too high, by three to five degrees, or the responsiveness of the heating system needs to be programmed into the heating controller.

4. The extract fan in the roof-space should be replaced with a much more powerful one. This should be controlled by a thermostat rather than by a timeclock. The fan should be used to cool the building over-night, when necessary, to take advantage of the cooler night-time air and prepare the hall for the following day.

5. There should be some larger apertures at low level to allow ingress of fresh air. This would help improve the air quality, reduce over-heating and avoid the fire-doors having to be propped open in hot weather.

6. Although there have been substantial energy savings with manual switching performed only by the caretakers, there could be benefit from having at least some form of automatic control. There have been occasions when artificial lighting was required, but it was too irksome to get the lights switched on.

APPENDICES

INSTRUMENTATION AND LOGGING SCHEDULE:

The data requirements discussed in the EPA specification (See Preliminaries) led to a specification for measurement and logging. The details of this are given below.

External Temperature:

A Platinum Resistance Thermometer was placed at a height of four metres from the ground on the North western side of the building on the boiler house wall. It was placed in a white-painted naturally ventilated beehive enclosure away from sources of heat such as flue pipes, windows, vents. **DATA: 15 minute averages.**

Internal Low Level Temperatures:

Two PRTs were placed at low level in the main hall. One was placed near the entrance and one diagonally opposite at the other end of the hall. They were mounted with black globes at a height of about 2.5 metres above floor level in protective cages against the wall. **DATA: 15 minute averages.**

Internal High Level Temperature:

One PRT was placed without a black globe underneath the catwalk above the velarium at the northern end of the hall. **DATA: 15 minute averages.**

Internal Light Levels on the Horizontal:

Two *LICOR* light sensors were mounted flush with the base of wooden cones and suspended from chains 1 metre below the velarium. One was hung near the north western corner, and one near the south eastern corner. These sensors faced vertically down to receive reflected light. A later calibration converted the upward light reading into a downward light reading. **DATA: 15 minute averages.**

Internal Light Level on the Vertical:

One *LICOR* light sensor was mounted flush with the base of a rubber collar and fixed to the southern wall 3½ metres above the floor level and facing directly away normal to the wall. **DATA: 15 minute averages.**

Use of Extract Fan:

A relay was wired in parallel with the supply to the extract fan at the northern end of the hall. **DATA: No. minutes of use each 15 minutes.**

Electricity Consumption:

Three *Responder* meters were wired to record the electricity consumption of the 33 main overhead lights, miscellaneous electricity use and the total use. **DATA: No. of kWh pulses each 15 minutes.**

Gas Consumption:

An existing *IMAC* gas meter was used to measure total gas use. Two gas meters were installed, one on each space heating boiler, to measure space heating gas. **DATA: No. of cubic foot pulses each 15 minutes.**

Incident Solar Radiation:

A Kipp and Zonen pyranometer was mounted horizontally above the roof of a separate hall some 75 metres away. This measured total incident solar energy on the horizontal. **DATA: 15 minute averages.**

Use of Building:

Definite school use of the hall was not recorded but the times of PE periods, etc., were obtained from the caretaker. Use of the school outside school hours was obtained by the caretaker from booking sheets. **DATA: Information entered into analysis software.**

These sensors were wired to a Campbell Scientific data logger (Type 21X). A suitable programme was entered into this logger to enable data to be averaged or totalled every 15 minutes. It was necessary to measure one more pulse count than could be accommodated directly on the logger. Software was written to emulate pulse counting on the ordinary voltage channels.

The data were stored on a cassette recorder, which enabled the building to be monitored with a visit required only every 140 days. Visits were made every six weeks however in order to check for data integrity.

The accuracy required for the EPA was easily met by the logging system.

Two one-time tests were required to test the hypotheses. These were the daylight factors test and the night-time light level test. A small trolley was set up with a pole at one end. At the top of the pole four light sensors were mounted orthogonally to receive light on a vertical plane. One sensor was mounted above to receive light on the horizontal plane. These were wired to a junction box and thence via a long lead to a 21X logger. (For the daylight factors' test an external pole was also used with a light sensor attached and a 100 metre lead back to the logger.) A hand held push-button controller was assembled with a small piezo-electric transducer. This enabled the simple pressing of a button each time the trolley was moved to a new position whereupon the remote logger was triggered to take all measurements of light levels in sequence. When it had finished and allowing for switch bounce (one to two seconds) the logger initiated an acknowledgment bleep on the hand held controller. The measurements were taken at one metre intervals over the whole floor, 464 sets of measurements in all. The actual test took about 45 minutes.

No calibration of a model was needed.

DATA HANDLING & EQUIPMENT:

Additional information on data collection and handling is given here.

Data were gathered by a single 21X data-logger made by Campbell-Scientific. This stored information in 5 days' worth of internal memory and simultaneously on cassette tape.

All temperatures were measured using Platinum Resistance Thermometers connected in a three wire half-bridge to the 21X via a multiplexer controlled by the 21X.

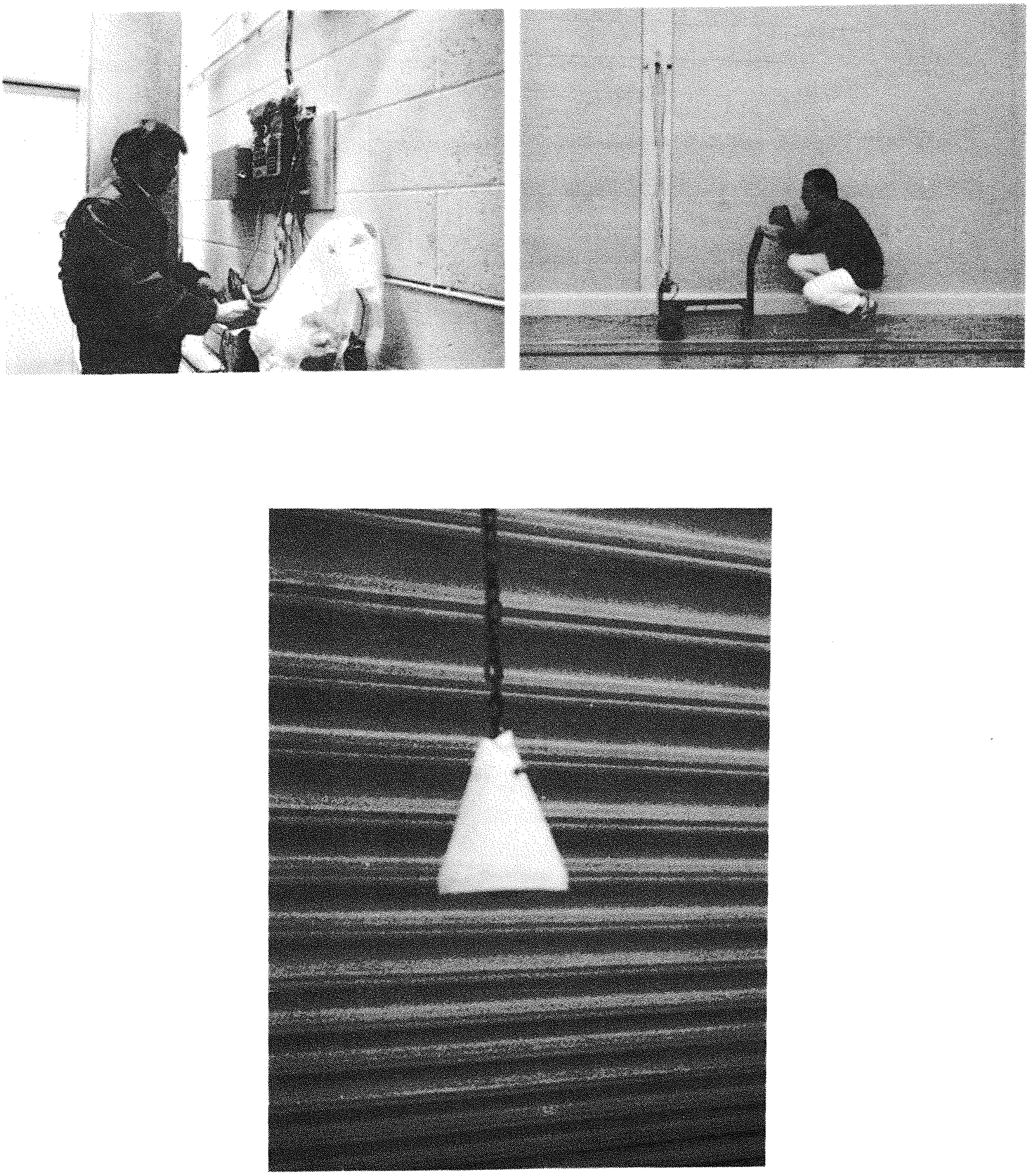
The holders for the hanging light sensors were made of turned hardwood in the form of a cone with a rebate in the base to accept a *LICOR* sensor. An axial hole and cross-axial locking pin allowed a chain to be safely secured to the cone, the whole of which was suspended some 7 metres above players. The integrity of these cones was obviously important for safety reasons. They were bound to be hit by cricket balls, etc., and were designed to withstand this impact and return to the vertical afterwards.

Data from the logger were collected either directly by transfer on to a portable computer (an Olivetti lap-top), or more usually by simply exchanging the cassette. Each new set of data was converted to an elementary database format (a file of real numbers), and appended to single quarter-hourly data file. Daily data were produced from this and exported to spreadsheet software (QUATTRO PRO).

The database format and software (POLYOPS) were specifically developed to enable quick random, or sequential access to (in the case of the Brune Park hall) 9 Megabytes of data. Subsets of data (e.g. only school hours, only the maximum temperature each day, only booked hours of non-school use) are selectable by number. All selected data may be processed simply by issuing the number of the procedure and the time span (in days) of the processing. All data may be viewed graphically (or as a spreadsheet) on the screen or plotted or exported to word processing packages. The package was designed to specifically address the needs of monitorers to be able to check, explore and process a large volume of sequential data, but for the structure to nevertheless allow random access as well. This is a role not well fulfilled by available software that is usually directed towards the business market; the monitoring market is a much smaller niche.

