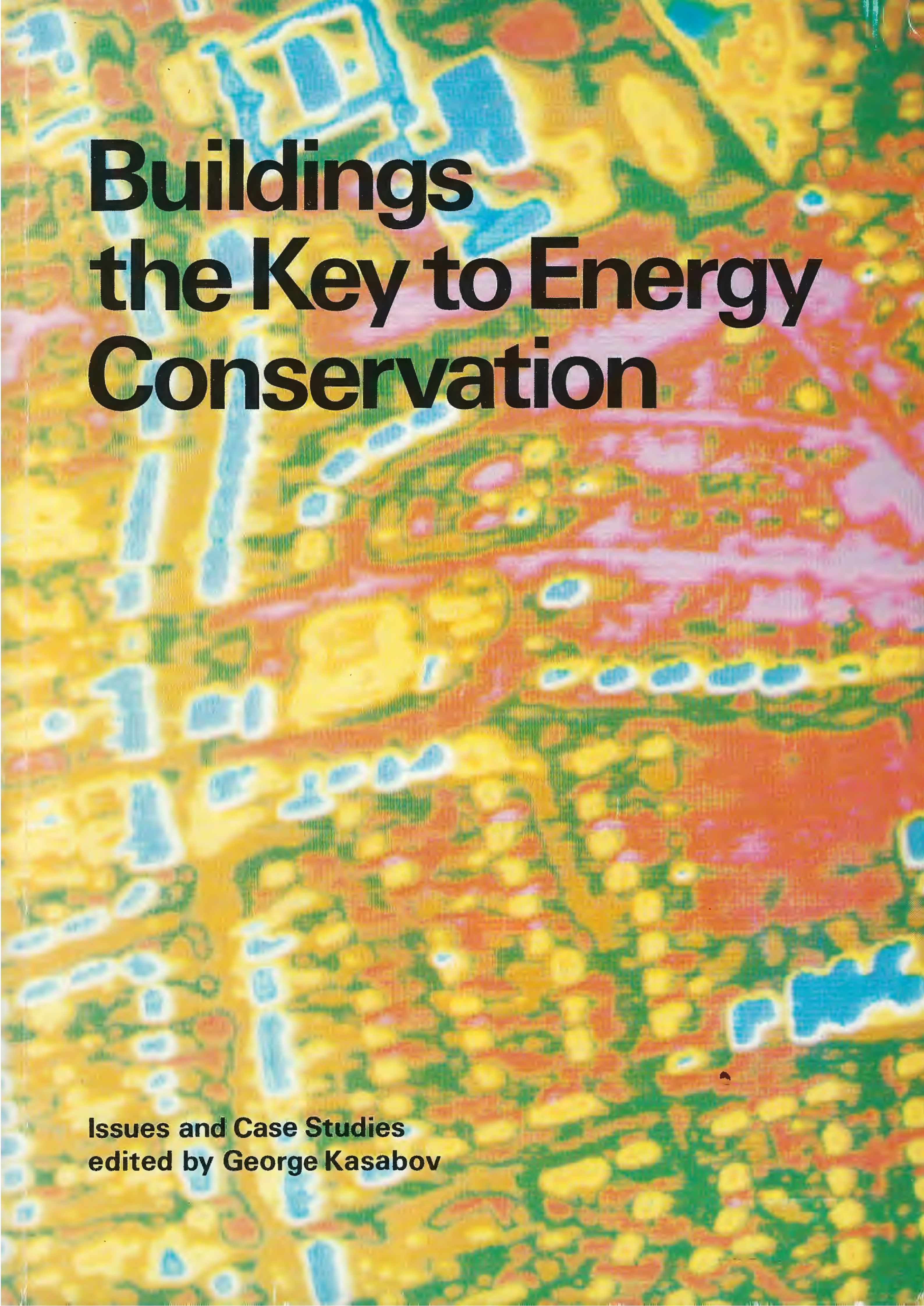


Buildings the Key to Energy Conservation

Issues and Case Studies
edited by George Kasabov

Published by The RIBA Energy Group
The Royal Institute of British Architects
66 Portland Place, London W1

ISBN 0 900630 75 2

Editor
George Kasabov

Assistant Editor
Ian Hogan with Paul Pirak

Graphic Design & Production
Philip Gell with Edwin Belchamber
and Peter Fleissig

Typing and General Assistance
Polly Blanchard
Aideen Brennan
Anne Colbourne
Olive Drake

Diagrams
derived from the contributors' material
and drawn by
Ian Hogan, George Kasabov and Paul Pirak

Typesetting by
Red Lion Setters
22 Brownlow Mews, London WC1

Printed by
Grangewood Press Limited,
Queens Yard, Queens Buildings,
Whitepost Lane, Hackney, London E9 5EN

Contents

Foreword

The RIBA's interest in energy began in 1972 when the then President, Alex Gordon, initiated the programme entitled 'Long Life, Loose Fit, Low Energy'. For some years the significance of buildings for Energy Conservation remained generally unrecognised. However, two key conferences in 1976 brought the issue into focus, the CIB Conference, organised by the Building Research Establishment, and 'Solutions to Energy Conservation in Buildings', organised by the Institute with what was then the IHVE. Following this, the Institute began to search for a more effective way of tackling the many problems associated with energy and buildings. This search culminated in a paper outlining the future course of action for the Institute. It was presented to the RIBA Council in October 1977. The paper concentrated on three main areas—Education; Information and Tools; Exemplars. It got overwhelming Council support.

Gordon Graham, then President, took up the subject as a major task of his Presidency and immediately formed the RIBA Energy Group to steer the intitiative. The result has been that almost every goal mentioned in the Council paper has been achieved in two years. In this seemingly unique professional involvement with Energy Conservation the Institute has received enormous support from Government, especially from the Department of Energy and the Department of the Environment, as well as from each Fuel Industry, the Watt Committee on Energy, and from a small band of enthusiastic members of this and sister institutions, who have formed Regional Groups to tackle the complex of inter-related problems. This successful collaboration has formed links between groups of sometimes previously reluctant professionals and others in a way which no other subject has done.

It became obvious as the work continued that Buildings were the key to Energy Conservation at a national level and that there was a need to show this publicly. Thus, a major exhibition and conference were planned to discuss and disseminate these ideas. The advent of the International Energy Conservation Month, planned by the Department of Energy and the International Energy Agency, gave our proceedings an International significance and we were asked to expand our programme and participate in the month.

Our Conference and Exhibition are the result of hard work by many, however, we would like to mention specifically George Kasabov who organised the material for the Conference and Exhibition, Ric Romig who was our policy adviser, Teresa Pritchard who has organised the Conference and Will Pascall the Institute's Energy Co-ordinator.

We are particularly indebted to the following major sponsors who have given us financial and moral support:

Department of Energy

Department of the Environment

Department of Education & Science

The Watt Committee on Energy

The Fuel Industries

and the International Energy Agency

Professor Patrick O'Sullivan and Richard Burton for the RIBA Energy Group

---

Acknowledgements

This book is the work of many people: the authors of background papers, the hundreds of people whose work is described in the Case Studies and the team who worked very long hours to produce the copy and artwork. However, the key people are undoubtedly those who have put together the individual Case Studies. Without their generosity and patience in assembling and checking the complex information which was required, this project would not have been possible. In many cases this has involved great inconvenience to a busy Private Practice or an understaffed Energy Conservation Unit, and we hope that this transformation of their work into print retains the balance and accuracy of the originals.

We are also indebted to the many individuals and groups of people who responded to requests for material but whose work has not been included in this book, because there was insufficient time to process the information which they sent and cross check the accuracy of our interpretation. In particular, we regret not being able to include some of the interesting studies which were sent from outside the United Kingdom, as they would have helped to show the very real effect of differences in cultural assumptions and economic development on patterns of energy use.

Finally, we should like to acknowledge the encouragement and advice received from: Per Backer, David Button, Barry Evans, Tony Johnson, Tony Kirk, Stan Leach, David Lush, Peter Owen, Derek Poole, Clive Trigg, the Chairmen of the RIBA Regional Energy Groups, and many others who have helped to identify the work included in the book and added to the clarity of its presentation.

Introduction *George Kasabov*

In 1976 an exhibition was mounted at the RIBA showing buildings which had been designed with particular attention to the conservation of energy and the use of fuel. It accompanied a one day conference and consisted of twenty examples. Today there are scores of examples from which to choose and it is clear that both Government and the Professions are far more aware of the kinds of buildings needed in this era of shrinking fuel supplies.

It is now possible to estimate the contributions that the building sector can make in limiting fuel demand. Buildings use over half the nation's energy and, given the will, savings of over 30% would not be difficult to achieve. Moreover, these savings would be long lasting if less profligate patterns of use become generally accepted, and unlike transport and industry, a reduction of fuel use in buildings would not constrain economic growth.

All this has stimulated recent energy demand modelling studies, which identify the costs and opportunities for fuel conservation in buildings and project these into the future, so that conservation can at last be balanced against future fuel supply options.

However, vital though it is, energy conscious design must not become an end in itself. Too often a preoccupation with energy use has led to the neglect of other factors which make for good architecture. It is a response to increasing fuel prices, and like good structural design, which is a response to the need for strength, economy and elegance, it must become an integral part of good practice. It can no longer be considered just another fad. But neither is it just a matter of technical expertise on the part of the professions. For it is important to remember that *people use energy — not buildings.* Thus, designers have to produce buildings which not only *can* be used with a low input of energy, but which *will* also be used that way. People may be motivated to use less energy, but they cannot do so without the means for monitoring how much they are using — and the means for controlling that use: the fuel equivalent of a car's speedometer and throttle. On the other hand, people cannot even choose to economise if a building is inherently wasteful. Thus, building owners and the Professions must learn to optimise spending on energy efficient buildings by considering them as a whole and avoid wishful tinkering with the performance of individual components, which may only make an intrinsically inappropriate building slightly less profligate.

The fifty Case Studies in this book are a representative selection of the state of the art in the United Kingdom today. Existing buildings are given some importance, as the largest impact in terms of conservation will come from upgrading existing stock, even though this work may lack the glamour of new building. However, new buildings are important as exemplars, to develop and demonstrate new approaches to energy efficiency.

Each example is analysed to show how conservation has been achieved and either an estimated or measured annual energy consumption figure is given, set out on a common base of kwh per m^2 and per person. This is intended as a rough guide only and cannot be used to form a league table of efficiency, as there is so far no common method for estimating consumption in detail and the context for buildings of the same type varies so much. Current methods of estimation are notoriously complex and their results are not strictly comparable, relying as they do, on differing mathematical models and a host of assumptions about such variables as use and climate.

Agreement on how target levels for demand or consumption should be set and checked, presupposes a commonly accepted method which is easy to use. Moreover, it poses the problem of whether such targets should be set out in terms of *primary* fuel (relating use to global reserves) or in *delivered* energy (relating use to individual costs). It is doubtful if targets formulated in terms of primary fuel can be an adequate measure of performance, as long as the cost of delivered energy is manipulated in response to social and strategic priorities. The individual building user, who has to pay money for *delivered* energy such as electricity, has little incentive to consider *primary* fuel except as a rough guide to costs. The final decision regarding this balance has to remain a matter of individual judgement.

The designers of many of the examples have also been concerned that their buildings can be adapted for use in a changing and, perhaps more stringent economic climate. This attitude reflects the idea put forward in an earlier RIBA initiative, that all buildings should be designed for 'long life' and 'loose fit' as well as for 'low energy'.

Finally, in every case, successful low energy design is dependent on close cooperation, not just between all the building professions, but also between them and the building's users, without whom continuing conservation is not possible.

The accompanying papers and the Case Studies have two complimentary objectives. Firstly, to show policy makers who have to make decisions involving fuel supply, investment and buildings, what can be achieved and secondly, to show architects, engineers and other professionals involved how this has been done and what effect their work can have at a national level.

George Kasabov is an Architect, Industrial Designer and Consultant on Energy Conservation.

Buildings and the Energy Future

Frederick Romig and Professor Patrick O'Sullivan

During the last few years energy conservation in architecture has become a national issue. Energy-efficient buildings and numerous case studies have been completed in many countries but rarely have these achievements been linked to national energy planning. This is because of the way energy issues were, and in some cases still are, analysed. Briefly, most countries have assessed future energy needs using traditional forecasting techniques which relate energy use and economic output. But this type of analysis does not take into account how energy is actually used and how much can be saved.

The failure to consider what architects, engineers, quantity surveyors and town planners can contribute to energy conservation is one of the major omissions in national energy policy planning. The built environment dominates every demand in industrialised countries. In the United Kingdom, for example, housing, commercial, institutional and industrial buildings took 56 per cent of the country's total energy in 1978. Recent studies show that over half the energy in manufacturing industry is used for buildings (see Figure 1). Also energy demand in buildings is characterised by three other very important features. First it is far more homogeneous than energy used in other sectors. More than three quarters goes to low-temperature space and water heating; the rest is for cooking, lights and appliances. In contrast, energy in manufacturing is very fragmented with over 30,000 different industrial processes and a temperature spectrum of at least six levels for process heat alone. As a result, buildings require relatively few conservation techniques because they are mainly needed to manage heat in a uniform temperature range.

Secondly, this low temperature heat can be provided by any of the four main fuels, by power station waste heat, or the sun. Since it does not matter what fuel is used to heat buildings, we can make the best use of a multi-fuel economy by switching fuels in buildings to alter our fuel mix if we have to.

Dramatic changes in the fuel mix of United Kingdom buildings have already occurred since 1950 (see Figure 2). Unlike transport, which is highly fuel specific and depends almost exclusively on petroleum, buildings can be used as a buffer against fuel shortages which have a far greater impact on other sectors.

Thirdly, energy conservation in buildings does not threaten economic growth. More than half the nation's wealth, mostly from services, is generated in buildings which only require 12 per cent of the country's total delivered energy — mainly for heating and lighting buildings. This is because the GDP from services is created by the skills and activities of people and is unrelated to energy.

The built environment, by its very nature, is a long term proposition. Buildings last a long time. Over 10 per cent of the UK housing was built more than a century ago. Heating systems, on the other hand, need to be replaced completely every 10 to 20 years — about the same as any other industrial machinery. This means that a building may have more than four different heating systems during its lifetime.

New building designs which allow for the use of different fuels, including the sun, help keep future energy options open. An existing building can be completely redesigned for energy efficiency when its heating system is replaced. The permanence of buildings gives long-term continuity while frequent opportunities for energy conservation arise as heating systems wear out. The rate at which different elements turn over indicates how rapidly energy saving measures could be introduced by business-as-usual if new, better designs and equipment replace old ones (see Figure 3).

One important principle of energy conservation is that people, not buildings, use energy. During the past few years, new analytical tools have been developed at a national level. These energy demand scenarios divide the building stock into categories by building type and age. Energy is broken down into its

Figure 1 Breakdown of delivered energy use in the United Kingdom 1978. Source, Digest of United Kingdom Energy Statistics.

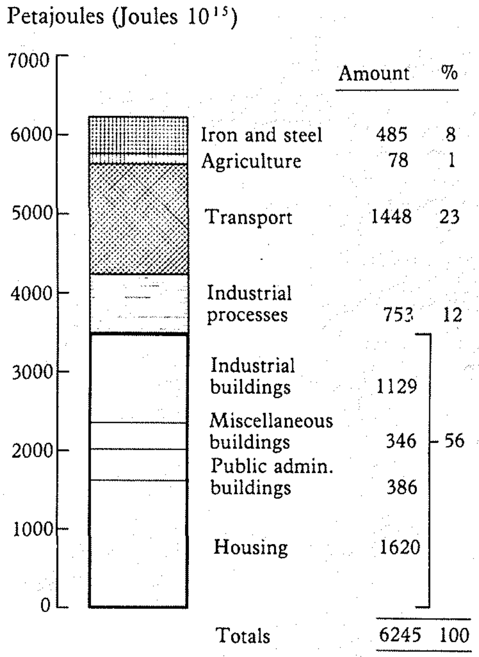


Figure 2 Changes in the built environment fuel mix, United Kingdom 1950-1978 (housing, commercial and industrial buildings).

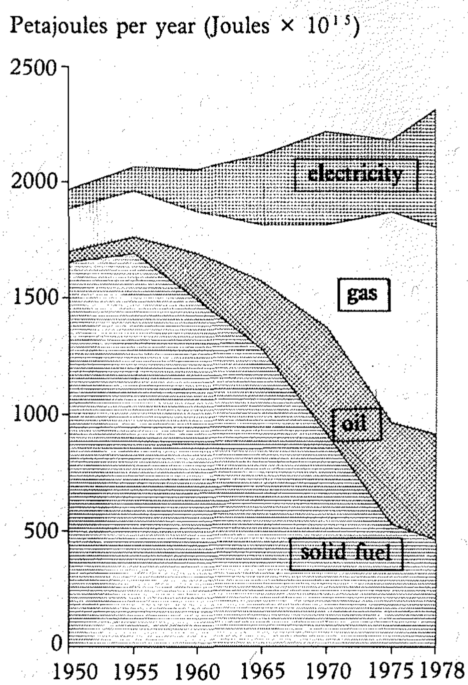
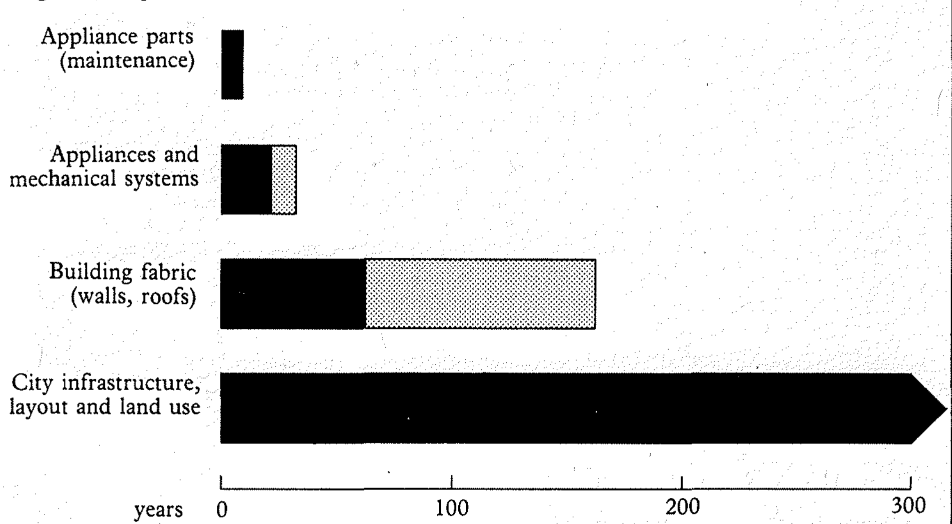


Figure 3 Replacement rate of different elements of the built environment.



uses by fuel type. Each end use is further broken down into activity levels (how long or how frequently a task is undertaken) and energy intensity (how much energy is needed to perform that task). Energy-saving measures and the way a building is used can be analysed along with other important long-term trends.

A wide range of possible energy futures for many industrialised countries has now been analysed in this way. Some scenarios, based on known cost-effective technology, show that the potential impact of energy conservation is much larger than many analysts have

makes it far more manageable or controllable than other sectors.
Most long-term energy models are based on a 50 year period, which is beyond the practical planning limits of most governments and private concerns. Lacking in detail, they are not of practical or immediate use for national energy planning. A policy-making model of much greater detail can now be developed for a much shorter time horizon (to 1990 or 2000) with information available from fuel industries, government agencies and research institutions.

Based on physical features of buildings,

the UK and abroad do not encourage continued architectural innovation. They rely on specifying the thermal properties of building components, so hindering subtle developments such as the use of passive solar energy. Advanced building regulations which account for the performance of a building as a system are already law in several countries including France and the United States. These performance-based regulations make better use of the design skills of architects and engineers.

The successful implementation of known technical measures relies heavily on the

Figure 4 Scenarios and forecasts of delivered energy-use for United Kingdom buildings 1970 — 2000.

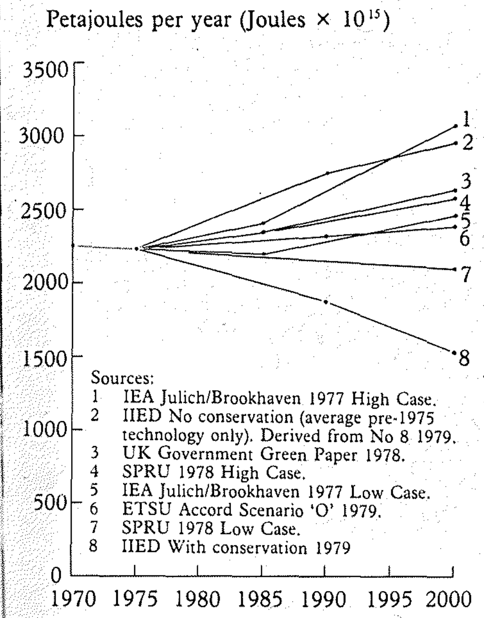
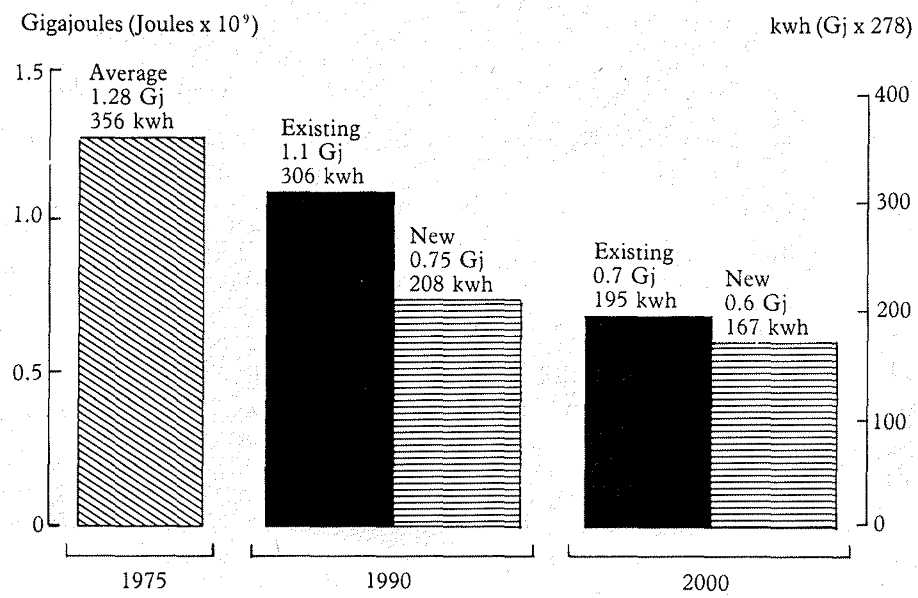


Figure 5 Target average delivered energy-use per $1m^2$ of floorspace by educational buildings 1975-2000 to achieve low-energy scenario. (Some existing schools have already achieved the target for the year 2000.)



RIBAJ

been able to detect in the past. A range of forecasts and scenarios of UK energy use to the year 2000 are given in Figure 4.

The low energy scenario shows a possible future which could occur if energy efficient buildings become commonplace. Buildings needed for the year 2000 to achieve this scenario are in use today (see Figure 5). But this scenario assumes that current best practice becomes the norm.

Energy scenarios show what the future could be. By contrast, energy forecasts attempt to predict what the future will be. But forecasts of how much energy will be needed in the future are notoriously wrong. Instead of attempting to predict what will occur, we need to decide what we want to achieve in the future and then make plans to carry out those decisions.

Predictions should be made for events which are beyond our control. Plans are made for events we can control. The permanence and other advantages of the built environment

occupancy patterns and economic factors, the hybrid economic/physical model of energy demand in buildings could be used for five purposes: to analyse a wide range of complete energy strategies, to examine the lateral connections between policies needed to carry out such strategies; to evaluate the likely impact of policies before they are carried out; to monitor the progress of policies so that their effect can be assessed after they are under way; and to plan future conservation programmes.

Buildings are the only area of the economy in most countries that already has an accepted mechanism for regulating energy. Building regulations enable more efficient designs to be introduced as technological innovation permits. This is a vital aspect of energy conservation for two reasons. First, conservation is new so adopts existing institutional mechanisms to its purpose. Secondly, building regulations which are now used in IEA countries are given in Table 1.

But many aspects of current regulations in

ability of institutions and administrations to adapt. In the past, energy shortages were overcome by increasing supply which meant that energy policy concentrated on oil, gas and coal reserves, centralised solutions which quite naturally appealed to central government decision-makers. But energy conservation calls for many decentralised social and technical solutions.

To manage this problem in the built environment, governments need to work with the professions and building users. Energy expertise can be disseminated through professional mid-career training courses. Such programmes have been successfully undertaken in the UK, initially with architects and engineers, and courses are being expanded to include all professions concerned with the built environment. Also greater emphasis must be placed on administrative measures which allow individual building users to understand, and hence control their use of energy.

Professional institutions can offer another

Table 1: Building Regulations in International Energy Agency Member States 1978

	New Homes Federal	Local	Existing Homes Federal	Local	Federal/ Public Buildings	Maximum temp. Air	Water	Prohibition of bulk meter
Canada	●		●		●	□	□	●
U.S.A.	●	★	□		●	□	□	□
Japan	□		□		★	□	□	□
New Zealand	★		□		□	□	□	□
Austria	●		□		●	□	□	□
Belgium	●		□		●	●	□	□
Denmark	●		●		□	●	●	□
Germany	●		●		●	□	□	□
Greece	□		□		□	□	□	□
Ireland	★		□		□	□	□	□
Italy	●		●		□	●	□	□
Luxembourg	□		□		□	□	□	□
Netherlands	●		□		□	□	□	□
Norway	●		●		★	□	□	□
Spain	●		□				□	★
Sweden	●		●		●	●	□	□
Switzerland		●		●	★	★	□	□
Turkey	★	□	★		□	□	□	□
U.K.	●		□		□	□	□	□

● Existing measure □ No measure ★ Planned measure

RIBAJ

asset to governments. Codes of practice can educate and inform members prior to energy conservation legislation. In this way tougher energy saving regulations can be efficiently introduced and implemented.

The rapid rise in energy use we have witnessed in the past has been caused by a transition. In the last 100 years many Western nations have gone from a low-energy agrarian economy to an energy-intensive industrialised one. Many of these countries are now or will soon be mature industrialised nations. The UK is a good example of a mature state which is characterised by zero population growth and near saturation levels of energy-using appliances, automobiles, industrial plant, roads and buildings. It is a nation which has already acquired most of the energy-intensive goods and services it needs.

It is now changing into a 'maintenance economy' where goods and services only need to be maintained. This stage of development of a nation provides the opportunity for zero energy growth in the built environment or even a decline in energy use while allowing for continued growth in material standards and economic prosperity.

With energy problems, as with many other national issues, there is no solution — only the need to manage it on a permanent basis. The built environment is far more manageable than other economic sectors. Vigorous energy conservation policies in buildings reinforce the intrinsic qualities and a logical transition of industrialised nations.

There need not be an awkward or abrupt transition to a maintenance economy from an acquisitive one. Energy efficiency can ease the way and the many advantages of the built environment make it the key to a smooth transition.

Frederic Romig is a Policy Analyst and the joint author of "A Low Energy Strategy for the United Kingdom".

Professor Patrick O'Sullivan holds the Chair of Architectural Science at the Welsh School of Architecture and is the Chairman of the Buildings Working Group of the Advisory Council on Energy Conservation.

The User Contribution to Domestic Energy Conservation

It is sometimes assumed that planned reductions in energy can be achieved by technical means alone, without social or economic intervention. As social scientists working in energy research, we would argue that even though technical solutions have an important contribution to make to conservation policy, they are likely to be of limited effect unless accompanied by the co-operation of energy users. For example, although insulation and other technical innovations can be introduced into new buildings by legislation, there may be considerable problems in persuading people to take them up.

Secondly, we question the assumption that the only way of bringing about reductions in national energy consumption is through planned gradual conservation, such as a programme to improve building standards. Forced reductions may occur as a result of unforeseen political and social upheavals, in which case user-oriented policy will be essential to cope with the resulting social problems.

Technical conservation strategies tend to focus on solutions which take control for energy use out of the hands of individual consumers. The automation of control systems may or may not be a feasible method of producing a more efficient and rational use of energy in institutional buildings, but in the domestic sector, on which our own research concentrates it is unlikely to produce this result.

As the Advisory Council on Energy Conservation asserted in Energy Paper no. 25: 'People waste energy ... even with technically good systems because of ignorance, forgetfulness or perversity. The first two reasons can be met by education and training, perversity is a far more complex state, but all require further study and action.'[1] While forgetfullness and to some extent ignorance might be overcome by sophisticated control systems, the 'perversity' of domestic consumers could be extended to finding ingenious ways of by-passing such systems. Recent social scientific research has shown that conservation strategies which aim to increase rather than reduce consumer control may help to deal with all three of the ACEC's concerns of 'ignorance, forgetfulness and perversity'.

Before discussing how to achieve such increases in control, we should note that there is now considerable evidence that user behaviour accounts for a large proportion of variance in the energy consumption of buildings, and particularly that the predicted effects of higher insulation are often not achieved (Ellis and Gaskell 1978.)[2]

Although there is a lack of research data in this area, a number of reasons for this phenomenon have been pinpointed. The benefits of higher insulation may be taken not as reductions in energy use but as increase in temperature levels in dwellings. Part-house heating prevails on a wide scale, even in that half of the national housing stock which is centrally heated. Improved insulation allows householders to heat more of their dwellings for the same cost, thus not only increasing their comfort but meeting better cultural expectations.

Fresh air is also highly valued by many for comfort and health, and perverse though it may seem to some, householders prefer opening doors and windows. From the householder's point of view, the control of ventilation and heat flow in this way, together with a powerful heating system, is the quickest and most convenient control system there is.

The best way of dealing with such 'perversity' is to make sure the householder knows that he is being uneconomical. Of course in highly insulated dwellings the relative effect on consumption of heat loss through doors and windows will be disproportionately large. Allowance is not generally made for this factor when calculations of the benefits of improved insulation on a national scale are made (eg Leach 1979).[3]

Social scientists at the US Department of Energy have therefore been evaluating a feedback device which allows a consumer to monitor his consumption and performs various cost calculations for him so that from day to day he can see the gains and losses resulting from the various decisions he makes on how to use his domestic system.

Other studies on the effects of providing feedback of this kind are producing consistent results which show that 10-15 per cent reductions can be brought about relatively easily purely by eliminating waste and inefficiency, and without a lowering of comfort standards. If effective, this conservation technique will prove cheaper than insulation.

A criticism which may be made of these studies is that they have not examined the long-term effects of feedback. It may be that the novelty value of feedback information has an immediate impact on the consumer which wears off leaving him to revert to his former habits. But the motivating effect of feedback is only one of its functions and in a situation of very high prices or shortages of energy it becomes the less important one, for then the economic factors would supply the motivation.

The other functions of feedback which research has highlighted relate to the consumer's awareness, and his knowledge. The location of a feedback device in a prominent position makes it difficult to ignore, and should counter 'forgetfulness'. But if a householder is aware of it and uses it regularly, feedback information allows him to learn about his energy system. Since the effects of making changes to energy inputs (eg turning down the thermostat) are reflected in the output information on consumption, the relationship between inputs and output is gradually learned. Energy literacy in the domestic context means knowing which are the major energy consumers in the system (eg space heating and hot water), and which appliances are hardly worth bothering about (eg switching off the odd lightbulb).

The provision of feedback devices is not the only way in which energy literacy can be brought about. Information on how to conserve can be communicated in a number of ways (the British Government SAVE IT campaigns, for example). Our own research suggests that different kinds of information may be suited to different types of consumers. For example, the less literate but motivated consumer may respond best to fairly simple instructions via the mass media, while the more literate householder may take better advantage of the potential in a feedback device. More research is needed.

We have argued that feedback and other kinds of information would make an important contribution to the success of a programme of planned energy conservation. But if consumers were faced with forced reductions in energy due to very high prices or sheer unavailability these measures to combat excess consumption would become essential. There would be hardship but this could be easy if consumers knew how to make best use of limited supplies of fuel. A policy now for generating that knowledge will not only prepare people to cope with a difficult future but should also, through contributing to conservation in the short term, reduce the likelihood of such a future coming about.

References

1 Dept. of Energy (1978). *Energy Paper No. 25: Advisory Council on Energy Conservation Paper No. 7; Report of the working group on buildings* (HMSO).

2 P. Ellis and G. Gaskell. *A review of social research on the individual energy consumer. LSE report; September 1978.*

3 G. Leach (1979) *A low energy strategy for the United Kingdom. IIED Science Review.*

Dr. George Gaskell is a lecturer and Peter Ellis is a Research Officer in the Department of Social Psychology at the London School of Economics.

ABOUT THE ENERGY MONITOR

What does it do? The Energy Monitor tells you in dollars and cents the electrical usage of any connected load, over any measured period of time. You can measure the cost of operating anything electrically powered from a small coffee maker up to a giant production machine, from a small room air-conditioner to a huge chill or heater system, from an efficiency apartment unit to an entire factory area.

How does it work? In operation, the Energy Monitor detects a small current of electricity that comes from a transformer connected to the main power cables entering your home or business. This small detected current is proportional to the main current flowing through your power meter. The circuits in the monitor translate this current into a monetary figure and display the appropriate numbers on the monitor's face. The circuits are similar to and even more advanced than small business computers and the newest digital watches and calculators.

How do you read it? The time and accumulated energy cost in dollars are displayed automatically on the monitor face and alternated every 5 seconds. The time of day is displayed when the colon appears between the hours and minutes. The date, bill date, budget, power company rate, next bill, last bill and accumulating cost in cents are displayed on the monitor face by pushing the appropriate buttons.

The monitor will start from zero for timed metering and will automatically zero out on any date. Also it will store for future access the "thus far accumulated bill" in dollars.

Every 24 hrs. (at midnight) the monitor will calculate your current dollar/cents consumption and automatically add it to the previously collected consumption. Also, when using the calendar time-base it will calculate your next bill based on how much you have used in the month and how much of the month is left. If the next bill exceeds a pre-selected budget, the display will flash a warning and this warning will continue until another calculation is made 24 hrs. later. If the warning occurs, you know your consumption is exceeding your desired budget.

User Response and Environmental Controls

Diane Haigh and Dean Hawkes

Much recent work in energy conservation and environmental control in buildings has explored the use of automatic controls on plant output to maintain the environment at present levels with predictable efficiency. The role of the building occupant has received scant attention. Human 'interference' with the building systems has been seen as too erratic to be relied on as a method of control and thus the scope for response from the occupants has been minimised. This wide range of 'unpredictable' reactions might, however, indicate a subtlety of response unmatched by automatic controls which can take no account of complex activity patterns, or subtle human feelings. A research project, funded by the SRC and undertaken in association with Essex County Council, set out to study the extent to which the occupants of buildings take active steps to modify their environment and the point at which they do so. This should lead to better correlation between predicted and real performance of buildings and suggest ways of making energy savings.

The study observed activities and environmental conditions throughout the school year of 1977/78 in five different types of school building; a Victorian school (built in 1872), an Inter-War school (1929), a post-War system built school (1963), a demountable classroom (1970) and a recent energy-conscious school (1975). The physical performance of the building was continuously monitored and, at the same time, the state of adjustment of the fabric and activities and responses of its occupants were logged, to provide a dynamic picture of conditions in the classrooms and the occupants' reactions to them.

It soon became clear that the occupants expected to play a very active role in manipulating conditions. Indeed the staff felt most unhappy when deprived of this role in the most recent automatically controlled school and blamed all environmental shortcomings on the plant controls.

In primary schools, requirements vary rapidly with the pace of a teaching day and automatic controls totally failed to adjust to such changes. In many cases, this meant an inefficient use of energy.

Provided no dramatic environmental failure occurred, the staff considered environmental control entirely as an aid to their main task of teaching. A classroom is constantly adapted to cope with the varying needs of mathematics lessons, story time, dramatic enterprises or the mass production of Father Christmas. Staff use the means available to set changes in mood and value their ability to vary the lighting, heating and ventilation. Frequently they would seek to improve concentration by throwing open the windows. In energy terms, such ventilation rates are clearly undesirable, but for the occupants, they are an important factor in control.

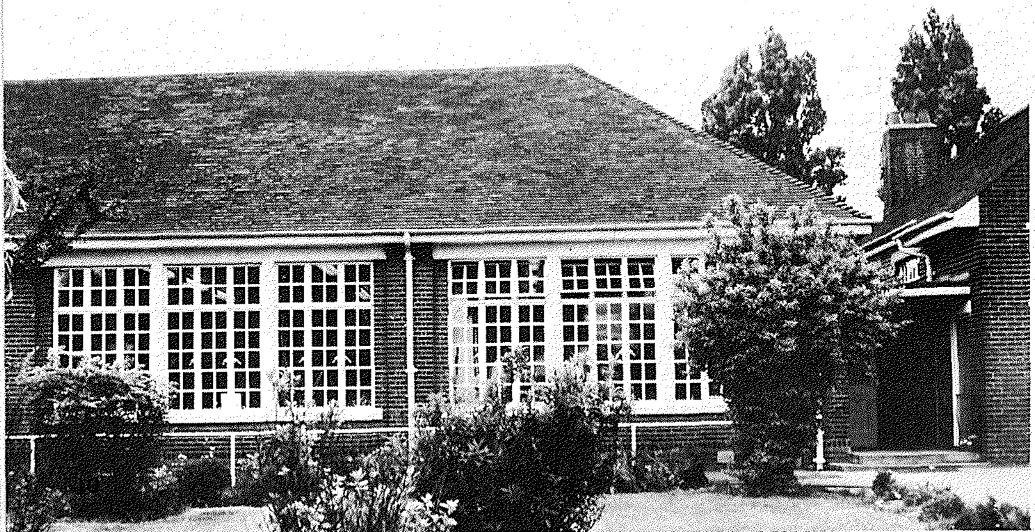
A school timetable is not only varied, it is also interrupted by morning, lunch and afternoon breaks. Even within this time, some periods are spent in specialist rooms or at games, so that a class space may only be occupied for three hours on some days of the week. Conventional heating plant and controls are totally unable to cope with this spasmodic occupancy. Heat poured into unoccupied spaces.

As one would expect, quick response heating systems coped much more easily with such complex and highly intermittent use. However, the controls on these systems could take no account of an empty classroom and often boosted additional heat into the room to make up for a temperature drop due to the loss of heat gain when thirty children left for lunch or play. Clearly some interactive control is required so that the teacher can signal when the room is vacated and conversely, switch on the heating when they return.

Not all the schools had been designed with the care taken over the 1929 school (see illustration). In this, the range and position of opening windows offer many options in ventilation rates and the windows are shaded from direct summer sun by the roof overhang and by the mature trees in the garden outside.

Effective environmental control can be achieved by paying attention to the design of the building at two levels:

1 By careful attention to the thermal properties of the fabric, its orientation, fenestration and layout.



2 By designing the secondary elements of the fabric, such as windows, blinds and shutters so that they can be used effectively to control environmental conditions. Also by installing heating and ventilation controls that are sensitive to changes in patterns of use. All this would acknowledge that the interaction between the occupants and the fabric are an essential part of design for energy conservation.

The implication of extending, instead of reducing, the occupant's control over his environment are fundamentally different from the compact, heavyweight, minimally glazed designs which tend to follow the approach which relies only on automatic controls.

In an occupant controlled building the fabric will have relatively high thermal capacity and a good standard of thermal insulation. Major windows will be orientated to the south and will have solar control devices which are easy to operate. A range of opening lights will allow natural ventilation to be achieved with ease and relative precision. The windows will be big enough to allow good natural lighting for much of the school year, although not as big as in some post-war buildings, which suffer from problems of winter heat loss and summer heat gain. Insulated shutter systems may reduce overnight heat loss in the heating season. The mechanical plant will have quick response characteristics to cope with the highly intermittent pattern of use, and a new generation of controls will allow the occupants to achieve more subtle control and hence, more efficient use.

In winter, the environmental control will be predominantly *automatic* and *mechanical*, in summer the bias will shift towards the *occupants* using *natural means*.

The effect of all this would be to limit major energy consumption to the winter months. Outside the heating season such buildings would be effectively 'energy free'. The design problem then is to achieve efficient winter time energy performance.

Within this outline it should be possible to design buildings whose energy performance is at least comparable to designs which rely on automatic control and mechanical plant. Moreover, throughout the year these buildings should allow a better relationship between the way in which the building is used and the operation of the systems.

Diane Haigh is a research assistant and Dean Hawkes is director of the Martin Centre for Architectural and Urban Studies at Cambridge University.

Energy in the Home an Open University Course

David Crabbe

The Open University course is concerned with domestic energy usage with an emphasis on energy conservation. It is aimed at householders who wish to investigate the merits of various conservation measures within their own home and is written very much with the layman in mind. The course lasts eight weeks and is presented twice a year, in October and January. It consists of eight units, each of which represents one week's part-time study of about six hours. In addition to this material, students are provided with two supplementary booklets containing information on fuel costs, practical activities, optional assignments and four television programmes which are transmitted at convenient weekend viewing times.

Although the course is designed to appeal to people who are in some respects aware of the scope that exists for energy conservation within their homes, its aim is to go beyond do-it-yourself advice and useful money saving hints, though, of course, these are included. The attention of those studying energy in the home is brought to the basic principles of energy inputs and outputs, useful energy, heat losses and thermal comfort. Furthermore, measurement and monitoring of domestic energy uses in all its guises, is encouraged so that the householder can gradually build up a clearer picture of where all his energy, and money, are going. By understanding why, and how, these quantities of energy are being consumed, an 'Energy in the Home' student can arrive at the most appropriate set of conservation measures for him, given his own set of circumstances, e.g. house size, type of construction, heating system, geographical location, occupancy pattern etc.

The first two presentations of the course were in October 1978 and January 1979, when over 1700 students were attracted; an increased number of applicants is anticipated for the autumn/winter 1979/80 presentations given the topicality of energy conservation, following the recent disruptions in oil supplies and general increase in energy prices. It appears that most of our 1978/79 students enjoyed the course and found it very worthwhile; indeed it encourages many of them to employ specific conservation measures in their own homes, as one might expect.

The course was written with a four-year lifetime in mind, and ways in which initial efforts in this field might be improved are being considered, should the opportunity to re-write the course in the near future arise. This is very much an exploratory step into what might be described as "Energy Literacy" education, which the Energy Research Group feels to be desirable, appropriate and necessary, given likely future trends in energy supply, price and availability.

'Energy in the Home' was written with the aid of a grant from the Department of Energy, and during the preparation of the course, the Open University was at various times in touch with the Department, the fuel industries, consumer organisations and trade associations, all of whom proved most helpful. They were clearly sympathetic to efforts in this important area of energy education. Further details on 'Energy in the Home', and application form may be obtained from: The Associate Student Office (ASCO), Open University, Milton Keynes MK7 6AA.

David Crabbe is Assistant Director of the Energy Research Group at the Open University.

Consumers – the Joker in the Pack for Energy Policies

Consumers don't *waste* energy, they *use* it in buildings, systems and equipment designed for them by others who should know better. The choice for using energy inefficiently has already in most cases been made for them. Some consumers can modify some of their behaviour. Travel less, or more slowly; accept being too hot or too cold for comfort; juggle with slow cookers and pressure cookers and generally organise the little things of life so that they can feel the stimulating prickle of hair shirts. People can stand for longer in fewer trains or queue for fewer buses. They can be persuaded or rewarded for improving the insulation of their home. They can cut down on the use of their car.

Most people will not want to do any, let alone all, of these things. Yet the use of energy is critical to the way in which they live and the standard of living they want to have and it is they who organise the priorities of their lives with unpredictability that seems to planners to be perversity.

There are a number of options for using energy efficiently. People will need to get to like many of them. Some have already been forced to choose which option because they can't afford not to. But the only way the majority of people will accept changes in the way they use energy is because they can see the sense of the changes, not because someone else decides they ought to.

Some of the options for using energy efficiently involve decisions made for consumers e.g. the setting of minimum standards for buildings, equipment and appliances, where the trade off between say, extra cost and energy efficiency is demonstrable. Other options involve efforts to modify consumer behaviour by imposition e.g. the use of speed limits for cars. They don't often work. An option that can work is setting a realistic price for energy and demonstrating to consumers that they can still get what they want by modifying their behaviour, e.g. motoring at 50 m.p.h. to use petrol more efficiently.

Consumers need and want to make their own choices and trade offs. The challenge to energy policymakers is to decide which keys will open up public understanding and acceptance of the need to use energy more efficiently. It is primarily a challenge to communicate effectively.