The 21X data logger proved to be robust and reliable.

Picture 4. THE DATA LOGGING EQUIPMENT: (CLOCKWISE FROM TOP LEFT) THE DATA LOGGER; THE "DAYLIGHT FACTORS' TROLLEY"; VIEW OF HANGING WOODEN CONE (A LICOR LIGHTS SENSOR WAS SET FLUSH WITH ITS BASE).



DATA ANALYSIS ROUTINES:

No special analysis routines have been used in analysing the sports hall.

CONFIDENCE IN RESULTS:

The main result is that this design of sports hall could be used from 09.00 to 21.00 hours with daylight alone providing the internal illumination for 48% of the year.

There were two main steps in arriving at this result. It had to be decided what was **adequate illumination** in the hall and the internal illuminance from daylight alone had to be **determinined from the external solar radiation.**

Adequate illumination was assumed to exist from the artificial lighting at night, as there had been few complaints of this. A frequency distribution of *nightime* internal horizontal illuminance was produced from the measured data. Nearly all the measured values in the distribution lay between 300 and 360 lux with a peak at 330 lux. The approach adopted was simply to take the highest value. This obviously led to a conservative estimate.

The ratio of internal horizontal illuminance from daylight alone to external solar radiation on the horizontal was required to allow the former to be predicted. A distribution of these measured ratios showed a variation from about 1.6 to 4.4 lux/W/m^2 with a peak at 3.0 lux/W/m^2. Again, the approach was to take a value in the tail of the distribution. 2.1 lux/W/m^2 was chosen as 96% of measured values lay above this. This similarly led to a conservative estimate. The variation in this effectiveness of the sun in illuminating the hall varies when the sky type changes. Time of day affects this as well, as reported in *Measured Amenity.* A more thorough analysis would use a varying effectiveness ratio appropriate to the prevailing sky type. This would have the effect of increasing the proportion of time that daylight alone could adequately illuminate the hall.

To illustrate the sensitivity of the main result to these values of adequacy and effectiveness, it has been re-computed using different values. First the adequacy level has been decreased by 60 lux, then the solar effectiveness ratio has been increased, then the effects of both are shown. The first line shows the numbers that have been used in the report.

ADEQUACY ILLUMINANCE, lux	SOLAR EFFECTIVENESS RATIO, lux/W/m^2	RESULTANT THRESHOLD LEVEL OF ADEQUATE SOLAR RADIATION, W/m^2	% TIME IN THE YEAR WHEN DAYLIGHT ALONE WOULD BE ADEQUATE FOR USE OF THE HALL FROM 09.00 TO 21.00 HOURS, %
360	2.1	171	48
300	2.1	143	52
360	2.5	144	52
300	2.5	120	57

The adjustments to the two parameters are reasonable given the measured data. The results they give show that the main estimate of a 48% saving in the need for artificial lighting for 09.00 to 21.00 use may be low by about 10%. It is not thought that they over estimate the saving.

DATA AND THEIR AVAILABILITY:

All data have been stored and processed on an MS-DOS based Olivetti computer (M380 XP1, 20MHz, 80386 based) or an MS-DOS based Amstrad (ALT-386SX, 16 MHz, 80386SX based). There are two sets of data: raw data and RDB data (real database format).

The raw data are held in fixed format ASCII code, with a carriage return character after each line of data (i.e. each time period). There is one file of raw data for each data collection that was made. These files are stored on 3½" disks.

The RDB data are structured as follows:

All data in an RDB file are numeric.

All fields are real numbers as defined by "Turbo Pascal" version 5, and occupy 6 bytes each.

A file consists of fixed length records and each record contains a fixed number of fields in it, for that particular file.

The first record in an RDB file is special in that it is a header record describing the file. It does however have the same structure as all other records in the file. Only the first two fields are used. Field 1 is the number of fields/record. Field 2 is a number that describes the time frequency of the data. Three frequencies are directly supported: 0::= supported, but not directly, or not time series data; 1::= daily data; 96::= 15 minute data.

There are two restrictions to RDB files that reflect their basic applicability to time series data. The first field usually represents the day number (especially the Julian day number) of that data record. The second field usually represents the time number (especially the 21X datalogger's format of 0000, 0015, 0030, 0045, 0100, 0115, ..., 2345). Both these numbers must at least stay the same or increase. Non-time series data may have an arbitrary record number used for field-1 and a fixed (and unused) field-2.

The POLYOPS software supports from 8 to 100 fields of data per record. The number of fields per record is only limited by memory. The number of records per file has no reasonable limit.

The main Brune Park data are held in one 9.2 MByte RDB file. This contains all the 15 minute data. It has been processed into engineering units, and new data have been created. The file is 30 fields wide by 30904 rows, or records. It can be archived on to 1.44 Mbyte floppy disks.

The above file has been grouped into a 292 Kbyte spreadsheet daily file in Quattro Pro version 2.0 format.

All other data are stored in Quattro Pro spreadsheet format. These include meter readings of electricity and gas data.

A listing of the daily data file for all measured (not derived) variables appears in the following pages. Each line of data represents the mean or total, as appropriate, for one day. Most data are good data, though there was one significant loss in May to June 1990. Notes on the data appear below. The code -99999 is used to represent missing or bad data. Only data between October 1989 and September 1990 are shown, the period for analysis.

Notes on the daily data:

The data:

Average values such as solar flux and temperature are 24 hour means.

-99999 indicates missing data.

Gas Meter1 and Gas Meter2 measured the two space heating boilers.

Events:

All data were lost from 10.05.90 to 08.06.90, because cassette was put in on wrong side.

DAILY DATA: Brune Park

Date	Day (1=Monday)	Solar Flux Horiz-ontal [W/m2]	T-ext [oC]	T-int1 Hall [oC]	T-int2 Hall [oC]	T-int3 Velarium [oC]	Licor-1 North [lux]	Licor-2 South [lux]	Licor-3 Wall (S) [lux]	Fan On Time [mins]	Resp-onder3 DB2-Misc [kWh]	Gas Meter1 Total [ft3]	Gas Meter2 Boiler-1 [ft3]	Gas Meter3 Boiler-2 [ft3]	Resp-onder1 Main Riser [kWh]	Resp-onder2 Lghtng-33 [kWh]
01-Oct-89	7	49	14.0	18.9	18.1	18.3	65	74	114	0	10	0	0	0	10	0
02-Oct-89	1	55	12.9	18.7	17.8	18.3	100	114	171	630	41	307	0	0	112	59
03-Oct-89	2	70	12.4	17.7	16.7	17.3	97	109	161	601	25	0	0	0	41	7
04-Oct-89	3	145	15.9	19.0	18.2	20.4	187	211	269	601	24	279	0	0	91	56
05-Oct-89	4	54	15.2	19.5	18.6	19.7	107	115	173	715	23	323	0	0	91	57
06-Oct-89	5	34	13.4	18.0	17.0	17.3	65	75	111	719	17	241	0	0	89	38
07-Oct-89	6	39	14.3	18.0	17.1	17.3	56	65	98	210	7	134	0	0	10	0
08-Oct-89	7	128	12.1	18.0	17.3	18.4	151	168	218	0	11	0	0	0	11	0
09-Oct-89	1	74	13.3	17.8	17.0	18.1	123	137	193	631	45	283	0	0	113	62
10-Oct-89	2	80	13.4	18.2	17.2	18.1	104	116	157	601	23	215	0	0	45	12
11-Oct-89	3	41	14.4	18.7	17.6	18.7	87	101	154	600	38	242	0	0	123	77
12-Oct-89	4	108	15.6	19.5	18.5	20.3	152	172	228	719	28	308	0	0	74	39
13-Oct-89	5	67	14.6	20.0	19.0	19.7	104	116	171	720	24	1977	780	894	72	36
14-Oct-89	6	82	12.3	19.9	18.4	19.1	99	112	154	210	8	1133	455	540	15	0
15-Oct-89	7	88	12.1	19.2	17.8	18.9	108	124	168	120	15	840	315	370	17	0
16-Oct-89	1	78	14.8	21.0	19.7	21.7	150	170	245	630	46	2124	812	1008	193	137
17-Oct-89	2	116	13.3	22.0	20.6	22.2	147	166	216	720	30	1993	725	1001	99	54
18-Oct-89	3	45	15.2	22.6	21.2	22.8	127	147	234	601	44	1445	593	805	217	161
19-Oct-89	4	61	15.9	22.4	21.0	21.7	94	106	151	600	22	880	234	273	69	34
20-Oct-89	5	59	14.6	20.7	19.4	19.7	89	101	142	719	36	1011	340	400	91	43
21-Oct-89	6	29	16.8	21.2	20.1	20.8	61	71	112	210	8	878	354	413	63	47
22-Oct-89	7	53	15.9	20.4	19.3	19.7	71	80	112	0	4	0	22	20	5	0
23-Oct-89	1	32	15.3	20.8	19.8	20.0	57	65	98	630	8	2199	841	1020	48	28
24-Oct-89	2	96	12.6	21.4	20.1	21.0	127	141	186	600	25	1770	738	949	84	45
25-Oct-89	3	85	14.7	21.6	20.3	21.2	105	117	149	600	28	1656	686	895	64	22
26-Oct-89	4	23	14.9	21.9	20.7	20.9	55	63	94	600	13	1669	678	881	76	48
27-Oct-89	5	90	16.3	22.4	21.3	22.2	115	130	175	600	33	1580	543	762	74	31
28-Oct-89	6	54	14.6	21.6	19.9	19.9	69	78	109	210	5	974	377	450	10	0
29-Oct-89	7	27	13.9	18.8	17.4	17.5	40	45	66	0	4	0	21	20	4	0
30-Oct-89	1	70	15.0	20.3	19.3	20.2	102	115	160	749	39	2858	1090	1325	98	47
31-Oct-89	2	64	14.9	22.3	20.9	21.8	107	119	172	600	28	1500	525	739	99	58
01-Nov-89	3	42	12.5	21.9	20.3	20.7	90	102	157	600	50	2141	803	1012	138	79
02-Nov-89	4	17	12.3	22.0	20.4	21.0	84	99	162	719	38	2301	829	1076	202	147
03-Nov-89	5	74	11.2	21.8	19.7	20.3	96	108	144	600	43	2012	771	981	89	37
04-Nov-89	6	58	10.8	20.1	18.2	18.3	67	76	101	210	4	1097	429	514	11	0
05-Nov-89	7	58	7.2	17.4	15.7	15.8	70	79	107	0	14	0	21	19	15	0
06-Nov-89	1	71	8.4	16.7	15.4	16.0	102	116	156	811	63	2494	971	1179	137	64
07-Nov-89	2	29	11.2	19.6	18.2	19.3	102	118	187	840	57	3321	1360	1665	227	151
08-Nov-89	3	31	10.4	21.0	19.0	19.5	98	113	179	601	54	2411	948	1164	210	142
09-Nov-89	4	42	10.2	20.0	18.1	18.4	80	93	140	720	22	3107	1229	1529	111	70
10-Nov-89	5	22	13.9	21.6	19.8	20.5	83	96	156	720	38	1962	713	920	181	127
11-Nov-89	6	67	14.0	21.4	19.8	20.3	75	83	106	210	4	912	364	436	10	0
12-Nov-89	7	57	12.4	19.8	18.9	18.7	68	77	102	0	7	0	21	19	7	0
13-Nov-89	1	56	9.8	19.4	18.4	18.5	91	102	143	630	58	2882	1094	1351	120	56
14-Nov-89	2	20	8.6	20.7	19.2	19.5	90	104	166	720	39	3132	1200	1494	206	151
15-Nov-89	3	23	10.8	21.2	19.9	19.4	60	69	109	600	45	2322	914	1139	129	72
16-Nov-89	4	45	9.8	20.6	19.4	18.5	82	92	133	720	34	3149	1229	1524	122	74
17-Nov-89	5	14	10.0	20.7	19.5	19.5	88	101	163	720	45	2953	1150	1434	228	168
18-Nov-89	6	36	11.8	21.3	20.1	19.8	68	78	120	330	26	1516	582	713	90	56
19-Nov-89	7	38	11.5	19.5	18.7	17.7	48	54	75	0	4	0	21	20	6	0
20-Nov-89	1	30	11.8	19.3	18.5	18.2	69	78	120	631	75	2778	1061	1306	159	75
21-Nov-89	2	48	11.0	21.1	19.8	20.0	89	100	148	719	51	2834	994	1249	156	89
22-Nov-89	3	45	8.7	21.2	19.9	19.4	83	93	137	720	55	2743	1029	1311	143	74
23-Nov-89	4	54	4.8	19.8	18.4	17.5	90	102	147	720	26	3662	1411	1797	113	69
24-Nov-89	5	57	3.6	19.7	17.8	18.6	128	147	223	600	35	3006	1164	1489	206	157
25-Nov-89	6	55	5.5	19.1	17.6	17.2	83	95	134	330	13	2063	814	1017	78	58
26-Nov-89	7	56	2.4	17.3	15.5	15.4	72	82	114	347	18	2356	918	1170	57	33
27-Nov-89	1	47	3.1	17.4	15.6	15.4	75	84	120	750	57	4122	1610	2056	116	51
28-Nov-89	2	14	6.3	18.8	17.1	16.7	53	61	100	720	48	3806	1505	1869	152	88
29-Nov-89	3	49	6.0	19.9	18.4	17.7	76	86	119	600	24	3114	1228	1539	95	56
30-Nov-89	4	47	4.2	19.3	17.8	17.2	89	100	139	600	35	3336	1334	1691	141	92
01-Dec-89	5	40	2.3	19.0	17.4	16.8	86	97	138	840	49	4750	1843	2374	175	107
02-Dec-89	6	37	4.3	19.5	17.7	17.3	66	75	108	330	16	2116	828	1040	87	63
03-Dec-89	7	37	3.8	17.6	15.8	15.4	55	62	86	120	12	1034	403	494	49	33
04-Dec-89	1	33	4.3	17.4	15.6	16.0	99	117	179	750	47	4203	1668	2122	226	164
05-Dec-89	2	17	7.4	19.7	18.1	18.3	91	107	176	720	33	3568	1399	1746	223	174
06-Dec-89	3	38	7.2	20.5	18.6	18.6	78	88	133	719	49	3346	1322	1649	152	90
07-Dec-89	4	18	7.5	20.6	18.9	18.4	61	70	111	719	29	3404	1339	1679	140	90
08-Dec-89	5	15	7.6	20.9	19.4	19.0	73	84	135	839	48	3732	1461	1826	197	129
09-Dec-89	6	37	5.8	20.4	18.8	18.1	66	75	112	448	24	2645	1046	1316	94	60
10-Dec-89	7	30	7.4	19.8	18.1	17.7	52	58	81	240	18	1546	607	746	69	45
11-Dec-89	1	22	6.1	19.4	17.6	17.5	96	111	177	630	56	3287	1314	1641	240	171
12-Dec-89	2	36	9.2	20.2	18.2	18.9	94	108	166	600	42	2903	1156	1422	180	127
13-Dec-89	3	18	10.0	20.8	19.1	19.4	88	103	167	601	44	3734	1475	1866	228	167
14-Dec-89	4	25	12.7	22.5	20.4	21.0	89	102	163	720	36	2563	927	1282	196	143
15-Dec-89	5	22	9.8	21.5	19.8	19.7	66	75	120	720	38	2888	1134	1421	146	94
16-Dec-89	6	14	12.8	21.6	19.8	19.7	42	49	79	329	23	1594	627	760	90	60
17-Dec-89	7	24	12.0	19.9	17.9	18.0	48	56	84	0	13	0	22	19	61	48
18-Dec-89	1	6	10.6	19.6	17.9	18.1	50	60	101	631	56	3207	1252	1541	183	111
19-Dec-89	2	29	6.5	19.9	18.0	17.9	73	83	130	719	46	3908	1539	1934	149	88
20-Dec-89	3	12	13.5	21.7	19.9	20.5	69	79	130	600	25	2093	821	1048	171	131
21-Dec-89	4	25	12.6	20.7	18.9	19.1	58	66	101	0	11	1714	749	925	86	65
22-Dec-89	5	36	8.6	20.0	18.2	17.9	56	63	91	601	15	2868	1124	1388	74	48
23-Dec-89	6	25	9.2	18.3	16.4	16.0	28	32	45	210	4	1191	529	651	9	0
24-Dec-89	7	12	11.3	17.2	15.7	15.4	16	18	26	0	4	0	22	20	4	0
25-Dec-89	1	18	10.2	17.3	16.0	15.4	23	26	38	631	4	3217	1267	1556	18	0
26-Dec-89	2	32	8.4	18.5	17.2	16.3	37	41	57	600	4	3012	1190	1468	18	0
27-Dec-89	3	27	8.3	19.0	17.6	16.7	33	37	51	601	4	3036	1207	1499	18	0
28-Dec-89	4	10	7.6	18.9	17.6	16.2	12	14	21	601	4	2914	1235	1538	18	0
29-Dec-89	5	9	5.4	18.0	17.3	15.0	11	13	20	601	4	3063	1291	1621	18	0
30-Dec-89	6	8	4.7	16.7	15.7	13.9	10	12	18	211	4	1408	618	769	9	0
31-Dec-89	7	11	4.9	14.8	14.1	12.4	18	17	25	0	7	0	21	19	22	14
01-Jan-90	1	10	7.3	15.1	14.0	13.2	14	16	23	0	4	3547	1488	1852	17	0
02-Jan-90	2	45	7.0	17.2	15.7	15.3	54	59	76	0	9	3872	1506	1872	39	15
03-Jan-90	3	29	7.0	18.4	16.5	15.8	33	38	54	0	19	3238	1276	1594	28	0
04-Jan-90	4	11	7.8	18.8	17.2	16.5	14	16	23	0	12	2834	1203	1490	26	0
05-Jan-90	5	9	8.9	19.2	17.6	16.9	11	13	20	0	4	2810	1089	1344	20	0
06-Jan-90	6	10	10.2	19.0	17.5	16.9	13	15	22	0	4	1194	473	576	10	0
07-Jan-90	7	24	6.8	16.9	15.4	14.7	28	32	46	0	4	0	21	20	5	0
08-Jan-90	1	50	9.0	17.5	16.3	16.3	52	58	78	0	42	3259	1278	1566	54	5
09-Jan-90	2	16	9.7	19.5	18.2	18.9	88	102	167	0	35	3207	1293	1601	212	163