The nature of the energy issue is too universal and important to be left for debate by specific and often quirky pressure groups, or to elitist decisions by technologists and planners. It is an issue which challenges the marketplace and those who sell and buy in it, builders as well as architects, designers as well as engineers, parents as well as school building administrators, the community as well as the transport planners. Energy policy is a giant macro technological problem, with important implications for capital and labour, for transport and planning, for national strategic issues. But it is also a micro issue which affects every individual and every household. A crucial factor in gaining public acceptability for an energy policy (and in democracies this means electoral support) is the believability of that policy. It is also a recognition that there are private decisions to be made about using energy efficiently.

Public understanding of the issues involved and public belief that there are no "secret treaties" with powerful lobbies and that the implications and consequences of the agreed strategies have been considered and weighed and debated in the public interest is vital for the credibility of energy policy in an open society. Without this, public understanding and acceptance of the importance of energy efficiency any energy forecast must build into its model an unquantifiable factor; the response of people as citizens, workers and consumers. So far, there are not many signs that this has been recognised by politicians and planners, bureaucrats and businessmen. That is dangerous, because consumer response to energy issues is the joker in the pack for energy policies. If we don't find out how to get a positive consumer understanding of a response to the short and medium term issues of energy efficiency, how are we going to gain public understanding and support in the long and complicated process of energy pushed industrial, social, political and environmental adjustment in the years to come? *Rosemary McRobert*

Rosemary McRobert is a member of the Advisory Council on Energy Conservation, Council member of the Consumers' Association, Member of the Design Council and Director of the Retail Trading Standards Association.

The Economics of Energy Conservation in Buildings

Dr. David Fisk

In 1973, with the classic work of Peter Stone[1] and others some 10 years old, life cycle costing was still more talked about than applied. There seemed little reason to review the traditional allocation of resources between elements of a building design. Then came the oil crisis and with it energy prices which blatantly challenged that traditional thinking. Six years later what progress have we made in using economic appraisal to rebalance our ideas?

Economic analysis based on the new price levels did not establish itself instantly as the approach by which to react to the new circumstances. Many people thought that energy conservation could not possibly be just a matter of economics, an implication that some elements of the problem were somehow excluded from consideration by the methodology. Some of this misgiving had its source in part to confusions in terminology.

Firstly the term 'energy conservation' itself has misleading connotations. 'Conservation' has more than one meaning. Unlike whales, oil fields do not get more numerous if you leave them alone. 'Conserving' scarce resources is actually a matter of *timing and scheduling* irreversible consumption. (This, as it happens, would also be shown by an economic analysis of natural resource depletion[2, 3].) Secondly 'energy' is quite the wrong term, unless used in an entirely non-technical context. As every schoolboy ought to know, energy is a quantity that is conserved anyway. It is the 'thermodynamic grade' of energy that is critical. You can do anything with a 1GJ of electricity, from melting steel to driving a tram, but 1GJ of water at 32°C leaving a power station is good only for watering tomatoes. So different forms of delivered energy have different intrinsic values to the end user and different implications for the quantity of raw fuel or primary energy consumed. Naturally enough it is the highest grades of delivered energy that carry the highest overheads in raw fuel consumed. It is these consequences of value and cost between different fuels that appear to be missed by those advocating the definition of a building's energy consumption in terms of its total delivered, rather than total primary energy consumption. Value and resource cost differences of this kind are of course the basic building blocks of an economic analysis.

A third confusion has arisen between the terms financial and economic, not least in the building services literature. Strictly an economic appraisal is concerned with all the resource implications of a decision, not just with those in which money changes hands. An economic appraisal in principle, ought at least to make reference to all the costs and benefits[4], and therefore cover any 'soft' costs such as environmental impact, or safety.

The case for claiming that, in principle, an economic analysis can provide a comprehensive guide to design which is conscious of both fuel and other scarce resources must be viewed as robust. It is however quite a step from establishing validity in principle, to believing that in practice a methodology will fulfill its promise. One major contender, at least in applied policy analysis, against which economic analysis had to demonstrate its realisable advantages, was the so-called energy accounting approach.

Faced with a set of fuel prices in 1973 that were believed to be unrepresentative of the underlying resource costs, the idea of energy accounting analysis gained much support. Basically it involved comparing the saving in primary energy of a conservation option with the primary energy consumed to implement it, the latter being traced back right through the industrial system[5]. Although now a very respectable part of resource forecasting, the methodology appears to have lost popularity as a simple decision making tool. One possible reason was that in its usual form, it gave no preference to the relative scarcity of different finite reserves, except by any incidental differences in energy consumption associated with differences in their extraction. A second possible reason was provided by the example of buildings themselves. In any long life structure the arithmetically accumulated energy savings could be vast, and if the only criterion was that these should equal the energy to construct the energy conservation measure, the latter could sometimes represent a daunting outlay in other resources.

To its credit, however, it must be said that an energy accounting cost is deduced from the objective source of the Census of Production and not like prevailing prices by the undeclared calculations of marketing departments.

Even when there exists a courageous national commitment to charge the full 'resource' cost of delivered energy, it must not be assumed that all the elements of that cost can be determined without controversy. The continuing debate on the 'true' price of UK natural gas is indicative of just such technical uncertainty underlying the determination of economic costs. However the great scare of energy accounting; that the energy to make a conservation measure might exceed the energy saved during its life, in fact can be shown to only apply in a condition in which the economic analysis would already have rejected the measure[6].

Given that the principle of economic analysis of energy conservation options has just about survived the rigours of the last six years, how have the techniques survived? The air of ritual that had entered from the beginning literature has been forcedly challenged. Although some authors still think that the optimum level of thermal insulation is a simple matter of applying the differential calculus, against a future of uncertain energy prices the artificial ritual is revealed for the charade that it is. Probability analysis and sensitivity analysis from the corporate planning literature also appear not to have served too well. In the experience of many, sensitivity tests merely show that everything is sensitive. Similarly as far as probability analysis is concerned, few clients would be impressed if told that the white elephant they appeared to have bought for their money would, based on a probability analysis, only appear one more time if they allowed the designer another 1000 attempts at designing the building. In fact the approach which has survived best, is not far from that proposed by Peter Stone[1] over fifteen years ago, of using economic analysis as a method of sharpening our judgement rather than acting as substitute for its exercise.

What has been achieved? Firstly chasing the economic optimum has taught us to understand optima more clearly, in particular the difference between global optima and local optima. Sometimes with a given design it is possible by making a small number of changes in detail to identify a 'local optimum' in a design.

It is quite another matter, however, to be confident that even by making sweeping changes in the major design decisions, no further improvement on the design's economic performance could result. It is these imaginative leaps in design that locate a solution that is 'globally' optimal. It has been too easy to assign the accolade of 'energy saving' to a building because of 'detailing' in say insulation and plant selection, a blatant local optimum, when a review of the whole brief, which might for example remove the need for air conditioning, would have produced a better global optimum[7]. This search for global solutions has taught us, for example to look beyond just varying the thickness of thermal insulation, to see that trade-offs do exist between the capital cost of thermal insulation and the capital cost of more energy efficient plant. Thus although the stock of solid wall buildings is sometimes said to represent a 'problem' because it is hard to up-grade its thermal insulation, it represents a more lucrative market for the application of more costly high efficiency plant such as heat pumps or CHP. It has also taught us that scheduling of measures is far more important in buildings than in other energy saving areas of shorter economic life, and that among the 'soft' costs, exists an option cost of a design representing its ability to respond or be amended to different options[8].

The underlying basic economic principle[9] remains the minimisation of the net present value (NPV). Although a somewhat abstract criterion, it is the only one to guarantee that the chosen project leaves the maximum net cash in the pocket at the end of the project's life time. The use of the NPV requires the client to identify the trade-off between expenditure now and in the future that he uses consistently on all of his project approvals. This might for example be the cost of borrowing money. Of course, this may be different for two clients and it is formally meaningless to talk of a cost effective energy conservation measure without relating it to the client involved. The internal rate of return (that is the discount rate at which the measure would just break even[4]) has recently gained popularity as a means of describing the cost effectiveness of energy conservation measures independently of client status. One recent study has shown just the type of important results gained by tabulating all the options in their descending rates of return[10]. The simple pay back method is often used in this context, but can give non-sensical results because it pays no attention to the life of the measure, which may account for its popularity in manufacturers literature.

The importance of identifying the optimum time to undertake an energy conservation measure has already been mentioned. For most remedial treatment in existing buildings, the optimum timing is very close to that when the measure is justified by the prevailing level of prices[8]. The NPV analysis using constant real term fuel cost is therefore by far the most important of any of the set of sensitivity analyses conducted. Guesses about the future trend in prices only become important when decisions which would be costly to reverse come under discussion. These include many of the cost advantages to be found in a new design. However the options to be compared are not simply whether to undertake the measures now or forget it forever, but rather whether to undertake it now or at some later date, possibly with an additional cost associated with a remedial action. As a particular example, the optimal level of thermal insulation is not that derived by simple application of the differential calculus to building elements, but one which devotes extra resources to those elements difficult to upgrade at a later date, such as walls, and sets levels justified by current prices for those elements easy to upgrade, such as excessible lofts. The element of guesswork is also somewhat eased by the structure of the costs involved which tends to increase in discreet steps rather than in a continuous manner.

Where have we still to go? Far too much appraisal is based on design assumption about patterns of use rather than actual use. This has tended to under-value the significance of controls and user reaction to price levels. We have been far too reluctant to set alternatives side by side and too keen to let interesting design options detract our attention. Above all, there is still nationally a need to see investment in energy conservation as an alternative to expansion in energy supply, appraised on the same economic basis and with access to funds on the same terms.

Dr. David Fisk is Head of Mechanical and Electrical Engineering Division at the Building Research Establishment.

Acknowledgement

This paper is based on the work of the Building Research Establishment and permission to use the work is acknowledged. The views are those of the author alone.

References

1 *P Stone. Building Design Appraisal — Costs in Use. Spon. London 1967.*
2 *R M Solow. The Economics of Natural Resources. Amer Eon Rev, pp.1-14 64 (2), 1974.*
3 *D J Fisk. The economic value of conserving energy. Jn Inst Fuel pp.187-190, 51 (409).*
4 *T A Markus. Cost benefit analysis in building design. Jn Architectural Research, pp.22-34, 5(3), 1976.*
5 *E N Morton. Housing energy economics. Building and Environment, 21-31, 1976.*
6 *D J Fisk, S J Leach. Economic aspects of energy conservation. Energy Conservation and Energy Management in Buildings, ed A Sheratt, 159-184 Construction Press, London 1976.*
7 *N O Milbank. Energy consumption in tall office buildings. Conference 'Tall Buildings and People', Institute of Structural Engineers, 1974.*
8 *D J Fisk. Energy consumption: energy costs and option value. Current Paper CP 57/76, Building Research Establishment, Garston, Herts. UK 1976.*
9 *W J Baumol. Economic theory and operation analysis. Prentice Hall, New Jersey, 1961.*
10 *P Freund. The cost effectiveness of some measures for energy conservation in buildings in the UK. CIB Symposium Energy conservation in the Built Environment.*

Costing Energy Conservation in Buildings

Patrick Venning

ALTHOUGH appraising energy conservation measures in terms of user costs leaves out many factors that are relevant in a national or global context, it will be widely continued despite its shortcomings, for we live in a capitalist society where money is a convenient measure.

The problem with comparing initial expenditure with its revenue implications is that the two are invariably separated by time. Money in hand will grow because of interest, but costs separated by time are not consistent because of inflation. The relationship between initial cost and subsequent return (or revenue) is probably best-discussed by way of an example.

Assuming to start with that money is free (it cannot earn interest when lent or invested) and that it does not inflate, then a measure like insulating the roof which costs £100 now and saves £20 per year in energy costs can be said to pay for itself in five years.

However, money is not free. Because of interest, you could invest less than £100 to bring you in the equivalent of your five returns of £20. The effect of this is popularly taken by discounting the annual energy savings progressively so that the higher the interest rate taken, the more the payback period is extended.

Table 1 shows the effect of various interest rates on the pay back period. It is up to the individual which rate he chooses. As a measure of movement the minimum lending rates during April of the last six years are shown below in Table 2. An average over a substantial period could be taken, bearing in mind the effects given in Table 1. Clearly, mistaken estimates of discounting will have a marked effect on whether to invest at all, but less when considering which conservation measures to adopt.

The example above is further complicated by inflation. The energy savings produced by our initial investment of £100 will increase relatively as the cost of the energy rises: the higher the rate of inflation, the faster you get your money back, as shown in Table 3. But Table 3 also shows that the initial investment that produces the energy saving may also be affected by inflation. This is particularly relevant to measures that may involve recurring renewal or replacement.

How do inflation and discount rates affect our example? Graph 1 shows how the simple pay-back ratio (the initial cost divided by the first year's energy saving) is affected by the various rates that could be assumed. The range of effect is smaller than might be supposed and it is suggested that the typical householder can currently take 10 per cent discount and 15 per cent inflation without running the risk of seriously distorting his appraisal. Again, the maximum pay-back period is up to the individual but should clearly not be longer than the life of the measure being contemplated. An individual householder will not wait, say, eight years to get his money back when he knows that he is likely to leave his home within that period. This is particularly relevant as about 30 per cent of households move at least once over five years.

Generally an energy conservation measure will be cost effective if the pay-back time is less than ten years, however some local authority treasurers require a three to five year pay back for an investment. This cuts down the alternatives available considerably, but as financial constraints on local authority spending tighten and energy prices continue to rise there will be greater flexibility.

Working out the cost of conservation is also affected by the real cost of the conservation measure. Changing a building's pattern of

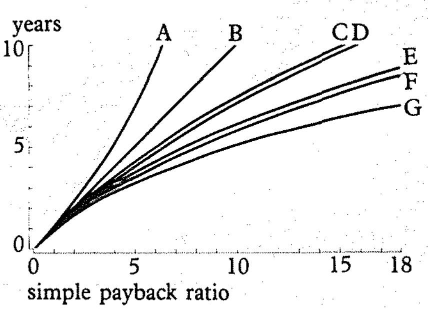
Table 1: Payback period for £100 investment resulting in a £20 p.a. return (energy saving).

Period (years)	Free	Cost of borrowing money 5%	10%	15%
1	£20.00	£19.05	£18.18	£17.39
2	£20.00	£18.14	£16.53	£15.12
3	£20.00	£17.28	£15.03	£13.15
4	£20.00	£16.45	£13.66	£11.43
5	£20.00	£15.67	£12.42	£ 9.94
6		£14.92	£11.29	£ 8.65
7			£10.26	£ 7.52
8			£ 9.33	£ 6.54
9				£ 5.68
10				£ 4.94
Discounted value	£100.00	£101.51	£106.70	£100.36
Discounted value after ten years	£200.00	£154.43	£122.89	£100.36
Payback period	5 years	5-6 years	7-8 years	10 years

Table 2: Minimum lending rate

Date	Percentage
April 1974	12.25
April 1975	9.75
April 1976	10.50
April 1977	9.00
April 1978	7.50
April 1979	12.00

Graph 1 Simple payback.



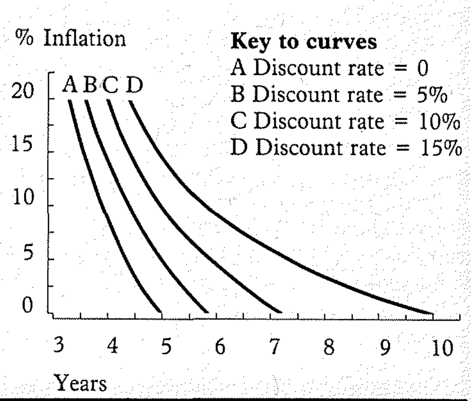
Simple payback ratio equals 'initial cost' divided by 'first year energy saving'.
Key to curves:
A discount rate 15% inflation 10%
B discount rate equals inflation
C discount rate 10% inflation 15%
D discount rate 5% inflation 10%
E discount rate 10% inflation 20%
F discount rate 5% inflation 15%
G discount rate 5% inflation 20%

Table 3: Comparison of movements in energy prices and building costs

	1974 %	1975 %	1976 %	1977 %	1978 %
Energy					
Electricity	32	41	19	11	8
Gas	7	35	11	10	0.2
Heating oil	49	28	26	5	0
Solid fuel	25	27	21	15	12
Building indexes					
Retail price	20	22	17	10	10
Costs*	23	19	18	8	12
Tender price*	4	−4	9	8	

*Figures supplied by Davis, Belfield and Everest.

Graph 2: Effect of inflation on an energy saving 5 year payback period



use by operating a heating system at a lower temperature, closing doors and windows, turning more lights off or shutting down appliances in rooms not in use all affect energy savings without incurring capital costs.

Changes to the building fabric and to its engineering services, on the other hand, do have initial cost implications and these can be predicted. Surveyors and contractors will give estimates while do-it-yourself jobs can be costed from suppliers' price lists.

For larger scale work, the contractual approach can have a significant effect by combining smallish jobs together to obtain economies of scale. Where there is likely to be a delay between ordering work and its execution, the contract terms regarding inflation should be understood and allowance made in the financial appraisal. Grant and taxation advantages can be offset against the initial costs.

Secondly, delivered energy savings are difficult to predict if consumption is not known accurately enough. Energy savings will depend considerably on how the building is actually used and how one measure relates to others. For larger buildings, computer programmes can analyse how a building is used and what it is made of to explain how the energy is consumed. An advantage here is that each possible measure can be judged against the total energy performance of the building. This is vital, for clearly it is no use spending money on insulation if the heating system is never switched on!

It is not so easy for the home-owner. He has to know how much energy his house uses each year. Most manufacturers will now give insulation values for their products and provided these are not accepted at face value but allowance made for actual performance he should be able to work out what insulating the roof space or the wall cavity will do to the annual heating bill.

The need to know the energy performance at the outset cannot be emphasised enough and it is unfortunate that too little is known about how much buildings cost to run. A general preoccupation with capital costs at the expense of running and maintenance costs has been regrettable but high interest rates — and therefore high discounting rates — have been the cause. This preoccupation will decrease as the cost of delivered energy inflates.

Patrick Venning is a partner of Davis, Belfield and Everest and a member of the Watt Committee on Energy.

Example 1: Introduction of insulation into an uninsulated roof

Roof specification: Pitched roof of tiles on battens, roofing felt and rafters with plasterboard ceiling. U value = 1.8W/m²C°.
Insulation: 50mm fibreglass laid between ceiling joists. Revised U value for roof = 0.6W/m²C°.
Cost of insulation: £1.50/m² of insulated roof space.
Energy saving: 0.15 GJ/m² p.a.
Heating system: Oil fired heating system.
Fuel cost saving: Oil = £2.00/GJ. £2.00 × 0.15 = £0.30/m².
Inflation rate: 15%.
Discount rate: 10%.
Simple pay back ratios: (Initial cost, £1.50, divided by first year energy saving, 30p).
Pay back period: Using Graph 2 = 4.2 years. The pay back period is such that this energy conservation measure would be worthwhile.

Example 2: Introduction of secondary windows

Window specification: Single glazed timber framed windows. U value = 5.6W/m²C°.
Secondary windows: Single glazed timber framed secondary windows. Revised 'U' value for windows = 3.4W/m²C°.
Cost of secondary windows: £30/m² of window area.
Energy saving: 0.25 GJ/m² p.a.

Assuming the same heating system, fuel cost, discount and inflation rates as example 1 the following conclusions can be drawn.

Fuel cost saving: £0.50/m²
Simple pay back ratio: 60 (£30 divided by 60p).
Pay back period: The pay back period for this measure is such that it would not be cost effective.

Example 3: Replacement of manual heating control with thermostatic valve

Energy conservation measure: Replacement of manual controls to radiators with thermostatic radiator valves with remote sensors.
Cost of replacing valves: £20/radiator.
Energy saving: 1.50 GJ/radiator p.a.

Assuming the same heating system, fuel cost, discount and inflation rates as example 1 the following conclusions can be drawn.

Fuel cost saving: £3.00.
Simple pay back ratio: 6.67 (£20 divided by £3).
Pay back period: Using Graph 2 = 5.4 years. The pay back period is such that this energy conservation measure would be worthwhile.

Explanatory Notes on the Case Studies

The fifty Case Studies that follow have been arranged according to building type. This is not merely the result of administrative convenience, but reflects the fundamental correlation between the characteristic patterns of use of a particular building type and annual energy consumption within it. Thus, energy use in schools, which are really only occupied for part of the year, is in a different range from commercial buildings to which a different set of environmental standards and patterns of use are commonly applied. Each case study has been edited from material which was received in response to a detailed questionnaire which asked for: Basic Numerical Data; Descriptive Notes and Visual Material.

The Numerical Data has been used in compiling the tables which occur at the end of each Case Study and which we hope will give a useful comparison between different schemes. Such a comparison is inevitably approximate, as in some cases energy consumption has been measured and in others it has only been calculated and the calculation of energy consumption is particularly vulnerable to inaccuracies. Many methods are available which range from first approximation manual calculation to detailed computer analysis. Most of these methods have been devised to compare different design options for the same building under carefully defined conditions, using the same assumptions regarding occupancy, weather etc. The relationship of the calculation to actual energy consumption of a building in use is therefore only approximate. Nevertheless there is a growing body of knowledge correlating theoretical with actual consumption, so that predictions are becoming more accurate.

Three levels of energy consumption are used in most analyses:
Primary Energy or fuel measures the total energy input into the economy in terms of coal, crude oil, natural gas, nuclear or hydro-electricity.
Delivered Energy measures the heat content of fuels purchased by final consumers and is always less than primary energy owing to conversion losses, distribution losses for electricity and fuel consumed by the energy supply industries. It is sometimes called final energy demand, or heat supplied (as in the UK Energy Statistics).
Useful Energy measures the final amount of heat or work available to consumers and best expressed the actual demand for energy. It is usually less than delivered energy because of the losses in end-use equipment.

Figures in this book are given for Delivered Energy and Primary Energy consumption per annum. Their derivation and probable accuracy can be judged from reading the notes on occupancy and on the method of estimation or measurement which was used.

The energy flow diagrams (Sankey Diagrams) are all drawn-up on a percentage basis, starting with the Delivered Energy to the site. This is expressed as a percentage of all the energy going into the building, including that from occupants, machines and the sun. The ratio between Primary and Delivered Energy is noted for each one. Primary Energy factors in all cases, except number 27 are taken from BRE Digest 191.

This gives the following factors for converting Delivered into Primary Energy:

Coal	Delivered x 1.03
Natural Gas	Delivered x 1.07
Oil	Delivered x 1.07
Solid Fuel	Delivered x 1.38
Town Gas	Delivered x 1.42
Electricity	Delivered x 3.82

All figures are in kilowatt hours (kwh), as this unit for energy consumption is likely to be more familiar to those without a technical background. Conversion to Gigajoules (GJ), the unit commonly used by engineers is 1 GJ = 278 kwh.

The following is a list of important issues which was sent out as part of the questionnaire to all the contributors. In some cases contributors were able to respond fully, and in others only some of the points had been considered, or were relevant. The range of responses gives an indication of the current state of the art of energy-conscious designs.

Context — assumptions and predictions: What is the attitude of the designers regarding the effect on the building of changes in economic and technical conditions, in particular the future availability of different fuels? Need there be options for changing fuel use and mechanical systems? What degree of adaptability in the building and what level of complexity of systems is advisable, particularly in relation to problems of maintenance and the availability of replacement parts?

Cost: What was the method of financial analysis from which the investment strategy was derived? What assumptions were made regarding future cost of fuels? Were any special sources of money available, such as grants, without which the project would not have been feasible?

Environmental standards: What range has been assumed for temperature, ventilation and humidity conditions, and for quality ar intensity of lighting? Is there an option for using the building with reduced standards i a more stringent economic climate?

Patterns of use: What assumptions have be made at the design stage? What changes car be accommodated or have occurred and wh effect do these have on energy consumption e.g. Flexitime or cleaning during office hours?

Methods for controlling consumption: Hov is energy use monitored and controlled and this done directly by the users, by a building manager or automatically? Is there any education of the users and how are they made aware of the effect on energy consum tion of the way they use the building?

Maintenance: What unusual maintenance procedures are entailed in the "Energy Efficient" use of the building?

Building form and spatial organisation: What is the approach to the extent of external envelope, plant location, temperature zoning, etc.?

Ambient energy: What is the approach to orientation and shape of the building, desig of external envelope and fenestration?

Building fabric: What is the approach to insulation standards, thermal capacity, method of construction to achieve control o infiltration and avoid condensation etc.?

Mechanical and control systems: What are the lighting, heating and ventilation systems — how do these interact and how are they controlled?

Fuels: What were the reasons for the choice of fuel used?

Design team organisation and method: Are there any special characteristics of the desig process which have produced an "Energy Efficient" building? Were the building user involved? Were there any extra professional costs associated with unusually detailed, though desirable, analysis of the design and also with more onerous supervision of construction, commissioning and monitoring o performance?

Monitoring, evaluation and modification: Have monitoring arrangements been made for experimental purposes? What lessons have emerged regarding how such a building should be designed and used and have these lessons been successfully applied in modifying the building?

Fifty Case Studies

BRS Offices, Garston

1 This three storey office building, now under construction, will provide cellular offices arranged along a central corridor on an east-west axis.

At an early stage it was decided to give special attention to design measures which could result in energy conservation. BRS research staff advised the PSA design team and together they prepared two lists of design features:

(a) Features already proved to be cost effective. Particular attention was given to thermal performance of windows as fenestration is the 'weak link' in energy terms, between indoor and outdoor environment.

(b) Features likely to prove cost effective, based on theoretical studies which need validation by experimental measurement. These features will be monitored by BRS who will compare actual with predicted thermal behaviour.

Ventilation
The building will be naturally ventilated during the summer but in winter mechanical ventilation will be used, with the windows locked. The system has been designed to provide 4 ac/hr at normal room temperature. The intake of fresh air into the system can be varied from ½ to 4 ac/hr: BRS will adjust the rate for their experiments on fresh air requirements. Heat will be recovered from the extract air and transferred to incoming fresh air by means of a heat wheel.

Heating
Low temperature hot water perimeter convectors with thermostatic valves heat the building. It has been divided into two heating zones, north and south, each controlled by a three-way mixing valve which varies flow temperature according to external conditions on the facade. The space heating system has been designed to achieve 18.5°C ± 1°C environmental temperature in offices and 16°C ± 1°C elsewhere in the building.

A solar heating system providing hot water for wash basins has been included for research purposes.

Artificial Lighting
To conserve electrical energy (and provide BRS with a facility for future lighting experiments) it will only be possible to switch on lights when a roof mounted photoelectric sensor detects insufficient sky illuminance to provide adequate daylighting indoors.

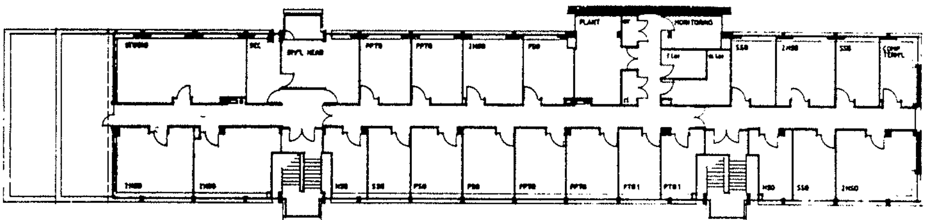
This sensor will be calibrated so that:

(a) when daylight falls below 300 lux at a point 2m into the room the rear bank of lights becomes available for use should the occupant wish to switch on.

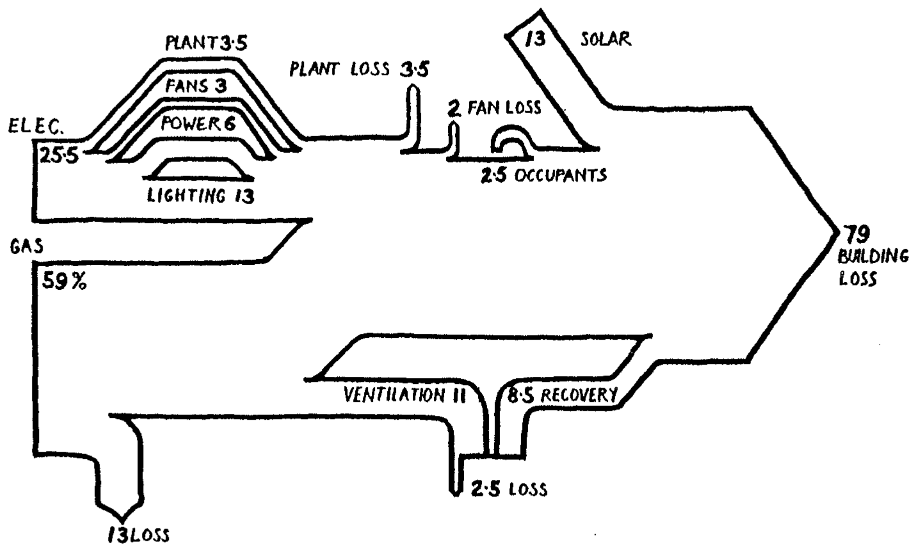
(b) when the level of daylight falls to 200 lux at this point the front bank of lights becomes available. Office light intensity is 350 lux, corridors, etc. are 125 lux.

Building Envelope
Windows of A1 airtightness grading have been specified to reduce infiltration. The windows are double glazed and wall cavities injected with expanded polystyrene to give an overall external wall U value of 1.8 w/m²°C. Care has been taken to avoid cold bridges wherever possible.

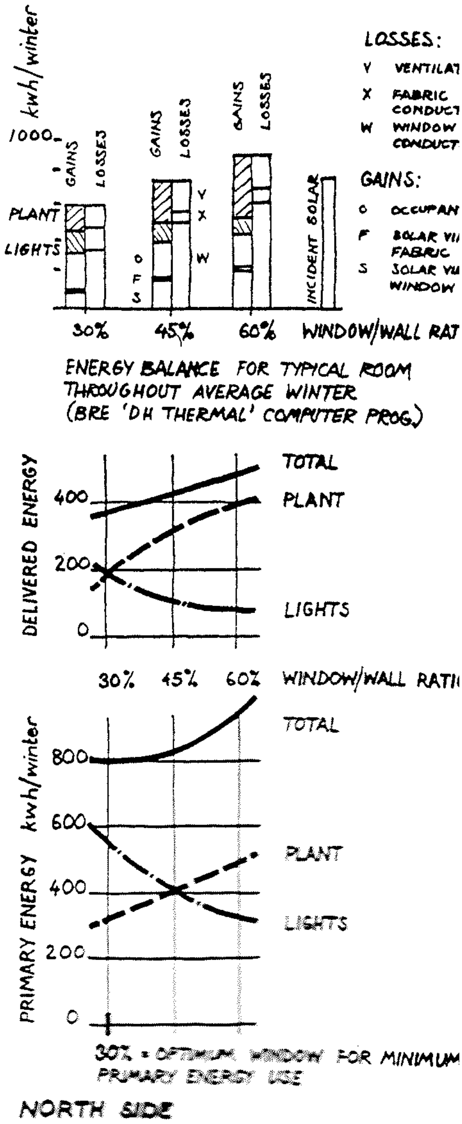
Although the north and south facades look identical there is a considerable difference in area of fenestration. Those on the north are 30% and on the south 50% of the total facades. These ratios were determined by studying the relationship between window size and primary energy consumption of typical rooms over an average winter. Solar heat gain makes a significant contribu-



Second floor plan



Total fuel use per annum Primary 0.36 × 10⁶ kwh **Delivered** 0.19 × 10⁶ kwh **(Primary: Delivered Ratio 1.9:1)**



Analysis of window/wall ratio for minimum energy consumption

BRS Offices, Garston

1 This three storey office building, now under construction, will provide cellular offices arranged along a central corridor on an east-west axis.

At an early stage it was decided to give special attention to design measures which could result in energy conservation. BRS research staff advised the PSA design team and together they prepared two lists of design features:

(a) Features already proved to be cost effective. Particular attention was given to thermal performance of windows as fenestration is the 'weak link' in energy terms, between indoor and outdoor environment.

(b) Features likely to prove cost effective, based on theoretical studies which need validation by experimental measurement. These features will be monitored by BRS who will compare actual with predicted thermal behaviour.

Ventilation
The building will be naturally ventilated during the summer but in winter mechanical ventilation will be used, with the windows locked. The system has been designed to provide 4 ac/hr at normal room temperature. The intake of fresh air into the system can be varied from ½ to 4 ac/hr; BRS will adjust the rate for their experiments on fresh air requirements. Heat will be recovered from the extract air and transferred to incoming fresh air by means of a heat wheel.

Heating
Low temperature hot water perimeter convectors with thermostatic valves heat the building. It has been divided into two heating zones, north and south, each controlled by a three-way mixing valve which varies flow temperature according to external conditions on the facade. The space heating system has been designed to achieve 18.5°C ± 1°C environmental temperature in offices and 16°C ± 1°C elsewhere in the building.

A solar heating system providing hot water for wash basins has been included for research purposes.

Artificial Lighting
To conserve electrical energy (and provide BRS with a facility for future lighting experiments) it will only be possible to switch on lights when a roof mounted photoelectric sensor detects insufficient sky illuminance t provide adequate daylighting indoors.

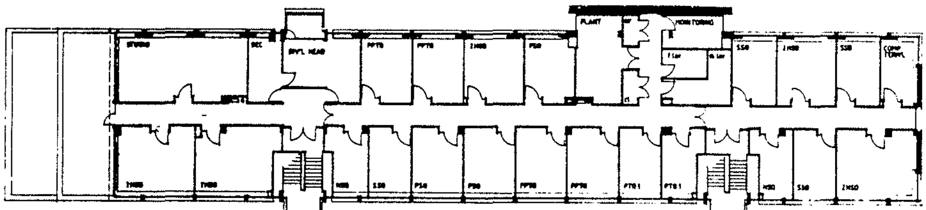
This sensor will be calibrated so that:

(a) when daylight falls below 300 lux at a point 2m into the room the rear bank of lights becomes available for use should the occupant wish to switch on.

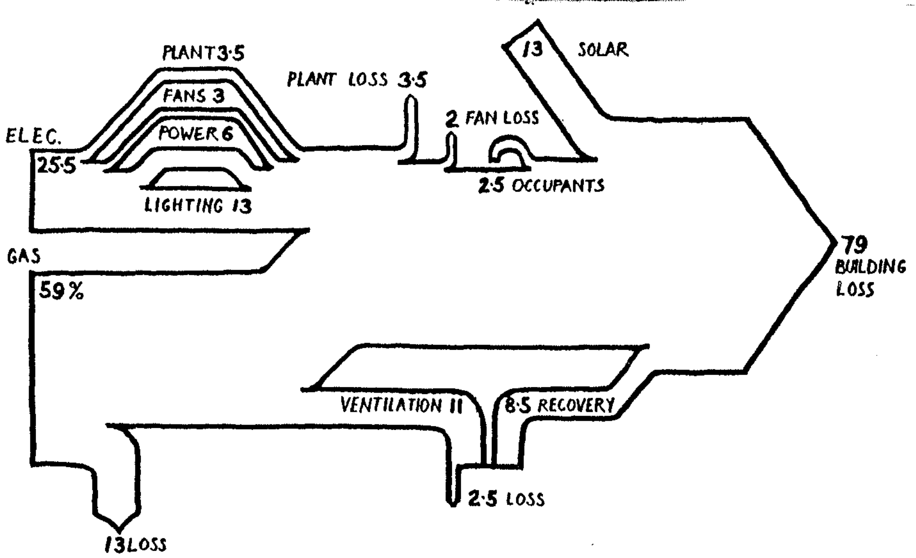
(b) when the level of daylight falls to 200 lu at this point the front bank of lights become available. Office light intensity is 350 lux, corridors, etc. are 125 lux.

Building Envelope
Windows of A1 airtightness grading have been specified to reduce infiltration. The windows are double glazed and wall cavities injected with expanded polystyrene to give a overall external wall U value of 1.8 w/m²°C Care has been taken to avoid cold bridges wherever possible.

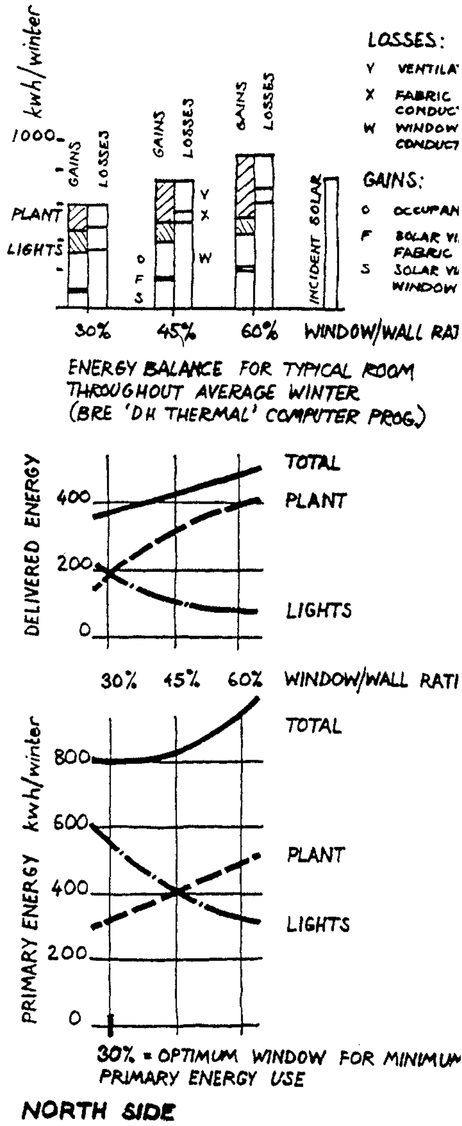
Although the north and south facades look identical there is a considerable difference in area of fenestration. Those on the north are 30% and on the south 50% of the total facades. These ratios were determined by studying the relationship between window size and primary energy consumption of typical rooms over an average winter. Solar heat gain makes a significant contribu



Second floor plan



Total fuel use per annum Primary 0.36 × 10⁶ kwh **Delivered** 0.19 × 10⁶ kwh **(Primary: Delivered Ratio 1.9:1)**



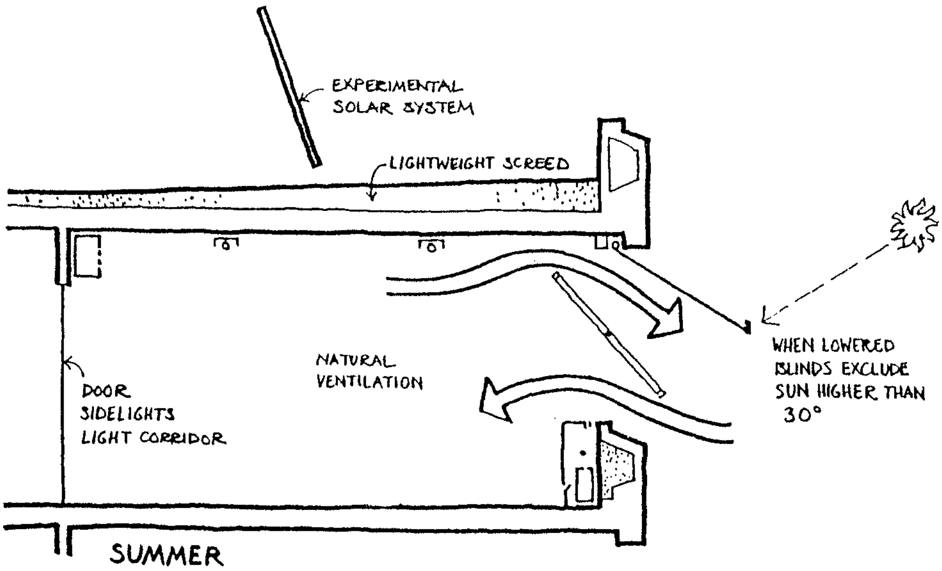
Analysis of window/wall ratio for minimu energy consumption

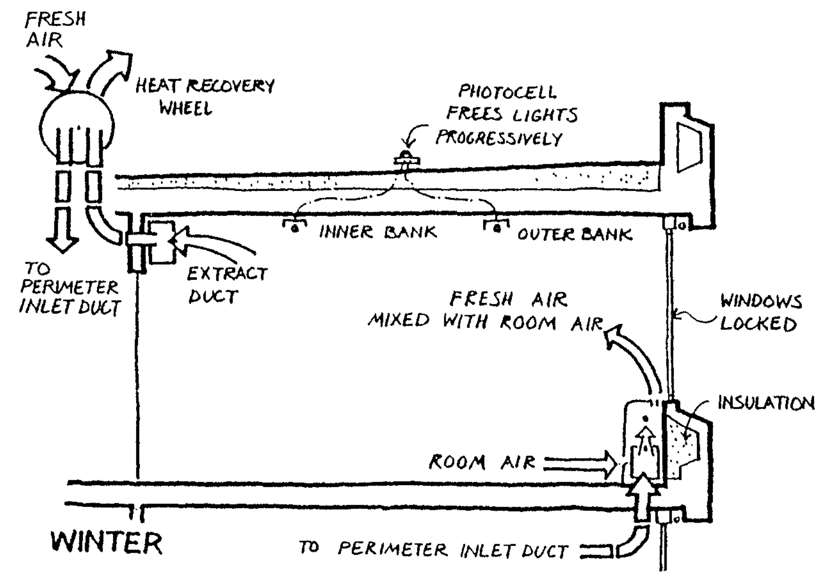
tion to the winter energy balance of a south-facing room.

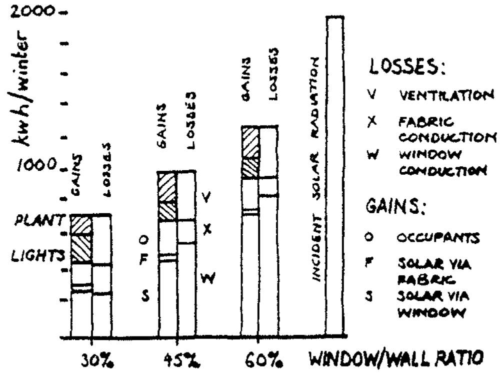
The calculations assumed that these gains could be effectively used, requiring a heating system that can rapidly respond to the varying solar input. Fast response will be achieved in this building by the use of thermostatic radiator valves with a remote sensor in each room, thus rapidly adjusting the heat output from the perimeter convectors to suit demand.

External Sun Blinds
Windows on the south side can be protected from strong sunshine by blinds, controlled by a central solar sensor. These will lower automatically. Each blind is individually motorised and an override facility has been included to allow the room occupant to raise the blind if desired. Prediction techniques indicate the design risk of peak indoor temperatures exceeding 26°c (with the variation in temperature during working hours not exceeding 4°c) to be 30 days in 10 years.

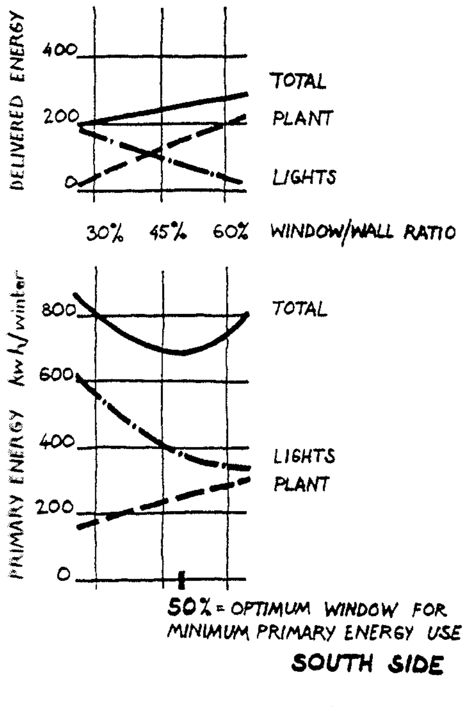
The blinds will not lower until the building has reached design temperature. Full advantage therefore can be taken of available solar radiation to heat the building.







ENERGY BALANCE FOR TYPICAL ROOM THROUGHOUT AVERAGE WINTER (BRE 'DH THERMAL' COMPUTER PROG.)



Analysis of window/wall ratio for minimum energy consumption

Research
The following experiments will be carried out to provide data for future low energy design:

Lighting

1 Assessment of whether lighting installations based on 'visual performance' criteria use less power than traditional designs.
2 Estimation of energy savings that can be achieved when automatic lighting controls are used.

Ventilation

1 To determine the fresh air requirements of office workers.
2 To measure the reduction in ventilation heat loss when using a heat recovery wheel.