Date	Day (1=Monday)	Solar Flux Horiz-ontal [W/m2]	T-ext [oC]	T-int1 Hall [oC]	T-int2 Hall [oC]	T-int3 Velarium [oC]	Licor-1 North [lux]	Licor-2 South [lux]	Licor-3 Wall (S) [lux]	Fan On Time [mins]	Resp-onder3 DB2-Misc [kWh]	Gas Meter1 Total [ft3]	Gas Meter2 Boiler-1 [ft3]	Gas Meter3 Boiler-2 [ft3]	Resp-onder1 Main Riser [kWh]	Resp-onder2 Lghtng-33 [kWh]
10-Jan-90	3	13	10.4	21.2	19.5	20.0	75	89	149	0	48	2883	1019	1298	214	152
11-Jan-90	4	24	10.2	20.8	19.0	18.6	42	48	73	0	17	2470	986	1213	68	33
12-Jan-90	5	15	8.8	20.4	18.6	18.4	61	70	116	0	66	3137	1234	1531	180	104
13-Jan-90	6	48	4.7	19.7	18.0	17.9	79	90	133	0	24	2724	1060	1335	94	60
14-Jan-90	7	28	7.9	19.1	17.2	17.2	41	49	71	0	11	838	328	398	80	46
15-Jan-90	1	14	10.9	19.1	17.3	18.2	86	100	164	0	67	2862	1159	1425	245	168
16-Jan-90	2	13	11.3	20.5	18.6	19.3	77	92	155	0	57	2846	1035	1273	225	156
17-Jan-90	3	62	8.5	20.5	18.6	18.7	80	90	128	0	36	2778	1084	1348	110	63
18-Jan-90	4	61	6.7	19.6	18.0	18.0	92	103	149	0	29	3581	1408	1768	120	73
19-Jan-90	5	9	9.4	20.4	18.5	18.7	73	87	147	0	58	3163	1224	1520	234	161
20-Jan-90	6	22	9.8	20.1	18.3	18.4	54	63	100	0	18	1179	471	577	84	62
21-Jan-90	7	20	11.2	18.9	17.1	17.3	44	50	74	0	21	0	21	20	72	51
22-Jan-90	1	44	11.3	19.3	17.8	19.2	118	137	218	0	45	2894	1132	1384	230	172
23-Jan-90	2	15	10.3	20.4	18.6	19.1	81	95	157	0	48	3123	1245	1538	219	156
24-Jan-90	3	69	7.5	20.0	18.1	18.3	96	110	157	0	41	3049	1199	1498	128	76
25-Jan-90	4	33	9.6	18.7	17.1	16.4	99	117	186	0	30	2390	967	1176	205	162
26-Jan-90	5	48	8.1	18.1	14.4	13.8	108	124	195	0	21	3463	1379	1728	172	139
27-Jan-90	6	23	8.1	16.6	14.8	14.6	28	30	45	0	4	1327	589	724	10	0
28-Jan-90	7	76	7.4	15.6	13.8	14.3	68	76	98	0	3	0	21	19	5	0
29-Jan-90	1	10	8.8	15.9	14.5	14.3	32	36	62	0	28	4236	1684	2077	93	48
30-Jan-90	2	30	9.5	19.3	17.4	18.4	116	132	218	0	29	2948	1188	1467	239	198
31-Jan-90	3	16	8.8	20.1	18.1	18.8	92	105	176	0	50	3370	1362	1696	237	173
01-Feb-90	4	46	8.9	20.6	18.5	19.5	119	136	218	0	40	3140	1216	1527	222	167
02-Feb-90	5	62	8.2	20.4	18.2	19.3	136	154	240	0	35	3377	1328	1660	247	197
03-Feb-90	6	37	7.3	19.3	17.5	17.1	63	70	107	0	14	1305	514	629	80	60
04-Feb-90	7	48	10.1	18.1	18.4	18.8	72	82	125	0	10	1510	592	727	80	45
05-Feb-90	1	92	10.5	19.8	18.3	20.0	153	172	252	0	51	2640	1035	1285	211	150
06-Feb-90	2	26	10.3	20.5	18.7	19.3	93	107	174	0	28	2751	1084	1344	191	150
07-Feb-90	3	12	11.8	20.7	18.7	19.3	84	96	167	0	38	2529	998	1236	220	169
08-Feb-90	4	95	9.4	20.5	18.6	19.2	118	132	182	0	19	2508	1072	1336	105	69
09-Feb-90	5	61	9.0	20.3	18.8	19.0	98	108	165	0	45	3246	1240	1544	134	76
10-Feb-90	6	32	8.7	20.0	17.7	17.8	57	64	100	0	25	1793	711	878	91	54
11-Feb-90	7	28	6.2	16.6	14.1	13.9	35	38	57	0	4	0	22	20	7	0
12-Feb-90	1	93	5.9	15.9	14.1	15.0	110	122	173	0	32	3901	1537	1930	114	68
13-Feb-90	2	20	8.3	18.0	18.1	16.9	88	101	170	0	43	4027	1494	1854	213	155
14-Feb-90	3	17	6.8	19.8	18.0	18.8	94	107	179	0	41	3575	1460	1818	229	173
15-Feb-90	4	100	6.3	20.2	18.3	18.7	115	127	178	0	25	3051	1213	1524	97	53
16-Feb-90	5	80	6.3	20.5	18.8	20.5	157	180	278	0	43	2721	1055	1357	255	198
17-Feb-90	6	47	10.2	20.3	18.3	18.9	85	94	145	0	20	1122	466	563	87	61
18-Feb-90	7	104	8.9	19.3	17.7	18.8	118	137	188	0	9	823	338	405	74	61
19-Feb-90	1	25	11.0	19.0	17.5	17.2	36	38	58	0	9	3147	1139	1405	34	5
20-Feb-90	2	23	12.5	20.3	18.8	18.9	49	55	89	0	11	2664	939	1153	75	42
21-Feb-90	3	128	10.4	21.0	19.5	20.2	130	146	191	0	15	2082	890	1121	80	48
22-Feb-90	4	141	10.4	20.9	19.4	20.5	136	149	189	0	7	1930	806	1044	26	0
23-Feb-90	5	128	10.6	21.1	19.7	21.0	148	162	220	0	20	1882	778	1019	90	53
24-Feb-90	6	36	11.8	20.6	18.8	19.0	69	77	121	0	30	992	441	537	91	57
25-Feb-90	7	39	9.6	18.4	16.5	16.3	51	54	82	0	9	740	340	406	13	0
26-Feb-90	1	96	9.7	18.1	16.4	17.2	128	140	197	0	57	3925	1514	1860	137	69
27-Feb-90	2	115	7.3	18.8	16.7	17.6	144	159	225	0	26	3211	1273	1592	120	80
28-Feb-90	3	26	8.7	18.9	16.8	17.4	91	106	173	0	41	3295	1319	1646	200	144
01-Mar-90	4	129	5.2	18.7	16.7	17.5	149	162	222	0	36	4022	1580	1987	114	62
02-Mar-90	5	148	4.3	19.0	17.9	18.1	171	188	256	0	23	3068	1186	1514	120	81
03-Mar-90	6	143	6.0	18.9	17.3	18.7	162	177	236	0	18	1410	552	684	82	58
04-Mar-90	7	76	9.0	17.8	15.9	17.1	111	122	187	0	23	0	21	19	90	66
05-Mar-90	1	91	8.9	17.6	15.9	16.6	127	140	207	0	36	3284	1282	1568	111	80
06-Mar-90	2	57	10.0	19.5	17.7	18.8	114	128	202	0	35	3243	1271	1571	160	109
07-Mar-90	3	38	10.0	20.8	19.0	19.9	102	118	195	0	44	2493	966	1204	203	144
08-Mar-90	4	157	9.2	21.2	19.6	21.0	166	183	245	0	25	2173	814	1063	74	36
09-Mar-90	5	136	10.1	21.0	19.2	20.5	160	175	248	0	22	2314	892	1140	98	58
10-Mar-90	6	121	11.4	20.9	18.9	20.3	162	178	260	0	30	1116	438	530	96	61
11-Mar-90	7	63	10.5	19.3	17.4	18.5	103	118	190	0	12	0	21	19	80	67
12-Mar-90	1	169	8.5	19.4	18.2	19.9	181	197	260	0	56	2846	1080	1352	107	43
13-Mar-90	2	41	9.2	20.7	19.1	19.9	111	126	205	0	35	2686	1025	1282	201	151
14-Mar-90	3	170	9.3	21.1	19.6	21.4	197	208	279	0	38	1998	830	1075	91	46
15-Mar-90	4	198	9.7	21.6	20.2	22.1	209	223	286	0	24	2036	727	976	63	28
16-Mar-90	5	158	10.5	21.8	20.4	22.3	198	206	287	0	28	1947	714	961	103	64
17-Mar-90	6	179	12.4	22.1	20.8	23.3	200	215	287	0	24	747	330	410	76	48
18-Mar-90	7	177	13.3	21.4	20.4	22.3	184	195	252	0	3	0	22	19	5	0
19-Mar-90	1	33	11.9	21.1	18.9	20.6	107	122	202	0	57	2351	853	1091	224	155
20-Mar-90	2	98	10.4	21.6	20.0	21.0	132	141	210	0	33	2028	734	986	89	44
21-Mar-90	3	32	11.8	21.3	19.5	20.4	102	117	194	0	44	2224	853	1078	206	150
22-Mar-90	4	179	10.3	21.6	19.9	21.9	209	228	306	0	27	2366	881	1162	106	67
23-Mar-90	5	92	9.7	21.0	18.9	19.5	140	153	232	0	20	2410	918	1186	90	57
24-Mar-90	6	84	9.7	20.0	17.7	19.0	129	146	218	0	13	1164	459	550	78	59
25-Mar-90	7	164	7.2	17.8	16.2	17.3	173	188	253	0	10	976	372	446	14	0
26-Mar-90	1	186	6.3	18.8	17.8	19.2	218	223	309	0	51	3327	1273	1609	101	43
27-Mar-90	2	150	7.3	20.8	19.5	20.8	183	195	275	0	21	2651	1008	1289	81	41
28-Mar-90	3	135	8.6	21.3	19.9	21.0	173	187	271	0	41	2258	844	1101	101	50
29-Mar-90	4	182	7.9	21.4	20.0	21.7	218	226	318	0	34	2613	938	1270	97	47
30-Mar-90	5	187	11.0	22.4	21.0	23.3	226	243	335	0	38	1735	607	858	104	57
31-Mar-90	6	211	11.7	22.1	21.2	23.3	244	260	350	0	13	954	425	515	76	57
01-Apr-90	7	231	11.9	21.2	20.2	22.1	237	253	327	0	10	0	22	19	11	0
02-Apr-90	1	126	11.1	21.3	20.2	21.8	194	215	313	0	40	2242	819	1064	173	122
03-Apr-90	2	183	5.8	19.2	17.7	18.9	222	226	317	0	24	352	37	84	85	55
04-Apr-90	3	214	4.2	17.6	18.3	18.6	245	249	338	0	31	376	37	97	81	44
05-Apr-90	4	256	4.6	16.9	15.5	18.4	270	279	363	0	40	370	37	96	78	31
06-Apr-90	5	242	6.8	17.1	16.0	19.3	315	335	470	0	19	353	36	80	195	164
07-Apr-90	6	226	8.4	17.0	16.3	18.1	248	261	349	0	12	46	37	43	40	24
08-Apr-90	7	194	7.0	16.4	16.0	17.0	211	219	302	0	8	0	21	18	8	0
09-Apr-90	1	248	6.9	16.0	15.4	17.9	282	289	380	0	14	1321	401	530	58	32
10-Apr-90	2	106	10.7	18.9	17.9	19.1	144	156	240	0	24	2967	1192	1431	82	44
11-Apr-90	3	171	11.7	20.9	19.6	21.4	212	224	304	0	7	2178	920	1157	39	17
12-Apr-90	4	155	12.0	21.6	20.0	21.4	199	210	303	0	9	2045	747	959	50	28
13-Apr-90	5	101	7.9	20.6	19.1	19.2	124	136	190	0	3	2826	1118	1345	17	0
14-Apr-90	6	119	7.2	19.4	17.4	18.6	171	179	273	0	17	1292	514	616	83	60
15-Apr-90	7	206	8.6	18.0	15.9	18.7	242	252	336	0	2	0	21	19	3	0
16-Apr-90	1	208	8.1	18.4	16.8	18.8	245	252	347	0	2	3271	1264	1546	17	0
17-Apr-90	2	205	7.4	19.6	17.8	19.9	255	265	366	0	11	2846	1121	1374	68	43
18-Apr-90	3	179	7.8	19.9	18.3	20.1	213	219	301	0	3	2929	1156	1407	18	0
19-Apr-90	4	156	8.0	20.6	19.1	20.5	217	229	334	0	3	2428	949	1169	102	84
20-Apr-90	5	124	8.3	20.3	19.1	19.6	177	189	276	0	10	2404	1027	1261	82	58
21-Apr-90	6	222	12.4	21.6	20.7	23.2	278	297	411	0	15	1014	459	541	71	50
22-Apr-90	7	170	11.9	21.0	20.5	21.1	202	223	316	0	6	0	21	19	6	0
23-Apr-90	1	236	12.1	21.6	21.1	23.0	283	294	406	0	38	2212	828	1071	82	37
24-Apr-90	2	212	12.3	22.7	22.0	24.0	256	271	391	0	31	1557	627	865	80	39