Heating

1 To determine the energy savings resulting from improved heating controls.
2 To determine the energy savings resulting from the use of solar water heating equipment in an office environment.

BRS Offices, Garston

Date of completion		October 1978
Capital cost		£850 000
Occupancy 12 hours per day, 5 days per week, 50 weeks per annum		
No of persons		75
Persons per m²		0.039
		m²
Usable area		1745
		m³
Usable volume		4450
Delivered annual energy consumption Estimated by BRE Admittance method and Degree-day method		
		kwh
Total	min	166 × 10³
	max	193 × 10³
Per m²	min	95
	max	110
Per m³	min	37
	max	43
Per person	min	2.2 × 10³
	max	2.6 × 10³
Primary annual energy per m²		209

Client
Building Research Establishment

Address
Building Research Station, Garston, Watford

Architects, M & E Engineers and Quantity Surveyors
Property Services Agency

Environmental Consultants & Monitoring
Building Research Establishment

Main Contractor
Lovell Construction

Salford District Offices

2 Design of this building began in 1972, a year before the first oil crisis, with the objective that it should have a lower energy consumption than had been usual in the proceeding years.

The building form results from the requirement for adaptable cellular offices, with a 12 metre internal width accommodating the desired room sizes. This provides a 1% daylight factor at the centre. Siting requirements resulted in a linear building, with north-west to south-east axis, serving as a communications spine to which later phases can be linked.

The reinforced concrete structure is clad with heavy loadbearing concrete external wall panels. Much of the thermal capacity of this structure was unfortunately reduced by carpets and acoustic suspended ceilings. Also, the precast concrete wall panels were thermally insulated on the inside, as sandwich construction was precluded for structural reasons. Thermally speaking, the building is therefore of medium weight, but its thermal capacity is sufficient to effect a significant reduction in the peak air-conditioning load.

In 1972 air-conditioning was becoming one of the expectations of office staff and it was believed that the availability of energy during the life span of the mechanical services installation would be sufficient to justify this. When this needs to be renewed in 25 years, the building can be converted to simple heating, with ventilation by opening windows. This would reduce the annual energy demand by about 20%.

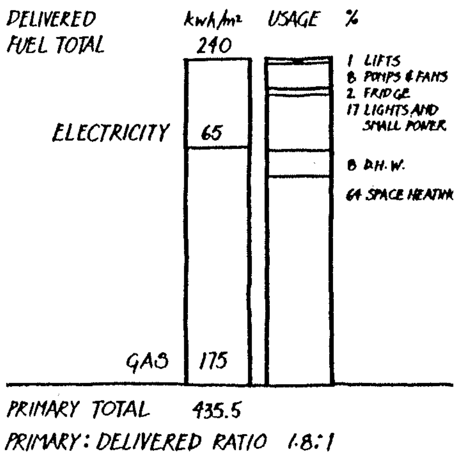
The design features which lead to a low cooling load, also reduce summer overheating in a naturally ventilated building. Thus a comfortable environment can be achieved in this building without air-conditioning, except on a few summer days, when high temperatures coincide with still air conditions.

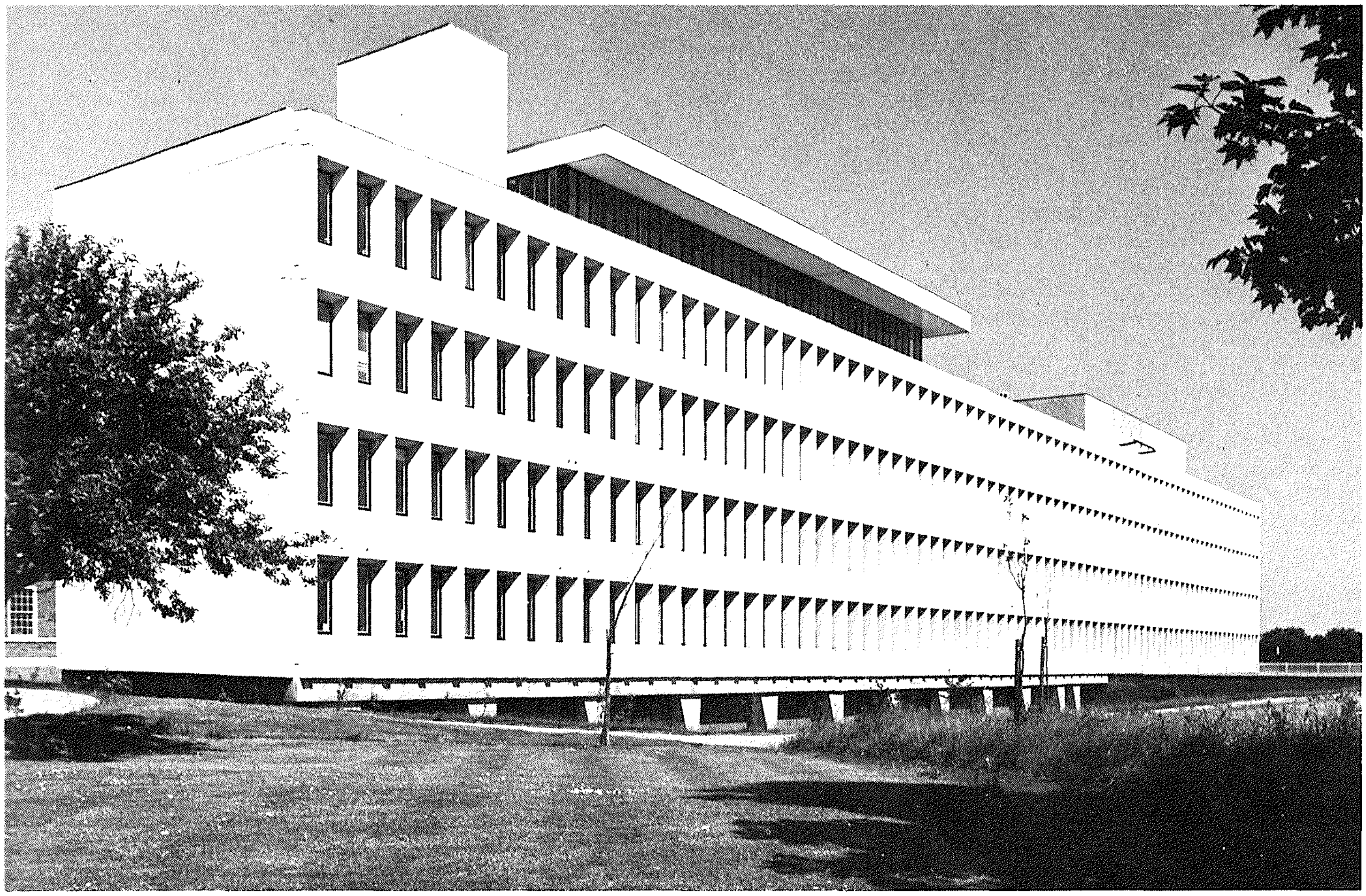
The design of the window panels provides effective daylight distribution, reduces heat loss and cooling load. An analysis of the various factors involved, led to a glazed area of 26 per cent of the external wall area, when seen from inside. The windows are double glazed with mid-pane venetian blinds. The deep reveals of the precast concrete panels shade the windows. External blinds would have been considerably more effective but cost more to maintain.

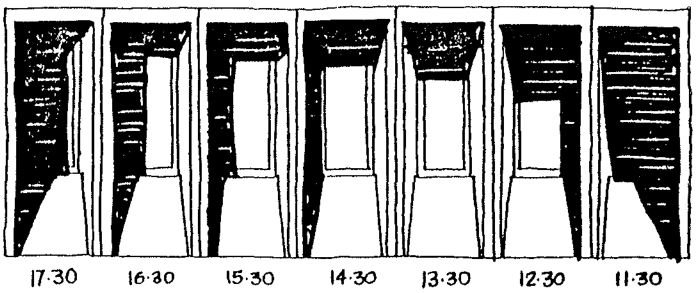
Having designed for a good standard of daylighting, it was important to arrange the switching of the artificial lighting in a way which would be conducive to economy. The luminaires are therefore switched in rows parallel to the windows. In dull conditions the central rows can be switched on before the outer rows which are switched on progressively towards evening. Each luminaire is fitted with a pull switch. Photo-electric switching would have given further energy savings. The lighting installation provides approximately 500 lux.

Air-conditioning is by a 2-pipe change-over induction system, without heat recovery. Lower energy consumption could have been achieved by a 4-pipe induction system with heat recovery, but the increased capital cost could not be justified in 1972. The services cost was 16 per cent of the total building and engineering cost; an abnormally low percentage for an air-conditioned building, reflecting the emphasis on passive control by the building fabric.

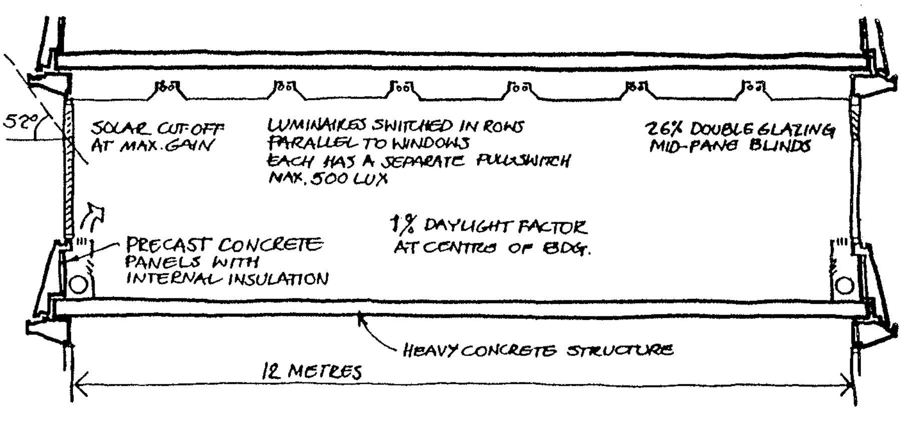
The total primary energy consumption per square metre of usable area in 1978 was 1.55 GJ (430 kwh). Typical primary energy consumptions for air-conditioned buildings designed before the 1973 energy crisis, tend to be about twice this figure.







Shading effects on SW elevation in mid-July



Section through typical floor

Salford District Offices	
Date of completion	March 1976
Capital cost	£1 845 815
Occupancy 8.30-17.00, 5 days per week, throughout the year	
No of persons	400
Persons per m²	0.068
	m²
Usable area	5867
	m³
Usable volume	17498
Delivered annual energy consumption Measured for 1978	
	kwh
per m²	240
per m³	80.6
per person	3527
Primary annual energy per m²	428

Client
City of Salford

Address
Civic Centre, Chorley Road, Swinton, Manchester, M27 2AW

Architects
Cruickshank & Seward

M & E Engineers
How Group Northern Ltd

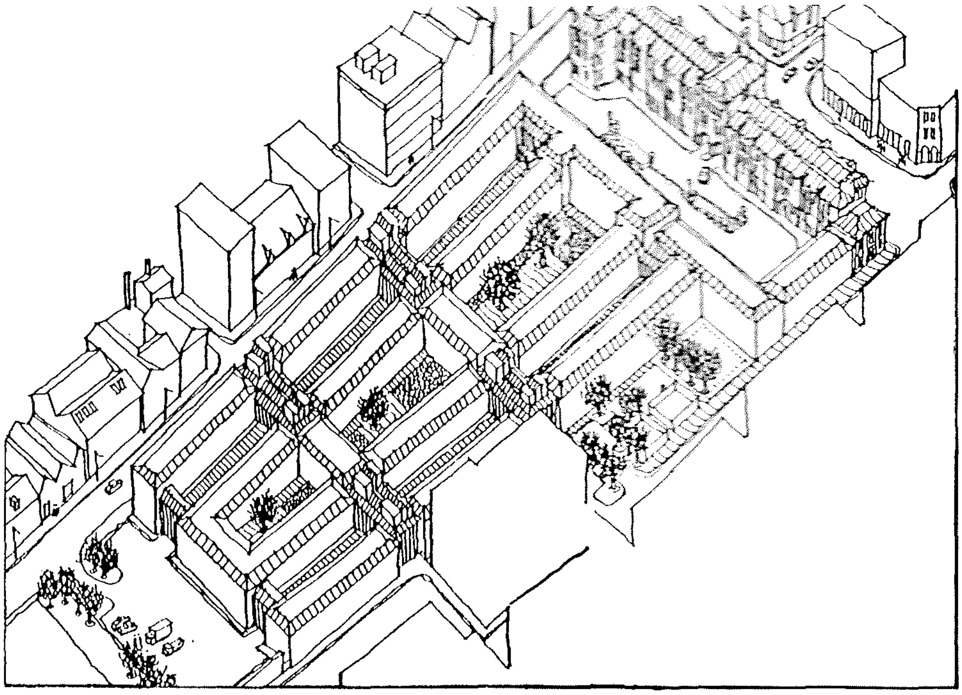
Environmental Consultants
G.R. Winch & W. Burt, University of Manchester

Quantity Surveyor
Michael Seward & Partners

Structural Engineer
Ove Arup & Partners

Monitoring Organisation
The Electricity Council

Crown Offices Liverpool



3 This development is part of the Government's planned dispersal programme for relocating Government offices from the London area.

The site is long and narrow, situated within the commercial district of Liverpool. The development consists of:
(a) the refurbishment and conversion into offices of an existing 'Victorian' hotel;
(b) the construction of new office accommodation, 4 to 5 storeys high, over the remainder of the site. The number of personnel accommodated totals 2,400.

Only the new offices are described below.

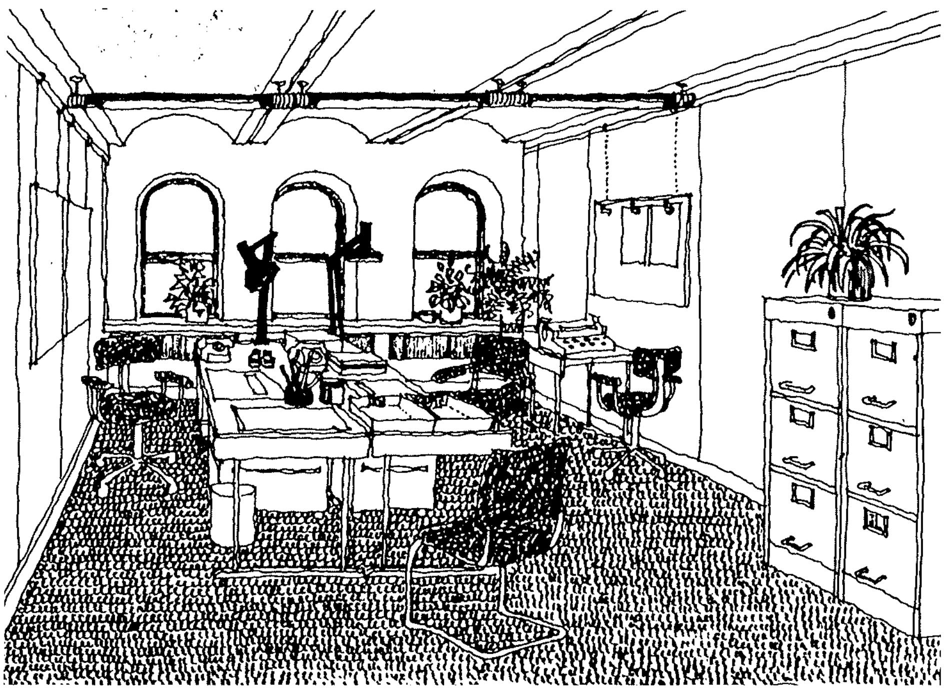
The requirement for adaptable cellular offices resulted in the adoption of a 1.5m planning grid and a cavity floor within the office spaces, designed to take services.

As a result of studies on low energy buildings, it was decided to naturally ventilate the offices, wherever practical and thus limit the maximum width of the blocks to 12m.

Investigations into the best method of achieving adequate ventilation led to the selection of vertical sash windows. Each window is at least 1.5m high, to ensure that maximum benefit is obtained from natural buoyancy. The specification for windows requires well fitting seals to minimise infiltration rates to 1.5 ac/h.

To limit heat losses, the total area of glazing for the office blocks is restricted to 33% of external wall area. There is also a 450m overhang within the window recess to provide a degree of solar shading. The depth of overhang is a compromise between good solar shading and adequate daylight levels. Walls are constructed from pre-cast concrete panels, the thermal transmittance of which is well within the value required by the new Part FF requirements.

Separate background and task light is envisaged with background illumination of 200 lux, from ceiling mounted 40W fluorescent fittings, supplemented by individual 40W tungsten task lights. Installation of block switching for the control of the background lighting is being considered, controlled by a combination of time-clock and daylight level sensors.

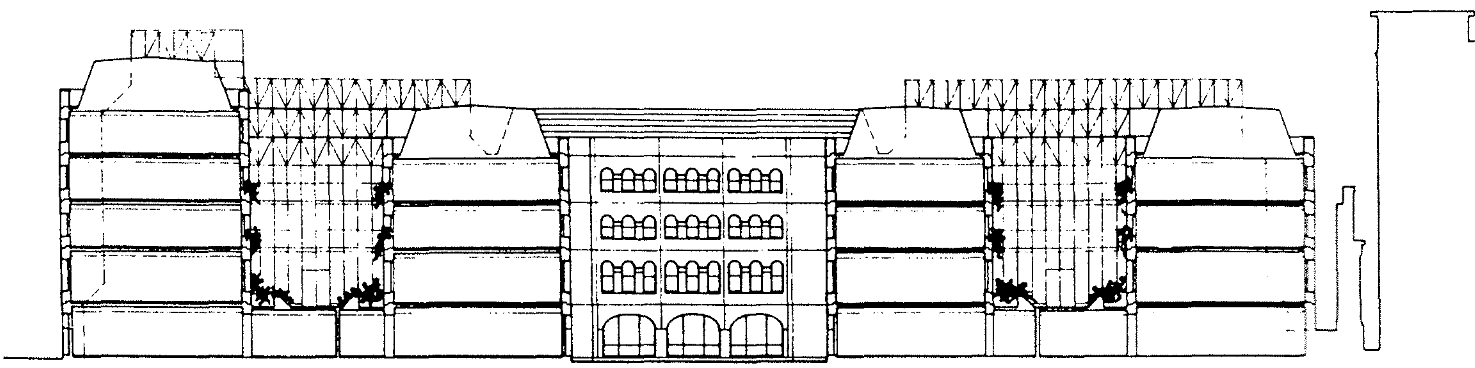


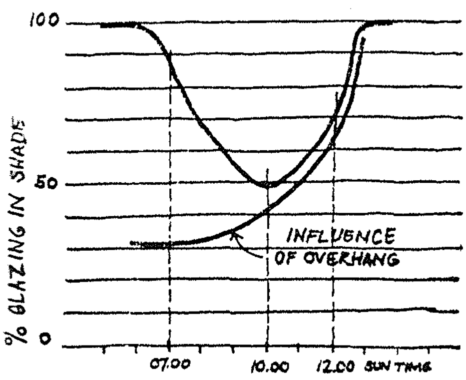
Typical cellular office.

Offices are heated by low temperature hot water radiators, with thermostatic radiator valves (TRV). The range of temperature adjustment of the TRV is limited to a maximum of 20°C. Most of the internal surfaces have low thermal admittances, allowing a rapid response to changing conditions, but high admittance (concrete) ceilings have been used in order to mitigate temperature swings, due to solar gain in summer.

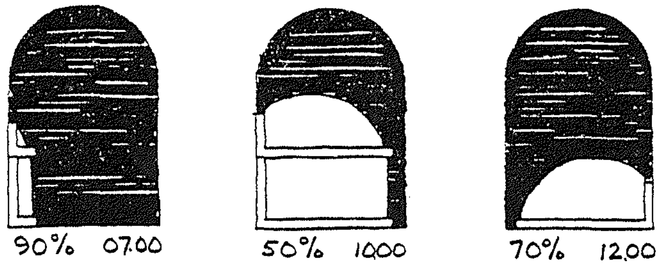
Domestic hot water is provided in the toilet

Section through linear courtyards, showing how 12m span allows cellular offices 4.5m and 6m deep. The building is mostly naturally ventilated, except where external noise levels require mechanised ventilation or air conditioning. The next scheme — Cleveland Crown Offices — is mechanically ventilated for most of the year and can therefore use heat reclaimed from extract air. It therefore has a lower delivered energy consumption, but a higher primary energy consumption.





GRAPH SHOWING % GLAZING INSHADE THRO' DAY ON A SOUTH EAST FACING WINDOW IN MID JUNE



Shading of window by overhanging external walls.

areas by instantaneous electric water heaters, as this approach proved the most cost effective and energy conscious of the alternatives considered.

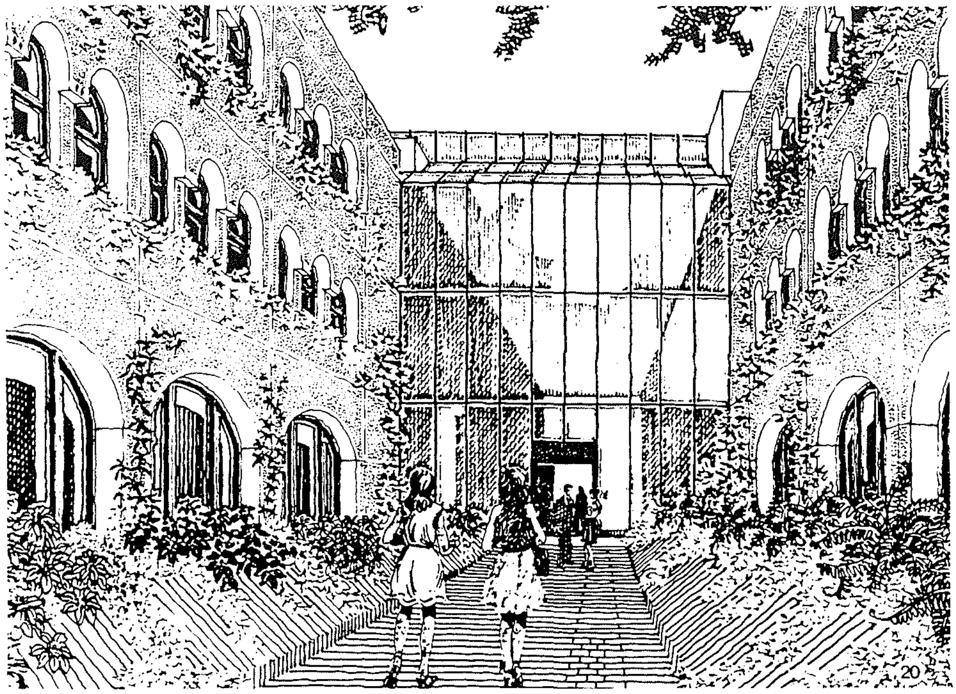
A cost comparison exercise, based on discounted cash flow techniques, resulted in the selection of natural gas as the heating fuel.

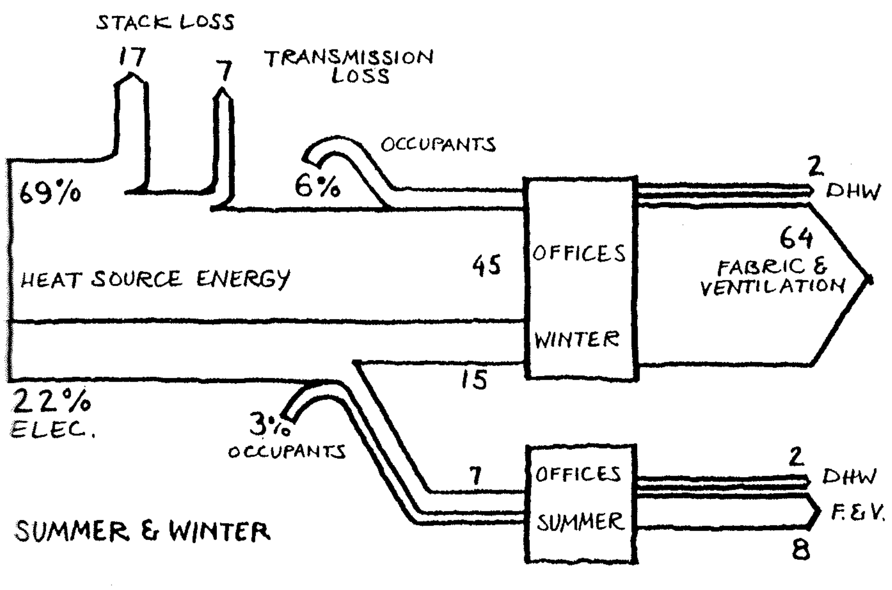
This is supplied to four boiler houses sited at strategic positions around the site. Each boiler house contains either two or three boilers supplying LTHW for office heating, plus in certain cases a limited amount of bulk hot water storage for calorifiers (used for catering and photographic purposes).

Allowance has been made within the scheme for future conversion to alternative energy sources, once natural gas becomes uncompetitive. The scheme incorporates an underground walkway which is also used for primary circulation of bulk materials as well as engineering services. Facilities have been incorporated within the route for oil lines, electrical cables or heating distribution mains. Space has been reserved for a centralised boiler house to allow for the future use of coal.

Optimum start controls are fitted to heating services but mechanical ventilation and air conditioning plant will be on a fixed time control instead of optimum start.

The maintenance of the building services will be supplemented by a central supervisory system which will give instantaneous indication of fault conditions on major items of plant. Facilities are incorporated within the system to monitor energy flows.





Total fuel use per annum Primary 10.1 × 10^6 kwh **Delivered** 5.8 × 10^6 kwh **(Primary: Delivered Ratio 1.7:1)**

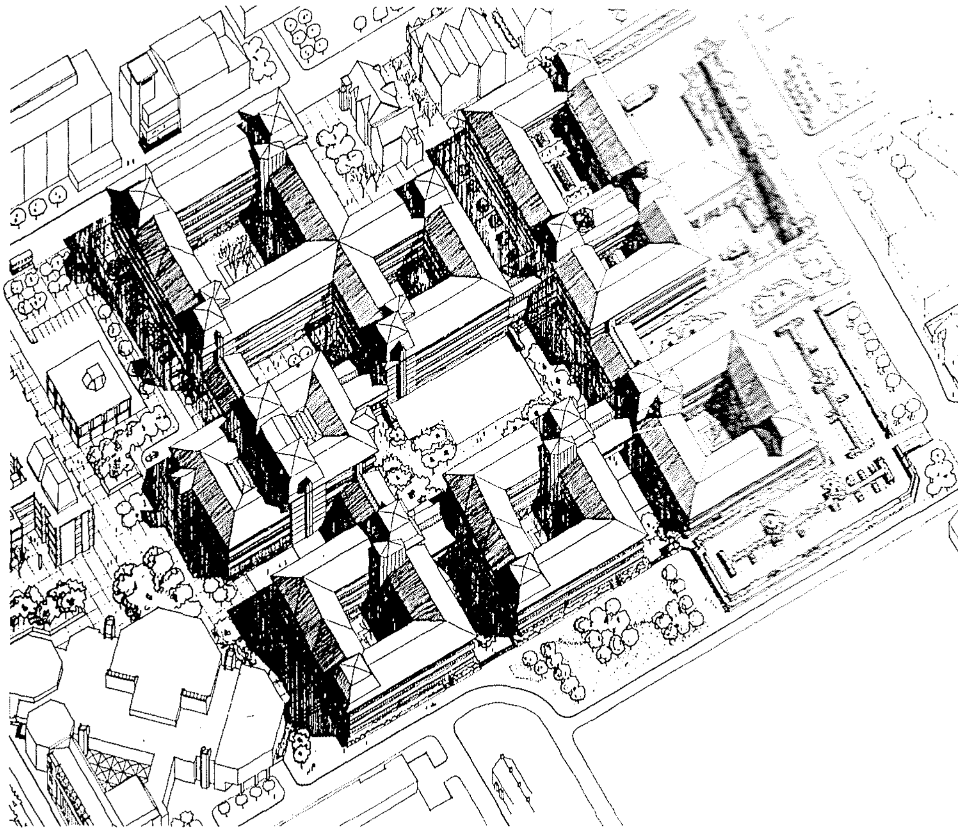
Crown Offices, Liverpool	
Date of completion	unknown
Capital cost	£36 000 000 (June 1979)
Occupancy	
9.00 to 17.00 daily, Monday to Friday	
No of persons	2395
Persons per m²	0.04
	m²
Usable area	48 247
	m³
Usable volume	168 865
Delivered annual energy consumption	
Estimated by CIBS methods	
	kwh
Total	5.75 × 10^6
Per m²	120
Per m³	34.2
Per person	2400
Primary annual energy per m²	209

Client
Various Government Departments

Address
Exchange Station, Liverpool

Architects, Engineers, Quantity Surveyors, Monitoring Organisation
DGDS Design Office, Property Services Agency of the DOE

Crown Offices Cleveland



4 The scheme consists of a series of courtyard buildings, housing offices in a 13.5 metres, clear spanned, precast concrete structure. This allows for subdivision into cellular offices. Two deep plan buildings house the support facilities such as library and warehouse.

The principal objective of the design was to make maximum use of natural ventilation and restrict mechanical ventilation and particularly air-conditioning, to areas where it was absolutely necessary. Studies of traffic noise, air pollution and climate showed that only 11% of the 70,000m² require air conditioning. The 'Speed' computer programme was used to assess the effects of thermal admittance and thermal transmission of the structure, glazing, artificial lighting and occupancy levels on predicted internal summertime temperatures. From this, a band of optimum building widths were selected which could accommodate the required office sizes without the use of mechanical cooling. It was assumed that internal temperatures would exceed the limit of 22°C for five days a year.

The deep plan areas which needed air-conditioning are concentrated in one building to achieve maximum utilization of plant.

The avoidance of mechanical cooling for the offices was dependent upon effective solar protection. The client did not favour mechanical blinds, so a computer analysis was made of the optimum overhang above the windows to provide shading. Two programmes were used, one to predict the degree of shading on each day of the year on each building facade with various overhangs, the other to relate these to internal summertime temperatures. The design has made a compromise between energy and aesthetic considerations, with overhangs of 1.8m at roof level and 0.5m at other levels. West and South facades will also need internal venetian blinds.

The relationship between solar shielding, daylight factor and internal artificial lighting levels is one of the most important factors affecting annual primary energy consumption. If only delivered energy is taken into account, and not primary energy, daylighting does not appear to be so important. However, it is primary energy which is reflected in the cost per unit of energy consumed. Artificial lighting levels are 350 lux generally and 550 lux in deep plan areas. The glare index has been reduced by 19 by utilising the 'T' beam ceiling to give improved cut off angles. In this instance an optimum glazing level of 37% was chosen. The resultant energy savings are dependent upon the lighting control systems. Economic appraisals were made of the various automatic control systems available and compared with the energy costs associated with normal manual switching. The greatest saving occurred with simple photocell 'on/off' controls giving a high index of profitability and a pay-back period of eighteen months. Dimming systems and solid state logic switching systems gave even greater energy savings, but lower indices of profitability.

Optimum 'U' values for both roofs and walls are 0.4 w/m²°C. The exposed concrete 'T' beam ceiling enables thermal admittance to be kept high enough to obviate summer cooling (10 w/m²°C) but low enough to restrict the winter energy requirement associated with intermittent heating and optimum start controls.

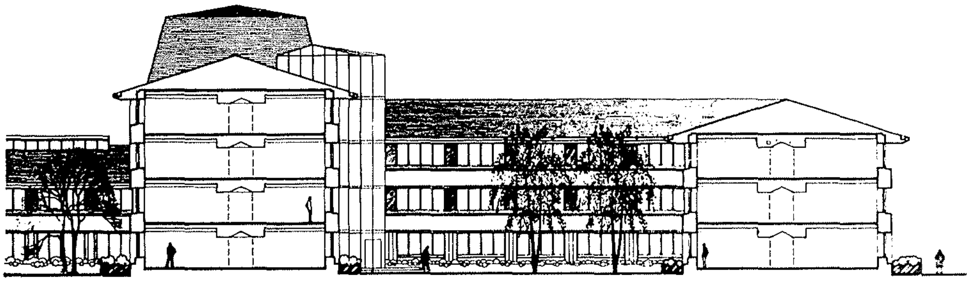
Air infiltration is minimised and made predictable by the use of high performance openable windows fitted with compression seals.

Heating is by means of under sill panel radiators. Tests on existing buildings have shown that a combination of individual thermostatic radiator valves and external weather detectors can use 15% to 17% less energy than traditional external detectors and associated zone controls operating on the open loop principle.

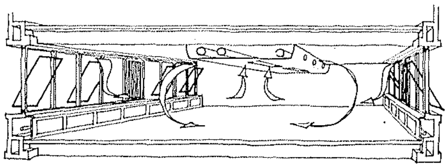
Because of the requirement for 'flexible' office space, there was a need for a supplementary mechanical ventilation system to internal zones during the summer months and this also provides winter ventilation when windows are kept closed. The air is heated to ambient temperature and 70% of the heat in the extract air is recovered by rotary heat exchangers, housed in rooftop plant-rooms. The same heat exchangers recover heat from air extracted from the basement substations and calorifier rooms.

Electrical energy for hot water around the site via the group heating mains is achieved by the use of variable speed pumps. The pump drive electrical energy is reduced to a fraction of that demanded by constant volume pumping systems by the use of variable speed pumps for hot water and heating mains.

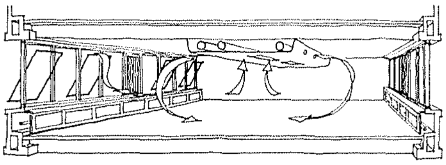
A similar principle is used in the air conditioning system for the Central Building



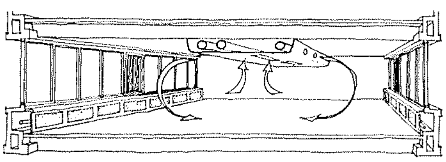
Section through typical court. 13.5m clear sp allows division into 4.5m to 6.3m deep cellul offices. Such a deep building requires mecha cal ventilation and permanent supplementar artificial light — this in turn makes possible t use of heat reclaim from the extract air. The preceding Liverpool Crown Offices scheme i naturally ventilated and so cannot use heat reclaim, and so has higher delivered energy consumption, but a lower primary energy co sumption.



Summer. *Heating off, windows open, mechanical vent on (8 air changes/hour).*

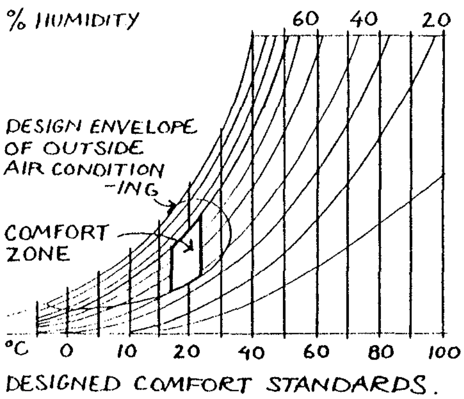


Spring. *Windows open south side, radiators off (automatic), windows closed north side, radiators on (automatic).*



Winter. *Heating and mechanical vent on, windows closed, (1½ air changes/hour).*

which houses conference rooms, training areas, lecture theatre and restaurant. The variable air volume system enables air to be supplied at constant temperature and the supply volume to be varied in proportion to the cooling load. A 40% saving in fan energy consumption is achieved. The system design incorporates two other energy saving concepts. First, internal temperature and humidity are allowed to float between 18°C to 22°C and 35% to 70% RH between winter and summer. Secondly, the variable volume system allows maximum use of free cooling whereby outside air is mixed in continuously varying proportions with recirculated air. As a result the refrigeration plant is only used for 450 hours per annum.



By allowing a temperature float of 4°C and a 30% humidity float between winter and summer, a 50% energy saving can be obtained.

Energy management is by a computerised monitoring and control system. Energy savings produced by this facility result from:
(a) increased efficiency and performance of plant and equipment
(b) automatic load shedding of plant or lighting in a pre-determined order of priority when energy consumption targets are encroached
(c) good housekeeping, such as correct control of cleaners' lighting and pre-occupation heating schedules.

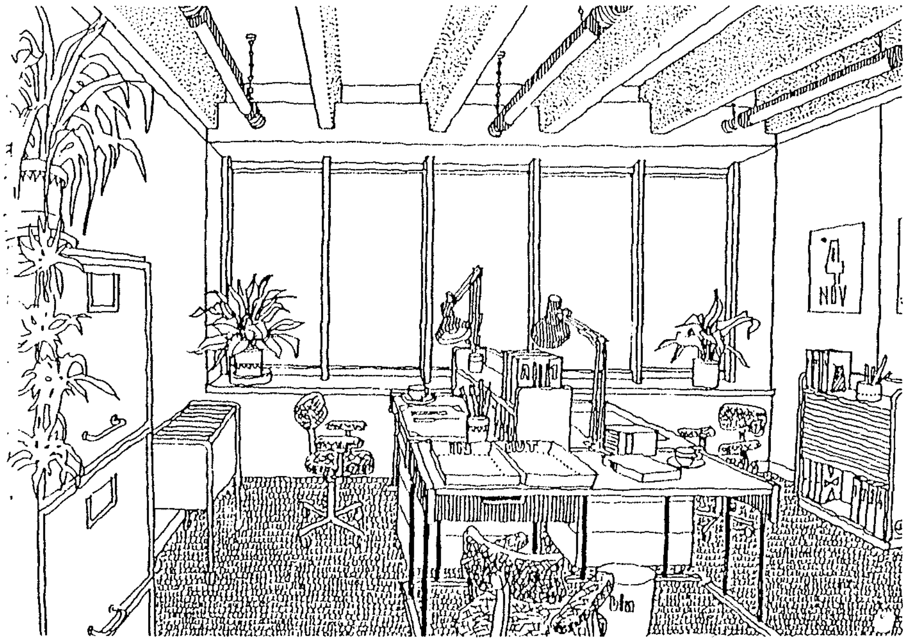
Capital expenditure for energy recovery systems is granted by the Treasury for Government projects provided that the rate of return on investment, termed the Index of Profitability (IOP) is greater than zero, where —

$$IOP = \frac{(AN)}{C} - 1$$

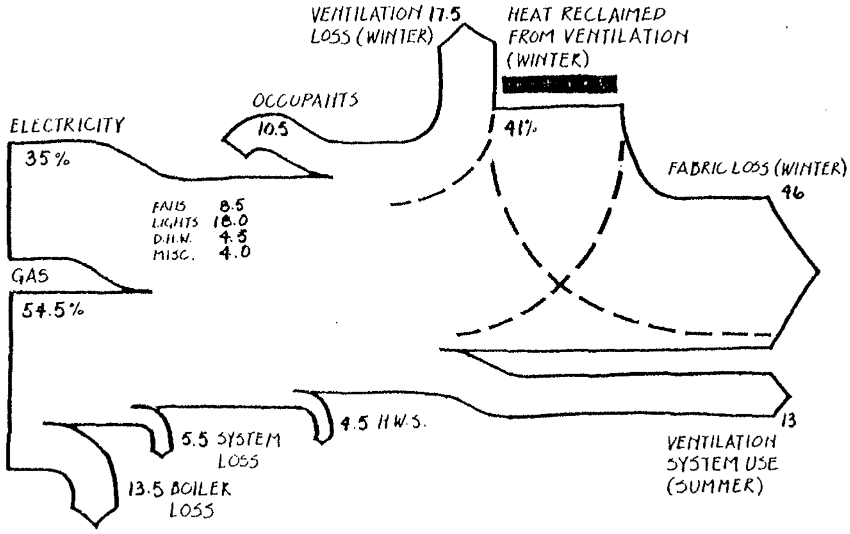
C — Capital investment
A — Annual return
N — Discount factor applicable to the life span

An investment is considered highly profitable if the IOP is greater than 1.5. This analysis excluded solar heating panels and the recovery of heat from air conditioning plant to provide domestic hot water.

The main conclusion of the design studio is that, as the combined fabric and ventilation heat losses are only a quarter of the electrical load, the need for good lighting control systems and correct optimisation of glazing areas is all important.



Typical cellular office



Total fuel use per annum Primary 15.2 × 10⁶ kwh **Delivered** 7.10 × 10⁶ kwh **(Primary: Delivered Ratio 2.1:1)**

Crown Offices, Cleveland	
Date of completion	project suspended
Capital cost	£33 000 000 (June 1979)
Occupancy 8 hour working days throughout the year plus computer loads	
No of persons	3076
Persons per m²	0.047
	m²
Usable area	65 876
	m³
Usable volume	231 897
Delivered annual energy consumption Estimated by 'Degree Day Speed' computer programme and CIBS procedures.	
	kwh
Total	7.13×10^6
Per m²	108
Per m³	30.7
Per person	2320
Primary annual energy per m²	230.3

Client
The Department of the Environment

Address
Middlesbrough

Architects, M & E Engineers, Quantity Surveyors, Structural Engineers, Monitoring Organisation
DGDS Design Office, Property Services Agency of the DOE

Crown Offices Cardiff

5 The new Crown Offices provide accommodation on 5 floors for 2500 people with underground parking for 500 cars. The building has a low, deep plan form which is penetrated by two glazed-over courts. Offices are 80% open-plan with cellular offices facing the courts.

Performance Evaluation
The designers' approach was to provide heavyweight construction, high standards of thermal insulation and limited areas of glazing. This was initially intuitive, based on traditional practice in the British climate, but was supported by research into the complex interaction of factors governing external fabric as a climate modulator.

Fabric
The heavy construction, with low surface resistance, attenuates and delays the effect of heat gains, so that peak loads on air conditioning are reduced considerably.

The intermittent use of the building and relatively low internal heat gains led to the adoption of what were, at the time of design, high insulation standards: 0.45 w/m²°C for walls and 0.65 w/m²°C for roof, though fabric losses are generally not critical for a building of this form.

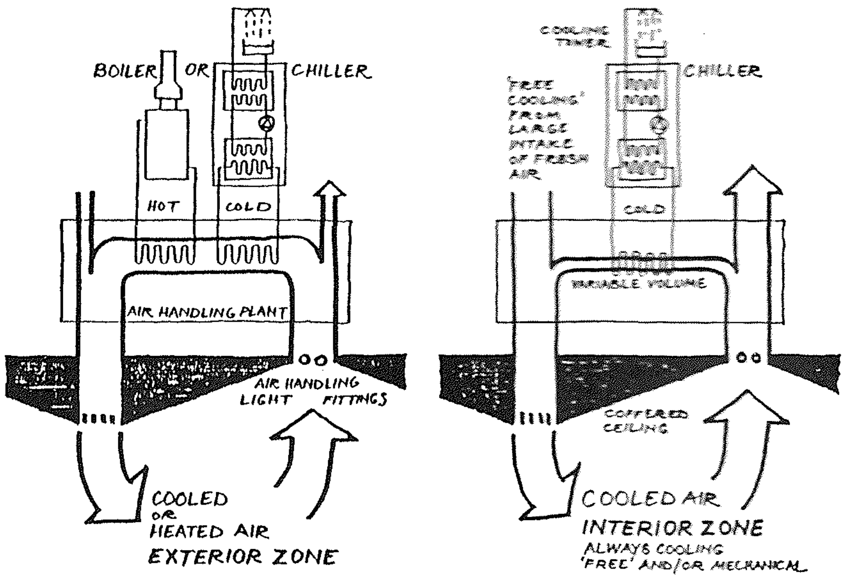
Overhanging upper floors shade the lower 3 floors.

Windows
Reducing glazed areas in sealed, deep-plan, buildings has much less effect on primary energy requirements than shallow ones. Internal gain is more critical than solar gain.

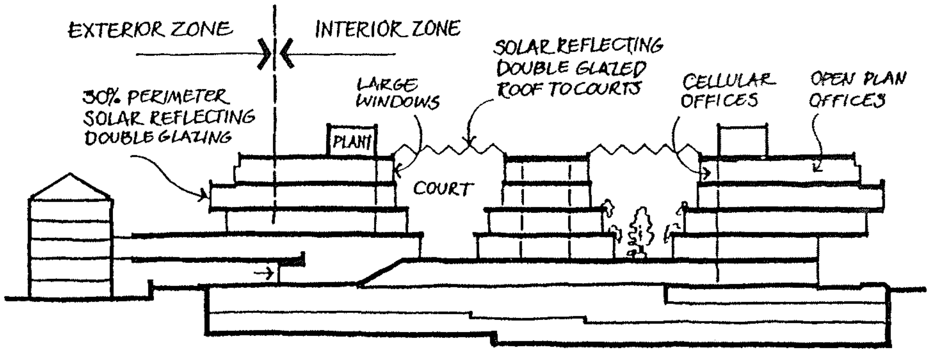
The deciding factors on the percentage and type of wall glazing provided were:
Reduction of traffic noise
Reduction of contrast between naturally lit and artificially lit areas of open-plan offices
Reduction of glare
Minimisation of discomfort from down-draughts and 'cold radiation' without under-cill heating, allowing mechanical services to be limited to the ceiling only.
Lastly, avoidance of solar gain
Windows are 30% of total wall area, and are sealed, double glazed and heat-reflecting.