Date	Day (1=Monday)	Solar Flux Horizontal [W/m2]	T-ext [oC]	T-int1 Hall [oC]	T-int2 Hall [oC]	T-int3 Velarium [oC]	Licor-1 North [lux]	Licor-2 South [lux]	Licor-3 Wall (S) [lux]	Fan On Time [mins]	Responder3 DB2-Misc [kWh]	Gas Meter1 Total [ft3]	Gas Meter2 Boiler-1 [ft3]	Gas Meter3 Boiler-2 [ft3]	Responder1 Main Riser [kWh]	Responder2 Lghtng-33 [kWh]
25-Apr-90	3	251	12.8	22.8	21.9	24.6	292	310	422	0	21	1421	542	814	52	20
26-Apr-90	4	120	11.0	21.8	20.4	21.2	172	187	285	0	34	1841	842	854	80	37
27-Apr-90	5	285	10.3	22.2	21.1	24.2	348	361	481	0	43	2012	746	972	91	40
28-Apr-90	6	285	10.8	22.3	21.0	24.5	347	363	482	0	31	79	21	19	67	34
29-Apr-90	7	285	12.2	21.8	20.5	24.4	339	353	465	0	7	0	21	20	8	0
30-Apr-90	1	285	16.4	22.6	21.7	25.9	356	367	500	0	27	298	21	19	74	39
01-May-90	2	291	18.0	24.0	23.4	27.4	365	383	514	0	23	0	21	19	76	44
02-May-90	3	299	18.5	24.7	24.1	28.1	357	369	484	0	51	147	21	20	53	0
03-May-90	4	290	19.7	25.5	25.0	29.4	362	376	504	0	12	0	22	19	64	41
04-May-90	5	303	18.7	25.9	25.4	29.5	374	386	519	0	35	0	21	20	86	43
05-May-90	6	298	18.8	25.9	25.2	29.4	347	363	481	0	15	0	22	19	19	0
06-May-90	7	277	18.0	25.4	24.7	27.8	319	330	452	0	13	0	21	20	15	0
07-May-90	1	284	13.3	23.8	22.7	25.0	336	345	466	0	7	99	22	20	17	0
08-May-90	2	311	12.9	22.7	21.6	25.5	388	405	548	0	14	109	21	19	69	43
09-May-90	3	145	13.0	21.5	20.5	22.0	184	198	293	0	15	124	21	19	44	19
10-May-90	4	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
11-May-90	5	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
12-May-90	6	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
13-May-90	7	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
14-May-90	1	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
15-May-90	2	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
16-May-90	3	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
17-May-90	4	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
18-May-90	5	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
19-May-90	6	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
20-May-90	7	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
21-May-90	1	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
22-May-90	2	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
23-May-90	3	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
24-May-90	4	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
25-May-90	5	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
26-May-90	6	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
27-May-90	7	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
28-May-90	1	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
29-May-90	2	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
30-May-90	3	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
31-May-90	4	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
01-Jun-90	5	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
02-Jun-90	6	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
03-Jun-90	7	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
04-Jun-90	1	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
05-Jun-90	2	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
06-Jun-90	3	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
07-Jun-90	4	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
08-Jun-90	5	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999	-99999
09-Jun-90	6	184	13.5	19.3	18.2	20.8	245	272	403	0	20	158	22	20	53	28
10-Jun-90	7	244	16.5	20.8	20.0	23.6	312	345	477	0	5	0	21	19	6	0
11-Jun-90	1	73	14.0	20.4	19.5	20.4	116	130	199	0	20	277	21	19	77	41
12-Jun-90	2	126	12.4	19.9	19.0	20.5	186	205	312	0	23	235	21	19	80	51
13-Jun-90	3	121	12.6	19.4	18.7	19.9	170	191	289	0	23	218	21	19	65	30
14-Jun-90	4	95	13.8	19.5	18.6	20.1	143	160	243	0	28	256	21	19	79	41
15-Jun-90	5	138	15.5	20.1	19.2	21.7	202	225	331	0	11	208	21	20	77	55
16-Jun-90	6	307	16.3	21.8	20.7	25.3	375	412	576	0	12	144	21	19	18	0
17-Jun-90	7	198	15.5	22.0	20.9	23.3	245	268	398	0	2	0	21	20	3	0
18-Jun-90	1	110	15.3	21.1	20.0	21.5	159	171	266	0	27	265	22	19	56	21
19-Jun-90	2	343	16.3	22.2	21.0	25.6	454	502	708	0	20	191	21	19	70	39
20-Jun-90	3	221	15.2	22.3	21.1	23.8	296	321	484	0	4	206	21	20	17	0
21-Jun-90	4	92	13.9	20.5	19.1	20.0	137	154	233	0	10	204	21	19	50	27
22-Jun-90	5	171	14.6	20.1	18.8	21.3	254	284	404	0	12	0	21	19	99	76
23-Jun-90	6	229	15.2	20.7	19.3	22.9	319	356	542	0	10	4	21	19	74	58
24-Jun-90	7	148	14.7	20.1	19.0	20.9	198	212	327	0	13	211	21	20	18	0
25-Jun-90	1	154	17.0	20.6	19.7	22.2	224	248	359	0	11	200	21	19	68	43
26-Jun-90	2	176	17.5	22.0	21.0	24.6	252	280	408	0	7	191	22	19	59	41
27-Jun-90	3	250	17.6	23.0	22.0	25.5	342	375	520	0	4	189	21	19	52	36
28-Jun-90	4	230	15.6	22.3	21.0	24.1	308	347	505	0	20	243	21	20	52	26
29-Jun-90	5	274	15.7	22.5	21.3	25.0	362	392	529	0	5	166	21	19	20	5
30-Jun-90	6	222	16.9	22.8	21.6	24.4	307	338	462	0	10	0	22	20	57	46
01-Jul-90	7	108	15.0	21.1	19.6	21.0	158	177	286	0	6	0	21	19	41	38
02-Jul-90	1	245	14.9	20.8	19.5	23.2	318	348	523	0	11	267	21	20	55	33
03-Jul-90	2	272	14.9	21.7	20.6	24.3	363	395	565	0	7	175	22	19	58	39
04-Jul-90	3	79	14.3	20.7	19.5	20.7	136	154	241	0	12	176	21	19	97	71
05-Jul-90	4	134	15.3	20.0	18.8	20.5	180	201	293	0	10	190	20	19	34	9
06-Jul-90	5	258	14.9	20.5	19.3	22.9	354	388	547	0	6	192	22	19	70	49
07-Jul-90	6	164	17.0	21.1	20.0	22.4	230	257	382	0	5	120	21	20	37	25
08-Jul-90	7	262	17.4	21.9	20.7	24.0	341	389	536	0	2	0	22	19	14	12
09-Jul-90	1	155	15.9	21.3	20.1	22.1	201	230	338	0	13	230	21	20	20	0
10-Jul-90	2	225	16.1	21.5	20.4	24.2	324	358	527	0	20	115	21	19	66	41
11-Jul-90	3	342	17.0	22.8	21.7	26.5	455	494	686	0	6	0	21	19	56	40
12-Jul-90	4	319	19.7	24.3	23.5	28.2	409	445	609	0	16	0	21	20	28	0
13-Jul-90	5	339	20.9	25.8	25.2	30.1	456	496	679	0	7	286	21	19	63	44
14-Jul-90	6	335	20.1	26.3	25.8	29.7	430	469	630	0	8	84	22	19	10	0
15-Jul-90	7	290	20.4	26.2	25.6	29.1	359	393	546	0	2	0	21	20	3	0
16-Jul-90	1	206	19.3	25.4	24.7	27.1	255	283	396	0	5	223	22	19	17	0
17-Jul-90	2	306	19.1	25.6	24.9	29.2	398	434	608	0	7	173	21	20	72	52
18-Jul-90	3	314	18.7	25.7	24.9	28.8	391	419	587	0	10	168	21	19	34	14
19-Jul-90	4	330	19.8	25.9	25.0	29.3	411	452	606	0	19	156	22	20	28	0
20-Jul-90	5	321	21.1	26.6	25.9	30.8	415	458	618	0	11	0	21	19	65	45
21-Jul-90	6	308	22.1	27.3	26.8	30.9	379	416	565	0	7	0	22	20	27	15
22-Jul-90	7	292	20.9	27.3	26.8	30.0	346	385	530	0	4	0	21	20	2	0
23-Jul-90	1	283	17.5	25.9	25.4	27.8	336	372	514	0	4	335	22	19	15	0
24-Jul-90	2	309	17.0	25.1	24.2	27.8	397	436	589	0	8	0	21	20	71	54
25-Jul-90	3	271	17.4	24.9	24.0	27.7	390	430	565	0	6	146	22	19	29	7
26-Jul-90	4	301	18.6	25.0	24.1	27.7	363	399	527	0	7	227	21	20	20	0
27-Jul-90	5	116	19.6	24.5	23.9	25.3	173	201	288	0	13	178	22	20	68	47
28-Jul-90	6	202	19.2	24.7	23.7	26.6	266	305	399	165	5	108	22	20	11	0
29-Jul-90	7	268	20.1	25.0	23.9	27.5	351	389	510	0	2	0	21	20	1	0
30-Jul-90	1	110	19.3	24.2	23.4	24.5	153	172	252	630	7	0	22	20	20	4
31-Jul-90	2	283	20.1	24.8	24.0	28.4	377	421	552	619	16	0	22	19	52	24
01-Aug-90	3	289	21.9	26.1	25.6	29.8	372	410	535	718	14	0	21	20	42	17
02-Aug-90	4	274	24.9	27.4	27.0	31.0	340	380	495	600	13	0	22	20	25	0
03-Aug-90	5	272	27.3	29.8	29.4	33.9	350	387	515	601	17	0	22	20	75	43
04-Aug-90	6	267	27.5	31.2	30.8	34.4	335	364	483	350	10	0	22	20	26	8
05-Aug-90	7	203	22.0	29.9	29.0	31.2	265	286	403	0	1	0	21	19	5	0
06-Aug-90	1	228	18.7	27.0	26.1	28.4	288	309	419	630	13	260	22	20	26	0
07-Aug-90	2	218	18.3	25.6	24.8	27.7	297	318	449	600	15	213	21	20	85	59

Date	Day (1=Monday)	Solar Flux Horiz-ontal [W/m2]	T-ext [oC]	T-int1 Hall [oC]	T-int2 Hall [oC]	T-int3 Velarium [oC]	Licor-1 North [lux]	Licor-2 South [lux]	Licor-3 Wall (S) [lux]	Fan On Time [mins]	Resp-onder3 DB2-Misc [kWh]	Gas Meter1 Total [ft3]	Gas Meter2 Boiler-1 [ft3]	Gas Meter3 Boiler-2 [ft3]	Resp-onder1 Main Riser [kWh]	Resp-onder2 Lghtng-33 [kWh]
08-Aug-90	3	270	19.0	25.5	24.6	28.2	349	374	486	600	25	0	22	20	52	19
09-Aug-90	4	275	20.1	26.0	25.0	28.3	350	378	485	600	12	245	21	19	20	0
10-Aug-90	5	250	20.0	26.3	25.4	28.7	336	366	476	601	16	197	22	20	61	34
11-Aug-90	6	265	20.5	26.5	25.5	29.3	339	363	477	210	14	128	22	20	26	12
12-Aug-90	7	266	21.1	26.9	25.8	29.9	327	353	459	0	6	0	21	19	6	0
13-Aug-90	1	262	20.3	26.8	25.7	28.7	331	354	460	630	17	278	22	20	25	0
14-Aug-90	2	163	20.5	26.2	25.2	27.2	223	251	355	601	16	183	22	20	63	34
15-Aug-90	3	89	19.8	25.2	24.1	25.8	165	190	288	600	11	211	21	20	144	117
16-Aug-90	4	160	17.0	23.9	22.6	24.1	208	224	309	600	13	207	22	19	17	0
17-Aug-90	5	154	16.6	22.6	21.3	23.4	221	234	343	830	27	270	21	20	101	60
18-Aug-90	6	111	19.4	23.0	21.9	23.7	149	165	236	210	1	105	22	20	5	0
19-Aug-90	7	79	19.5	22.8	21.9	22.7	113	126	183	0	2	0	22	20	1	0
20-Aug-90	1	219	18.5	23.2	22.2	24.7	282	297	386	630	9	253	21	19	22	0
21-Aug-90	2	129	19.5	23.5	22.6	24.7	176	196	275	601	13	182	22	20	38	11
22-Aug-90	3	191	20.1	24.2	23.3	26.0	265	295	384	601	14	163	21	20	69	44
23-Aug-90	4	190	20.8	25.1	24.4	27.3	240	264	349	600	7	0	22	19	19	0
24-Aug-90	5	196	22.9	25.9	25.4	28.8	256	280	380	600	2	0	22	20	31	17
25-Aug-90	6	185	22.3	26.3	25.8	28.6	246	271	359	210	2	0	21	20	5	0
26-Aug-90	7	196	20.7	26.2	25.6	28.4	245	269	364	0	1	0	22	19	2	0
27-Aug-90	1	206	20.6	25.9	25.1	27.7	268	289	383	630	1	101	22	20	10	0
28-Aug-90	2	223	20.5	25.9	25.2	28.5	287	305	388	600	1	0	21	20	12	0
29-Aug-90	3	159	20.2	25.5	24.9	27.1	220	233	295	600	3	0	22	20	15	1
30-Aug-90	4	182	17.2	24.1	23.0	25.2	236	247	327	600	2	0	22	20	12	0
31-Aug-90	5	151	17.4	22.9	21.8	23.8	198	210	287	0	1	0	21	19	3	0
01-Sep-90	6	232	19.0	23.7	22.8	26.7	298	316	386	210	1	0	22	20	5	0
02-Sep-90	7	206	19.4	24.0	23.4	26.1	264	280	355	0	2	0	21	19	1	0
03-Sep-90	1	193	19.7	24.2	23.6	26.1	251	264	347	631	8	0	22	20	21	0
04-Sep-90	2	153	16.3	23.2	22.5	24.4	210	223	302	600	7	0	21	19	63	43
05-Sep-90	3	106	16.0	21.9	21.0	22.1	138	149	209	600	9	250	21	20	22	0
06-Sep-90	4	174	16.9	22.1	21.0	23.4	222	235	300	600	13	176	21	19	24	0
07-Sep-90	5	175	16.5	21.6	20.6	23.3	234	255	338	600	11	198	21	19	81	56
08-Sep-90	6	129	14.7	21.6	20.7	23.0	165	201	284	210	5	143	22	20	62	50
09-Sep-90	7	190	15.9	21.8	20.7	24.2	230	247	310	0	3	0	21	19	2	0
10-Sep-90	1	179	16.8	22.2	21.4	24.2	224	238	311	630	17	278	21	20	33	7
11-Sep-90	2	187	16.7	22.6	21.9	24.8	236	254	328	601	18	0	21	19	76	47
12-Sep-90	3	139	17.5	23.0	22.4	24.6	182	198	275	600	16	203	21	19	60	28
13-Sep-90	4	186	17.4	22.8	22.2	24.7	218	231	294	600	10	14	22	20	21	0
14-Sep-90	5	164	18.0	22.9	22.4	24.8	210	228	310	599	11	235	21	19	68	46
15-Sep-90	6	127	17.3	23.0	22.2	24.2	177	197	267	210	7	134	21	19	70	60
16-Sep-90	7	142	15.8	22.3	21.4	22.9	167	185	242	0	4	0	22	20	5	0
17-Sep-90	1	63	14.5	21.0	19.9	21.1	117	136	204	630	13	310	21	19	123	96
18-Sep-90	2	101	16.3	20.6	19.6	21.1	146	168	244	601	7	195	21	19	79	56
19-Sep-90	3	163	16.6	21.7	20.7	23.5	230	257	335	600	19	176	21	20	162	127
20-Sep-90	4	95	13.6	19.9	18.7	19.7	125	136	190	600	11	238	21	19	23	0
21-Sep-90	5	171	14.8	20.1	19.0	21.5	211	222	282	600	16	210	21	19	69	39
22-Sep-90	6	129	15.0	20.3	19.2	21.3	171	189	246	329	19	154	21	20	64	38
23-Sep-90	7	92	13.7	19.6	18.4	19.4	111	125	171	0	4	0	21	19	3	0
24-Sep-90	1	144	12.4	18.9	17.7	20.5	211	229	312	750	26	394	22	19	142	102
25-Sep-90	2	171	13.3	19.6	18.5	22.3	218	239	309	600	25	216	21	20	119	83
26-Sep-90	3	166	13.7	20.4	19.5	22.9	201	218	276	600	16	233	20	19	74	44
27-Sep-90	4	151	12.9	19.9	18.8	21.1	180	201	258	600	27	216	21	19	71	34
28-Sep-90	5	163	13.1	20.0	18.8	22.1	206	222	283	720	32	263	21	19	114	60
29-Sep-90	6	33	15.8	20.0	19.1	20.5	67	78	119	210	15	497	21	19	76	55
30-Sep-90	7	39	17.9	20.5	19.7	20.5	53	60	93	0	6	0	22	20	5	0

THE QUESTIONNAIRE USED TO ASSESS USER REACTIONS TO THE BUILDING

WHAT DO YOU THINK OF THIS SPORTS HALL?