Lighting
When design work began 1000 lux was considered desirable. The eventual design provides 570 lux by the use of high efficiency tubes with an energy input of 19.8 w/m². The emphasis is on quality rather than quantity of light. Ceilings are coffered and air-handling 'bat's wing' fittings with low-glare louvre fittings to illuminate the ceiling, reducing the influence of floor colour. (Flat ceilings reflecting the tint of the carpet had produced dull, tunnel-like effects in many open-plan offices.)

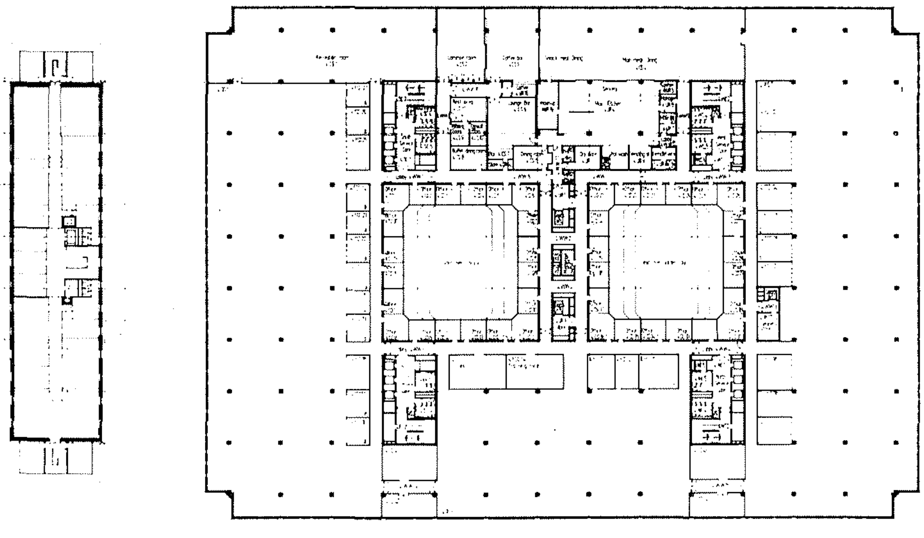
Mechanical Services
A comparison was made to determine the relative merits of air conditioning based on free cooling versus heat recovery, from the



Difference between plant for exterior and interior zones



Schematic section



Third floor plan

point of view of performance, capital cost and running cost.

This exercise showed that free cooling used slightly more energy at the building but less in terms of primary energy. Discounted cash flow analysis showed that it was both less expensive to operate and install.

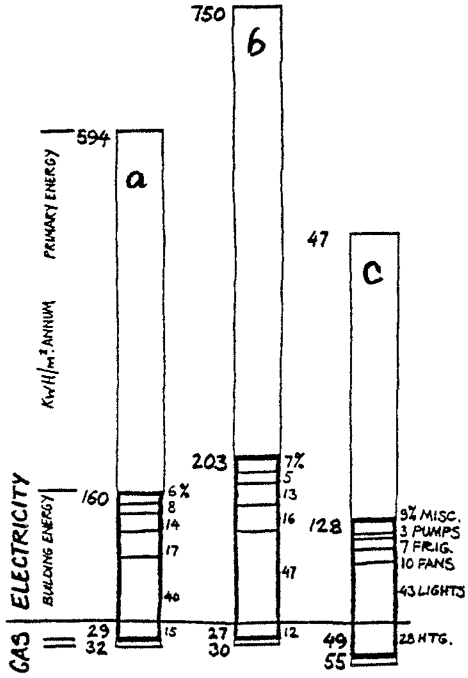
The main office areas are sub-divided into internal and external zones, and into four quadrants, each with its own variable volume air-conditioning system, with reheat.

A variable volume system is an exception to the rule that plant should be run at full load — it is inherently controllable and the fans draw considerably less power when on low load.

Natural gas is the main fuel used, with light fuel oil available in emergency.

Control System
Energy used is controlled and monitored continuously and automatically by the Central Supervisory System, which can be over-ridden to give early shut down when

Left. *Interior of open plan office mock-up showing 'batwing' ceiling*



Comparison of three air-conditioned schemes, showing delivered and primary energy uses (a) Heat recovery (b) Free cooling with high light levels (c) Free cooling with lower light levels using high efficiency tubes

conditions allow. Data logging facilities are also available to help with the adjustment of the building's performance. The building can operate at reduced standards, for instance, with 50% of the lighting, air-conditioning plant operating in the free-cooling mode and refrigeration plant off. Maintenance will be assisted by early warning of malfunction given by the control system.

Energy consumption has been calculated on the basis of flexitime working, with cleaning taking place out of office hours, when lighting levels are reduced.

Environmental standards are:

Temperature	20° to 22°C
Relative humidity	40 to 60%
Ventilation	0.005 to 0.01 m³/sec person.

Design Procedure

The design is the result of over three year's research and documentation using full 'Design Team Working' methods. Over three thousand working drawings were made. Reports were prepared quarterly for the project manager by the architects, containing studies on each issue contributed by the whole team. They provide a complete record of decisions made. A full size mock-up of the offices was made to check details of the design, allowing a response from the users before construction commenced.

Crown Offices, Cardiff

Date of completion	Autumn 1979
Capital cost	£15 576 765 (tender 1975)
Occupancy Flexitime from 8.00-18.00	
No of persons	2500
Persons per m²	0.064
	m²
Usable area	39 287
	m³
Usable volume	110 000
Delivered annual energy consumption has been calculated using B.E.E.P. computer simulation and then refined manually.	
	kwh
Total	6 961 700
Per m²	177
Per m³	63
Per person	2786
Primary annual energy per m²	527

Client
Directorate Civil Accommodation
Property Services Agency

Address
Cathays Park, Cardiff, Civic Centre Location

Architects
Alex Gordon & Partners

M & E Engineers
M. McCann & Partners

Quantity Surveyors
W.T. Hills & Co.

Structural Engineers
Veryard & Partners

Four Offices for the Yorkshire Electricity Board

6 The new Head Office of the Yorkshire Electricity Board at Scarcroft has been designed as an Integrated Environmental Design (IED), with total integration from the design stage of the building and its services. It is the fourth in a series of YEB/IED buildings and the most thermally efficient.

IED optimises on the following factors:
1 The building has the minimum possible surface area to reduce heat loss during the winter.
2 Good thermal values for the building fabric are adopted to minimise heat loss.
3 The windows are carefully designed to provide a reasonable view out while being thermally efficient.
4 Space is used efficiently to provide carefully designed open plan offices.
5 Heat output from lights, people and machinery is used to reduce supplementary heat required during the winter.
6 Space and services are designed to give maximum flexibility in building use.

The total building area is approximately 7,400 sq.m. and is designed for an office staff of about 450 and a printing department.

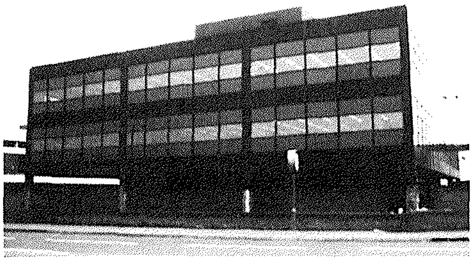
Following experience gained on the first three buildings the opportunity was taken to make some radical changes in the services.

Air Conditioning
In the air conditioning system, an induction system was incorporated to serve the perimeter of each floor, providing conditioned air through grilles in the cills. The inner zones are air conditioned through variable air volume boxes and conventional ceiling diffusers. The boxes are controlled by ceiling mounted thermostats. Care has been taken in the positioning of the diffusers to give good air distribution.

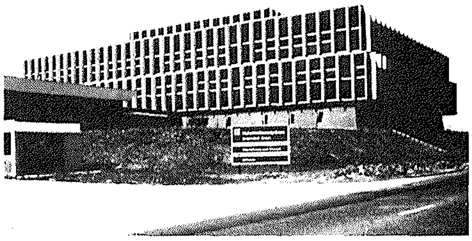
Lighting/Ceilings
It was felt that the flat ceilings of the other buildings, together with the same overall illuminance, tended to be monotonous. It was decided therefore to have a partly shaped ceiling and also grade the illuminance across the space; the illuminance is designed for 500 lux at the perimeter windows (clear glazing), 700 lux midway and 850 lux at the inner core. Bare tubes are used within a coffered ceiling in some areas and this gives a high coefficient of utilisation — the energy level in these areas is down to 16 watts per square metre. Thus, a substantial reduction in energy, and an increase in amenity is made.

Below right. *Gelderd Road, Leeds. The first building. Interior showing flat ceiling*

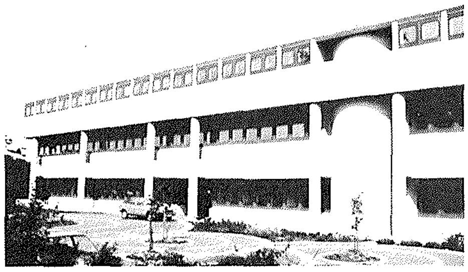
Below. *Scarcroft Leeds. The fourth building. Interior showing coffered ceiling with less tunnel-like effect.*



Gelderd Road, Leeds, exterior



Parkway, Sheffield. The third building. Parry Lane, the second building is similar

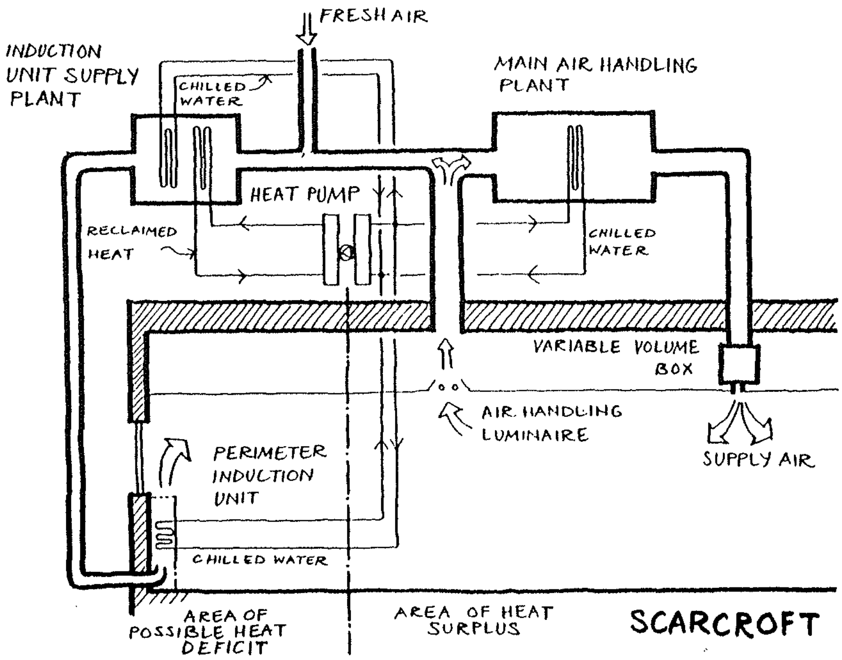


Scarcroft exterior

Comparison showing progressive improvement in energy use and environmental conditions

	Year occupied	Usable area m²	Occupants	Total kwh 1978 delivered	kwh/m² pa delivered	kwh/m²/pa primary	kwh/person pa	Window area	Type of system	Lighting
Gelderd Road, Leeds	1971	2630	241	0.75×10^6	285	1089	3109	30	Fixed volume heat recovery	1100 lux 47 w/m²
Parry Lane, Bradford	1974	2888	241	0.68×10^6	235	898	2819	30	Variable volume with self-controlling diffusers	1000 lux 30 w/m² Increased efficiency with changed ceiling modules
Parkwaly Sheffield	1975	5958	425	1.15×10^6	192	733	2926	21	Variable volume with perimeter radiators	1000 lux 30 w/m²
Scarcroft, Leeds	1977	6941	450	1.21×10^6	185	707	2688	30	Perimeter induction, fixed temperature variable volume for interior	500 – 700 – 800 from exterior to interior bare tubes in coffered ceilings 16-21 w/m²

Scarcroft interior



Title
Scarcroft Offices, Leeds

Client
Yorkshire Electricity Board

Address
Scarcroft, Leeds

Architects
Abbey and Hanson Rowe and Partners

Mechanical Engineers
How Group (Northern)

Electrical Engineers
YEB Leeds Area

Quantity Surveyors
Wakeman Guthrie and Rushbrooke

Structural Engineers
White Young and Partners

Other professionals involved in the 3 previous schemes:

Gelderd Road Offices, Leeds

Mechanical Engineers
Andrews Weatherfoil

Quantity Surveyors
Wakeman Trower and Partners

Parry Lane Office, Bradford

Mechanical Engineers
Thorn Benham

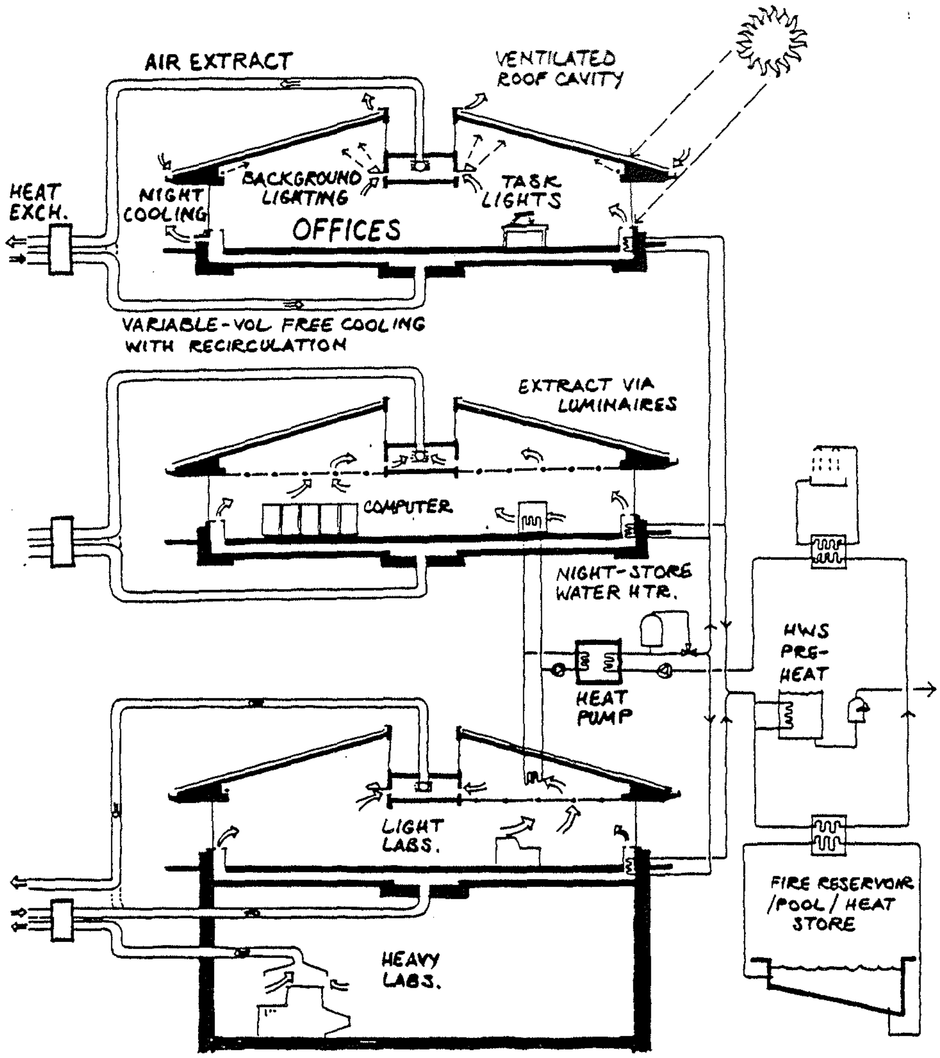
Parkway Office, Sheffield

Architects
Morrison and Partners

Quantity Surveyors
Gleeds

Structural Engineers
Ove Arup and Partners

CEGB
Bedminster Down



7 This low rise building on an open site has an irregular silhouette with a stepped section. It contains heavy industrial laboratories on the lower level, above which are light laboratories and offices.

These work areas are relatively shallow and naturally lit. They are grouped around landscaped courtyards with service spaces between them. The open ridge of the pitched roofs lets natural light into the centre of the work areas and the projecting eaves shade the perimeter.

The design of the environmental services is based on the following principles:-

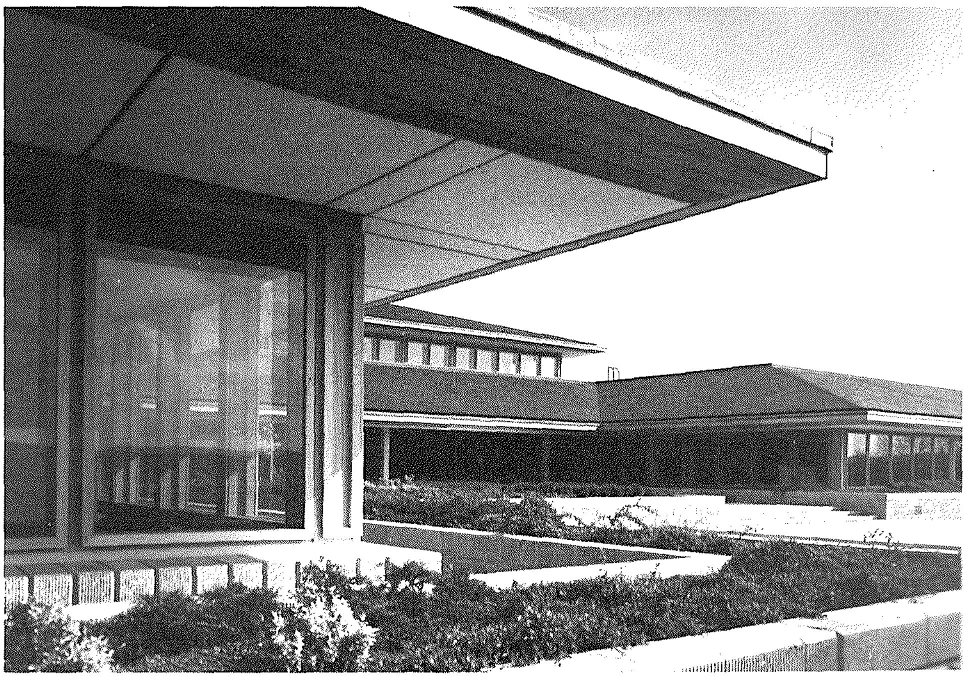
1 The amount of purchased energy should be minimised.
2 Maximum use should be made of natural energy sources.
3 Maximum use should be made of internal energy sources.
4 The control of the work station environment should be on an individual or small group basis.
5 The broad principles of IED should be followed.

Operation and maintenance of the systems should be simple and economical in terms of staff time and skill.

Natural daylight and temperature cycles are used to reduce purchased energy requirements.

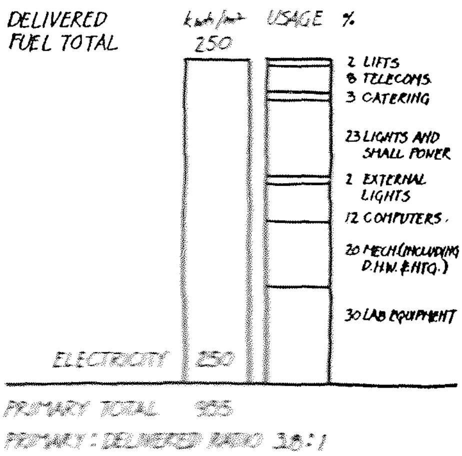
Outline investigation into the use of solar and wind power indicated that within the particular climatic region neither would be cost effective compared with conventional fuels.

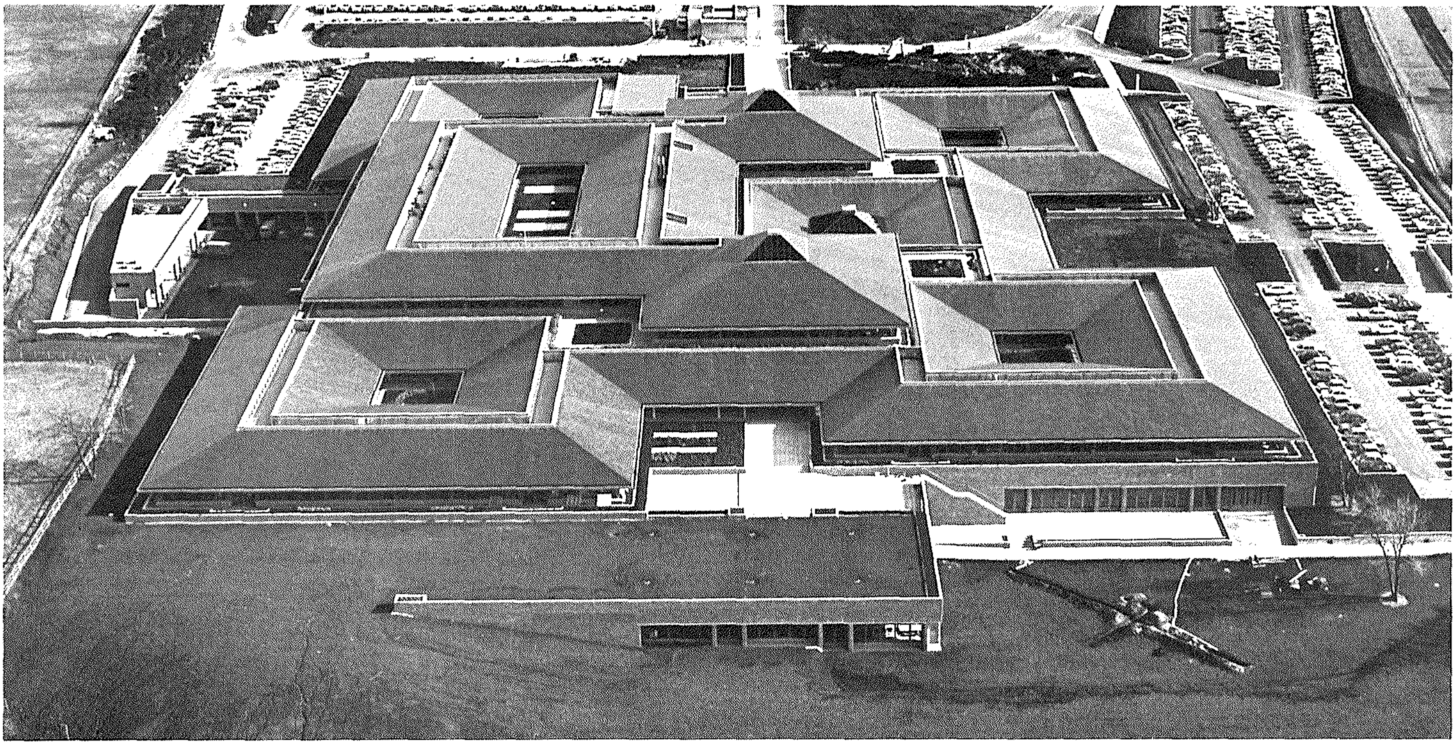
The balance between daylighting, views to the outside, sky brilliance control, solar gain and winter heat loss for various glazing/shading systems, were investigated by model and computer testing. Optimisation studies were carried out against diurnal temperature cycles for the period May to September and for winter conditions. The design provides 1.8m high perimeter double glazing, shaded by blinds between the panes, together with 750mm high double glazing adjacent to the minor bay shaded by fixed internal louvres. It satisfies the required design conditions, with an overall insulation standard for roofs, non-glazed walls etc. of 0.6 w/m²°C.

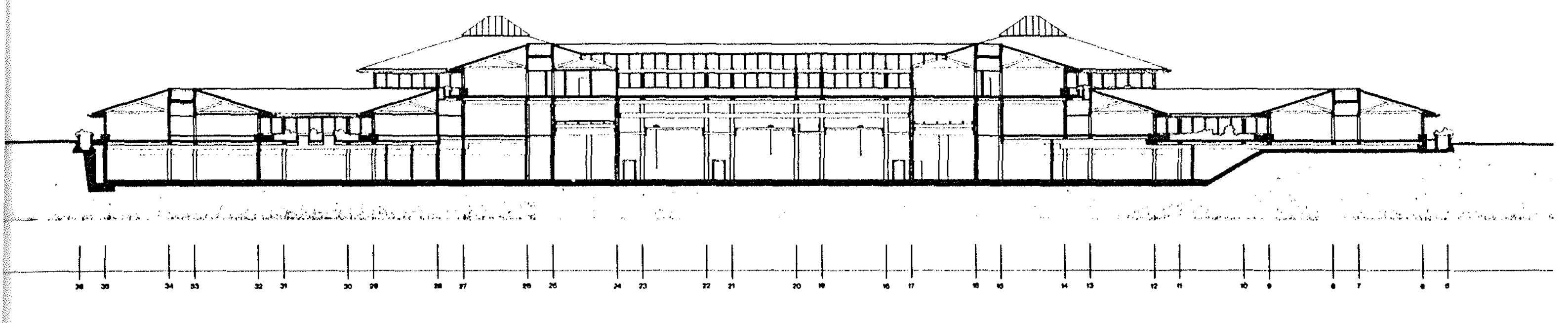


Laboratory equipment and computer installations account for almost half of the total annual energy input as well as using a significant proportion of the lighting and mechanical cooling load. Because of this heavy equipment load almost all the purchased energy demand is provided by electricity.

However, such a fairly steady heat input allows the building to operate efficiently in winter. The heat is removed from those areas by chilled water provided from central heat pumps, heat from which becomes available for redistribution. The redistributed heat warms the air for office areas through perimeter variable air volume units. On occasions when adequate heat is not avail-



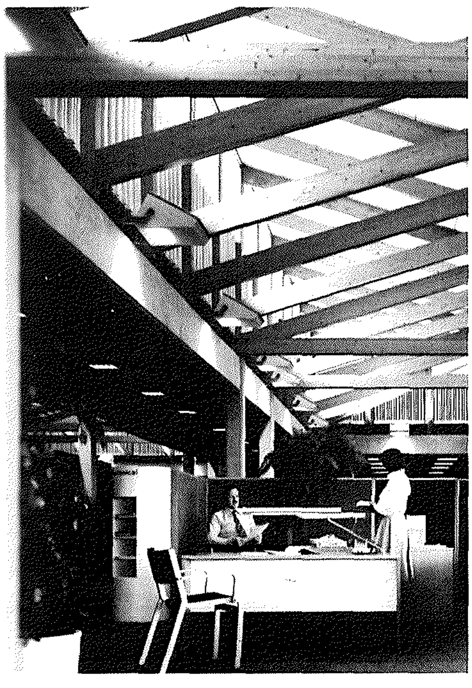




Section showing offices, light laboratories and computer building at right all on upper levels. Heavy laboratories are on lower level

able, hot water is drawn from the night store water heater.

Usually there is an excess of heat which is used to preheat the domestic hot water supplies and to heat the water in the swimming pool, which can be kept at a comfortable temperature during the day. At night, in winter, when the majority of the building systems are switched off, excess heat is stored in the pool, raising its temperature some



7-10°C overnight. This heat is drawn back into the systems in the morning to heat the building.

Standby generators are connected to the heating circuits to recover heat from the engine cooling water, and when run for a load test are connected electrically to the night store water heaters. In emergencies, the generators can thus be used for heating the building from their cooling water and electricity production.

In winter, heating requirements are greatest in office areas and use is made of heat-producing artificial lighting.

In summer outside air temperatures at night are low enough to pre-cool the building. Cool air is passed through hollow concrete floors which act as a thermal storage system to give the required phase shift for heat gains, thus eliminating the need for mechanical cooling in much of the building. Air is passed through these hollow concrete floor planks at night to cool them to a temperature below the desired room temperature of 22°C to 23°C. With the floor slab cooled to 16°C, for example, the daytime air passed through the floor slab will be cooled to about 18°C. This air will then absorb the internally produced heat from lights, people etc. maintaining a nominally constant room temperature.

Occasionally, towards the end of the afternoons of the third and subsequent days of a heatwave, the temperature is likely to rise above the control point. However, investigations indicate that the occasions where several successive days reach or exceed the design conditions will be rare.

CEGB Bedminster Down	
Date of completion	September 1978
Capital cost	£14 000 000
Occupancy Normal office occupancy with 130 kw of computer load and 100-700 kw variable load from laboratories	
No of persons	1200
Persons per m²	0.05
	m²
Usable area	24 000
	m³
Usable volume	70 000
Delivered annual energy consumption Estimated using Ove Arup Partnership programmes for cooling, heating and daylighting. CEGB programme for performance of hollow concrete floors plus manual optimisation.	
	kwh
Total	6.0×10^6
Per m²	250
Per m³	85.7
Per person	5000
Primary annual energy per m²	955

Client
Central Electricity Generating Board

Address
Bedminster Down, Bristol

Architects, M & E Engineers, Quantity Surveyors, Structural Engineers
Arup Associates

Monitoring Organisation
Arup Associates and CEGB

CEGB Offices Harrogate

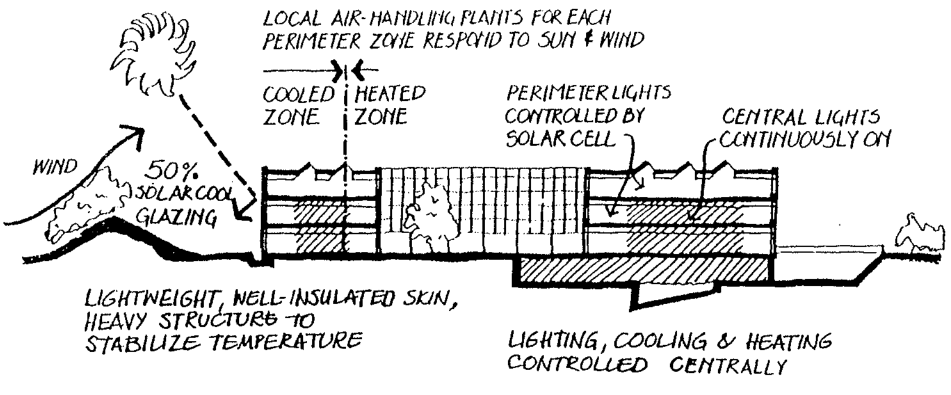
8 The client's brief emphasised the need to exploit the natural amenities of the hilltop site, and, at the same time, provide a sensitively engineered, low energy design.

The design was begun at a time when the electricity industry was promoting the IED deep plan office concept, in which thermal optimisation is achieved by minimising the ratio of external surface to floor area and reducing the window areas to enable the building to become self heating, under lighting alone. However, this may only reduce thermal load at the expense of primary energy use.

Whilst the designers felt it right to adopt a fully sealed external envelope (due to the exposed nature of the site) and the clients brief called for a deep plan solution (necessitating the installation of an air conditioning system) it seemed important that a balanced design should take account of natural energy when possible and also optimise the energy input of all other fuels.

The use of low grade fuels for heating, natural light to save artificial lighting, the use of IED reclaim principles to conserve high grade electrical energy and the provision of flexible operation of plant, all played a part in achieving the desired balance. A number of key design decisions were as follows:

1 Heat Reclaim
Optimising the reuse of heat generated by lighting, equipment and staff (employing the ceiling void as a negative plenum) the recycling of energy is achieved by heat transfer from an airborne source to a waterborne distribution medium, using the fridge plant as a heat pump.



This upgraded hot water is directed to the air handling units and domestic calorifiers to satisfy immediate demand. Surplus heat is then stored in the swimming pool, in readiness for reclaim, to satisfy any future need.

An improved reclaim formula was achieved by the introduction of chilled water heat recovery coils into air exhaust paths within each air handling unit. Exhaust air recovery by the use of thermal wheels was studied in some depth and eventually rejected on the grounds of viability and aesthetics. The one exception to this general statement was in the air conditioning plant for the pool. In this case, a thermal wheel was placed between supply and exhaust ducts.

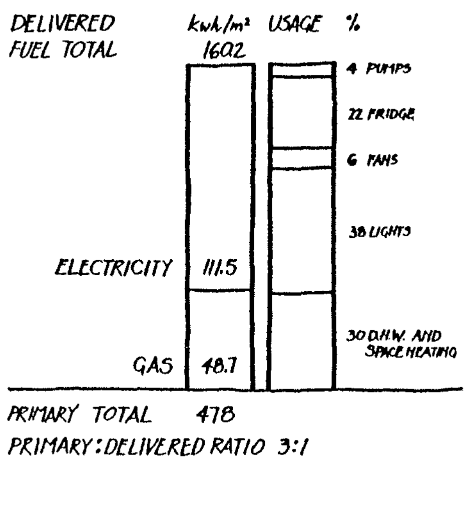
It was estimated that the heat reclaimed in this way would provide an energy balance point of 4°C and serve the buildings needs for 8-9 months of the year, leaving a 3 month deficit. A gas fired supplementary heating system offsets the imbalance.

2 Low Velocity Air Distribution
A low velocity air distribution system to 20 locally situated air handling plants was adopted in preference to a high velocity system with a centrally located plant. This provided the advantages of:

(a) Minimising power by limiting air travel distances.
(b) Plant can be switched off for partial occupancy.
(c) Omission of mixing losses through the use of single zone units.
(d) The provision of 'free cooling' by fresh air whenever external air temperatures fall below internal temperature.

3 Thermal Mass
The concrete structure provides considerable thermal mass, which is placed within a highly insulated lightweight external envelope to act as a stabilising influence over excessive internal temperature variation.

4 Energy Management Services
An automatic sensing and control system is used to make use of the full potential for energy optimisation. It permits up to 1000 readings of temperature and humidity



and brings in or cuts out plant as required.

5 External Envelope
Energy studies relating a variety of window areas and lighting levels, led to 50% windows with Pilkington 'Suncool' bronze 33/25 double glazed units, set in a reversed position. Spandrel areas were designed to a U value of 0.6, giving an overall cladding performance of approximately 1.0.

The plan form results in an external wall to floor area ratio of 1:3 whilst window to floor ratio is approximately 1:7. Compared with a 12m wide slab block of the same floor area the figures would become 1:1½ and 1:3 respectively. Such a plan form would have a much greater energy demand than the relatively deep plan at Harrogate.

The increased U value of reflective double glazed windows reduces heat losses and thus boiler load. They have a shading coefficient of 0.33 to reduce solar gain cooling load. Also, they permit a 2½% daylight factor 3½m from external windows, thus allowing perimeter lighting to be solar switched and cooling load reduced.

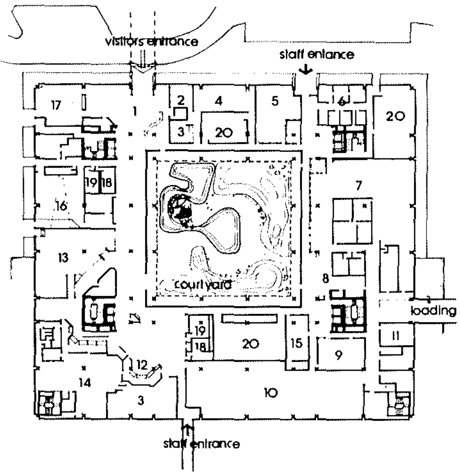
6 Rooflights
Energy studies led to the use of approximately fifty 1.8m sq. north facing rooflights with double clear glass at a 60° incline.

A daylight factor of 2% is provided over a large part of the floor for about 1400 hours per annum and solar switching has been incorporated into light units adjacent to the rooflights.

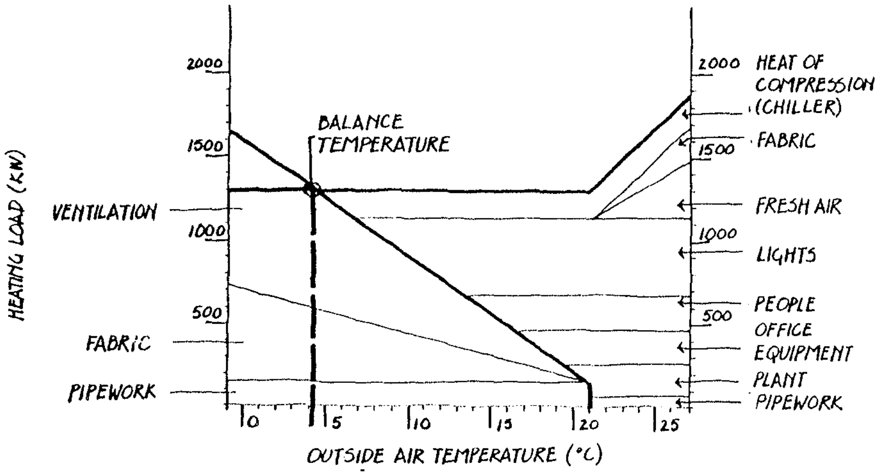
7 Lighting
Artificial lighting is designed for 750 lux in deep plan areas with 500 lux in the cellular zones in accordance with IES recommendations.

The vaulted ceiling was designed around the minimum luminaire layout necessary to provide the 750 lux and comprises 4 no twin 85 watt 1.8m warm white tubes in each 5.4m bay area, giving 23.3 w/m² lighting load, and a total installed lighting load of only 450 kw.

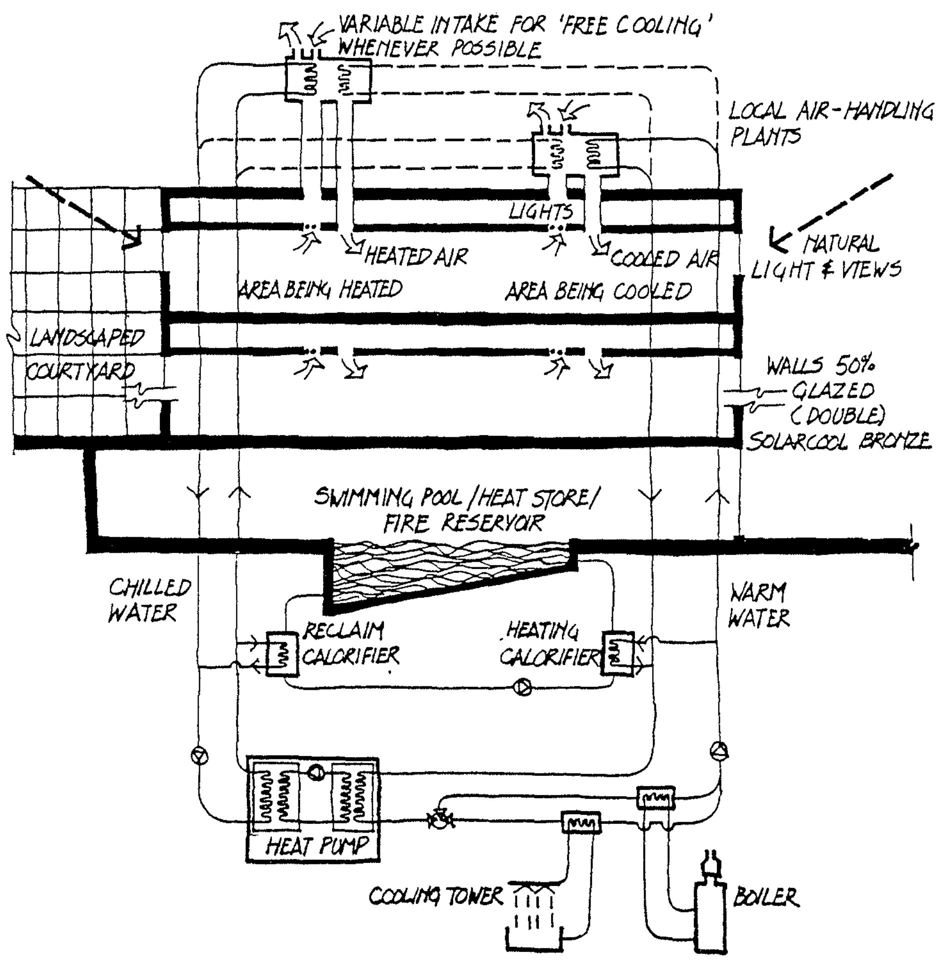
Decentralised air conditioning plants and local switching of electrical services permit any zones which are not in use to be switched off, without detriment to the rest of the building.



Ground floor plan



Heat balance diagram of instantaneous heat loads



Systems operation diagram showing alternative heating and cooling of different zones

The gas fired heating plant has been located at the exposed perimeter of the basement, and a masonry flue has been provided. Replacement or conversion to coal is possible without major re-organisation. Space has also been planned for possible introduction of electric boilers and hot water storage vessels.

CEGB Offices Harrogate	
Date of completion	November 1977
Occupancy 8.30-17.00 weekdays	
No of persons	860
Persons per m²	0.046
	m²
Usable area	18 600
	m³
Usable volume	61 000
Delivered annual energy consumption Estimated by CIBS for fenestration and roof lights, fuel selection and plant analysis. BEEP computer programme	
	kwh
Total	2.98×10^6
Per m²	160.2
Per m³	48.9
Per person	3465
Primary annual energy per m²	426

Client
Central Electricity Generating Board

Address
Beckwith Knowle, Otley Road, Harrogate, Yorks

Architects
Gillinson Barnett & Partners

M & E Engineers
Steensen Varming Mulcahy & Partners

Quantity Surveyor (Buildings)
Gleeds

Quantity Surveyor (Building Services)
Steensen Varming Mulcahy & Partners

Monitoring Organisation
All initial commissioning and monitoring by Steensen Varming Mulcahy & Partners. Current monitoring by CEGB

Hereford and Worcester County Hall

9 The designers aim was to provide an internal environment comparable with a full air-conditioned building, with substantial window areas at a low running cost and having maximum immunity to the effect of power cuts. The involvement of services consultants at the outset allowed a suitable design to develop, without the problems which might have arisen if energy efficiency had been considered later.

The following measures were taken in order to effect savings.

1 High thermal mass, particularly in the roof, to delay solar gains into the building with U value of 0.57 w/m²°C.

2 Double glazing of two-thirds of the windows and the use of overhangs and projecting horizontal louvres to reduce summer heat gains, but allow some solar heating during the winter.

3 Lower light level (600 lux) than was conventional at the time, and use of daylight by means of large windows and north facing roof lights.

4 Air handling light fittings.

5 Photoelectric, time and local controls for lighting.

6 Matching the operational mode of heating, cooling and ventilation systems to external conditions.

7 Zoning to allow parts of the building to be used after normal hours without the need to operate services for the unoccupied areas.

8 A building form, which does not suffer extreme heat gains or losses, is based on two and three storey high 'pavilions', arranged around landscaped courtyards. A typical 'pavilion' is sized to accommodate 40 to 50 work spaces, resulting in medium depth building where nobody is located more than 12 paces from a window.

Internal summer and winter design temperatures are 21°C and 23°C respectively.

Heating, ventilation and cooling are separated as far as practicable. Ventilation systems are low velocity, to reduce distribution losses. The systems consist of:

(a) Mechanical ventilation system for internal areas with facility for recirculation, heat extraction from lights, heating, cooling and humidity control.

(b) Supplementary perimeter radiator/convector system for winter.

(c) Supplementary perimeter recirculatory air system for summer.

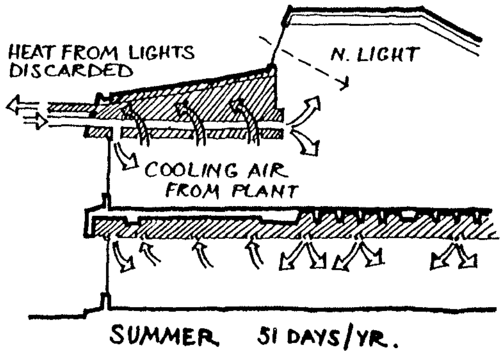
(d) Openable windows for use outside the peak heating/cooling seasons and in an emergency.

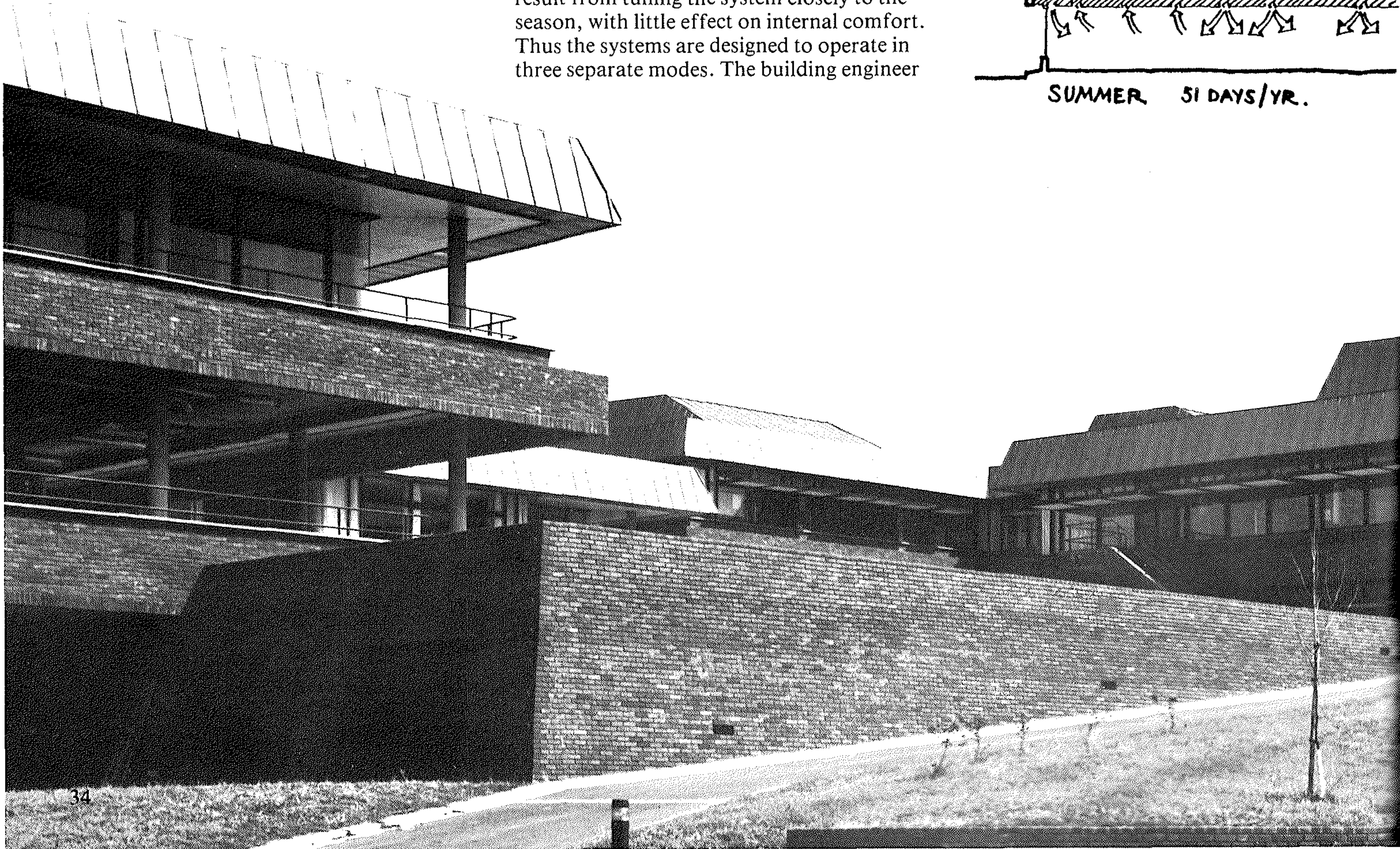
Many air conditioning systems, designed on peak summer and winter conditions, fail to operate economically in mid-season when very little heating or cooling is actually needed as internal heat gains provide the heating and fresh air cooling. Economies can result from tuning the system closely to the season, with little effect on internal comfort. Thus the systems are designed to operate in three separate modes. The building engineer

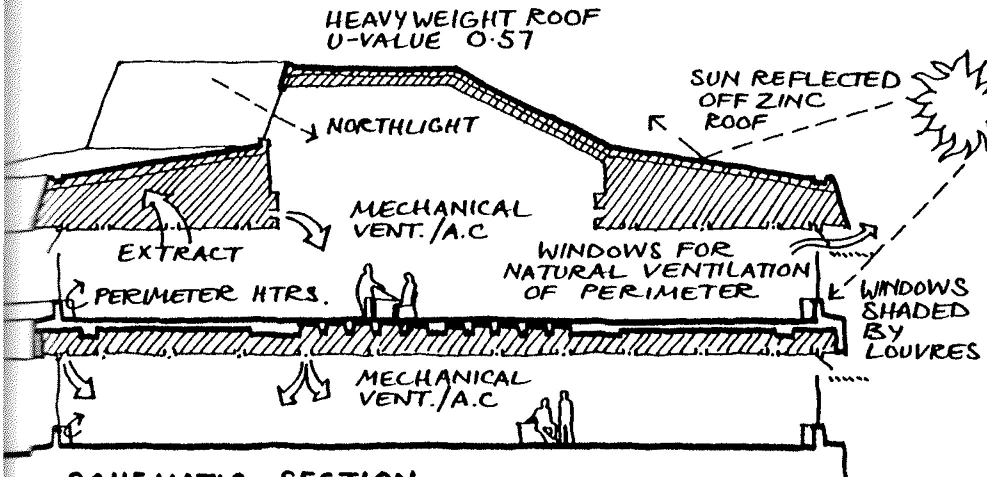
chooses the operating mode and further economies can be made if operation in 'Summer' and 'Winter' modes can be reduced without upsetting the occupants.

Gas was chosen on grounds of cost, maintenance and cleanliness, but the boilers are capable of burning oil. Standby oil storage is shared by the boilers and standby electric generators. The central cooling and heating plant allows more drastic alterations to the fuel used in the main plant to be made without major repercussions outside the boiler house.

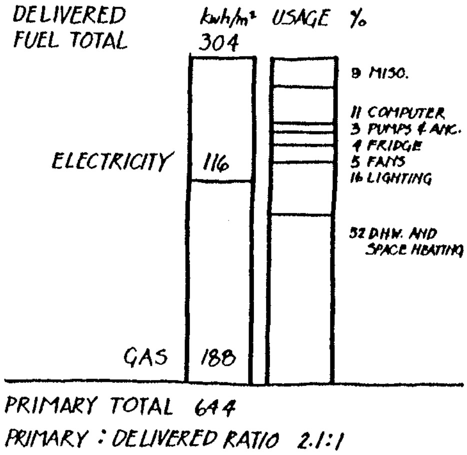
The use of daylight, opening windows and the mechanical systems selected allow the







SCHEMATIC SECTION



building to operate though at reduced standards, if fuel becomes short, or within limits, if power is cut off.

A supervisory data centre is installed to enable plants to be started and stopped from a central point. This also monitors plant operation and energy consumption, facilitating the building engineer's tasks of maintaining peak performance and energy efficiency.

A separate console provides photoelectric and time control of lighting; these controls can be over-ridden locally.

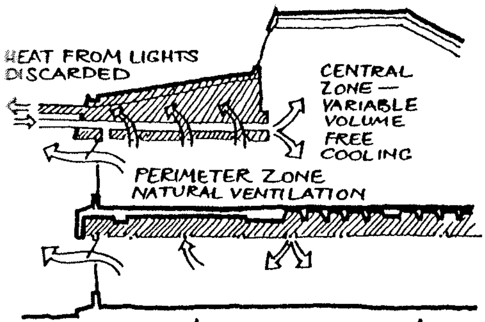
The client's engineers have monitored the use and energy consumption of this building and have made some modifications to the controls. These modifications have saved about 10% of the energy consumption.

The indefinite delay of projected future phases of the building has led to revisions to the circulation and use of some areas, making the services system less economic. The boiler house is also remote from this first phase of building, leading to additional distribution losses.

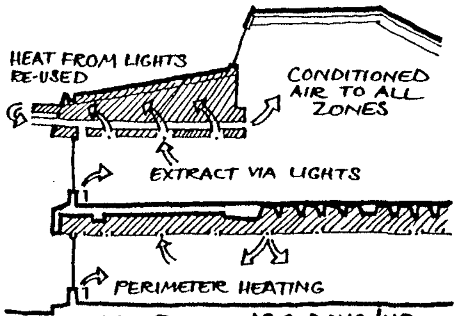
Working of the computer after normal office hours meant that some areas of the building were unnecessarily serviced, but modifications have now been made and energy consumption has dropped.

The energy consumption figures for the first year would appear to be approximately half that of a fully air conditioned and artificially lit building which might well have been designed.

It appears that people are less critical of the heating and ventilation in this building than with a completely controlled environment. However, they are not yet energy conservation minded; perhaps there is insufficient education and incentive. For instance, the photoelectric controls are often over-ridden, using more artificial light than necessary and windows are opened at times when this increases running costs and, in fact, reduces comfort.



SPRING/AUTUMN 195 DAYS/YR.



WINTER 120 DAYS/YR.

Hereford and Worcester County Hall	
Date of completion	November 1977
Capital cost	£4 940 000 (1974 prices)
Occupancy Flexitime from 7.30 to 16.30. Computer runs from 8.30 to 19.30, except during March/April when computer runs from 7.30 to 22.30 (computer heat 60 kw/h)	
No of persons	710
Persons per m²	0.091
	m²
Usable area	18 059
	m³
Usable volume	55 784
Delivered annual energy consumption Measured	
	kwh
Total	5.5 × 10⁶
Per m²	304.6
Per m³	98.6
Per person	7887
Primary annual energy per m²	601

Client
Hereford and Worcester County Council

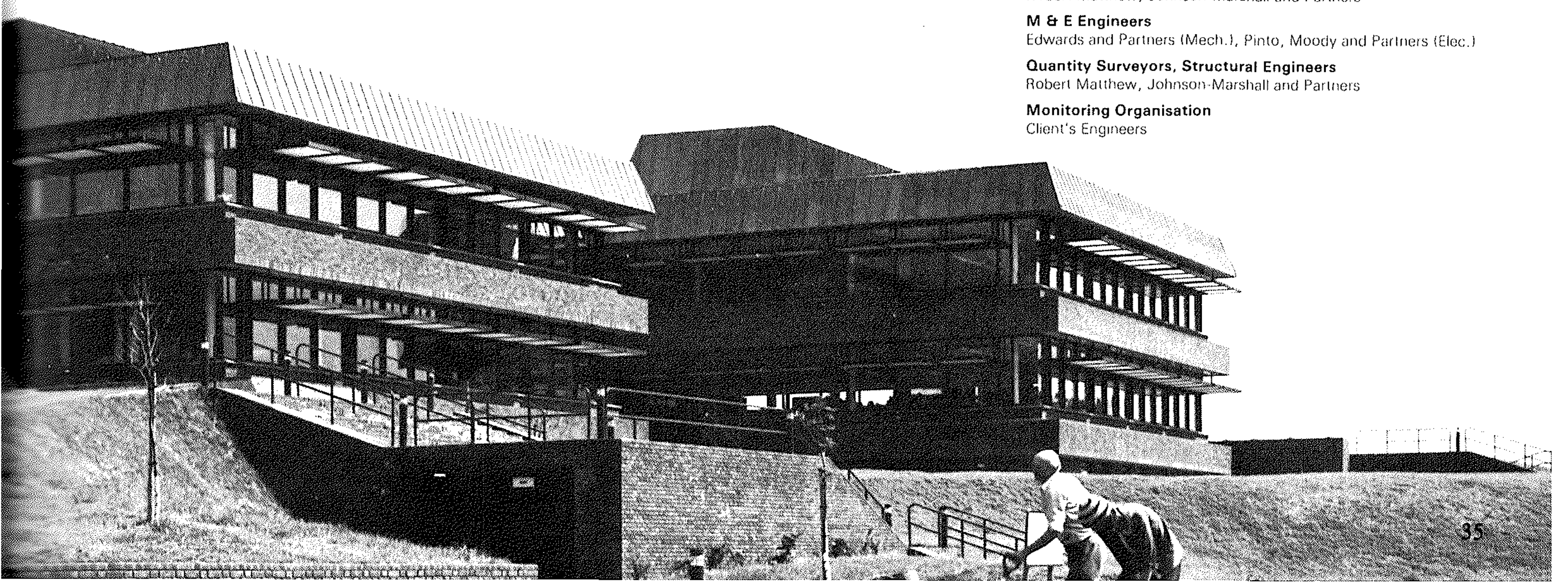
Address
Nunnery Wood, Spetchley Road, Worcester

Architects
Robert Matthew, Johnson-Marshall and Partners

M & E Engineers
Edwards and Partners (Mech.), Pinto, Moody and Partners (Elec.)

Quantity Surveyors, Structural Engineers
Robert Matthew, Johnson-Marshall and Partners

Monitoring Organisation
Client's Engineers



Ashford Godinton Primary School

10 This new school for 210 infants and juniors is the first result of research by the Kent County Council, in consultation with the DES and the energy supply industries, to obtain improved conditions with reduced energy use.

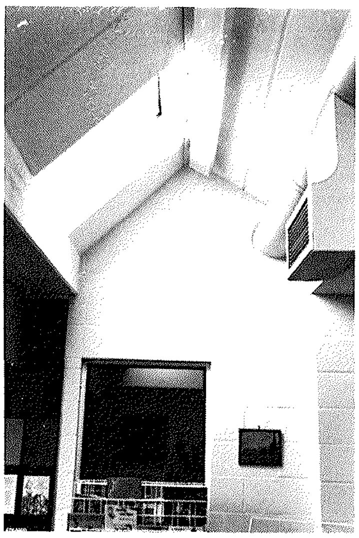
This has been achieved by means of a mechanically controlled environment, within a sealed building which uses heavy-weight construction to retain heat in winter and even out solar gain fluctuation in summer. Calculated U values are:

Floor	0.27 w/m²°C
Cavity Wall	0.55 w/m²°C
Single glazing (windows)	5.6 w/m²°C
Roof	0.57 w/m²°C
Double glazing (roof lights)	3.41 w/m²°C

The low window to wall ratio of 1:4 reduces heat loss through glazing, without destroying visual contact with the outside world.

The minimum requirement of 2% daylight factor is achieved from double-glazed roof lights, which face north to avoid solar gain. These admit about three times the light, area-for-area, than windows.

The average lighting level is 220 lux. A photo-sensitive over-ride makes artificial lighting available only when natural light falls below 100 lux. The teacher may then switch-on in any area, but an automatic time-delay switch will switch off again after a pre-determined period. The teacher must then switch on again, if electric lighting is still desired. Lights in the kitchen and staff areas are switched conventionally.



Heating and Ventilation

The whole building is mechanically ventilated throughout the year. In winter air is recirculated, warmed air being mixed with a proportion of outside air. In summer only fresh outside air is used.

Input air is filtered then distributed at high level and extracted at low level. Air change rate is variable between ½ and 2 ac/h in winter and about 10 ac/h in summer with 25 ac/h in the kitchen. Terminal velocity from grilles is a maximum of 50 ft/min.

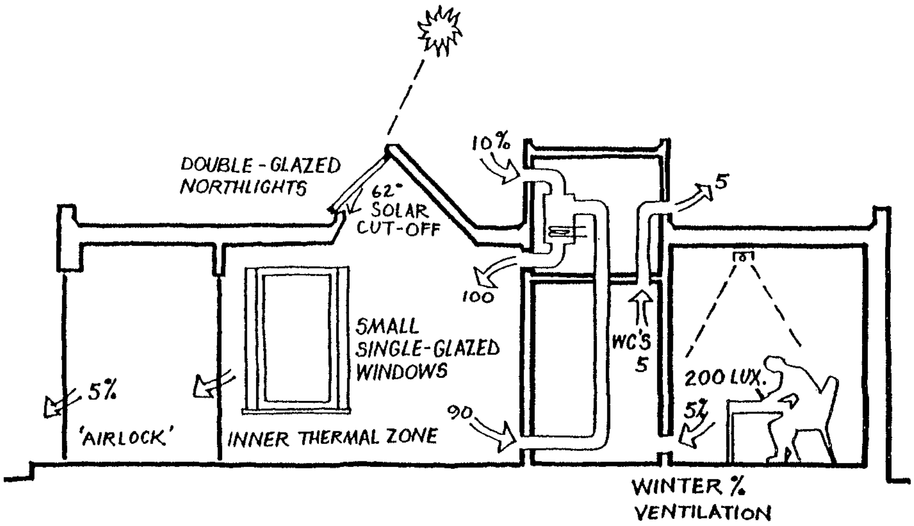
Air is extracted separately from lavatories and always discharged to the outside.
The rate of fresh air change in the winter can be increased to eliminate food odours by a special 'meal over-ride' switch, which operates for a pre-determined time and then returns the system to normal.

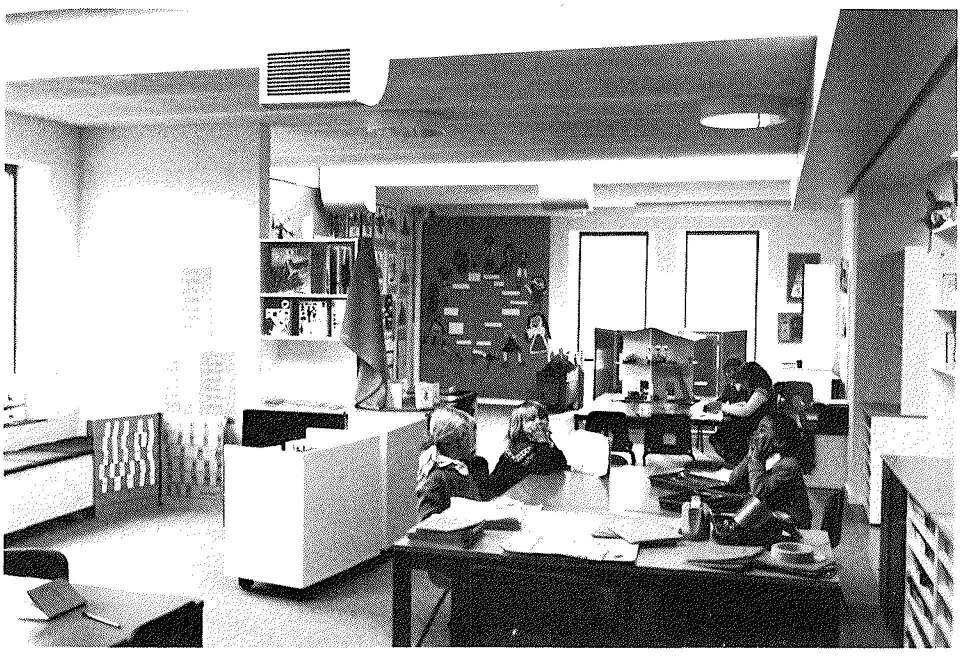
If in summer the outside air temperature rises above the desired internal temperature a 'summer over-ride' switch can be used to reduce the amount of fresh air drawn in. The structure of the building delays solar heat penetration until after closing time.

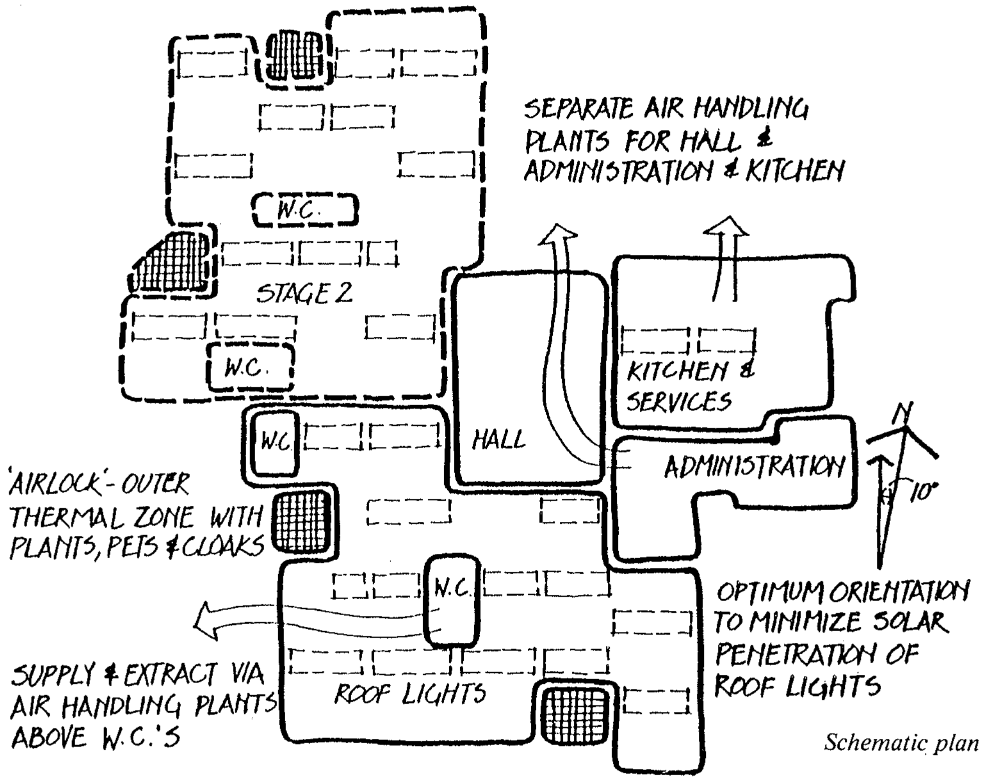
During the heating season temperature is controlled by locked, pre-set room thermostats. Internal toilets have time controlled extract fans. Toilets having access from the lobbies have extract fans which run for a pre-determined time after the light is switched on.

Windows do not open and external doors are few, always protected by lobbies and covered paved areas.

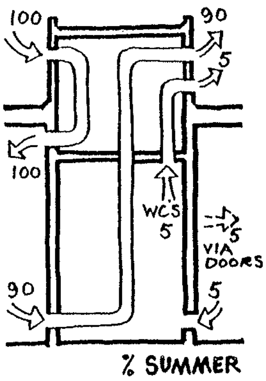
Experience in the first year of operation has shown that such a system requires careful adjustment of air-flows in the early stages of occupation in order to satisfy the occupants. Thereafter, the wholly controlled environment was acceptable. It has also shown unexpected benefits in that the filtered ventilation system has reduced the effects of hay fever.

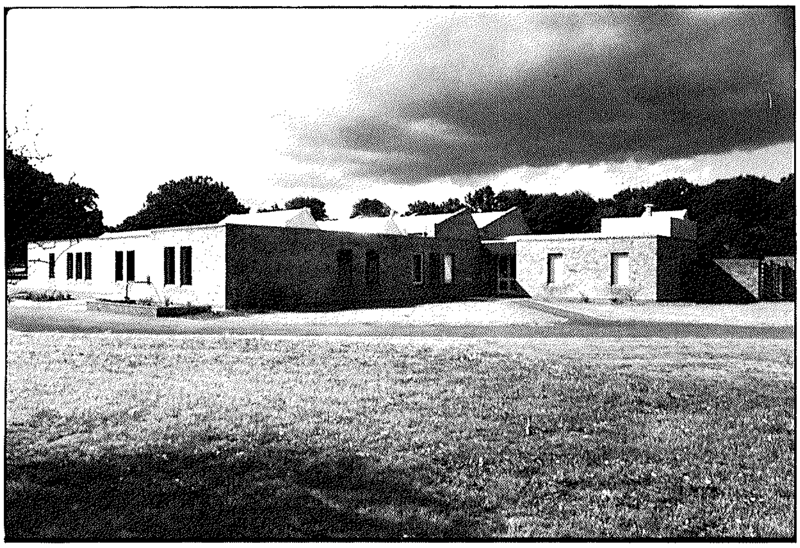


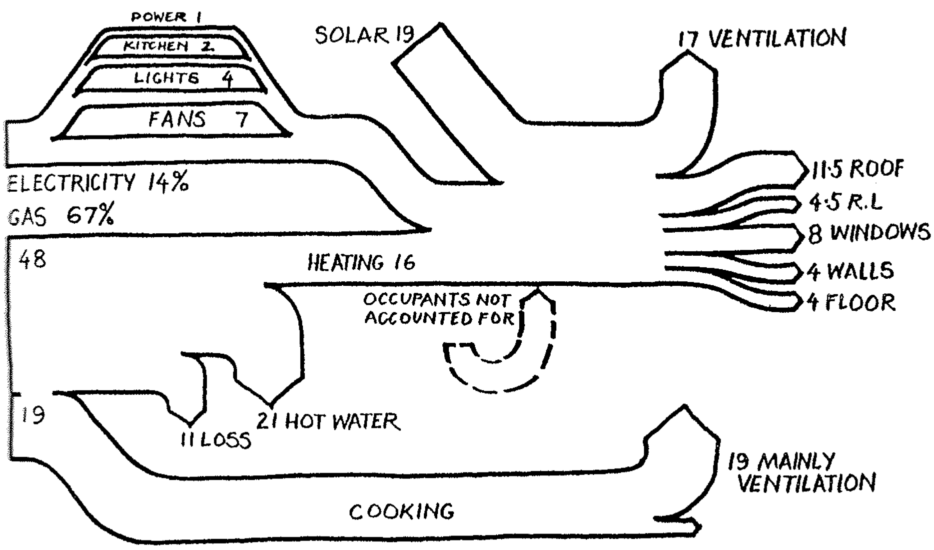




Schematic plan







Total fuel use per annum Primary 142.0 × 10^3 kwh **Delivered** 91.0 × 10^3 kwh **(Primary: Delivered Ratio 1.6:1)**

Ashford Godinton Primary School	
Date of completion	August 1978
Capital cost	£257 000
Occupancy 8.45-16.00 with occasional evening use Monday to Friday, in school terms	
No of persons	220 (presently 40)
Persons per m²	3.85 (21.16)
	m²
Usable area	847
	m³
Usable volume	2005
Delivered annual energy consumption Has been predicted only, using BEEP computer simulation	
	kwh
Total	91 392
Per m²	108
Per m³	45.6
Per person	415.4
Primary annual energy per m²	168

Client
Kent Councy Council Education Committee

Address
Lockholt Close, Ashford, Kent

Architects, M & E Engineers, Quantity Surveyors
County Architect, Springfield, Maidstone, Kent

Structural Engineer
Howard Humphreys & Sons

Monitoring Organisations
County Architect

Frogmore Secondary School, Hampshire

11 This project consists of two single-storey blocks added to an existing school. Its design relates closely to the existing SCOLA MK III buildings, with flat roofs and highly glazed walls. Despite this extensive use of glass, energy conservation was an important objective.

The buildings are constructed to normal Department of Education and Science cost allowances and environmental standards correspond to current school designs. Internal Design Temperatures are 18°C environmental in teaching areas (winter) and 27°C environmental in teaching areas (summer). Ventilation: 30 m³/hr/person minimum fresh air provision. Lighting: 400 lux in teaching areas.

The design relies on maintaining a delicate balance between building fabric and services, with glass making a positive contribution towards environmental control. Mechanical systems have a supplementary role. This has led to the following measures:

Although energy conservation did not influence the siting of the extensions, the buildings were designed with minimal surface area.

All elements of the building have insulation values well in excess of current standards, for instance, the roof has a U value of 0.29 w/m²°C.

The fully glazed north and south elevations have an inner insulating skin of lightweight partitions for much of their length. These can be moved to provide a variable window area equal to 20, 30 or 40 per cent of the wall area, and thus respond to different climatic conditions. Initially these will be moved seasonally by caretaking staff, but could be adapted so that teaching staff could make alterations throughout the year.

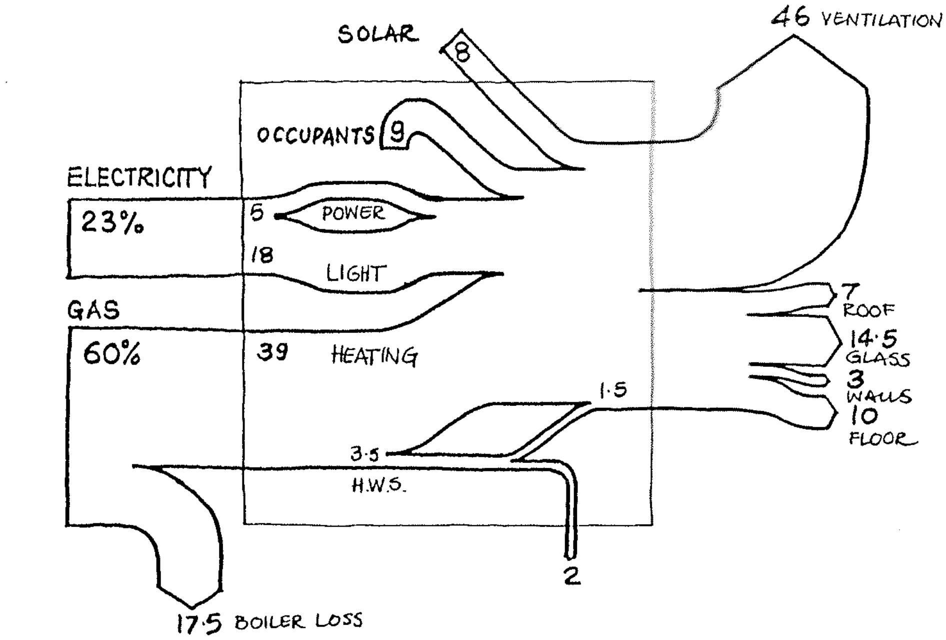
In winter, with a restricted window area, the inner skin raises the U value of the non-vision areas to 0.8 w/m²°C. In addition, the use of clear glass and a dark matt finish to the outer face of the inner skin transforms the south facing walls into solar collectors. Incoming ventilation air is thus preheated, before it is discharged into the building via perimeter fan convector heaters. The proportion of fresh air to recirculated air is controlled by dampers within the heater casing. During the summer months, when the window area is increased to 40 per cent, unwanted solar gains are prevented by external horizontal louvres. These do not significantly reduce the penetration of low angle winter sun.

This type of wall construction not only permits great architectural freedom in new buildings, but could be used to reduce energy consumption in many existing over-glazed schools and offices, provided the problems of condensation, which may occur between the insulation panels and the glass, are overcome.

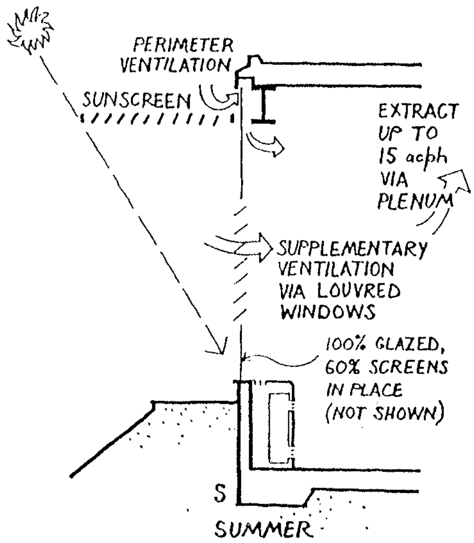
To maximise the benefits of the variable window wall, artificial lighting is controlled by photo-electric cells, with separate control for each row of fluorescent fittings in each room.

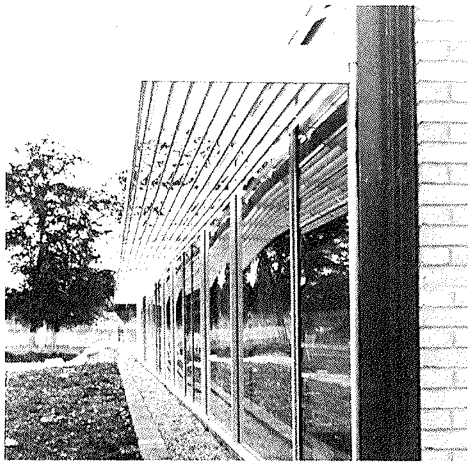
Fans, extracting from a central plenum, are capable of providing up to 15 air changes per hour in summer and can be supplemented by opening windows.

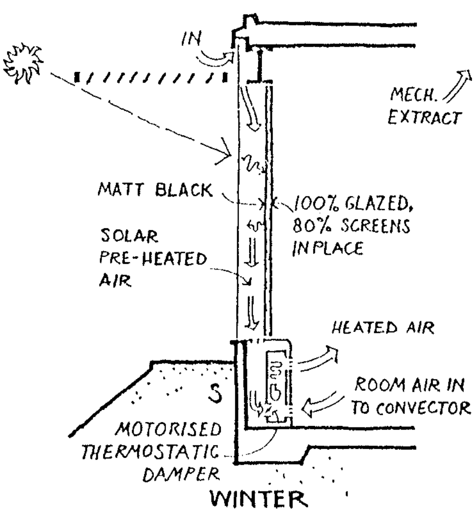
The perimeter fan convectors are supplemented in certain areas by hot-water radiators, fitted with thermostatic valves to give localised control.



Total fuel use per annum Primary 281.0 × 10³ kwh **Delivered** 156.0 × 10³ kwh **(Primary: Delivered Ratio 1.8:1)**







Frogmore Secondary School, Hampshire	
Date of completion	Autumn 1979
Capital cost	£378 000
Occupancy	
9.00 to 16.00 daily, plus possible evening use from 19.00 to 21.00	
No of persons	300
Persons per m²	0.2
	m²
Usable area	1500
	m³
Usable volume	3 934
Delivered annual energy consumption	
Estimated using DES method (Design Note 17) based on CIBS method, plus detailed studies using computer model	
	kwh
Total	156 000
Per m²	103
Per m³	40
Per person	0.52
Primary annual energy per m²	187

Client
County Education Officer, Hampshire County Council

Address
Potley Hill, Reading Road, Frogmore, Nr. Yateley, Hampshire

Architects
County Architect

M & E Engineers
County Architects Department

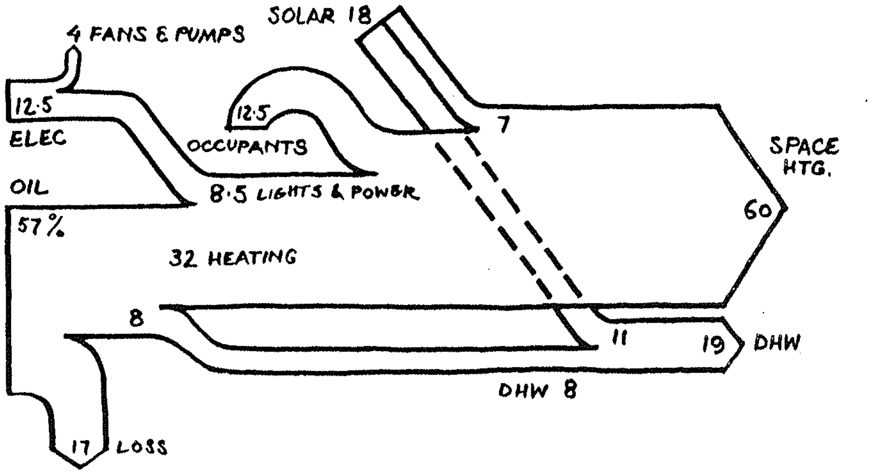
Structural Engineer
Anthony Hunt Associates

Solar Heated School Port Isaac

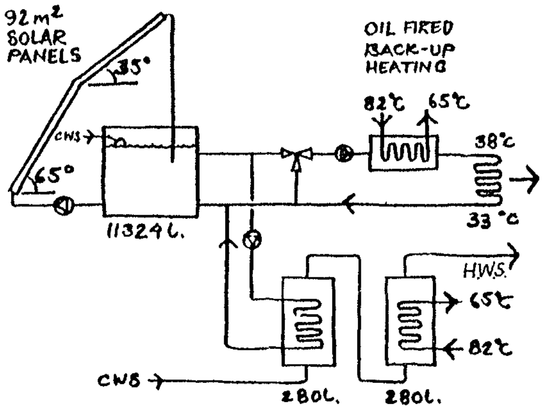
The new 80 place school is a single storey building with three classrooms on an exposed north coast location. It was selected as an experimental solar energy project in collaboration with the D.E.S. The aim was to explore the maximum use of solar energy, without compromising educational requirements.

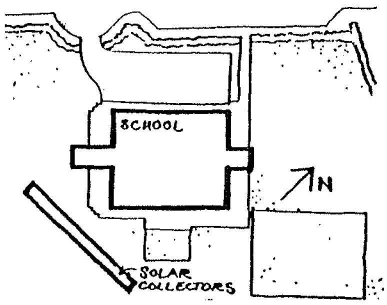
The solar panels and associated equipment are separated from the actual school building for the following reasons:
1 The form and layout of the building is not compromised.
2 Changes to the system can be made with minimum inconvenience and cost.
3 The system forms a separate 'package' which can be applied to similar buildings, both new and existing.

It was not practicable or economic to provide sufficient panel area and storage capacity to supply 100% of heat requirements. The collector area was chosen after considering the following factors:
1 Location of panel assembly
2 Area available for solar panels
3 Planning consideration
4 Cost limitations



Total fuel use per annum Primary 43.0 × 10³ kwh **Delivered** 54.0 × 10³ kwh **(Primary: Delivered Ratio 0.8:1)**





The volume of water stored was determined by an approximate optimisation of the annual contribution that solar energy could make to the total heat load of the school, balanced against the extra cost of thermal storage.

A collector of 92m² was chosen and storage for low grade heat is in 11324 litre tanks. (123 litres/m² of panel). Approximately, half a day's storage has been provided at peak winter loads to give reasonable operation for most of the heating season. About five days storage would have been desirable. However, the cost was prohibitive and this amount would still not have been adequate for December and January.

Single glazed solar panels are mounted in two rows, one at 65°C, the other at 35° to the horizontal, to take maximum advantage of summer and winter sun. The space beneath the panels houses the oil storage tank for back-up heating and the two 5662 litre, insulated mild steel water tanks.

When useful heat can be gained, water is circulated through the panels from the storage tanks. Direct heat transfer from the collectors, through the storage tanks and into the heating system, has been chosen. This eliminates the thermal inefficiency of heat transfer coils. A low temperature warm air, fan assisted convector heating system is installed, designed to operate with water at 38°C flow and 33°C return. Hot water for the kitchen and washing is heated in two 280 litre storage calorifiers. The first calorifier raises the temperature of the mains water using water from the thermal storage tanks. The second calorifier is used to boost this to a temperature of 50°C, using either back-up heating or, if possible, water from the thermal store. Back-up heat for both the hot water supply and space heating is from an oil fired boiler, operating at 82°C flow, 65°C return, feeding two heat exchangers.

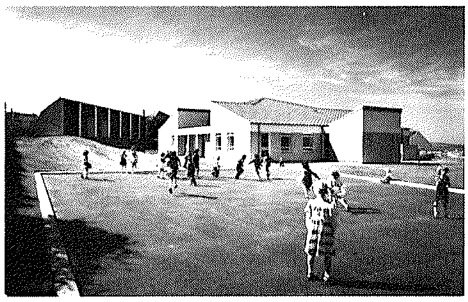
The solar panels were originally designed to drain down in case of frost or boiling. However, a cheaper and more effective system has been adopted in which water from the storage tanks is automatically recirculated in the event of frost or overheating. The storage tanks themselves provide feed and expansion: the water moving round the system pushes air out.

The small school has a domestic character, with good daylight distribution, contrast grading and adaptation conditions. It is estimated that the complete electric lighting system will be operating for about 200 hours per year and about 10% of the area will be lit permanently.

It is designed to take advantage of winter sunshine and exclude the effects of summer sun. Traditional construction with high thermal insulation, gives thermal capacity and low losses. All windows have curtains or blinds to conserve heat, as well as to control sky glare and sunlight. The U value of walls and roof is 0.44 w/m²k. The heating load is therefore reduced to an overall fabric loss of 40 w/m² of floor area — well below the DES guideline of 48 w/m².

In summer the spare capacity from the solar panel could be used to heat a swimming pool. Two spare bays under the solar panel structure could be used for changing.

The performance of the solar heating installation will be monitored for two years so as to obtain an indication of the economic viability of the system and its energy saving potential.



Solar Heated School, Port Isaac	
Date of completion	May 1978
Capital cost	£95 118
Occupancy normal during school terms	
No of persons	80
Persons per m²	0.23
	m²
Usable area	338
	m³
Usable volume	not available
Delivered annual energy consumption estimated using University of Bath computer programme	
	kwh
Total	53 600
Per m²	159
Per m³	–
Per person	670
Primary annual energy per m²	128 (including 41 kwh/m² active solar)

Client
Cornwall County Council, Education Committee

Address
Port Isaac, Cornwall

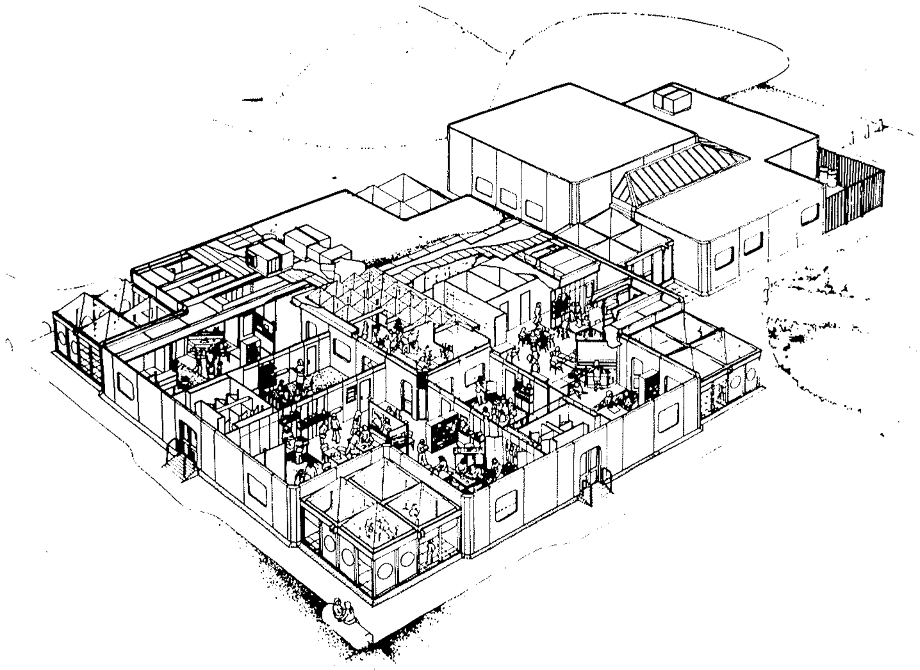
Architects
Cornwall County Architects

M & E Engineers
Hoare, Lea and Partners

Structural Engineers
Jenkins and Potter

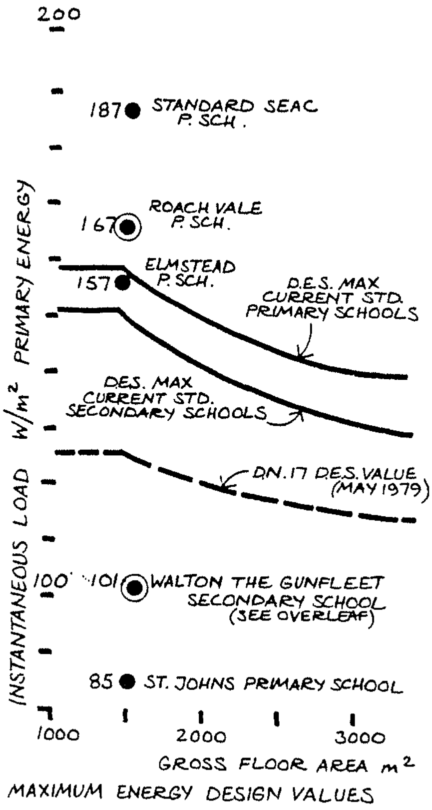
Monitoring Organisation
Bath University

Roach Vale School Essex

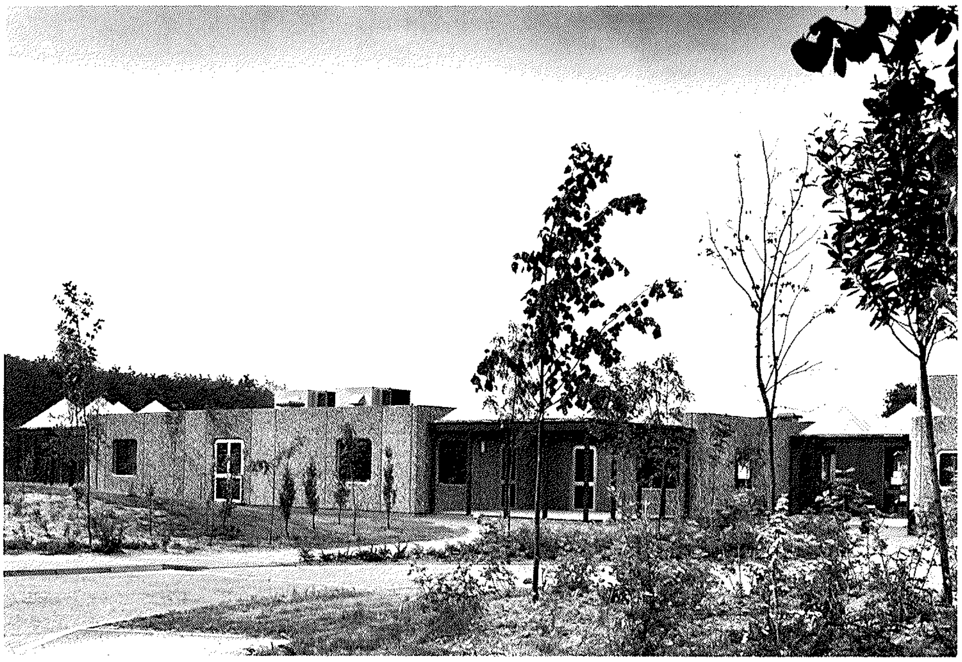


13 The concept of the modular component building (MCB) followed in the wake of the post war trend for structurally lightweight and thermally inefficient buildings featuring high glazing levels and with significant occupant discomfort during the two extreme seasons of the year. In contrast to this, the MCB is a load-bearing, thermally efficient, precast component system employing low glazing levels (17/25% of the wall area). Its overall 'U' value is 0.75 w/m²°C.