Brune Park Sports Hall

We would like to have your views about this sports hall. Please take a questionnaire.

There is a stamped addressed envelope attached. Please pop your completed questionnaire in the post.

Your answers will help to improve the design of sports halls.

We have been carrying out measurements to assess the lighting in this and other sports halls on behalf of the Department of Energy. The views of users will be extremely useful in the assessment of the hall.

This study is being carried out with the permission of the head teacher.

Please try to answer all the questions that you are able to answer.

PLEASE NOTE THAT ALL THESE QUESTIONS REFER ONLY TO THE MAIN SPORTS HALL. PLEASE DO NOT REFER TO ANY OTHER SPACE SUCH AS THE GYMNASIUM, SWIMMING POOL, ETC.

1. **What do you use the hall for and when? You may use it for more than one activity. Please list below your use of the hall.**
   Examples: **Badminton; after 7.00pm; Fridays**
   Keep-fit; 7.30pm to 8.30pm; Tuesdays
   Badminton; any time; at weekends

   Please list your *main* activity first.

	Description	**Normal Time of day**	**Normal day(s) of week**
Activity 1:			
Activity 2:			
Activity 3:			
Activity 4:			
Activity 5:			

2. **How frequently do you use the hall? Please state how often you use the hall using such a phrase as "more than once a week", "four times a year", etc.**
   Frequency of use:____________________________________

From this point on please answer the questions only in relation to your *MAIN ACTIVITY AT THE SPORTS HALL - ACTIVITY 1*.

3. Do you like this sports hall? Please tick one box for each aspect of the sports hall to indicate how satisfied or dissatisfied you are with it. All questions are concerned with the *inside* of the hall.

	Very dissatisfied						Very satisfied
	1	2	3	4	5	6	7
Its visual appearance							
Its temperature in summer							
Its temperature in winter							
Its air quality							
Its lighting							
The colour of its floor							
The colour of its walls							
The colour of its ceiling							
The type of floor							
What is your general view?							

Space for comments on question 3:

4. How suitable is the hall for your *main* activity? Please tick the appropriate box.

	Not suitable at all						Thoroughly suitable
	1	2	3	4	5	6	7
How suitable is the hall for your main activity?							

5. If appropriate for your *main* activity could you state at what level of competitiveness you play? Please put a tick in the appropriate box.

Level of play	
leisure	
friendly matches	
club matches	
county matches	

6. When engaged in an activity in the hall in daylight hours do you prefer the lights to be switched on or off?

Prefer lights OFF	Have no preference	Prefer lights ON

7. Please give a reason for your choice in question six.

____

____

____

____

8. When you are engaged in your *main* activity are you satisfied with the level of light?

	very dissatisfied						very satisfied
	1	2	3	4	5	6	7
During daylight hours:							
Outside daylight hours:							

9. How would you rate the following aspects of *this* sports hall compared to other halls you may have used?

	Very much worse 1	2	3	4	5	6	Very much better 7
Its visual appearance							
Its temperature in summer							
Its temperature in winter							
Its air quality							
Its lighting (natural)							
Its lighting (artificial)							
The colour of its floor							
The colour of its walls							
The colour of its ceiling							
The type of floor							

Finally, it would be helpful if you could give some information about yourself.

10. Age:

11. Sex:

12. Are you someone in charge of an activity? yes no

Thank you very much for taking the trouble to answer the questions. There is space provided below for you to make any additional comments that you might like to make concerning the design of this sports hall. Your ideas will be very useful.

The information gathered in this questionnaire will be used in part of the assessment of the design of this and other sports halls with a view to providing feedback to architects and other building designers. For further information, contact Richard Watkins, Databuild Ltd., 4, Venture Way, Aston Science Park, Birmingham.

QUESTIONNAIRE DATA: Brune Park

Activities are coded thus:
PE teacher (All): 0 : This is a special code only for pe teachers.
Badminton: 1
Volley Ball: 2
Net Ball: 3
Squash: 4
Keep-fit: 5
Hockey: 6
Cricket: 7
Cheerleading: 8
Football: 9
Basket ball: 10
Tennis: 11
Any Sport: 12
Rythmic Gym: 13

Times of use of the hall are coded thus:
Start time: 0..23
Finish time: 0..23
Day: 1..7
Monday=1..Sunday=7
Monday to Friday = 8

Frequency of use of the hall is coded thus:
a few times a year: 1
once a month: 2
once a week: 3
more than once a week:4