The Roach Vale Primary School is the latest built example using this method and is specifically designed for the integration of an air-to-air heat pump system. Believed to be the first school of this design in the UK, it derives from development work done at Elmstead School which used gas for heating and will be followed by the Walton Gunfleet School extension.



Comparison of performance of SEAC schools with MCB schools of Elmstead, Roachvale and Walton 'The Gunfleet' (Elmstead was heated by gas).



The school is for 280 children occupying eight teaching bases arranged on a cruciform pattern around a central, translucent roofed courtyard. A separate assembly hall, kitchen and administration area are adjacent. To provide the optimum amount of useful teaching space, the heat pump units are on the roof and use the coffered ceiling as the air supply and services duct.

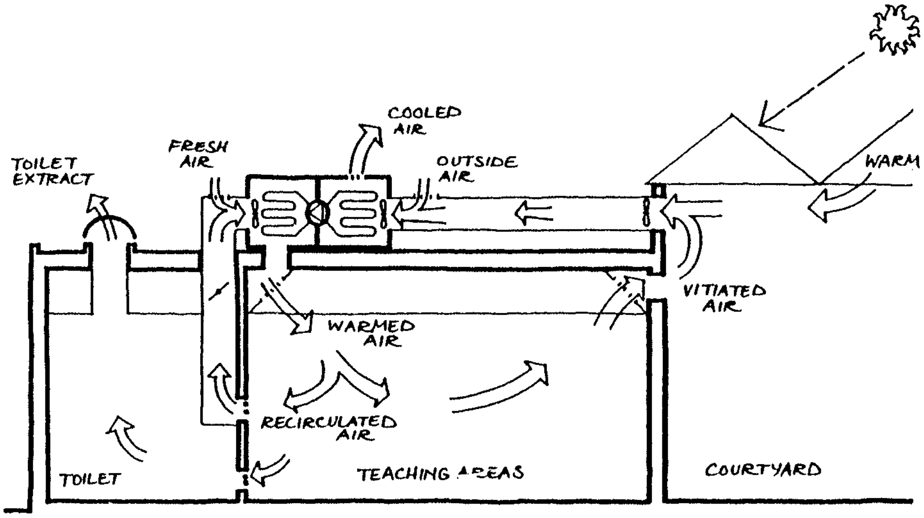
Each pair of teaching bases is supplied by a pump having a 14.54 kw heating cycle output together with a 13.83 kw cooling cycle output. Each unit is controlled by a heating/cooling thermostat in association with an optimum start controller having internal/external sensors. The optimum start controller predicts the system start-up time for minimal use of energy during the heat-up period, whilst ensuring the required level of comfort within the occupancy period. It also acts as a frost protection control out of school hours.

Each heat pump introduces a constant supply of mixed fresh and recirculated air via grilles in ceiling coffers. Vitiated air is extracted from the teaching areas either via the toilets by means of roof extract units, or through the central court internal transfer grilles to either the outdoor fan of one heat pump (during the heating season) or extract fans around the perimeter of the court. These are thermostatically controlled to operate on a build-up of temperature at high level.

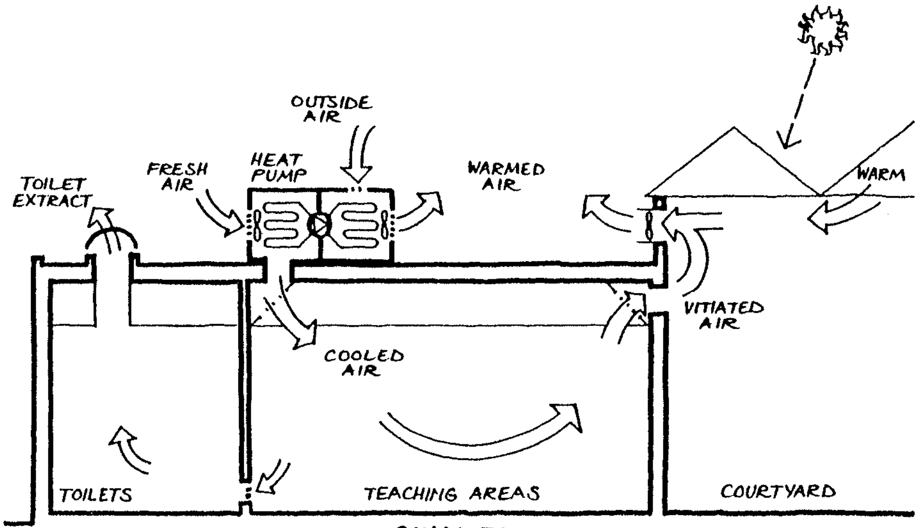
The heat pumps operate on the reversed refrigeration cycle principle, removing heat from one fluid medium (external or vitiated air which includes lighting and occupancy heat gains) and transferring the heat to another medium (supply air).

The coefficient of performance (COP) of such a system is estimated to be in the order of 3:1 which gives an overall efficiency of the same order as a conventional direct-fired fossil fuel system. The monitoring programme was therefore designed to investigate the heat pump operation, to ascertain the actual COP, to assess the degree of thermal comfort obtained, and to check the energy consumption figures for such a system.

Full results from the monitoring programme should be available by the end of 1979.



ROACH VALE PRIMARY SCHOOL **WINTER**



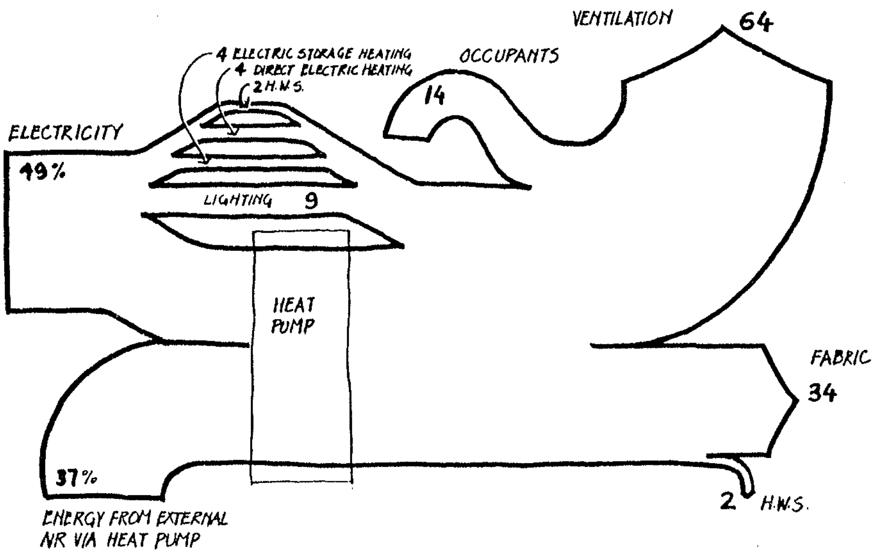
ROACH VALE PRIMARY SCHOOL **SUMMER**

At present three general statements about the system performance can be made:

1 The external fabric of the building provides a six-hour thermal time lag.

2 The heat pump using the warm air from the courtyard as the outdoor coil source operates far less frequently than the standard units.

3 Effective sealing of the extract fans, roof mounted units and coffers is required to prevent excessive loss of useful heat.



Total fuel use per annum Primary 247.0 × 10^3 kwh **Delivered** 66.0 × 10^3 kwh **(Primary: Delivered Ratio 3.7:1)**

Roach Vale School, Essex	
Date of completion	August 1977
Capital cost	£180 000
Occupancy 9.00-16.00 Monday to Friday during school terms	
No of persons	295
Persons per m²	0.307
	m²
Usable area	961
	m³
Usable volume	2 800
Delivered annual energy consumption calculated in accordance with Design Note 17 of the Department of Education and Science.	
	kwh
Total	66 309
Per m²	69
Per m³	24
Per person	228
Primary annual energy per m²	257

Client
Essex County Council Education Department

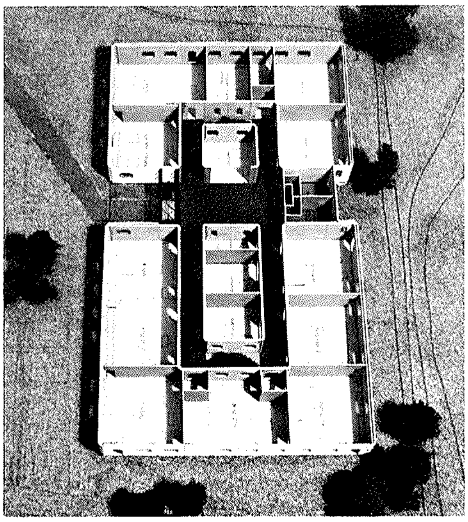
Address
Welshwood Park, Colchester, Essex

Architects, M & E Engineers, Quantity Surveyors
County Architect, Chelmsford, Essex

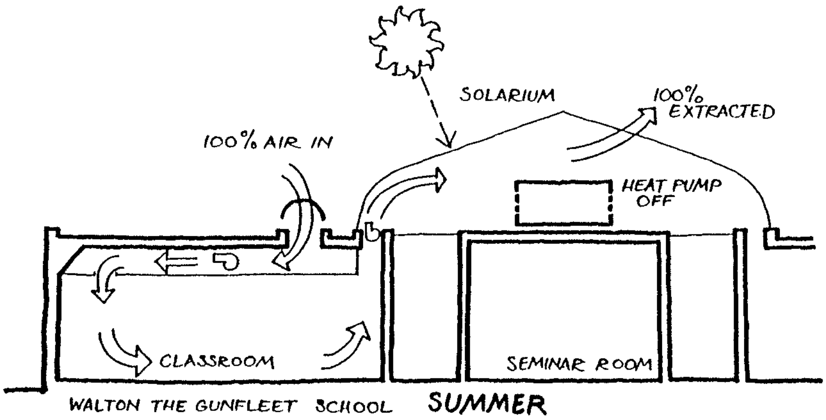
Structural Engineers
Roughton & Partners

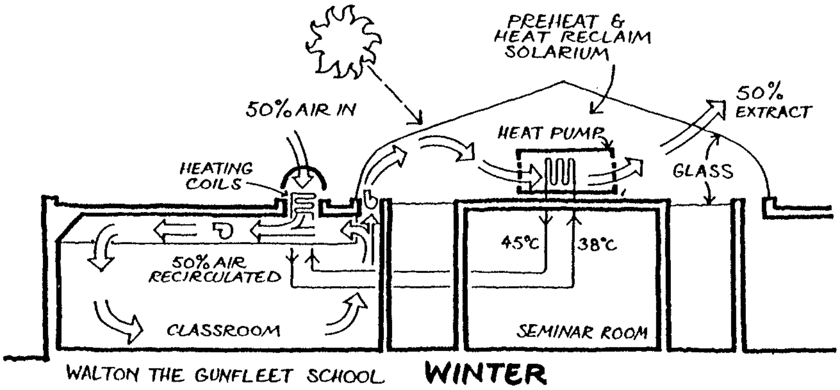
Monitoring Organisation
Electricity Council

Walton 'The Gunfleet' School Essex



14 This extension to a secondary school uses MCB construction, as at Roachvale, and is mechanically ventilated with all extract air taken out through the Solarium. Thus, air in the solarium is not only heated by the sun but also receives waste heat from the classrooms. Two air-to-air heat pumps are located in the solarium so that their Coefficient of Performance (COP) can be increased by virtue of the higher input temperature available.





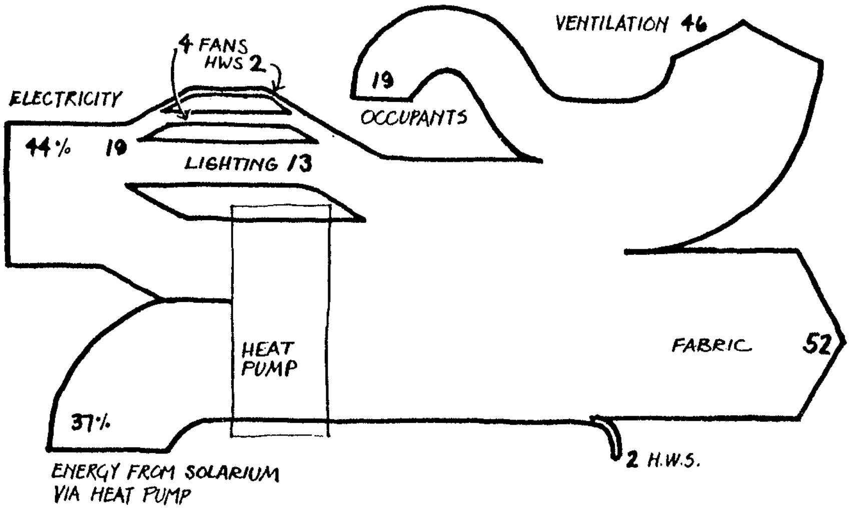
The heat pumps supply fan coil units in the ceiling voids of classrooms and seminar spaces. (Flow water to these is at 45°C with return at 38°C, when the external temperature is at 0°C.) The control system alters the flow water temperature in response to variations in external temperature, increasing the efficiency of the heat pumps in mild weather.

The two heat pumps provide 35kw each with a COP of 3:1, at an ambient air temperature of -1°C and RH of 90%. They are defrosted alternately, using hot water for 8 to 10 minutes every three hours.

Air supply in winter is varied automatically by classroom humidistats which control the proportion of air recirculated, and provide up to 50% fresh air. These humidistats switch the fans on in response to the occupancy of the classrooms. During the summer 100% fresh air intake provides free cooling. Air volume is controlled by thermostats and/or humidistats in the classrooms.

Ventilation air to the classrooms comes in at low pressure utilising the "Coanda" effect to cause secondary air entrainment.

In two similar classrooms, alternative methods of room ventilation and related air movement will be evaluated. In one, linear diffusion from a ceiling plenum chamber will promote entrained, recirculated air, in the other, air will come through perforations in the coffer duct (see internal photograph of Roach Vale).



Walton The Gunfleet School, Essex

Date of completion	June 1980
Capital cost ·	£235 000
Occupancy 9.00 to 16.30 Monday to Friday with possible evening use	
No of persons	300
Persons per m²	0.26
	m²
Usable area	1 015
	m³
Usable volume	2 800
Delivered annual energy consumption Calculated in accordance with Design Note 17 of the Department of Education and Science.	
	kwh
Total	47 705
Per m²	47
Per m³	17
Per person	159
Primary annual energy per m²	176

Client
Essex County Council, Education Department

Address
Frinton-on-Sea, Essex

Architects, M & E Engineers, Quantity Surveyors
County Architects Department

Structural Engineers
Roughton and Partners

Monitoring Organisation
Electricity Council, Environmental Engineering Section

Total fuel use per annum Primary 179.0 × 10^3 kwh **Delivered** 47.8 × 10^3 kwh **(Primary: Delivered Ratio 3.7:1)**

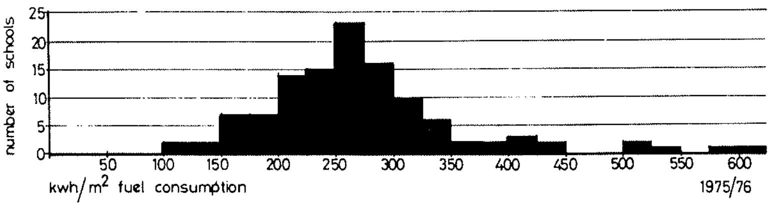
Essex Schools Energy Study

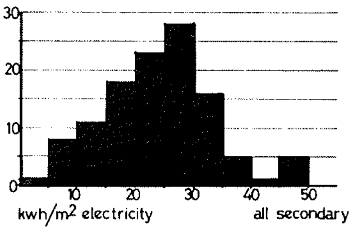
Over the past two years, a study has been made of existing schools in Essex to identify the main factors which effect energy use and suggest a strategy for improvement.

Figures for electricity, oil and gas delivered to each site for two consecutive years were analysed, with the following results:

1 The 116 secondary schools account for over half the county's fuel consumption and expenditure on energy for educational establishments (that includes over 700 primary schools and several technical colleges).

2 The average annual fuel consumption in secondary schools is about 270 kwh delivered energy per square metre. Secondary schools use on average slightly less energy per square metre than primary schools.





3 The average fuel consumption, corrected by a weather factor, declines over the two years of study indicating the effect of energy conservation programmes undertaken by the county.

4 Oil accounts for over 80% of energy delivered to secondary schools. Only 5% of the schools are heated by natural gas and electricity accounts for over 30% of fuel costs. Half the schools have temporary classrooms heated by electric off-peak storage systems. Many schools used on-peak electric heaters in administrative offices.

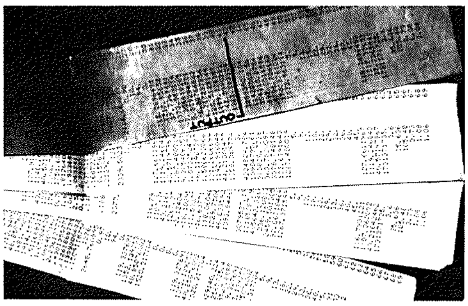
5 Fuel consumption per square metre varies by a factor of four, between different schools. 87% of the stock have fuel consumption figures varying from 150 kwh/m² to 400 kwh/m².

Use of electricity also varies by about a factor of four between schools and is a multiplier on fuel-cost variation. The effect of variables such as building construction, system efficiencies, special features, and occupation during evenings proved difficult to quantify. Estimates showed that variation by a factor of two is possible for physically identical schools, produced by differences in internal temperatures, plant efficiency, and hours of occupation. Subsequent monitoring established that environmental conditions between schools, and between rooms of different size, occupation, orientation or levels of glazing varied widely.

Having identified significant potential for energy conservation in schools, the study recommends systematically identifying those schools and energy uses where investment is likely to have high returns rather than applying saving measures to all schools indiscriminately.

In the second phase, twenty schools were visited and surveyed by the research team and an energy management programme (see Fig 1) was produced.

Certain schools were selected for further investigation and for these a breakdown of energy consumption by end-use and division of spaces into zones was necessary. Zones were then studied for their energy conservation potential. A set of flowcharts was produced to guide the analysis, leading to the identification of specific energy-saving measures.



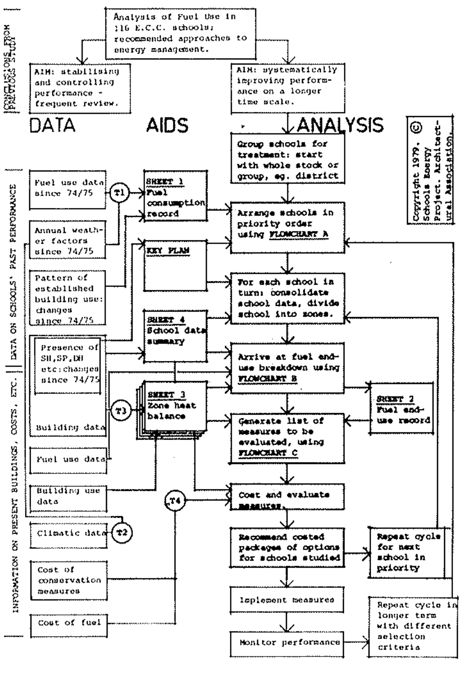


Fig 1. Diagram of recommended energy management programme.

These are accompanied by a set of data sheets, tabulated data and TI-59 programmable calculator programmes.

For example at St. Chad's School, Tilbury, the study identified potential savings

15

totalling about a quarter of 1977-78 fuel costs, estimated to pay back in two years. This is despite the fact that the school has a lower than average fuel consumption and is mainly heated by natural gas at favourable bulk tariffs. Further savings were shown to be possible with a mean pay-back period of less than three years. The 113 energy saving measures identified by the study included only technically proven applications that required little or no change in patterns of use.

The behaviour of the school population and management practices emerged as highly important but unpredictable factors affecting energy use. Teachers respond rapidly to rises in temperature or reductions of natural lighting; they open windows and switch on lamps for fear of sleepy classes. Energy conservation policies may have no effect if the school population has no clear understanding of what is involved. The school is the best starting point for education in energy management.

Two schools have joined in an experimental project to increase the awareness of both children and teachers of how energy is used in buildings. Pupils and teacher co-ordinators met with AA researchers regularly from February to July 1979. An introductory slide show gave an outline of the use of energy in buildings and in particular in Essex schools. Factors affecting energy consumption in schools were illustrated with examples from previous research showing energy flows in each of the test schools and the potential role of occupants in energy management. Later presentations dealt with the principles of thermal comfort and heat transfer. The school pupils then undertook various projects, including: assessment of the thermal environment; measurement of temperature variations in time and thermal gradients; survey of room thermostats, heating appliance and lighting surveys.

The projects have identified some of the areas where such savings are feasible, the extent to which conditions vary from room to room and the pitfalls of approaching even a single zone (such as a number of classrooms in the same building), as a consistent environmental entity.

Essex Schools Energy Study

Monitoring Organisation
Architectural Association Graduate School

Oxfordshire Schools Conservation Programme

16 In 1975 a team of engineers, architects and quantity surveyors from the Department of Education and Science, Oxfordshire County Architect's Department, Oxford Polytechnic and Rutherford Laboratory Energy Conservation Unit set out to examine the effects of energy conservation methods in educational buildings.

Incentive Scheme

Actual oil, gas and electricity consumptions were worked out from suppliers' bills for the preceding two years 1975/6 and 1976/7 and adjusted for weather using degree days. Targets for future consumption were set for each fuel, in each of eight schools, based on their previous average performance.

	Gosford Hill School	Matthew Arnold School
Autumn 1975	Optimum start control	Optimum start control
February 1976	Some windows insulated	
Summer 1976	500m² Loft insulation Flexible draught doors	1500 m² Loft insulation 1575 m² Cavity fill (foam)
September 1976	Fitted 12 thermostatic radiator valves	
October/ November 1976	Converted oil heaters to automatic firing	Improved boiler efficiency
April 1977	Separate boiler in F/E block	
September 1977	Zone valves fitted – evening use re- organised	

Schools which beat their targets were given half the value of the fuel saved for their capitation funds.

Interestingly, one school, Gosford Hill, increased its consumption by nearly 8% in 1977/78 in spite of a programme of improvements including insulation, additional controls and draught doors . The head caretaker was ill for most of the year and finally retired due to ill health, and no-one else was familiar with the plant. The improvement in 1978/79 corresponds with the appointment of a new head caretaker This strongly suggests that people have a large degree of control over the amount of heating fuel used and probably have a larger effect than any other single factor such as the addition of insulation or automatic controls.

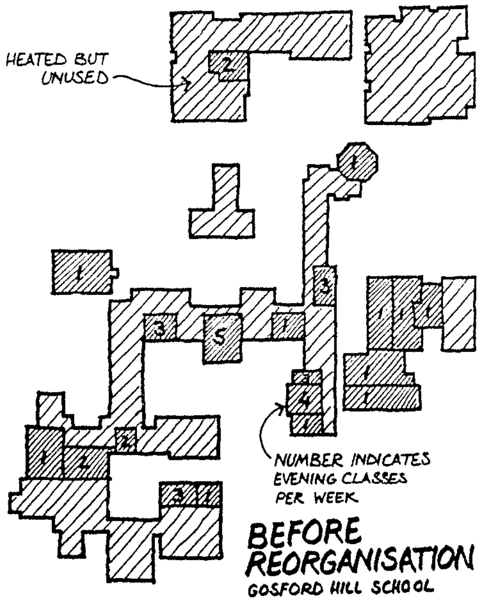
Curiously, the highly-glazed 1960s Consortium buildings perform in much the same manner as conventional pitched roof buildings. Apparently, quick heat-up and reasonable thermostatic control of fan convectors in Consortium buildings is balanced by the slow response of radiator systems in conventional buildings. Additionally, many Consortium buildings have quite well insulated roofs: most in Oxfordshire have a 'U' value of about 0.8 w/m²°C, which is only slightly worse than that required by the latest Building Regulations.

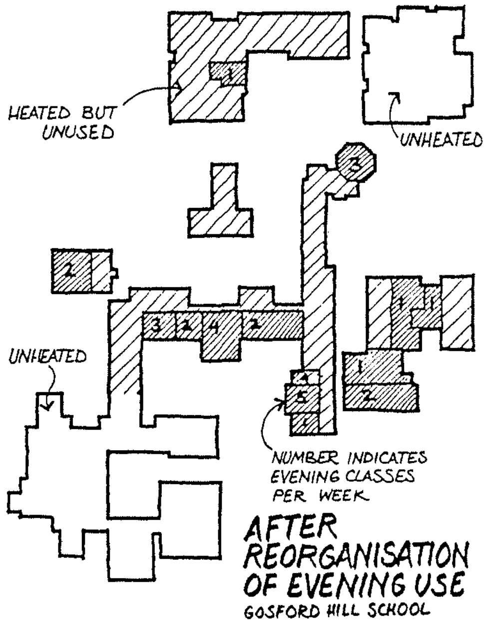
There is some evidence to support the view that slow-response systems waste fuel. At Matthew Arnold School, four classrooms were disconnected from the compensator-controlled radiator system and heated by on-peak electricity for experimental purposes. They used less than half the average consumption per square metre for the whole school. This is in spite of the fact that the experimental rooms are frequently heated during weekends and holidays to compare results of tests with and without occupants.

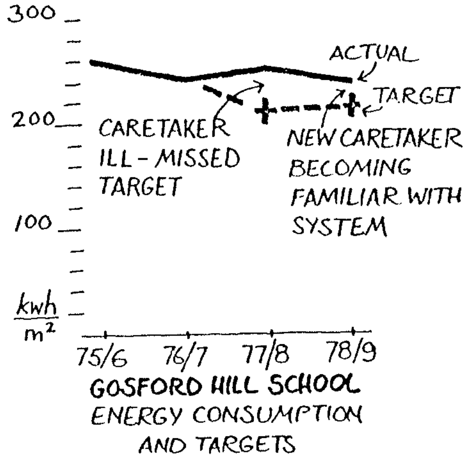
These results show that theoretical savings for various measures can be achieved, but that the building users have much more control over energy use than is often appreciated. If, for example, the heating were left running during the Christmas holidays, 7 or 8% would be added to the fuel bill, cancelling out savings made by fitting an optimum start controller. The experiments suggest that occupied buildings are complex organic things, the parts of which interact; after all, the eight schools saved about 5% of their total fuel, and most of the building and control systems were unchanged.

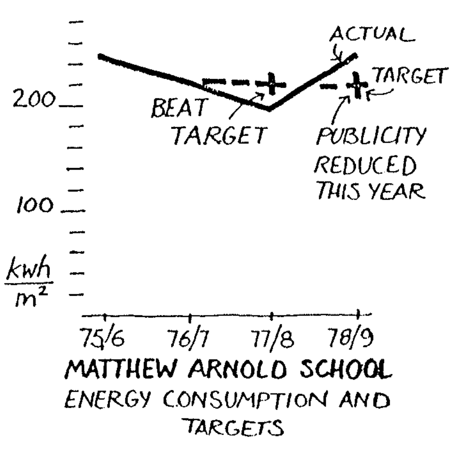
While energy study work was going on at Matthew Arnold School in 1977/78, conservation performance was good. In 1978/79 with publicity reduced to routine posters, performance slumped and the target was missed.

This demonstrates the importance of awareness, and the County Architects Department are mounting a campaign of exhibitions and meetings with caretakers and headmasters which will begin in October, and it is hoped will improve performance for the heating season of 1979/1980.









WHAT CLOTHES CAN DO FOR YOU

Clothes make a big difference in the amount of heat you will need to keep warm.

And the savings you can achieve by turning down the heating and putting on an extra layer of clothing are enormous.

The chart below shows how the temperature needed drops as you put more clothes on. Compare it with the diagram opposite which shows the enormous rise in fuel consumption caused by setting the thermostat higher.

EFFECT OF CLOTHING ON COMFORT

Type of Clothing	Comfortable temperature for person sitting down	
	°C	°F
Nude	28.5	83.3
Shorts and T shirt	25	77
Slacks and pullover	22	71.6
Lounge Suit	18	64.4
Overcoat and gloves	14.5	58.1

In Oxfordshire we try to aim for 65°F (18.3°C) which is roughly a comfortable temperature for someone wearing a suit.

Oxfordshire Schools Conservation Programme

Architects, M & E Engineers, Quantity Surveyors, Monitoring Organisation

Oxfordshire County Council, Architects Department

Cheshire CC Energy Conservation Programme

In 1974, Cheshire County Council established a unique fuel monitoring system, allied to a programme of investment measures to improve thermal performance of existing buildings. These included: exhortation to good housekeeping by users, reduction in hot water temperatures, scrutiny of plant efficiency and restrictions on the use of high energy consuming plant, together with improvements to buildings and controls. These measures are most effective when:
1 Buildings with high fuel consumptions can be clearly identified.
2 Savings can be accurately quantified to justify investment.
3 Incentives can be offered where users contribute to savings.

To meet these requirements, particularly to identify savings, Cheshire decided to establish a computer aided fuel monitoring system, starting in one district of the county. The system calculates theoretical consumptions for each building every 28 days, taking into account building use and weather conditions, and produces a performance measure by comparison with actual measured consumption.

The Computer requires the input of: 1. Base Data. 2. Weather and usage profiles 3. User Information.

1 Base Data
Individual buildings, or sections of buildings with different uses within a complex, are identified by a numerical code and surveyed to provide a detailed building record file in the computer which is then used for base data for calculations and comparison. This includes:

Detailed information on building type, age, location, general and specific construction details, area and volume.

Design Data on fabric and ventilation losses, mains losses, temperatures, hot water consumptions, occupancy, heat decay factor, preheat and frost boost factors.

Engineering details on boiler plant, efficiencies, fuels, type of system, control, theoretical preheat times of plant and boiler loadings for heating and HWS.

2 Weather and Usage
Regular four weekly input of weather data and usage profiles enable the computer to calculate weather factors for each type of use (i.e. night, preheat, normal day and special use) and take account of the type of control system used during the night and for preheat.

Using these weather factors, the building information file and the usage profile, the various theoretical consumptions are computed for each type of use; these are summated to give the total for each building for the period.

3 User Information
Fuel meters are installed in each building, together with meters to record the hot water consumption. Each period, information from these is returned by the building user on a pre-printed, prepaid postcard. The card also includes information on occupancy — i.e. hours and days of normal use as well as special use, such as night classes, etc.

Actual energy requirement for hot water is calculated and deducted from the total fuel meter reading to give space heating consumption. Separate performance levels are then derived for heating and domestic hot water by comparison with theoretical consumption figures.

If actual consumption varies from theoretical by more than a predetermined margin, plus or minus, an output is generated. This enables the buildings to be investigated in order of priority, starting with those of exceptionally high consumption.

Performance for the period is also compared with the previous period and the same period in the previous year. If an unacceptable variation exists, a second output is produced. This identifies a change in the consumption and aids quick identification of maintenance faults. It also checks the level and consistency of Good Housekeeping.

The monitoring system includes a number of other checks:
(a) An output on secondary fuel use, such as electricity ensures that good oil, gas or solid fuel consumption is not achieved by the use of electric heaters. An output on gas consumption compares catering by gas and electricity.
(b) A search programme can extract information from the building file on a wide range of criteria, to be used by other Departments e.g. window cleaning contracts etc.
(c) A model programme can simulate the effect of building changes such as improved insulation or a change in internal temperature on theoretical consumption.
(d) A comparison of actual occupancy with the original design gives a measure of over or under use.
(e) Building performance data, such as use of hot water per person per day aids in the design of new buildings.
(f) There is an automatic addressing facility.
(g) Fuel accounts can be checked for audit.

The input by building users is of critical importance to the fuel monitoring campaign; apart from the return of the monthly prepaid cards, a continual process of good housekeeping is essential for the momentum of the savings to be achieved. For this reason, the County Council decided that, for the first two years, the whole of the nett savings arising from the programme should be returned to individual committees to assist their budgeting problems in a period of severe restraint. This gives an incentive to the users.

During the 1975/76 heating season, comparisons of actual and theoretical fuel consumption by buildings in the pilot district of Ellesmere Port showed startling results. Buildings ranged from 50% below to over 900% above the target consumption.

This data was analysed, modifications made to plant, and a campaign for good housekeeping was instituted.

A dramatic 19.6% reduction in fuel consumption occurred, representing about half of the total excess consumption on the 49 buildings in the sample where no investment has been made. 17

As a result of this the County Council decided to extend fuel monitoring to the whole County. At a conservative estimate this can save at least 20% on the oil fuel bill, or over £800,000 annually at current prices.

During the year 1977/78 a further district was added to the scheme and a saving of 16.5% was established in this area, this, together with the further improvement by about 6% in the Ellesmere Port District, tends to confirm the estimate of savings possible by improved housekeeping and management.

Investment Measures
It was decided that, during 1976/77, a series of small research projects should be set up so that savings from these could be assessed by the fuel monitoring system. These measures included additional roof and cavity wall insulation, zone control valves, optimisers etc. at a cost of some £20,000. A total saving from this investment in one heating season was some £15,000.

Following this, the Council decided to invest £2.1m in building and plant improvements over a period of five years. By choosing projects with up to three years return on capital, the total cumulative saving, including the savings resulting from fuel monitoring, should amount to over £4m.

When the programme of investment is completed at the end of five years, actual savings will continue (at current prices) in the order of £1,350,000 annually.

Other Measures
In addition to the work directly related to existing buildings the fuel monitoring system enables the performance of buildings to be readily analysed against a wide range of criteria such as plan form, insulation standards, window/wall ratios. From this type of analysis, energy targets for various building types will be formulated.

Conclusions
Although the savings from the fuel monitoring programme and the investment measures may seem on first sight to be dramatic, they are really not surprising. Virtually every building in the Council's ownership was designed during a period of cheap energy. Work in Cheshire shows not only that energy consumption can be dramatically reduced, but there is positive evidence to demonstrate that reductions have been made; more important, the programme shows precisely the most wasteful areas and where action should be concentrated.

Cheshire C.C. Energy Conservation Programme
Cheshire C.C. Architects Department Energy Conservation Unit

Essex Conservation Programme

18 To achieve a five year pay-back on capital
expenditure and a three year pay-back on
19 revenue expenditure is the financial objective
that has been set by this county. These rates of return have been chosen arbitrarily by the finance committee for total annual expenditure, not for individual projects. Research and experimental work is financed by achieving a slightly shorter pay-back.

The aim is to concentrate on the largest and most inefficient premises to achieve large savings on a relatively small number of projects. Capital monies will be used for this purpose; revenue monies will be devoted to maintaining the rest of the building stock at its present level until it can become the subject of comprehensive energy conservation. Savings made in individual properties will therefore be reflected in the total annual fuel bill and not offset by increased expense elsewhere. A computerised Energy Monitoring System is being instituted. Work is in hand and it is hoped to have monthly energy consumption returns from each major property by November 1979. It will then be possible to identify the properties where consumption is on the increase.

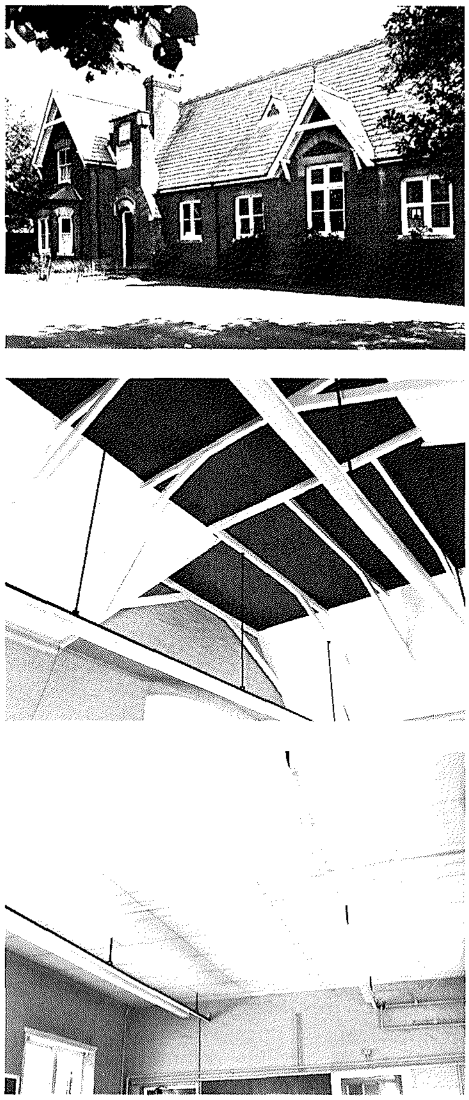
In order to achieve pay-back in four to five years, it will be necessary to reduce consumption by 25-30%. It is anticipated that this can be achieved by the upgrading of insulation levels, reduction of air infiltration and the improvement of engineering systems and controls. Work will also include a comprehensive assessment of lighting and a review of the patterns of building use, particularly evening use of schools. The pay-back achieved by individual measures will vary; the pay-back for insulation, for example, will exceed five years but there will be a much greater return on improved controls. To reduce the county expenditure by 25% will require an investment approximately equal to the annual expenditure on energy; this is expected to reach £8m in 1979/80. A ten year implementation programme is envisaged.

Until full-scale energy monitoring is in operation, across-the-board measures will not be applied; because there would be no effective way of verifying that savings were being achieved. So, for example, it is considered undesirable to carry out a widespread optimum-start control programme although a number of different types have been installed to date. Some problems have been experienced and it is essential that checks be made to ensure that the equipment functions as intended. Developments in this field are rapid and it would be very easy to install a considerable amount of equipment which would be rapidly superceded. Optimum start will be considered as one aspect only of overall control improvements.

Frost protection will be given careful consideration. It is estimated that out of £6.25m spent on fuel in 1978/79, £1m was for frost protection. Where internal thermostats are employed, the unoccupied temperature level was reduced from 10°C to 5°C. In the absence of comprehensive energy monitoring, the precise amount of saving is difficult to verify. It may soon prove to be advantageous in cost terms to accept a much higher risk of frost damage.

The across-the-board measure which is essential is the energy saving and good housekeeping publicity campaign. Direct returns on this may be low but it is vital in ensuring the co-operation of building users, chief officers and committees, to implement energy saving measures.

Work on energy conservation in Essex is seen as part of a three-fold responsibility, to use as little energy as possible, to pay as little as possible for that energy, and to ensure as far as possible the continuity of supply. Tariff work, energy cost control, selection of fuel and purchasing are an important part of the work. The Tariff Officer achieves regular savings of about £25,000 per annum. This is an extremely cost-effective deployment of staff.



Typical school building with volume reduced by false ceiling

Essex Conservation Programme

Architects, M & E Engineers, Quantity Surveyors, Monitoring Organisation
Essex County Council, Architects Department

Liverpool Energy Study

The Liverpool Energy Study is examining how a city-scale programme for energy conservation in existing buildings should be conceived and implemented. Funded jointly by the City of Liverpool and the Department of the Environment, it is analysing the technical, social and administrative aspects of energy conservation. It is being carried out by a team drawing expertise from many fields: architecture, engineering, surveying, social sciences, policy analysis and the computing sciences. It was initiated by the Chief Executive of the City of Liverpool in 1978 and will be completed by October 1979. The final outcome of the study will be a practical framework which Liverpool and other cities can use to initiate an energy conservation programme for the buildings it owns and maintains. The broad conclusions of the project team are given below.

1 Energy conservation is not simply a matter of technology alone but is crucially dependent on people. As a result, there is no quick technical solution to energy conservation; only the need to manage energy on a permanent basis.

2 Energy conservation has to be legitimized as business-as-usual. In recent cases where this has not occurred, it has become an unfashionable nuisance and consumption rose after temporary savings were achieved.

3 Modifications to existing energy management systems within the City are needed; not a completely new Department or Agency.

4 Initial technical and management modifications are needed mainly to record and control energy use in buildings. At present, most heating systems only control thermal comfort levels. These must be changed to control energy use while providing thermal comfort.

5 Energy decisions can no longer be treated as financial transactions alone. Most energy decisions are currently based on the costs of energy supplies whereas energy conservation is concerned with saving units (kwh) of energy demand. Conservation must be discussed in energy terms.

6 The main prerequisite to saving energy is the efficient use of the building stock as a resource available to the community. Resource management practices should ensure that buildings are being used near their design occupancy levels before conservation measures are taken.

7 Performance indices have been developed by the team based on the main factors which influence a building's performance, including energy. These can be used to check whether a building is being used efficiently as a civic resource.

Recommendations:
(a) Enough information is now available to give a clear picture of energy demand in the

buildings owned and operated by the City of Liverpool. A building stock and energy use book of statistics should be established and updated each year.

(b) The City should fit basic controls to all heating systems so that heating can be controlled centrally (from the boiler room) and adjusted in individual rooms.

(c) The City should ensure that each building has a meter for each fuel it uses. Meters should be in accessible positions so that they can be easily read at regular intervals.

(d) The Chief Executive should chair an Energy Council. It should be composed of one member of each existing Committee.

(e) Each member of the Energy Council should be responsible for the buildings of his Committee. He should use an agreed Index of Performance, such as the energy used in a volume per unit of occupancy, in reporting the performance of buildings in his sector of energy demand.

(f) Each Energy Council member should have a direct link with the most senior administrator in each building under his Committee's control.

(g) The caretaker or building operator should report directly to the senior administrator in each building.

(h) A caretaker for each building type should be given intensive energy conservation training. He should then be asked to advise other caretakers how to save energy while carrying out his normal duties.

(i) A demonstration project in each building type should be started. During this programme the buildings caretaker should be given his special training course in energy conservation.

The more detailed technical recommendations about what might be done to reduce the energy demand of individual buildings together with the manner of working can be drawn from the Report.

Methodology
One of the main objectives of the study was to determine how little information is needed by policy makers to make knowledgeable energy decisions about buildings.

With more than 2,500 buildings to look at, it was decided that the work would be divided into four stages. These overlapped in time, and involved the collection and checking of progressively more detailed information about energy use and an evaluation of how decisions are made about the control of energy use.

Stage 1
A broad survey was made of the information most readily available. This covered how much money was spent on energy by type of fuel and by committee in the year 1977/78 (Fig. 1). Internal floor area, age of the building and the occupancy over the year were readily obtained. This enables matrices to be drawn up for the different building types showing energy use against age.

Stage 2
This was concerned with energy use measured in kwh from the fuel supply industries records. These gave an assessment of the relationship between actual fuel use within different building types. The systems were described by the type of fuel mix and the fabric defined by age and area. Matrices were drawn to enable a representative selection of buildings to be made for survey in greater depth. The matrices showed whether the energy performance of different buildings was good, medium or poor.

Stage 3
Ninety buildings were chosen and details of the size and thermal properties of all structural elements were measured to show volume, perimeter, ventilation rates, type of heating system, system efficiency, number and type of appliances, zones of the building that are heated, orientation and overshadowing. Also, occupancy was measured by total number of hours per year and time clock settings and total hours of operations of the systems were checked.

During this stage an in-depth study of the social aspects of energy use was made and interviews were conducted in all types of buildings. From the data collected, potential energy savings were assessed in detail using a variety of computer programmes. Costs and pay-back periods for individual buildings were considered.

Stage 4
All the data collected was banked in a desk top computer and statistical analyses were made for each building category and by age.

This information covers building fabric, pattern of use, and the actual energy used in 1977. This is being subject to analysis in a variety of ways, firstly using statistical methods. This provided a full understanding of how the buildings have been used.

In considering the factors affecting energy demand, much has been learned from the use of multiple regression analysis holding energy demand as the dependent variable and area, perimeter, volume, occupation hours, age and other details as independent variables. This work has shown that total occupancy use for the year and the volume used are the most important factors governing energy demand. This means that a building should be used as the designers intended before the effect of improvements to the fabric and systems can be assessed.

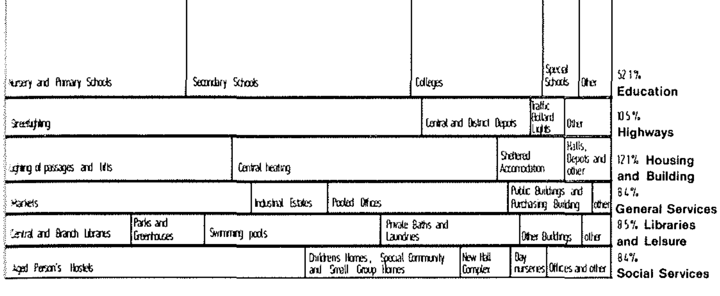
A recommendation has been made that for all buildings the relationship between Energy, Volume and Occupancy hours EV ÷ 0 is the best Index of Performance in terms of energy use. If occupancy is reduced, the space should be reduced also to keep energy use in balance.

Using moving average totals for the factors involved, a calculation of this relationship should give an Officer-in-Charge a much clearer indication of the management of the building than would be apparent from fuel meter readings alone.

By the use of computer models such as the RIBA calculator programmes, BEEP and ESP (the energy simulation programme at Strathclyde University), it has been possible to model, with more than 90% confidence, actual energy used in 1977. This enables predictions as to potential energy savings to be made with the same confidence. The use of dynamic models has enabled detailed consideration to be given to the thickness and relative position of insulation and boiler firing times. It is significant that dynamic models, such as ESP, produce significantly different results from static models which are based on the degree day method when considering the cost effectiveness of particular energy conservation measures. Nevertheless, the degree day method can give accurate predictions (within 90% confidence limits) of total annual energy consumption.

By considering energy saving alternatives over a number of buildings, an assessment can be made by further regression analysis ranking the savings in order of effectiveness. A successful conservation campaign should begin by doing the most rewarding things first.

Throughout the study, a review has been made of conservation programmes carried out elsewhere. The tendency of conservation programmes to fade in performance over time has been noted in many places. This confirmed the conclusion that unless it is clearly understood by building users that buildings and their systems have been purposefully designed to perform within certain limits of occupancy and systems control, any proposed alterations to the fabric of a building would have little chance of taking effect.



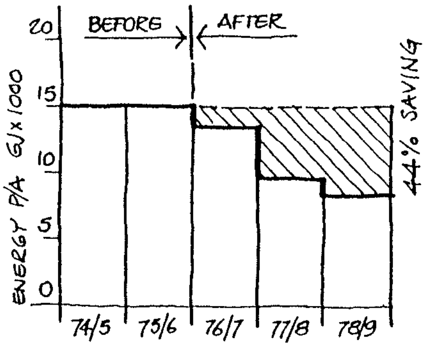
(Fig. 1) *Delivered energy purchases 1977-78*

Liverpool Energy Study

Project Director
Sydney Bolland

Pembroke College, Cambridge

20 This two and a half year study concerned a complex of mainly mediaeval and Victorian buildings. In the first year, cost savings of 16% were achieved, with no capital works, balancing fuel price inflation. Over three years, energy consumption reduced by 45% and costs by 54%, with full payback of capital costs and fees.

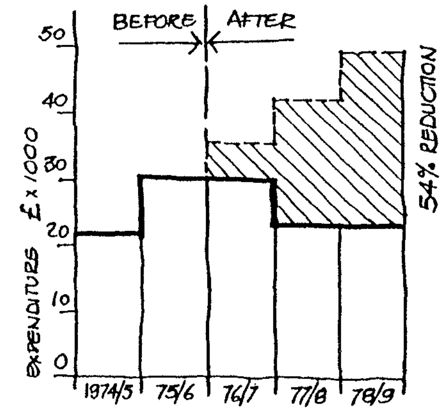


Annual energy consumption

Though all savings must to some extent reflect initial deficiencies, Pembroke College did not start from an outstandingly bad position. Its buildings had been extensively renovated over the preceeding 16 years, most had relatively modern heating and hot water systems, roof insulation and well-fitted windows. Prior to the programme, the College's heating energy index was slightly less than one of its modern neighbours, and its energy bill was 40% less than an old public school nearby. With such a background, many building owners might wrongly conclude that little further could be done.

This study began with the methodical logging and testing of all existing energy consuming systems. As is frequently the case with older buildings, mechanical services had been installed piecemeal over many years, with no full record and with no one person having full understanding.

The survey comprised not only the operating efficiency of the existing systems, the monitoring of fuel consumption, space and water temperatures, and the assessment of average and peak heating loads, but also scale drawings were prepared and patterns of use analysed. A detailed audit was instituted of energy purchases, use distribution and annual variations.



Annual cost of fuel and maintenance

Before alterations, there were four oil-fired boilers, one solid fuelled steam boiler and two small gas-fired units. Incoming fuel passed through 12 main electricity meters, 9 main gas meters and 3 oil storage tanks. In addition, there were some 300 gas and electricity bye-meters.

Following the main plant alterations, the bulk of the heat generation was centred on a single main boiler, installed in 1970, but not previously fully-loaded. It was now converted from oil to gas-firing, to take advantage of a cheaper and more reliable fuel and because gas consumption may be more readily monitored.

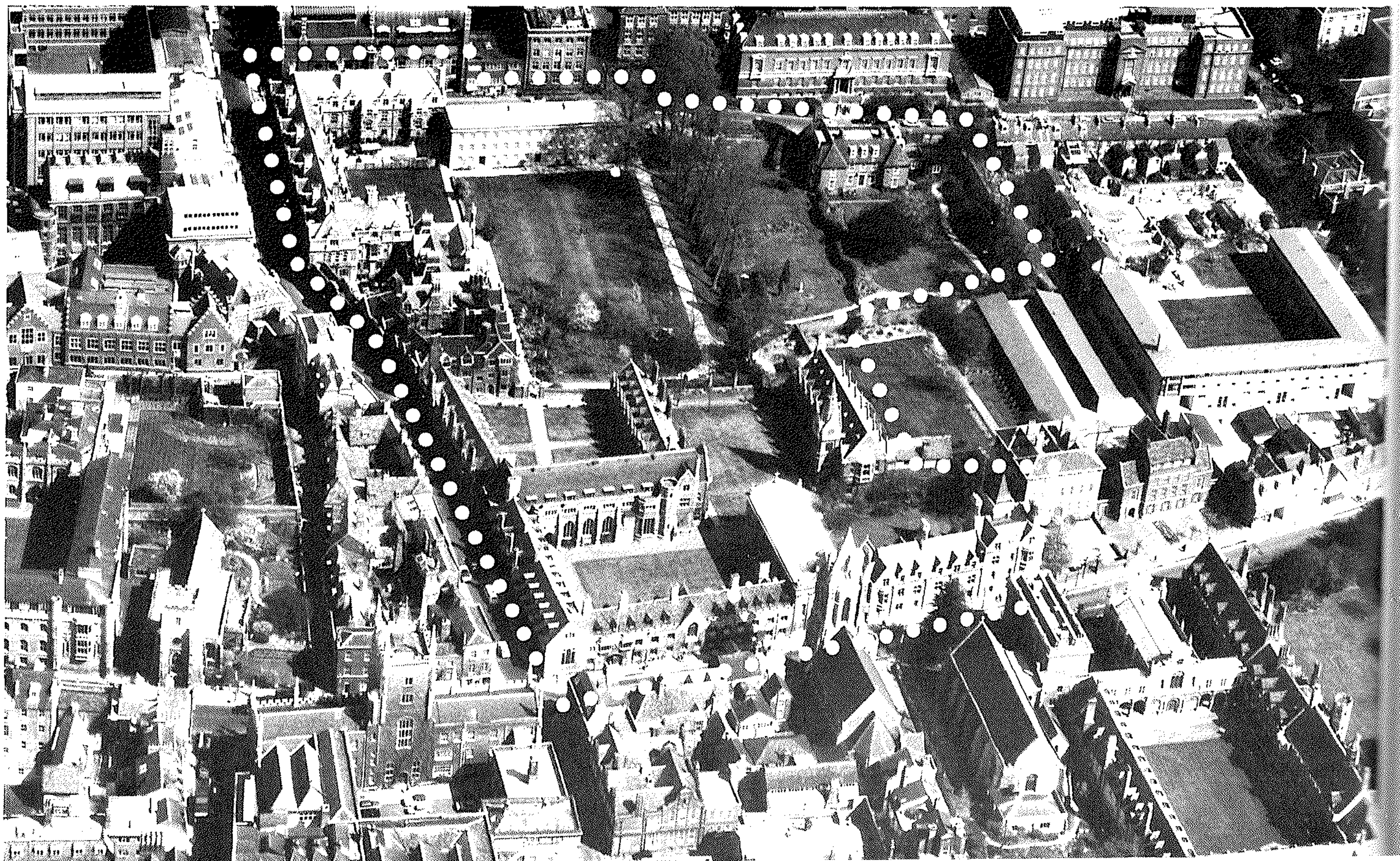
The essence of the new strategy was the central generation of heat in a modern boiler working close to its maximum capacity, and distribution in well-insulated mains to a series of 'service rooms'. These house controls and pumps compensated heating subcircuits and calorifiers for domestic hot water.

Cost and effect of measures

(a) Plant alterations accounted for 70% of £30,000 total capital expenditure on conservation measures and reduced energy consumption by 25% (56% of the total saving).

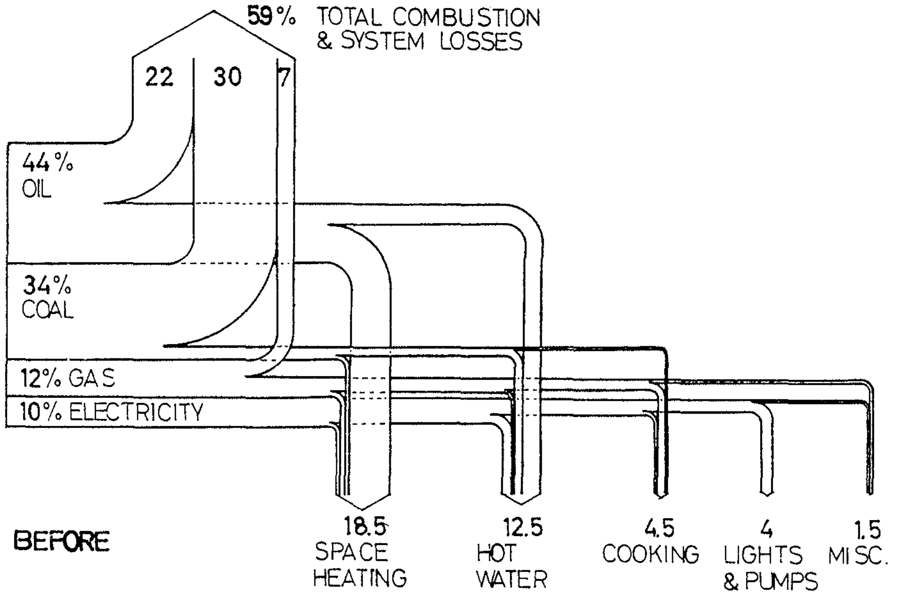
(b) Management measures reduced energy consumption by a further 17% (38% of the total saving). These cost very little (less than £600, or 2% of total capital cost) but were closely dependent on the plant alterations: a system cannot be 'driven' unless it is responsive and it should also be simple. Management measures included the close adjustment of previously arbitrary space temperatures and the adoption of a dual standard heating day, giving 15.5°C before noon and 18°C later. Each room has supplementary gas or electric heaters for residents who are prepared to pay for higher temperatures. The use of electric water heaters was discouraged, domestic hot water temperature was limited to 50°C and staff were exhorted to close windows.

(c) Structural insulation accounted for 28% of total capital cost for a predicted energy saving of only 3% (6% of total saving), indicating that the advantage of further insulation was marginal. The old buildings had inherently good thermal properties. In most cases thick brick and masonry walls and

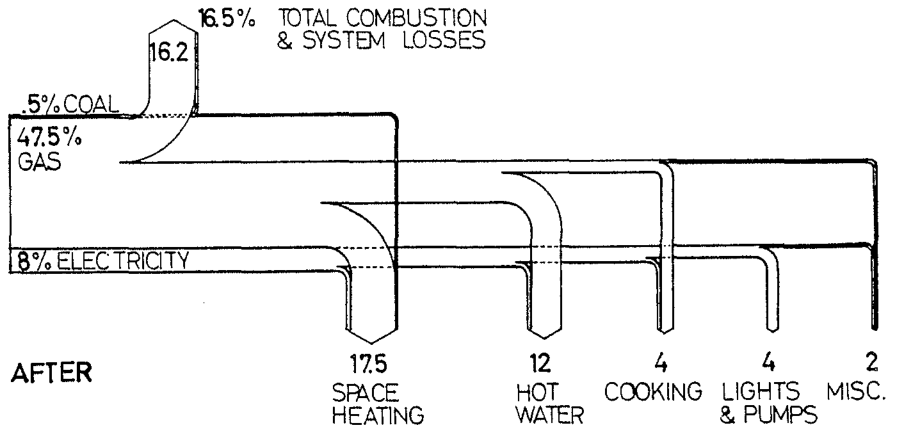


heavy, timber lined roofs with 25-50mm ceiling insulation (added during the previous renovation programme) had put 'U' values up to or above the standards of the pre-1975 Building Regulations. Nevertheless, further roof insulation was added to a standard equivalent to Part FF of the current regulations. This provided increased comfort in attic rooms, some of which did not have full central heating.

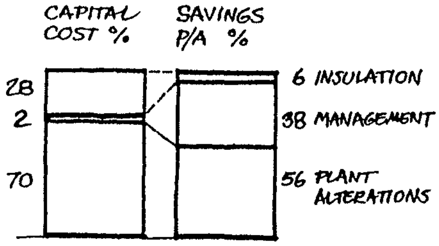
The practical alterations and management measures were planned with the aid of the British Gas computer programme 'Therm'. 14 simulations were made consisting of different insulation measures, ventilation rates, comfort levels and heating periods. Peak and average heat loads were checked to validate the basic heat generation and distribution strategy and the effect of individual simulations — for example, the addition of a further 25mm of roof insulation — enabled the calculation of the cost-benefit of various measures, both individually and in interrelationship with other measures.



Total fuel use per annum Primary 5.6 × 10⁶ kwh **Delivered** 4.2 × 10⁶ kwh **(Primary: Delivered Ratio 1.3:1)**



Total fuel use per annum Primary 3.4 × 10⁶ kwh **Delivered** 2.3 × 10⁶ kwh **(Primary: Delivered Ratio 1.5:1)**



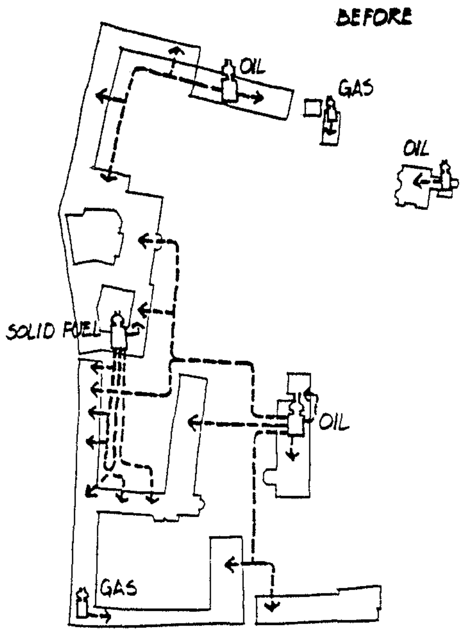
Comparison of capital cost and percentage savings

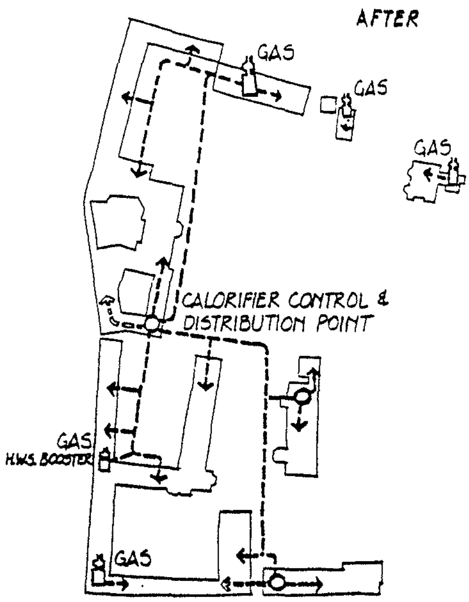
The chosen measures all satisfied the following methods of cost-benefit analysis:

(a) Comparison of annual saving, with a 12½% simple interest return on capital outlay in alternative investment.
(b) Capital payback period related to the anticipated life of the measure.,
(c) Annual saving related to total 'annual cost' based on interest in alternative investment at 12½% and linear depreciation.
(d) Derivation of the 'equivalent present value' of future savings over the life of measure under each of six scenarios of interest and inflation rates.

Developments, such as solar assisted water heating, were examined but seen to be much less effective than doing simple things properly, on the basis of full understanding.

Such a programme demands a lot of consultant's time at the outset, when the benefits to the building owner are seldom apparent. Also, the problems of conducting a thorough 'energy audit' in a complex of buildings are immense. One of these concerns the recording of temperature profiles in each room. This has now been solved by Anglian Architects who have developed a solid-state memory-store temperature recorder, which may be distributed around a building and then, after a period of measurement, variable both in frequency and length, 'de-briefed' by PET microcomputer.





Pembroke College Cambridge		
Date of completion	January 1978	
Capital cost	£31 000	
Occupancy Full time for 26 weeks per year by 230 students and staff others use facilities to a variable extent, additional occupancy for conferences to the extent of about 5 000 bed-nights per annum		
No of persons	525	
Persons per m²	0.04	
	m² (before)	**m² (after)**
Usable area	12 402	unchanged
	m³ (before)	**m³ (after)**
Usable volume	not available	
Delivered annual energy consumption Measured for previous consumption with estimates made for conservation study with British Gas 'Therm' computer programme, later validated by measurement		
	kwh (before)	**kwh (after)**
Total	4.2 × 10⁶	2.3 × 10⁶
Per m²	339	188
Per m³	not available	
Per person	occupancy too variable	
Primary annual energy per m²	455	275

Client
The Master & Fellows of Pembroke College

Address
Trumpington Street, Cambridge CB2 1RF

Architects
Anglian Architects

Environmental Consultants
S.F.S. Whitehouse and British Gas Corporation

Energy Economy in Government Buildings

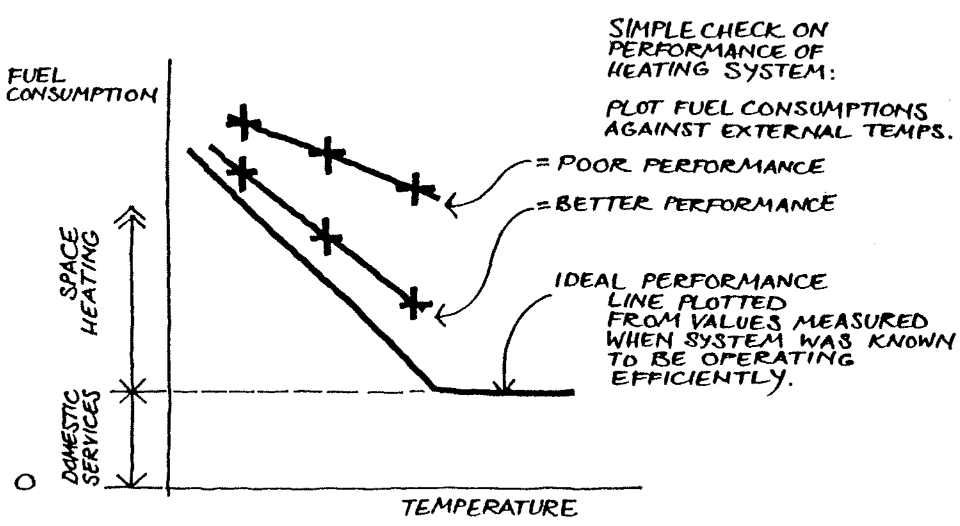


Fig. 1. *Simple check on performance of heating systems*

21 The Property Services Agency of the Department of the Environment is responsible for most Central Government Buildings.

In 1972 a Headquarters Fuel Economy Unit was set up to develop a centralised approach to the efficient use of energy and to exploit all possible ways of reducing expenditure. Early work concentrated on the development of Optimum Start Control in selected Crown buildings. At the same time Fuel Economy Officers were appointed in the PSA Territorial Organisation to assist in supervision of contracts and promote the efficient use of energy.

The OPEC crisis in 1973 caused work to concentrate on improvements in plant management. A training programme for Technicians and Craftsmen was instituted, together with the introduction of a new grade of multi-disciplinary Craftsmen and a procedure for monitoring the performance of heating systems. At about the same time it was decided that:

(a) An overall reduction of 30% on the 1972/3 annual fuel consumption should be achieved over a five year period from 1974. In 1977 this target was increased to 35% with no time limit.

(b) Nationally agreed environmental standards should be maintained.

(c) All measures should be cost effective.

(d) The conservation programme should be self financing using the savings achieved in one year to pay for the capital investment of the next.

(This policy has not been implemented in practice. Funding of fuel economy measures is now related to a commitment made to the Department of Energy to increase expenditure by a further £5m per annum.)

A programme of work was established under three broad headings:
1 Encouragement of Good Housekeeping by building users
2 Investment in Technical Measures
3 Plant Management

Good Housekeeping Measures
A publicity campaign launched in 1974 was aimed at the elimination of unnecessary use of energy consuming services. The initial response was encouraging, particularly in reducing electricity consumption, but current indications are that the benefits of propaganda may have peaked.

Studies showed that a major factor in the cost of lighting office buildings was the practice of cleaning during the hours of darkness. Cleaning contracts have now been re-arranged, taking energy costs into account.

A simple and effective method for measuring the performance of individual heating systems has been devised to direct attention to abnormally high consumption in any building. Fuel consumption and average outside air temperature are plotted at regular intervals and checked against previous values. (Fig 1) By this means abnormalities can be identified rapidly and it appears that the sophistication of the degree day system is not necessary. Up to now, the monitoring system has been used to detect installations in which control systems are not operating correctly, for example, where consumption is not related to weather. A further application will be the assessment of actual full load fuel requirement. Where burner capacities exceed these requirements a reduction in burner size may be possible to more accurately match the load, resulting in an increase in boiler efficiency.

An improved system for monitoring and recording the consumption of each separate fuel in individual establishments is currently under development.

Technical Measures
There is ample scope for improvements in the control of heating systems both in the operation of boilers and the control of heating demand. However, hopes for savings by the introduction of automatic lighting controls have not yet been realised and new switching or dimming devices are still under test. The development of solid state technology in conjunction with lower manufacturing costs is likely to introduce some scope for automatic control systems. Thermal measures, such as loft insulation and cavity filling have proved cost effective in cases where controls are adjusted to avoid excess air temperatures.

Plant Management
Improved plant management has accounted for the major proportion of savings achieved to date. Improvements were initially made through an intensive training programme on heating system controls and more effective application of the Agency's standard maintenance and operation procedures which covers all the most important and sensitive items of plant and equipment. The introduction of a new type of highly skilled multi-trade craftsman has also made a significant contribution.

Heating, ventilating and air conditioning control systems require a combination of mechanical and electrical skills which are not usually taught to engineering craftsmen. In order to generate the necessary skills a grade of Engineering Plant Operator (EPO) was created based on a four week training course, supplemented by on-the-job instruction on controls and control systems. The EPO's undertake regular inspections of boilers and heating control systems, adjust them to produce a high level of operating efficiency, undertake first-line maintenance and report serious faults for repair.

Conclusions
Considerable improvements in the average annual energy consumption have been made. Variation in consumption between different buildings is large (Table 1), remaining consistently at about 4:1 over a 4 year period (at 95% confidence limits). With such a wide spread it is unrealistic to introduce energy consumption targets/norms. The reasons for these variations are being studied and, although firm conclusions cannot be made at this stage, it seems that the dynamic performance of buildings need to be understood better and that 'steady state' calculations may not be an adequate guide to fuel consumption.

Table 1. Energy consumption heating and DHW – Gj/m² p.a.

Year	Mean	95% Confidence Units
1972/73	1.46	0.7 – 3.1
1973/4	1.39	0.72 – 2.7
1974/75	1.23	0.6 – 2.5
1975/76	1.2	0.6 – 2.5

Sample based on 54 randomly selected daylit naturally ventilated intermittently heated office buildings spread – 4:1 (95% confidence limits)

A peak saving of over 30% was achieved in 1976/77. In financial terms, the annual savings for the Civil Estate alone are worth about £18m. (Fig 2)

It has not been possible to identify the exact proportion of savings resulting from Good Housekeeping, Technical and Plant Management measures as they interact with each other. However, the following list shows how these can generally be ranked in order of effectiveness:

1 Plant Management
Improved operation techniques, performance monitoring and training maintenance and operational personnel.

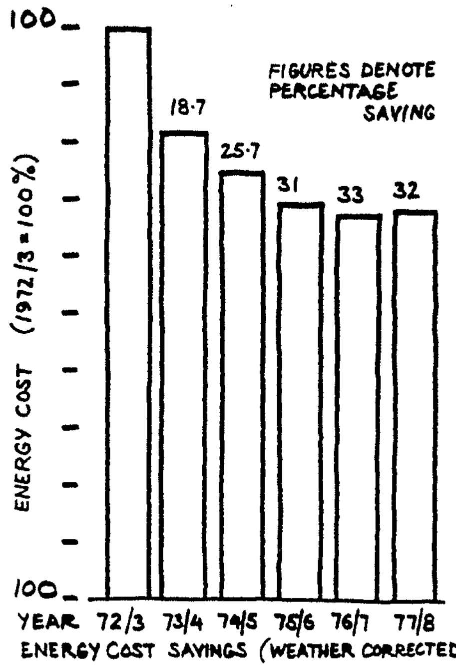


Fig 2. *Savings arising from the energy conservation programme for the UK Civil Estate related to actual expenditure incurred in 1972/73, revalued to take account of price increases, variations in weather and changes in the size of the estate. A peak saving of over 30% was achieved in 1976/77. In financial terms, the annual savings for the Civil Estate alone are worth about £18 million.*

2 Optimum Start Control
Replacing night set-back control systems in heating installations over 100 kw installed capacity, and where heating is required for less than 14 hours per day.

3 Simple Time Controls
Replacing night set-back control systems in intermittent heating installations below 45 kw installed capacity.

4 Optimum Charge Control
To regulate the charging rate of off-peak electrical storage heaters used in commercial buildings.

5 Power Factor Correction
Of inductive loads in industrial/commercial type accommodation.

6 High Pressure Sodium Luminaires
Replacing tungsten or combined mercury and tungsten luminaires for floodlighting, hangar and workshop areas, provided the tasks to be illuminated are not critically dependent on colour.

7 Internal Space Temperature Control
Individual and zone controllers in buildings otherwise using weather compensated control only.

8 Roof Insulation
In uninsulated roofs

9 Cavity Wall Foam Fill

10 Internal Insulation
Roof spaces and walls in workshop/store areas

11 Draught Stripping
Cost effectiveness is uncertain

The following case studies show the effectiveness of different measures when first applied under test conditions and then in other buildings.

Intermittent Heating — Optimum Start Control

Though the benefits of Intermittent Heating were well known for a number of years, its application was limited until the development of the Optimum Start Control. Tests were undertaken to compare optimum start controls with the existing night set-back system in a multi-storey office building in Central London.

The heating system consisted of three hot water boilers, one control valve and pumping sets serving a radiator system, with a separate summer hot water boiler.

As these tests were carried out under strictly controlled conditions, which would not normally be the case in practice, PSA assumes that Optimum Start Control saves only about 10% of consumption compared with Fixed Time Start Control and about 25% against Night Depression Systems.

A second-generation of these controllers is now available, using solid-state electronics which are easier to adjust and maintain and which also may become cheaper.

Optimum start control has been applied throughout the Civil and Defence Estates in offices, workshops, barracks, stores, hangars and schools. It is applied to buildings which are normally occupied for less than 14 hours per day and the higher cost of the equipment over other forms of time control generally limits its use to heating systems of over 100 kw installed capacity.

Experience gained over the last 7 years indicates that for an average size building of about 250 kw installed heating capacity, the capital cost of converting Night Depression Systems to OSC is normally recovered within two years. On large installations pay-back periods have been under 1 year.

Electric Storage Heating — Optimum Charge Control

Simple off-peak electric storage heating uses a thermostat for the user to control the charge. In practice, users alter the controls only at infrequent intervals. Consequently, off-peak storage heaters take in a greater charge than is needed and so will give out unnecessary heat later on. An Optimum Charge Control Unit (OCC) was fitted to regulate the charging rate in order to improve an off-peak electrical storage heating system, controlled from a central time clock in a pre-war, two storey office building in Aldershot.

An OCC unit will vary the amount of charge required, based on the exponential change of outside temperatures of the previous night. However, linking of charge to ambient temperature may result in more frequent failure to supply sufficient heat because the system cannot anticipate sudden changes in ambient conditions.

Measurements were taken on a monthly basis during 1976/77 and 1977/78. The overall savings were between 30 and 35%. As the tests were carried out under controlled conditions, an allowance must be made for practical limitations under normal use, and a savings figure of 25% is normally assumed for economic appraisal purposes.

The cost of the OCC unit and installation was about £100.

Annual cost savings, weather corrected, were £1,300. The rapid pay-back for this particular installation was possible, because of the easy installation of one OCC unit to control the charge demand to a large network of heaters.

Maximum Demand — Power Factor Correction

A number of Electricity Supply Authorities impose cost penalties for low electrical power factors in buildings because of the additional generator capacity needed. It is therefore in the interest of the Supply Authority and the consumer to keep the power factor as high as possible. Power factor correction can be achieved by installing static capacity banks either at the electrical supply intake to an establishment or at high induction load centres and by synchronous motors at the intake. There are, however, economic limits to the application of power factor correction equipment.

Static capacity banks were fitted at the electrical supply intake of an office building in Maidenhead to correct the lagging power factor to the minimum required by the Supply Authority.

A reduction in maximum demand of 17 kVA has been achieved which produced savings of about £350. At 1978 prices, the cost of supplying and installing power factor correction equipment was £773. Capital would therefore be recovered in 2.2 years. However, the savings achieved by this method are principally cost, not energy savings.

High Pressure Sodium Lighting

Lighting systems around hangars and aircraft hardstanding has often been fitted with tungsten or combined mercury and tungsten luminaires. The high pressure sodium luminaire has presented opportunities of maintaining lighting standards with reduced energy consumption. Tests have been undertaken at a number of Government sites to assess their potential and satisfy users that colour rendering was suitable and that there were no stroboscopic or glare effects. The colour of the light is adequate for outdoor use and in selected workshop/store locations, provided the tasks are not critically dependent on colour.

Two initial tests were made. At a vehicle workshop 150 watt high pressure sodium luminaires (SON) replaced 500 watt combined mercury and tungsten filament luminaires (MTBL). The total conversion cost using pre-wire kits for each luminaire was £59.25 at 1978 prices. Annual cost savings for each luminaire were £21.70. An aircraft hardstanding had been floodlit by 110-1000 watt tungsten filament luminaires. Using the Department's "Floodlit" computer programme it was found that the existing installation could be replaced by 60-400 watt high pressure sodium luminaires without reducing lighting intensity.

The total cost of conversion including labour and materials was £900 at 1978 prices. The estimated electrical saving based on an annual use of 4000 hours and 1978 prices was £750, resulting in a payback period of between one and two years.

Actual savings are likely to be greater as reductions in annual maximum demand (80kw) are not in the calculations. It should be noted that the savings with respect to other forms of lighting, such as high pressure mercury, would be considerably less.

Internal Temperature Control

The heating systems in many office buildings are only controlled by weather compensator controls. These regulate water temperature in relation to outside air temperatures and cannot take account of variations in internal conditions resulting from solar radiation, occupants etc.

In 1978, tests were made in a five storey cellular office in London to measure the energy savings produced by the addition of internal temperature controls to an existing weather compensated system. The work was supported by a detailed computer analysis.

The office block is built of solid brick. Offices face east/west and are about 50% glazed.

The existing heating system consisted of low temperature radiators with a single weather compensated controller and an Optimum Start Unit. The building was occupied five days a week.

Thermostatic radiator valves were fitted to most radiators. In addition, diverting circuits with room thermostats were installed at the end of each pipework loop to maintain water circulation.

The costs at 1978 prices were:

Cost of purchasing valves and associated equipment	£992
Installation cost	£990
Total cost	£1,982

INTERNATIONAL ENERGY CONSERVATION MONTH · OCTOBER 1979 · SAVE IT

The resultant fuel savings were between 11% and 24% with an average of 16.5%. This represents a cost saving of £577 and a pay-back period of about three and a half years. There seem to be no problems of maintenance.

Thermal Insulation

Insulation of the walls and roof of a store shed in Oxfordshire was undertaken. The building, a steel frame, asbestos clad structure ('U' value 5w/m²°C) with perimeter solid 225mm brick walls to a height of 1500mm ('U' value 2.67w/m²°C) has six pairs of sliding doors and is heated by oil fired warm air.

Plastic faced plasterboard wall lining with a 35mm thick polyisocyanurate backing improved the 'U' value to 0.6w/m²°C — these have a low spread of flame. This sandwich is fitted into a lightweight metal tee bar and channel grid system, with cavity barriers and fire stops at roof/wall junctions and at 20 metre centres vertically in the wall.

A new suspended ceiling of plastic faced plasterboard with a 12.5mm polyisocyanurate laminate insulation backing, for the wall lining, was also fitted into a lightweight metal grid tee bar system and overlaid with 100mm of fibreglass giving a 'U' value of 0.6w/m²°C. The whole system is suspended from the steel roof truss members.

The cost of the energy conservation measures, including the installation of a self-extinguishing plastic strip curtain to all door openings in regular use, was £32,000. Actual cost savings were about £6,300 resulting in a pay-back period of five to six years.

Thermal Insulation

Insulation of the walls of two and three storey Ministry of Defence type accommodation was accomplished by filling cavities with foam.

The building was originally constructed of 11" cavity walls with a 'U' value of 1.7w/m²°C. The total wall area was about 20,000m² and the insulation was improved by filling the 50mm cavity with a proprietary foam under a bulk contract. The calculated improved 'U' value is 0.45w/m²°C.

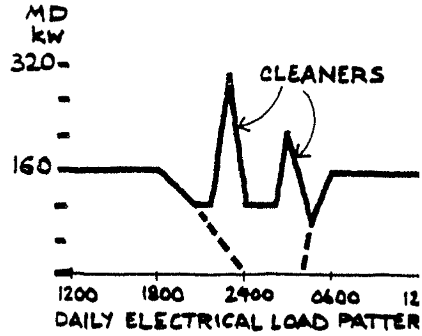
The total cost, including labour and materials was £12,400.

Estimated Consumption and Cost Savings 1977/78 prices are: 95,000 litres saving £6,600.

The payback period is about two years. Th bulk purchasing arrangements for cavity foam was a significant factor in the short pay-back period.

Good Housekeeping

A major factor in the cost of lighting offic buildings is the practice of cleaning during the hours of darkness. Usually, office workers will switch off lights when they le at the end of the day, but when the cleaner move in, all the lights tend to be switched again. The effects of this are shown in the diagram. Dotted lines show the effect on consumption, if cleaning is restricted to th beginning and/or end of the day. The effe



of such action on both electricity demand and costs are illustrated in buildings monitored from September 1973 to Augus 1974. This single action can save 18% on energy, 23% on maximum demand and result in a total net cost saving of 19%. Fr this experience, the lesson is clear. Cleanin contracts need to be arranged with energy cost in mind.

Good Housekeeping

	Night-time Cleaning	End of Day Cleaning
Annual unit consumption	2 049 440 kwh	1 688 741 kwh
Highest MD recorded	800 kw	600 kw
Annual unit cost	£16 908	£13 820
Annual MD charges	£6 722	£5 200
Total electricity cost	£23 680	£19 020

Comparison of recorded consumption and cost of office cleaned overnight and estima consumption and cost of office cleaned at beginning and end of a working day

Energy Economy in Government Buildings

Architects, M & E Engineers, Quantity Surveyors, Struct Engineers, Monitoring Organisation
Energy Conservation and Economics Group, Property Serv Agency of the DOE

Elderly Persons Home Essex

A number of energy conservation measures have been applied to a residence for 62 elderly people since 1976 and their effect has been monitored.

The home is normally heated to 70°F until 9 pm. This is usually sufficient to allow residents to retire up to midnight. From 5 am onwards, hot water and heating is required in bathrooms and consequently heating is on a fixed time start from 3.30 am. Between 9 pm and 3.30 am, extensive laundering is carried out.

All rooms are heated by radiators fed from two oil fired boilers which also heat the water. Electricity is used for lighting and general power, gas for cooking.

In the spring of 1975 the following improvements were made:
1 Roof Insulation: 889.26 sq. metres of 100mm blown pelleted mineral wool fibres.
2 Cavity Wall Insulation: 1018 sq. metres of cavity foamed with MPS urea formaldehyde foam.
3 Draught Stripping: approximately 300 metal framed windows and some external doors treated with silicon sealant to form draught exclusion gasket.
4 Air Vents: a number of 9" x 9" air bricks were sealed.
5 Chimneys: a copper shield secured by wing nuts, was fitted across the opening to Baxi underfloor draught open fire places to reduce loss of heat by under-floor draught. The shield can quickly be removed to allow fireplaces to be used if required.

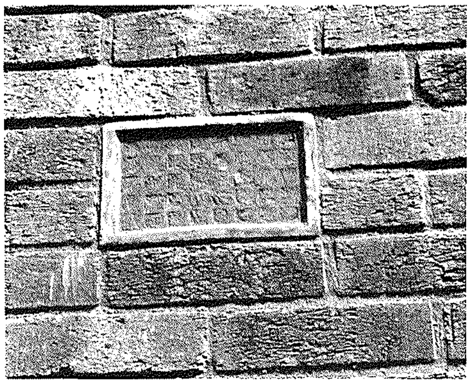
Following a publicity campaign for energy conservation, some savings occurred, but subsequent to insulation works a further 23¼% average annual saving has been made. The capital cost of £2,400 for the work was expected to be recovered within three years, but escalating fuel costs have accounted for a saving of £1,800 per annum at current prices.

A further cost reduction will occur when the boilers are converted to gas. This is being done on the grounds of lower fuel cost and better security of supply. However, a further 10% saving is expected due to reduced burner maintenance, boiler life, payment for fuel retrospectively instead of at delivery, avoidance of leakage and spillage risks, saving on space and avoidance of attendance on fuel deliveries.

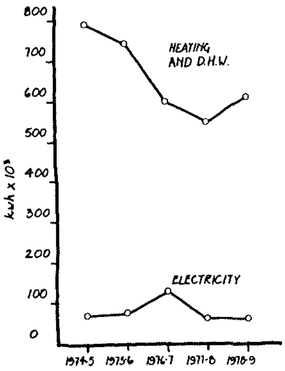
Two unexpected economies resulting from the insulation works:

(*a*) The residents have reduced from the normal 3 to 4 blankets per bed to 2 to 3 blankets per bed. As a result, fifty fewer blankets are in use with a corresponding saving in laundering (which is high for the incontinent).

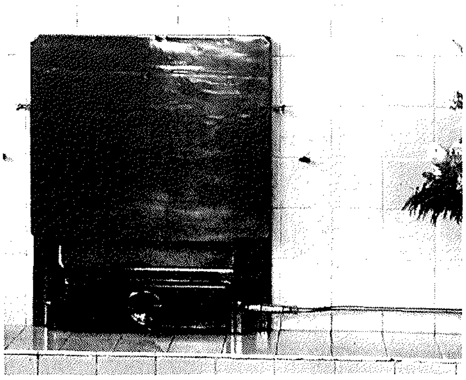
(*b*) There are fewer repairs to clothing. This is difficult to evaluate but the staff think that they stitch on fewer buttons due to the reduction of draughts. Less clothing is now worn by the elderly, who tend to pull at buttons, particularly on cardigans, which are removed and returned quite frequently if temperatures vary, or draughts are experienced.



Unnecessary air bricks are blocked up



Heating energy reductions since 1975



Covers for unused fireplaces

The occupants now need two blankets instead of four.

Elderly Persons Home, Essex

Client
Essex County Council

Address
Rayleigh Sweyne Court E.P.H., Hockley Rd., Rayleigh

Architects, Monitoring Organisation
Essex County Council Architects Department

Energy Improvement Kit Birmingham Project

23 The objective of this study is to develop an Energy Improvement Kit which can be used by local authorities and other building owners, as the benefits of improving the thermal performance of existing housing are likely to be greater than those gained by improving the thermal performance of new housing. HDD has begun to explore the scope and problems of a thermal improvement programme in collaboration with the City of Birmingham and the Polytechnic School of Architect at Birmingham. The stock of 150,000 dwellings consists of a wide variety of building types, most dating from 1919 onwards.

The City is undertaking the project in two phases. The first phase involved a random sample survey of 5,000 dwellings and concentrates on those aspects of the dwellings and their occupation around which energy saving programmes might be organised. The second phase, which began in July 1979, is intended to examine the results of the main survey through computer analysis of information concerning the fabric and condition of typical dwellings classified by energy type. It will also monitor a project, funded by the City, before and after the improvements are made.

Phase 1 — Survey
The results of this survey can be summarised as follows:

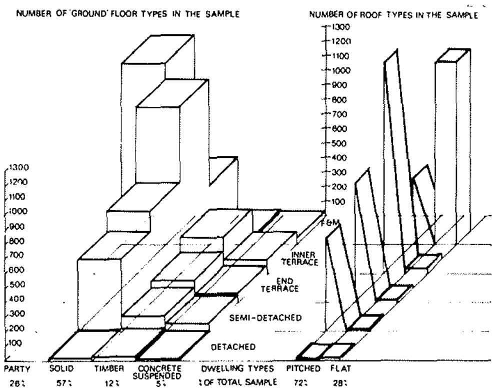
Dwelling Types
The preponderence of older terraced or semi-detached houses and post 1940 flats and maisonettes gives some indication of the scope of problems likely to be encountered in a thermal improvement programme. The range of building types in these categories is very wide, but this information provides an improved sample frame for deriving more precise categories of dwellings.

Dwelling Types in the Sample	
Flats & Maisonettes	36.3%
Inner Terrace Houses	31.1%
End Terrace Houses	17.8%
Semi-detached Houses	13.8%
Detached Houses	0.8%

Age of Dwellings	
Pre 1919	4.7%
1919-39	28.3%
1940-63	28.3%
1964-69	21.7%
1970+	17.0%

Number of 'Ground' Floors
The advantages and difficulties of insulating ground floors have not been fully researched, but those dwellings with timber suspended floors might benefit from floor insulation.

Ground Floor Type	
Party	26%
Solid	57%
Timber	12%
Concrete Suspended	5%



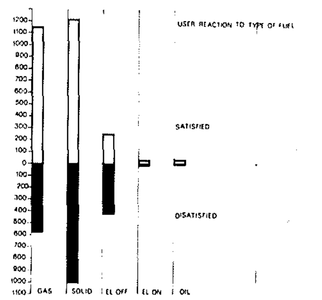
Roof Types
Loft insulation is inexpensive and simple, provided roof spaces can be ventilated. Approximately seventy per cent of the stock in Birmingham could benefit from existing subsidies but the complexity of some roofs may lead to some difficulties.

Roof Type	
Pitched	72%
Flat	2%
Party Floors	26%

Windows and Doors
Only 6.8% of the windows in the sample had weather-stripping while only 16.7% of all dwellings had draft lobbies. The obvious advantages, in terms of ventilation control, of at least weather-stripping windows is easily appreciated.

Wall Construction
The quantity of solid wall dwellings suggests that improvements in external wall insulation may be difficult and probably expensive for most of the Birmingham stock. Most of the 'other' constructions refer to 'non-traditional' flat and maisonette blocks where appropriate measures for improvement will require careful consideration.