For level of play,
most competitive entered: 1..4

For yes no questions: 0=no: 1=yes
gender: 1=male: 2=female

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25 1	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
Q 1	Activity 1 (MAIN):	1	1	1	3	13	3	1	3	1	3	10	3	3	5	1	1	3	1	3	1	3	1	1	1	1	1	1	1	1	1	1	1	1	1	3	1	•	1	1	1	1	1	1	1	1	1	1	10	1	1	1	1	1	0	0	0	0
	Start time:	2	8	8	18	19	18	20	18	20	18	11	18	18	20	•	20	18	20	18	20	18	18	20	18	18	20	20	19	20	19	20	18	20	20	18	20	•	19	19	20	9	19	19	19	18	19	19	12	19	9	19	19	19	•	•	•	•
	Finish time:	3	10	10	19	20	19	22	19	22	19	12	19	•	21	•	23	19	22	•	22	19	19	22	•	19	22	22	20	22	20	22	19	22	22	19	22	•	•	20	22	11	20	•	•	20	20	•	•	20	•	22	•	•	•	•	•	•
	Day:	4	4	1	5	4	5	3	5	4	5	2	5	5	2	2	5	5	4	5	4	5	2	1	2	2	1	1	1	1	1	4	2	4	1	5	4	•	5	5	4	7	1	1	1	1	1	1	6	1	6	28	1	1	•	•	•	•
	Activity 2:	5	•	1	•	12	•	•	•	•	•	1	•	•	•	1	1	•	•	•	•	•	1	•	1	1	•	•	•	•	•	•	1	•	1	•	•	•	3	•	•	•	•	•	•	•	1	•	•	•	1	•	•	•	•	•	•	•
	Start time:	6	•	8	•	10	•	•	•	•	•	15	•	•	•	•	17	•	•	•	•	•	19	•	19	19	•	•	•	•	•	•	19	•	20	•	•	•	18	•	•	•	•	•	•	•	19	•	•	•	9	•	•	•	•	•	•	•
	Finish time:	7	•	10	•	12	•	•	•	•	•	16	•	•	•	•	29	•	•	•	•	•	20	•	•	20	•	•	•	•	•	•	20	•	23	•	•	•	•	•	•	•	•	•	•	•	22	•	•	•	•	•	•	•	•	•	•	•
	Day:	8	•	5	•	8	•	•	•	•	•	3	•	•	•	5	6	•	•	•	•	•	5	•	5	5	•	•	•	•	•	•	5	•	5	•	•	•	5	•	•	•	•	•	•	•	2	•	•	•	7	•	•	•	•	•	•	•
	Activity 3:	9	•	•	•	•	•	•	•	•	•	9	•	•	•	•	1	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Start time:	10	•	•	•	•	•	•	•	•	•	11	•	•	•	•	20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Finish time:	11	•	•	•	•	•	•	•	•	•	12	•	•	•	•	22	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Day:	12	•	•	•	•	•	•	•	•	•	1	•	•	•	•	2	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Activity 4:	13	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Start time:	14	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Finish time:	15	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Day:	16	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Activity 5:	17	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Start time:	18	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Finish time:	19	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Day:	20	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Q2	Frequency of use:	21	3	4	3	4	3	3	3	3	3	4	3	3	3	4	4	3	3	3	•	3	4	3	4	4	3	1	3	3	3	3	4	3	4	3	3	•	4	3	3	3	3	3	3	3	4	3	1	3	3	4	3	3	•	•	•	•
Q3	Its visual appearance:	22	•	3	7	6	5	6	5	3	5	7	7	7	5	7	6	7	5	4	4	5	7	7	7	7	4	5	6	4	5	5	3	5	3	7	6	5	6	7	4	5	2	5	3	5	7	5	7	4	4	6	5	2	7	6	7	7
	Its temperature in summer:	23	1	1	1	1	1	2	1	2	1	4	1	2	6	3	2	2	2	1	3	1	2	1	1	1	1	2	2	1	1	2	1	2	2	1	4	1	1	1	1	6	2	2	1	2	1	1	6	1	1	2	1	2	2	2	1	4
	Its temperature in winter:	24	1	4	1	6	3	3	6	6	5	5	4	2	6	6	2	3	3	4	4	5	7	5	7	4	1	5	6	4	1	3	6	5	5	7	6	5	5	7	1	6	2	6	5	3	3	4	6	1	4	6	3	2	6	6	7	6
	Its air quality:	25	1	1	1	1	1	4	2	3	1	5	1	3	5	6	4	1	4	2	3	1	3	2	3	4	2	2	4	4	1	3	3	4	4	3	6	1	6	4	1	1	3	3	2	4	2	1	7	2	4	3	1	3	3	1	7	6
	Its lighting:	26	4	1	7	5	2	7	6	5	7	7	4	4	6	6	5	7	5	6	4	5	6	4	7	7	4	3	7	3	3	6	6	6	6	7	6	5	6	7	4	7	3	3	4	6	4	5	5	2	7	6	4	3	4	6	6	7
	The colour of its floor:	27	•	6	7	7	5	6	6	5	7	7	7	6	6	6	4	7	5	6	4	5	7	7	7	7	6	5	6	4	5	5	6	6	4	7	6	5	6	7	5	6	2	4	1	6	5	4	5	4	7	5	5	1	6	7	7	7
	The colour of it walls:	28	2	6	7	6	5	4	6	5	6	7	7	6	5	6	2	7	5	6	4	5	7	7	7	7	6	5	6	4	3	5	6	6	4	7	5	5	6	7	5	6	2	4	3	6	5	4	6	4	7	5	6	2	4	7	6	7
	The colour of its ceiling:	29	•	6	7	6	5	5	6	5	6	7	7	6	5	6	3	7	5	6	4	5	7	7	7	7	4	5	6	4	3	5	6	5	5	7	6	5	6	7	5	6	3	4	3	6	5	4	7	4	7	•	6	2	6	7	6	6
	The type of floor:	30	4	6	7	5	1	7	6	5	7	6	1	4	7	6	1	6	4	6	4	4	7	7	7	6	6	5	6	4	5	4	6	5	5	7	5	5	5	7	5	6	1	3	2	6	6	4	•	4	7	2	6	2	3	4	2	6
	general view:	31	2	1	•	•	4	5	6	5	3	7	•	6	7	6	4	•	4	5	4	4	7	5	6	6	4	5	6	4	4	5	4	5	5	7	6	4	6	7	4	6	2	3	2	5	5	5	6	3	6	5	3	2	5	6	5	7
Q4	Suitability:	32	2	2	4	6	4	7	6	6	5	7	4	5	5	7	4	4	5	6	4	5	7	7	6	7	4	6	6	5	3	6	6	7	5	5	6	7	4	5	4	6	3	5	3	5	5	4	7	6	6	5	3	3	3	7	7	6
Q5	Level of play:	33	1	1	3	1	•	1	3	1	1	2	3	3	•	2	3	3	3	3	2	2	1	1	2	1	1	1	1	1	1	1	2	2	2	1	1	2	3	2	1	1	2	2	1	3	3	2	1	2	1	4	1	1	2	2	3	2
Q6	Preference for lights on or off:	34	•	2	3	3	•	3	3	3	2	2	2	3	2	3	3	2	•	3	3	2	2	2	3	2	•	3	3	3	3	3	2	3	2	3	3	2	3	2	3	2	3	3	3	3	3	3	1	3	3	1	3	3	2	3	3	2
Q7	During daylight hours:	35	•	2	7	5	•	7	6	6	6	7	1	6	7	•	3	7	•	6	4	5	7	•	6	7	4	•	6	•	4	6	1	6	4	7	6	7	6	7	3	7	3	3	2	5	2	4	6	5	7	5	4	3	3	7	4	7
	Outside daylight hours:	36	4	1	7	6	•	7	6	6	6	7	1	6	7	7	5	5	5	6	4	5	7	5	6	7	4	5	6	4	4	6	6	5	6	7	6	7	6	7	4	•	2	3	2	5	2	5	•	•	•	5	4	3	1	7	6	7
Q8	Its visual appearance:	37	•	5	7	6	7	6	6	5	6	6	7	7	•	7	5	7	4	4	5	5	7	•	7	6	4	5	6	•	4	5	4	5	3	6	5	5	6	7	4	7	1	3	4	6	6	5	7	4	7	5	•	2	7	7	7	7
	Its temperature in summer:	38	1	1	1	2	1	2	1	2	1	5	1	4	•	3	2	3	4	1	3	1	5	•	1	4	2	3	2	•	1	3	4	5	3	4	4	1	1	4	1	5	2	1	2	3	1	1	2	1	4	2	•	2	2	1	2	5
	Its temperature in winter:	39	1	5	1	6	4	3	6	5	5	5	4	4	•	7	2	2	4	4	4	4	7	•	6	4	2	5	5	•	1	4	4	6	5	4	6	4	6	7	1	4	3	1	5	4	3	4	6	1	4	3	•	2	5	7	7	7
	Its air quality:	40	1	1	1	2	2	4	1	4	1	6	1	3	•	7	4	1	4	1	3	1	5	•	3	3	2	4	4	•	1	4	4	5	4	4	5	1	6	4	2	3	2	1	3	4	2	1	1	3	7	2	•	2	2	1	2	7
	Its lighting (natural):	41	•	3	4	5	4	4	4	2	3	6	7	3	•	7	4	7	4	1	4	4	7	•	4	•	3	2	•	•	3	•	4	4	5	4	•	4	6	7	4	7	2	2	2	4	4	3	7	4	7	5	•	1	5	5	3	7
	Its lighting (artificial):	42	•	1	7	6	4	7	6	5	5	7	7	5	•	7	7	6	4	5	5	4	7	•	4	6	3	5	6	•	3	6	4	5	6	4	6	4	6	7	1	7	2	3	2	6	6	5	7	4	7	5	•	2	6	7	7	7
	The colour of its floor:	43	•	6	7	6	5	5	6	5	4	6	7	5	•	7	3	4	4	4	4	5	7	•	6	4	6	5	6	•	5	4	4	5	4	4	6	5	6	7	4	7	1	2	3	6	6	4	6	4	7	6	•	1	6	7	7	7
	The colour of it walls:	44	2	6	7	5	5	5	6	5	6	6	7	5	•	7	2	4	4	4	4	5	7	•	6	6	6	5	6	•	3	4	4	5	4	4	5	5	6	7	4	7	1	3	3	6	6	4	5	4	7	6	•	1	4	7	7	7
	The colour of its ceiling:	45	•	6	7	5	5	4	6	5	6	6	7	5	•	7	4	4	4	4	4	5	7	•	6	4	4	3	6	•	3	5	4	6	5	4	6	5	6	7	4	7	1	3	3	6	6	4	6	4	7	5	•	1	4	7	7	7
	The type of floor:	46	4	6	7	5	2	6	6	6	6	6	2	5	•	7	1	4	4	4	4	4	7	•	6	4	6	5	6	•	5	4	4	4	4	6	5	5	5	7	4	7	1	1	1	6	6	4	7	4	7	3	•	1	2	6	2	7
Q10	Age:	47	47	27	30	50	29	43	31	43	30	16	35	22	44	47	18	16	39	27	29	32	26	30	40	42	45	33	40	52	26	34	46	44	28	32	64	44	37	39	44	37	24	29	24	19	22	26	29	29	31	25	29	26	35	37	31	43
Q11	Sex:	48	1	1	2	1	2	2	2	1	2	1	2	2	2	2	1	2	2	2	1	2	2	2	2	2	1	1	1	2	2	1	2	1	1	2	1	2	2	1	1	1	2	2	2	2	2	2	1	2	1	1	2	1	1	2	1	1
Q12	In charge of activity:	49	0	0	0	1	0	0	0	0	0	0	0	0	•	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	1

NORMALIZED PERFORMANCE INDICATOR

A method of computing a normalized performance indicator of energy efficiency is published by the Audit Commission. This method has been used to quote the NPI of Brune Park together with the Audit Commission's reference NPIs for similar building stock. The steps are given below in brief.

		Degree-days	Normalize to DD=2462
Space heating, kWh:	115854	1962	145378
Other fuel, kWh:	49135		
Total, kWh:			194513
			normalizing factor Hours=4,700
Hours of use:	3744		1.26
Normalized total, kWh:			244181
Area, m^2:	940		

NORMALIZED PERFORMANCE INDICATOR = 260 kWh/m^2/year

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

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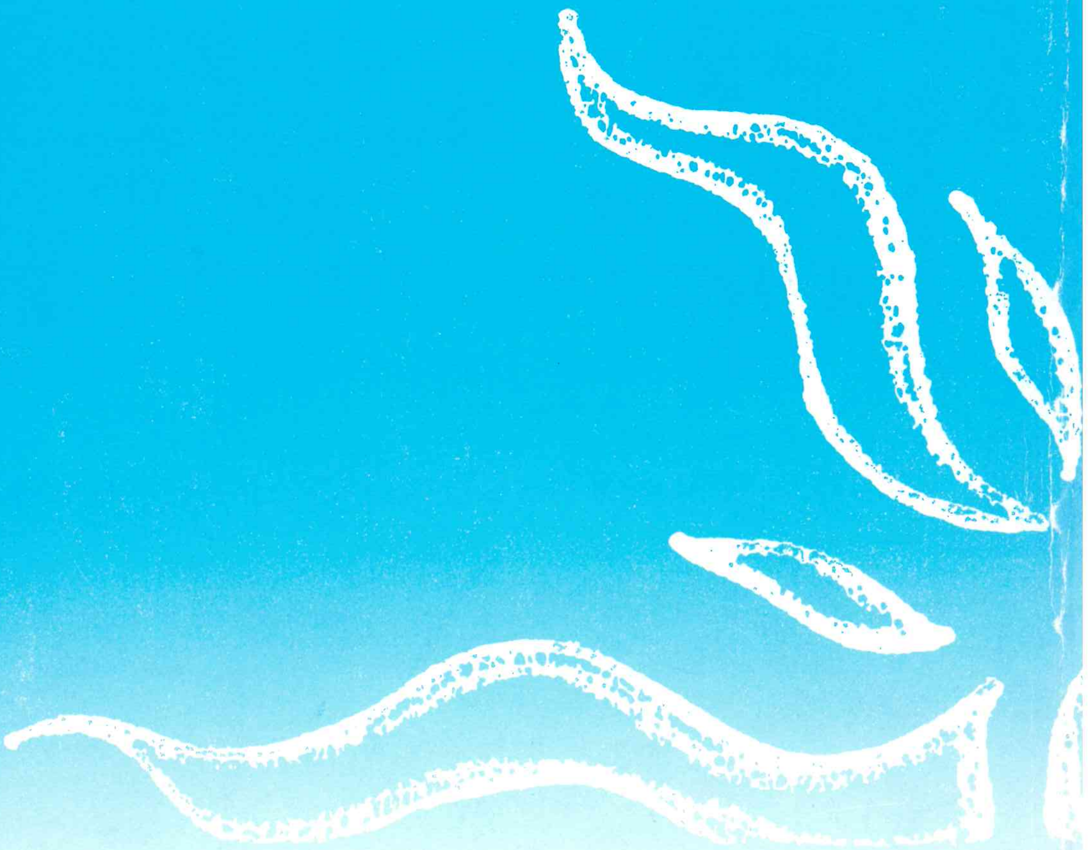

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