Type of construction	
Solid Wall	34.3%
Rendered Solid	8.1%
Cavity Wall	34.8%
Other	22.6%



User Reaction to Fuels
Gas provides the greatest degree of satisfaction but dissatisfaction is most marked with off-peak electricity. Reaction to solid fuel is divided equally between users.

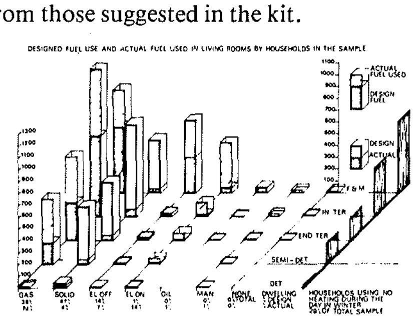
Design Use & Actual Fuel Use
Conversions from solid fuel to gas and under-use of off-peak electricity, with an increase in the use of on-peak electricity have accounted for the major changes from designed to actual fuel usage. Perhaps 30% of households heat their homes intermittently.

Fit of Actual Occupancy Compared with Design Occupancy
Family dwellings appear to be under occupied while dwellings for small households seem to be scarce. Consequently, a significant number of small households may be required to heat more space than they might use. Alternatively, they may heat only the living areas which could cause condensation problems in the un-used rooms.

Detailed diagrams of the data will help to provide a comprehensive description required to plan a thermal improvement programme for the Birmingham housing stock.

Phase 2 — Development
The main survey data will be analysed in greater detail to categorise dwellings with similar patterns of energy use. A sample of between 200 and 400 dwellings covering these energy types will be surveyed in detail. About thirty representative dwellings will then be improved by the City. Monitoring of existing patterns of use and the effectiveness of heating systems, draught proofing etc. will take place over the winter of 1979/80, during which time designs for appropriate levels of improvement will be developed. The cost-effectiveness of any measures to conserve energy should be considered in conjunction with the type of dwelling, its heating system and any other remedial works. They should not be assessed in isolation. Work will be carried out during the summer of 1980 to enable further monitoring during the next winter. This will provide a comparison with the first winter's results to aid in the interpretation of data from the larger surveys.

The Energy Improvement Kit
While the final form of the kit will depend on the results from Phase 2, it will be used to allow local authorities and other building owners to make assessments of their own stock, either by identifying energy types most similar to their own buildings and constructing a model based on up-to-date records, or by mounting a survey using methods selected from those suggested in the kit.



Research Team
Housing Development Directorate of the DOE (West Midlands Regional Office), School of Architecture at Birmingham Polytechnic and City Housing Architects and Engineering Departments. Coordinated by the Housing Management Department.

The Better Insulated House Programme

Housing Development Directorate of the Department of the Environment

24

This programme was the first and largest of HDD's current studies into energy conservation. It was started in 1974 and on completion in 1982 will have included nine UK projects. It includes both existing and new public sector housing in a variety of constructional forms, covering a range of households. The following descriptions of six of these projects show a number of useful teaching points.

All but one of these projects comprise test and control groups, each of about 20 dwellings. The test dwellings are insulated to about twice the present mandatory standard. The initial purpose of the exercise was to measure the cost-effectiveness of the insulation under real conditions and to see what technical barriers there might be to widespread adoption of new standards. The results that have been analysed indicate that it would be cost-effective to adopt such standards in place of the present ones, but that quality and detail of construction are crucial if building failures are to be avoided.

The monitoring of these projects has proved that in existing buildings which have been insulated, heat loss can be reduced by between 20 and 35% and total energy savings during the heating season can be reduced by between 15 and 25%. However, if insulation reduces the load on the existing boilers and these cannot be efficiently operated under the new conditions, no real energy saving occurs.

The other result of insulation is an overall rise in whole-house temperatures of between 10 and 15%. Some condensation problems have arisen from inadequate ventilation of roof spaces following insulation.

In new buildings, a variety of insulation levels, ventilation methods and heating systems were shown to provide highly efficient dwellings with much lower energy demands than the control dwellings to which they are compared. Certain initial results concerning ventilation and air-flow indicate that, due to the aging of the structure inadvertent ventilation does not remain constant over the life of the houses and heat loss, due to such ventilation, may increase above that measured immediately after the completion of the building. In the case of an example where mechanical ventilation was introduced, variations in windspeed led to uncontrollable over-ventilation more than half of the time. Finally, sociological studies indicate that although it is possible to educate people to be more energy conscious and thus reduce consumption, a concern for conservation is not always sustained.

The BIH programme has shown a good deal about the thermal performance of houses and heating systems as well as about the behaviour and preferences of tenants. These findings are relevant to the achievement of energy savings, in both new design and in the energy improvement of existing houses. New hypotheses have emerged about the design and layout of houses, heating systems, controls and natural ventilation. These will need to be tested out in further projects before they can be confidently recommended for adoption, and it is important to continue studies of the large bank of data which is still being acquired.

The team of Universities and Laboratories involved in this work has enabled important cross-fertilisation of expertise. This process is significant because all aspects of energy conservation are interactive. It will be some years yet before the 'ordinary energy efficient house of the future' emerges though a number of its design features and equipment can already be identified.

Plymouth Project (Retrofit)

These cavity walled terrace houses built in 1965 have gas fired warm air heating to the ground floors only with some electric living room fires and the hot water is provided by electric immersion heaters.

The calculated heat loss was reduced by about 22%. However, the effective energy saving was only about 15% of the total consumption as there was an increase in whole-house temperature of about 11%, both in living and bedrooms. Increases in bedroom temperature were to be expected, those in living rooms were unexpected and have been due to the use of supplementary electric heating or simply to the tenants desire for hotter living rooms. This would explain in fact that while saving in gas was achieved, there was no saving in electricity.

Some houses had suffered damp through cavity bridging but all known instances of this were corrected before the project started. After cavity filling more problems occurred, so further remedial work was needed. A tendency to bring out hitherto undetected building faults appeared to be one of the commonest problems of cavity fill.

	Living	Kitchen	Hall	Bed
Control houses	17.8°C	20.8°C	16.9°C	14.0°C
Highly insulated houses	18.9°C	20.3°C	18.8°C	15.2°C

Average temperatures from 1st December to 29th February

	Gas
Control houses	440 Therms
Highly insulated houses	325 Therms

Average annual gas consumption

Houses
Designed by Plymouth City Corporation

Monitoring
University of Bristol Dept of Architecture (meter reading by South Western Gas Board)

Project
Initiated by HDD

Hamilton Project (Retrofit)

These cavity walled two storey, four in a block, flats built in 1952 have new gas-fired radiator central heating/hot water systems with gas radiant living room fires.

Improved insulation reduced the calculated heat loss of the test flats by about 27%. Sample bias led to an apparent 'nil energy saving' result, but after correcting for bias a 'saving' of 10% was apparent, together with a 13% increase in whole-house temperatures for those flats in the Test Group. Theoretically, the improved insulation may have affected boiler efficiency for although the higher temperatures of the test flats was probably the result of user preference, the control flats were very cold.

A preference for higher temperatures after insulation should be expected in previously poorly heated houses. However, there were great differences in energy use from household to household. It was found that a loss of gas boiler efficiency, following insulation may occur if the boilers are greatly oversized.

	Bed	Whole flat	Living rooms at 2100 hrs
Highly insulated houses	14.4°C	16.6°C	21.5°C
Control houses	12.5°C	14.6°C	19.7°C

Mean temperature in test and control houses

	Gas	Electricity
Highly insulated houses	373 Therms	1028 kwh
Control houses	320 Therms	1050 kwh

Mean consumption over 36 weeks as measured and as corrected for sample bias

	Ave. household size	Ave. net weekly income
Highly insulated houses	3.4 persons	£43.5
Control group	2.9 persons	£29.7

Evidence of household bias due to size and income

Houses
Designed by Burgh of Hamilton

Monitoring and Analysis
BRE Scottish Laboratory

Project
Initiated by HDD in conjunction with the Scottish Development Dept

Whitburn Project (Retrofit)

These cavity walled terrace houses and flats, built in 1961, have partial electric storage heating and radiant on peak fires in living rooms.

The calculated heat loss was reduced by about 35%, but the saving in energy consumption was only 22% in winter with a 14% rise in whole-house temperatures, experienced mostly in bedrooms. This is a good example of the benefits of insulation in the 'partially heated house'. Bedroom temperatures must rise since they cannot be controlled and consequently savings are less than theoretical heat loss reduction.

	Roofs	Walls
Highly insulated houses	0.3	0.45
Control houses	0.7	1.7

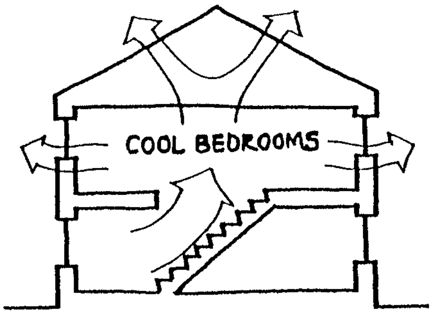
Insulation (U values) standards of test and control houses

Average increase for insulated houses in inside to outside temperature differences

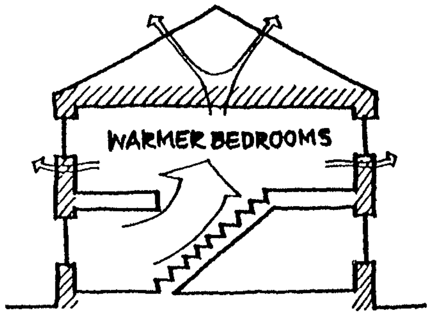
Living room weekly mean	9%
Living room 2100hr	2%*
Bedroom weekly mean	17%
Whole house weekly mean	14%

*Figure not statistically significant.

Average increase of inside/outside temperature difference for different rooms



Heat loss related to insulation level and fabric losses



Reduced fabric losses: concomitant rise in first floor temperatures

Houses
Designed by Scottish Special Housing Association

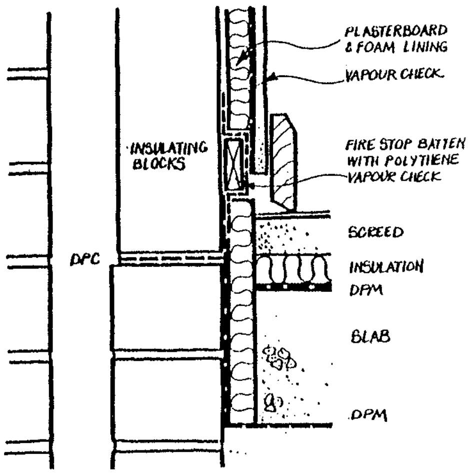
Monitoring and Analysis
BRE Scottish Laboratory

Project
Initiated by HDD in conjunction with Scottish Development Dept

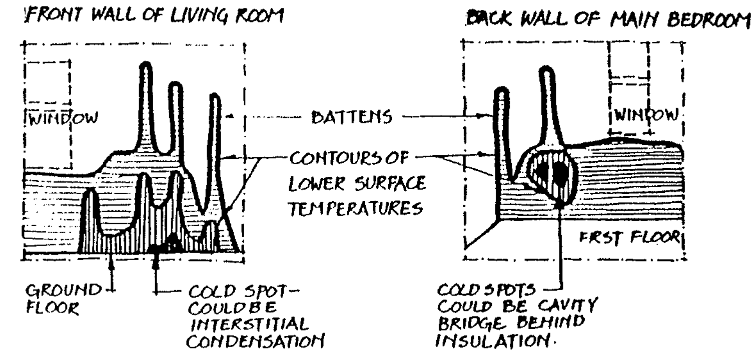
Abertridwr Project (New)

These cavity walled terrace houses being constructed between 1978 and 1980 are provided with insulating dry linings and gas fired radiator heating/HW systems. The highly insulated Test Houses have been given low-powered boilers (8.8kw) in order to test their adequacy for such dwellings. Under SRC funding a sociologist is resident on the site. Tests in the houses before occupation studied solar gain, both with and without heating, but full sample results are not yet available.

The heating systems appear to be adequate to warm the whole dwelling, even in severe conditions, such as those experienced in the winter of 1978/79. Infra-red thermography showed many 'cold spots' in the insulated envelope, mostly due to constructional defects which in conventional dwellings



Schematic section of insulating dry lining, ground floor detail (Experimental detail by HDD/NBA)



Sketches from infra-red thermographs

would be of minor significance. Some cold spots in insulating dry linings could be due to interstitial condensation from vapour barrier failure, but this theory has yet to be confirmed by physical examination in suitable weather conditions. Ventilation tests made just after completion indicated very 'tight' construction. However a year later the same houses were a lot more leaky.

Houses
Designed by NBA (Wales) for the United Kingdom Housing Assoc.

Monitoring
University of Wales Institute of Science and Technology in conjunction with the Rutherford Laboratory, with the help of British Gas Corp. and BRE

Project
Initiated by HDD through the Welsh Office, and jointly funded by the Science Research Council.

Bo'ness Project (New)

The detached, semi-detached and terrace houses of the Bo'ness Project were built in 1977-78 of 'no-fines' concrete construction and are heated by off-peak electric storage/warm air systems with the water also heated by off-peak electricity, since gas is not available. The monitoring is extensive and sophisticated, covering all temperatures, all uses of electricity, heat flow through structural elements, moisture in structural timber, as well as external temperature, windspeed and solar radiation.

analysis will be necessary, including information on family size and structure,

All houses have timber suspended floors and the addition of floor insulation to the Test Houses appears to make a noticeable difference to their response to the heating systems. Also the response of the houses to solar gains is very rapid. The walls of the highly insulated houses dry out more slowly after rain, which could in the long term increase their susceptibility to front damage.

	Space heating	Cooking	Hot water	Small power	Lighting
Highly insulated houses	3812	590	1623	1283	296
Control houses	4947	326	1082	1145	97

Average electricity consumption between late March and early July for thirty houses

Final results are not yet ready, but preliminary data suggests that the Test Houses are using less fuel for space heating and are considerably warmer than control houses. Other factors suggest that a more detailed

Houses
Designed by Scottish Special Housing Association

Monitoring
Heriot-Watt University, Dept of Building

Project
Initiated by HDD in associated with the Scottish Development Dept and part-funded by the Science Research Council

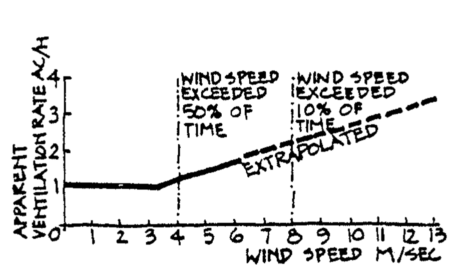
Coventry Project (New)

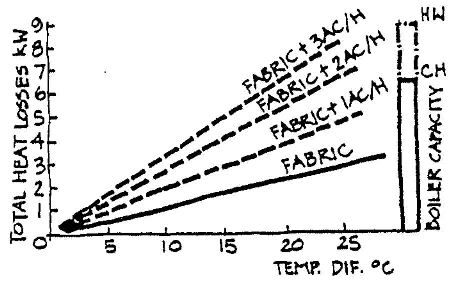
Constructed in 1975, these timber framed and brick clad terrace houses are provided with gas fired whole-house heating and thermostatic radiator valves. The water is heated by a gas system and the living rooms have gas radiant fires. Both test and control houses are fitted with mechanical ventilation system to guarantee 1 air change per hour and half of the test group have been double glazed.

Extra insulation gave a reduction in calculated heat losses of 16% for single glazed Test Houses and 28% for the double glazed houses. Savings of 15% and 18% in total gas consumption were realised for the two groups with 24% and 28% savings on space heating. Temperatures of better insulated houses were lower, which perhaps is due to the higher surface temperatures of these buildings, allowing lower air temperatures to achieve comfort.

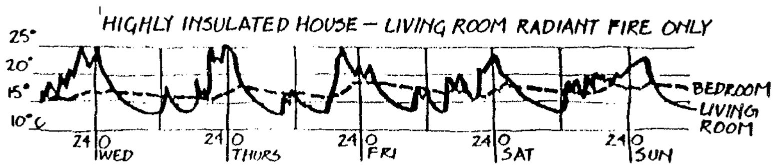
The mechanical ventilation systems led to over-ventilation more than half the time, varying with outside windspeed.

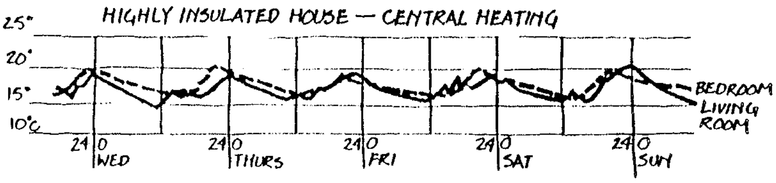
This project shows how savings equal to the theoretical improvement can be realised in controlled circumstances. It also demonstrates the significance of ventilation, which is responsible for at least 40% of total heat losses and even more in windy weather. The extra insulation seemed to make bedroom radiators redundant. Insufficient savings were made by double glazing to justify its cost.





Heat loss related to ventilation rate and windspeed





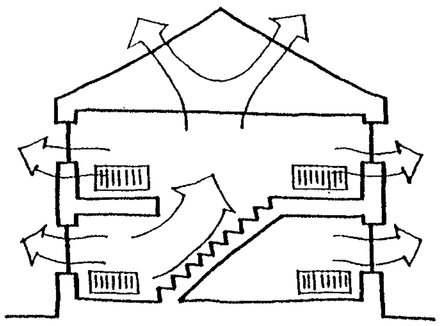
Temperatures in January show that houses are inadequately heated with only living room fires

	Total gas	Est. for H.W. and cooking	Est. for space heating	Approx. total gas cost	Total gas gas saving	Est. space heating saving
Control group houses	871	300	571	155	–	–
Single glazed test	736	300	436	143	15%	24%
Double glazed test	710	300	410	139	18%	28%

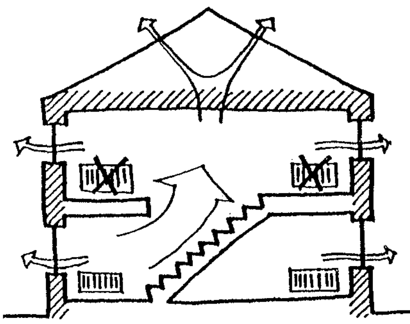
Gas consumption — costs and savings

	Living	Bed 1	Bed 2
Control houses	19.9°C	18.7°C	17.0°C
Single glazed test	19.0°C	19.5°C	17.9°C
Double glazed test	18.2°C	16.1°C	16.4°C

Average room temperatures – September/April



Normal insulation: upstairs radiators needed for comfort in bedrooms



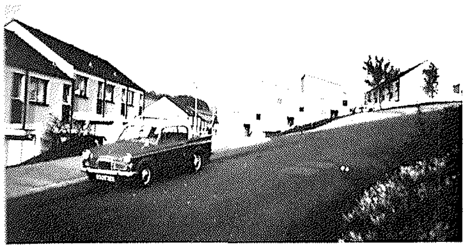
Better insulation: only downstairs radiators needed for comfort in bedrooms

Houses
Designed by Midland Housing Consortium for Coventry City Corp

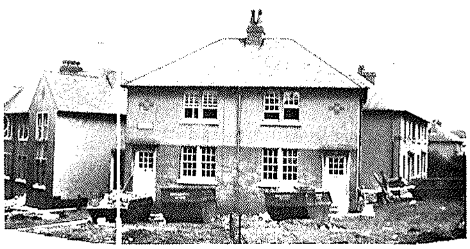
Monitoring
University of British Dept. of Architecture and West Midland Gas Board

Project
Initiated by HDD

Plymouth Project (Retrofit)

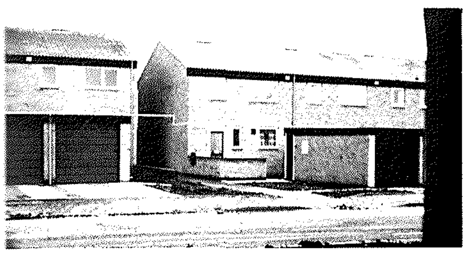


Hamilton Project (Retrofit)



Whitburn Project (Retrofit)

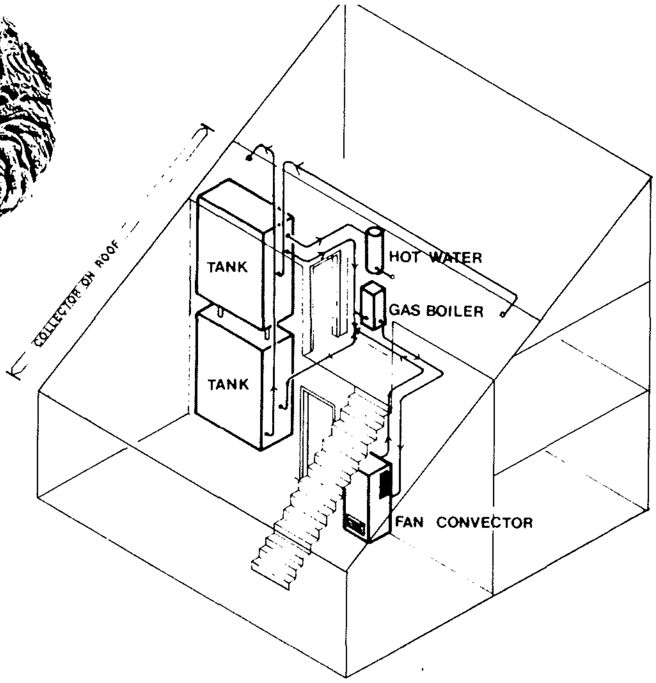
Abertridwr Project (New)



Bo'ness Project (New)

Coventry Project (New)

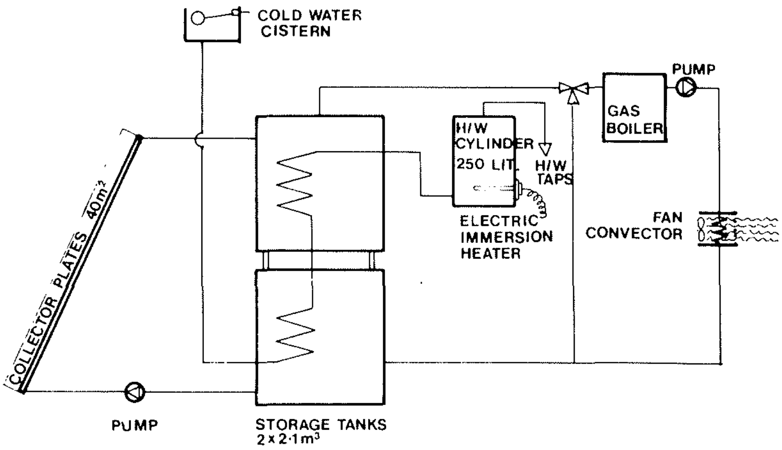
Milton Keynes Solar House



25 The performance of the Milton Keynes Solar House over its first two years' of operation — 1975/76 and 1976/77 — was poor, falling well short of what had been expected. A number of system inefficiencies were recognised, the most significant being —

1 Low absorbtivity of the anodised collector surface, giving low collector efficiency.
2 A non-optimum space heating control strategy causing inefficient use of low grade solar heat.
3 The malfunction of important control thermostats causing unnecessary wastage of solar heat, and limiting the potential solar contribution to space heating.

Modifications to the system were carried out between September 1977 and March 1978, when the house was re-occupied by new tenants. Performance was monitored during the 12 months up to March 1979 and the results showed a considerable improvement. Approximately half of the building's space and water heating energy is now provided by the sun (see Figs. 1a and 1b).



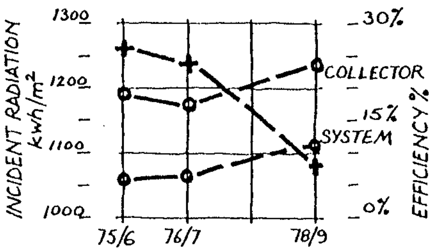


FIG 1a. INCIDENT RADIATION, COLLECTOR AND SYSTEM EFFICIENCIES

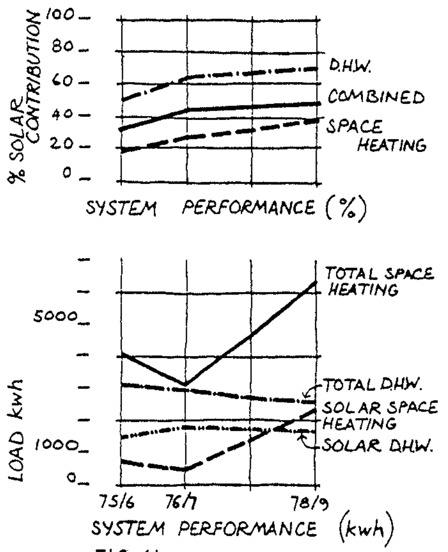


FIG. 1b

Painting the collectors with "Nextel" paint has increased their surface absorbtivity from about 0.8 to at least 0.9, giving about a 20% increase in collector efficiency.

The space heating control system was re-designed to separate the times of operation of solar and gas heating while using the same set of fan convector coils and circulating pump.

Previously problems had occurred with the by-pass and anti-frost thermostats. The settings of both thermostats drifted upwards by several degrees due to exposure to excessive temperatures during hot summer periods. In the case of the by-pass thermostat, the set point had drifted up from 28°C to 35°C, maintaining full gas space heating until the tank temperature rose above 35°C. This had severely limited the solar contribution. This is a recurring problem that has not yet been resolved; careful vigilance enabled the thermostat to be reset quickly during 1978/79.

In the case of the anti-frost thermostat, unnecessary wastage of solar heat occurred due to circulation at ambient air temperatures below 4°C.

This highlights the vulnerability of solar installations to small changes in control conditions; the use of reliable solid state control devices is thus strongly recommended.

Reverse circulation was discovered to occur around the collector circuit, causing a slow but steady loss of heat from the storage tank, mainly overnight. This was despite attempts at the design stage to position the inlet pipe to the collectors so that this would not occur. A non-return valve in the collector inlet pipe has since eliminated this.

The new system performance calculated over 20 years is estimated to be 53%. This could possibly be increased through further minor modifications, but it is difficult to foresee the performance of the present system exceeding 60% without the inclusion of long term heat storage.

It is intended to monitor the house for another year, after making minor modifications. It is also hoped to build a 'Mk II' solar house, with emphasis on reducing capital costs, and the possibility of including long-term heat storage.

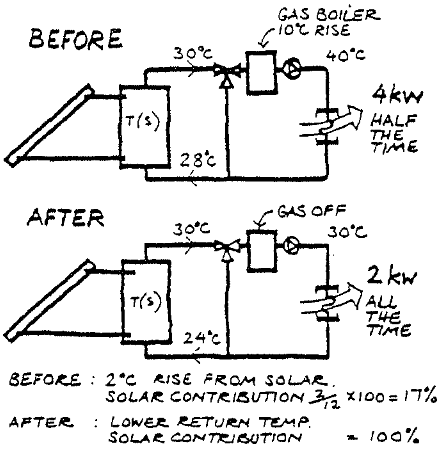


FIG.2 EXAMPLE TO SHOW HOW INCREASED USE OF SOLAR HEAT IS MADE POSSIBLE BY OPERATING BOILER AND SOLAR SYSTEM ALTERNATELY.

An example of the difference between the original and modified systems is illustrated in Fig. 2. Here, a steady state power output of 2kw is assumed necessary to maintain the desired room temperature, and the tank temperature is 30°C. Originally, the boiler would have raised the temperature of the water approaching the convector coils to 40°C. The return temperature to the tank would have been about 29°C, and the fan convector output about 4kw. The system, operating intermittently with equal on and off times, would give an average output of 2kw. The solar contribution would have been 17%.

Under the modified system the convector inlet temperature is 30°C, the return is 24°C and the output is 2kw. The system operates continuously, with 100% solar heating. The use of gas has been avoided and a lower return temperature achieved.

The modified system thus attempts unaided solar heating whenever possible, switching to gas only when the solar output is unable to match the heating requirement at any particular time.

Switching between solar and gas operation is achieved by using a two-stage room thermostat, and an additional thermostat attached to the top of the storage tank. Four heating modes are possible depending on the storage tank temperature T(s).

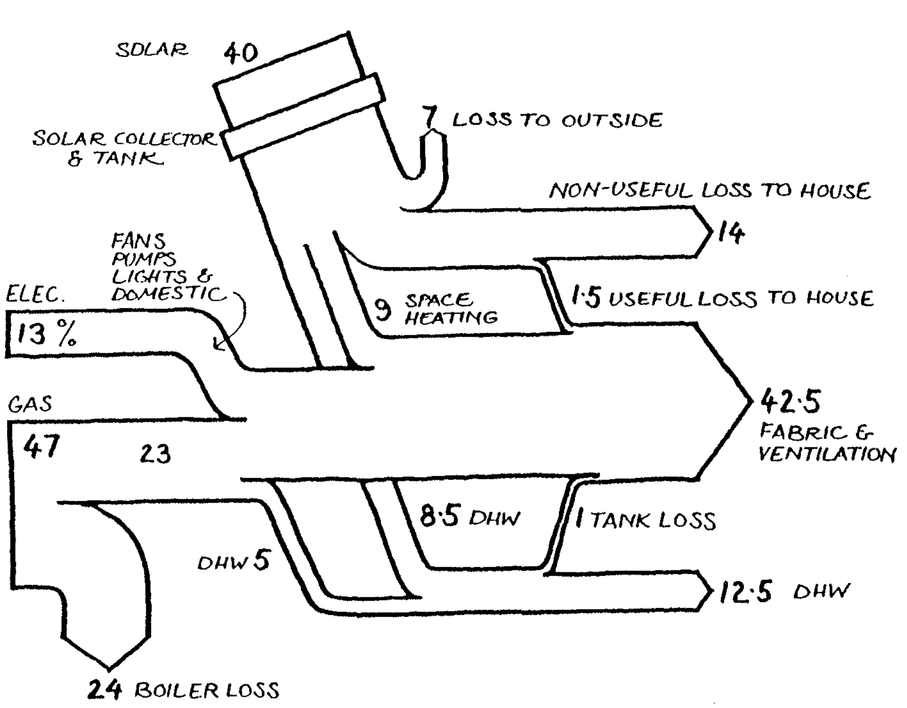
1 T(s) greater than 35°C. Solar warm-up followed by solar 'steady-state' heating (100% solar). The solar output is high enough to heat the house from cold in the early morning, under most conditions. The tank thermostat ensures the system starts up in solar mode. Following the warm-up period, the system continues to operate "solar only".

2 T(s) greater than 24°C less than 35°C. Gas warm-up followed by solar 'steady-state' (partial solar). The solar output is unlikely to be high enough to provide satisfactory warm-up heating, but could be high enough for steady state heating. The system starts up in gas mode, switching to solar at the lower stage of the two-stage room thermostat. If the solar output is high enough to meet the steady state requirement, the system continues in solar mode.

3 T(s) greater than 24°C, less than 35°C. Gas warm-up followed by alternate gas and solar (partial solar). As in 2, but the solar only output is not high enough to meet the steady state heat requirement. Following the initial gas warm-up the system oscillates between solar-only and gas-only operation controlled by the two-stage room thermostat.

4 T(s) less than 24°C. No useful heat output can be achieved in solar-only mode, and the by-pass thermostat (set at 24°C) will ensure full gas operation.

This system is not yet fully optimised. It would be even better to have separate circulation systems for solar and gas, enabling fully independent solar and gas operation.



Total fuel use per annum Primary 26.4 × 10^3 kwh **Delivered** 14.2 × 10^3 kwh **(Primary: Delivered Ratio 1.9:1)**

Milton Keynes Solar House

Date of completion	March 1975
Capital cost	£12 512 (1979)
Occupancy 4-person family, working husband, wife and children at home	
No of persons	4
Persons per m²	0.047
	m²
Usable area	85
	m³
Usable volume	260
Delivered annual energy consumption Estimated using degree days, computer modelling, and measured for three years	
	kwh
Total	14 200
Per m²	167
Per m³	54.6
Per person	3550
Primary annual energy per m²	310 kwh (including 46 kwh/m² active solar)

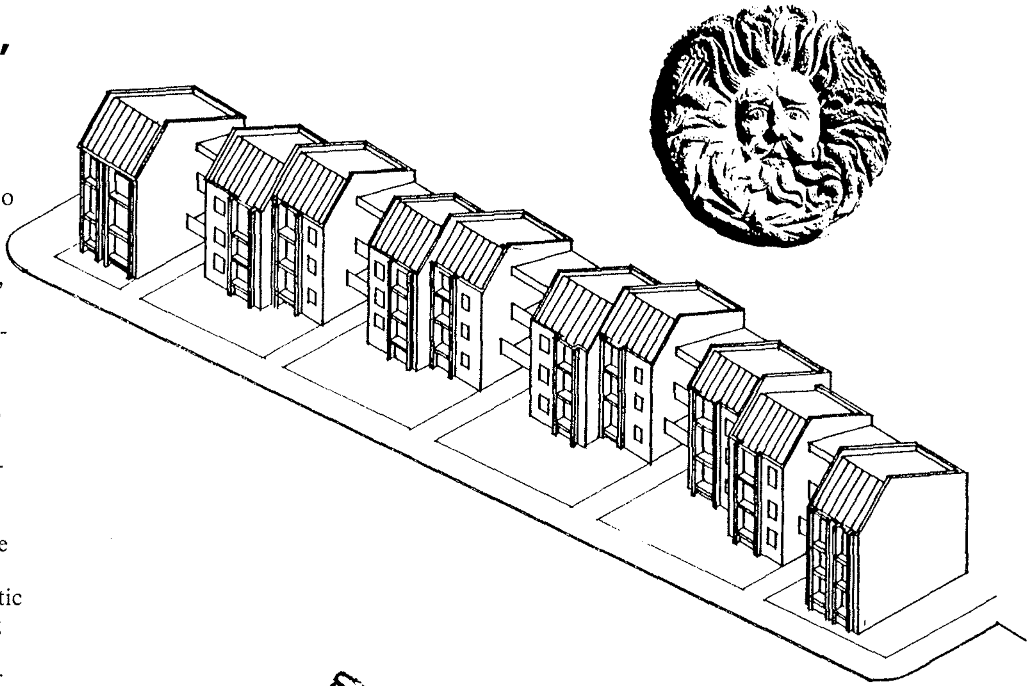
Client
Milton Keynes Development Corporation

Address
3 Harrowden, Bradville, Milton Keynes, Buckinghamshire

Architects, M & E Engineers, Quantity Surveyors, Structural Engineers
Milton Keynes Development Corporation

Mqnitoring Organisation
Built Environment Research Group of the Polytechnic of Central London

Brownhill Road Flats, Lewisham



26 The Brownhill Road scheme was designed to be normal, run-of-the-mill English Local Authority housing, built within the Cost Yardstick on a difficult site which,however, would consume the minimum possible amount of fossil-fuel. It is meant to demonstrate what any Local Authority can do.

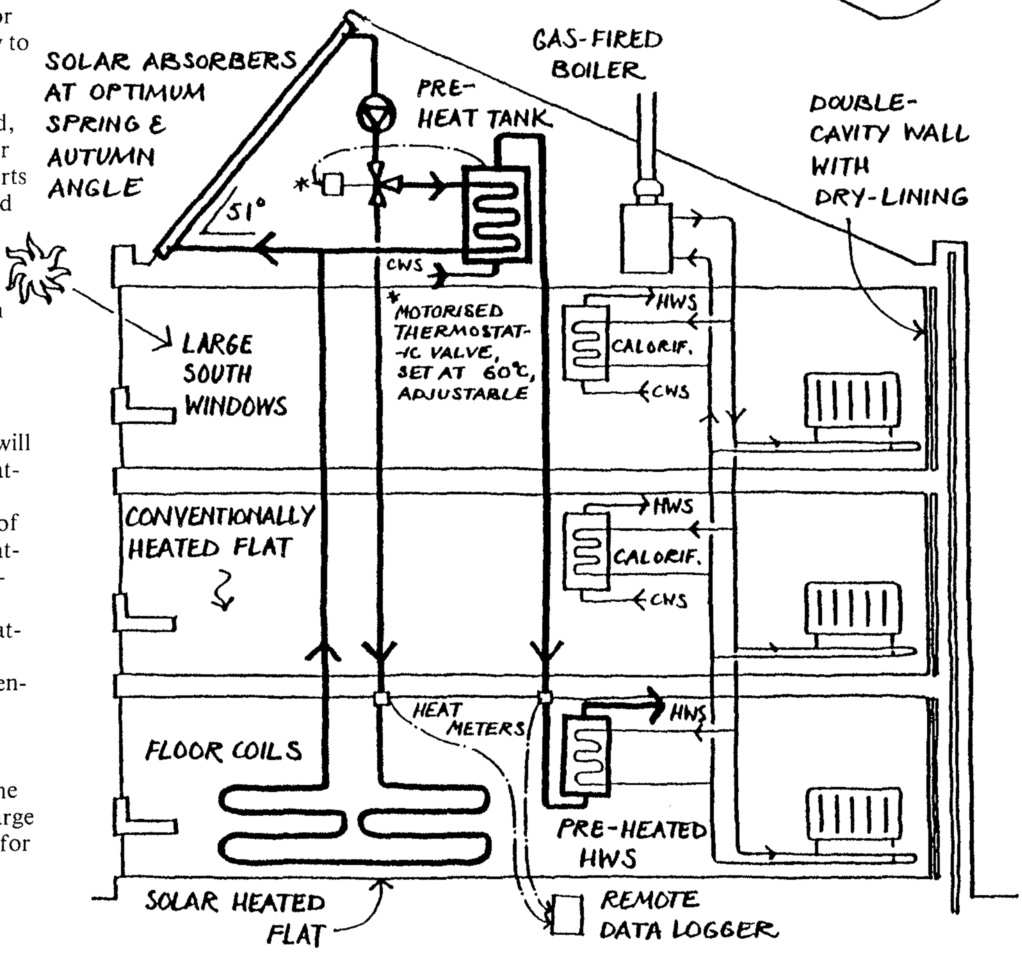
There are thirty, two and three-person flats in ten blocks. The entire south-facing roof area is occupied by water-filled solar absorbers. The absorbers have a high efficiency due to their low mass, which allows quick response, and to the low return temperature of about 30°C, which allows efficient heat transfer. These will heat or pre-heat domestic hot water and provide partial space heating for one flat in each block from low-temperature floor coils — five ground floor and five top-floor flats are heated this way to allow comparisons to be made.

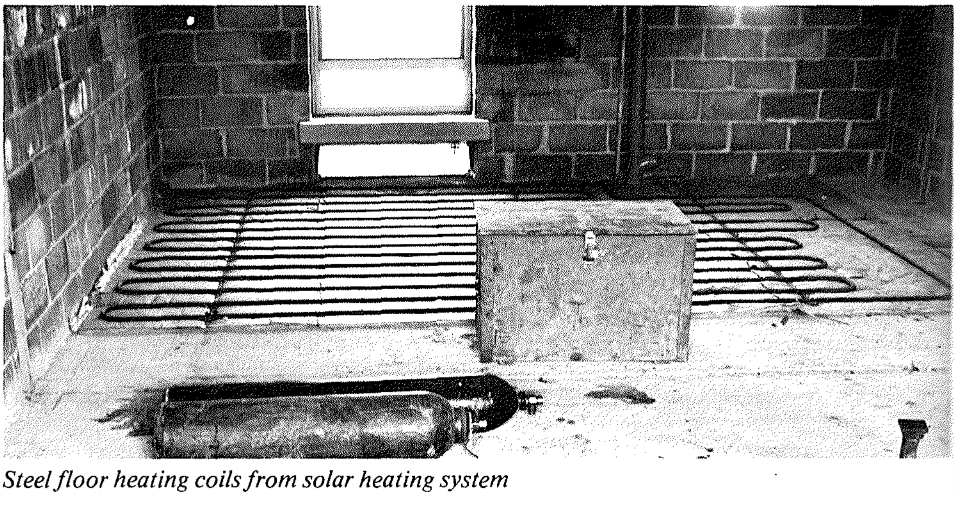
The gas-fired back-up system is centralised, allowing the substitution of another fuel or possibly heat-pumps at a later date. All parts of the system are off-the-shelf and installed by non-specialist subcontractors.

Environmental standards are normal for Local Authority housing — the system can maintain 21°C for old people on ground floors and 16°-21°C elsewhere.

The costs of energy consumption, shared equally between all flats of the same size, will probably be added to the rents as a fluctuating surcharge. A users' handbook is being prepared and this will include indications of how use of the active and passive solar heating installations will affect the heating surcharge. Tenants will be urged to make conscientious use of curtains to reduce heat-loss through windows at night or in dull, windy and cold weather; to restrict the opening of windows and doors, and take baths when the sun shines.

The Planning considerations have led to the building being highly articulated, with a large external envelope, which is less than ideal for limiting fabric heat losses.





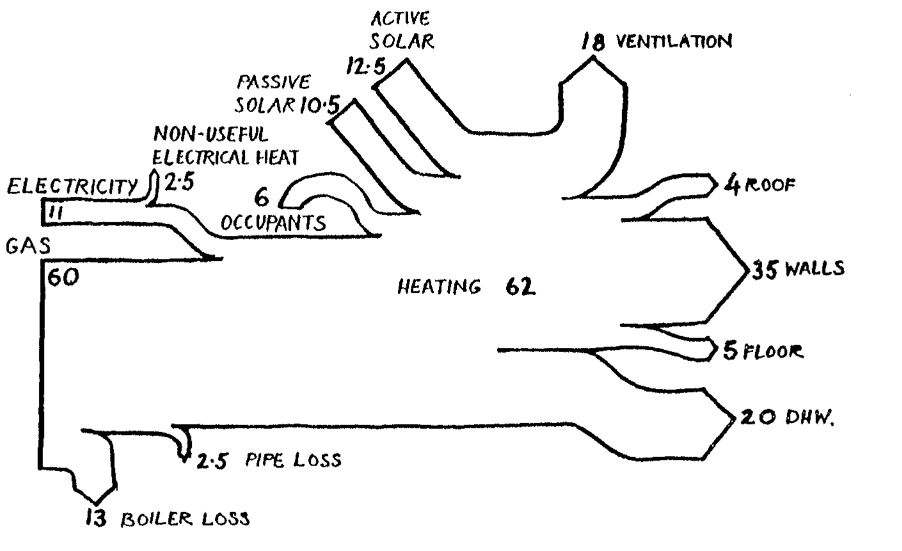
Steel floor heating coils from solar heating system

View of solar collecting roof

Cost Yardstick limits meant that only external walls have a double cavity with normal dry lining fixed to a 150mm Thermalite inner leaf. All fixed lights are double-glazed: opening lights are single-glazed and act as 'sacrificial elements' in terms of condensation, with condensation-channels discharging externally; they are virtually draught-proof when shut.

In order to take the greatest possible advantage of the active and passive solar-heating systems, the thermal capacity of the solar-absorbers has been reduced to a minimum, while the thermal capacity of the building fabric has been kept to a maximum.

The scheme will be monitored in use for at least a year by the South London Consortium, in collaboration with the consultant engineers. The initial monitoring programme will seek to establish how much of the total space-heating and domestic hot water demands are met from solar sources. The monitoring will be carried out automatically, and has been designed not to interfere with the normal use of the building.



Total fuel use per annum Primary 0.42 × 10^6 kwh **Delivered** 0.28 × 10^6 kwh **(Primary: Delivered Ratio 1.5:1)**

Brownhill Road Flats, Lewisham		
Date of completion		October 1979
Capital cost		£564 138
Occupancy		
Upper floors young married couples, lower floor old persons		
No of persons		67 bed spaces
Persons per m²		0.044
		m²
Usable area		1529
		m³
Usable volume		3712
Delivered annual energy consumption		
Calculated by the CIBS method		
		kwh
Total	min	275 000
	max	414 000
Per m²	min	180
	max	271
Per m³	min	74
	max	111
Per person	min	4100
	max	6180
Primary annual energy per m²		**273 kwh (including 27-41 kwh/m² active solar)**

Client
London Borough of Lewisham

Address
Rear of 161-203 Brownhill Road, Catford, London SE6

Architects, M & E Engineers and Quantity Surveyors
Royston Summers and Associates

M & E Engineers
Max Fordham and Partners

Quantity Surveyors
Frank N Falkner and Partners

Structural Engineers
Ove Arup and Partners

Monitoring Organisation
South London Consortium

BRS Low Energy House Laboratories

27 There are many ways that energy consumption in housing can be reduced, both in existing houses and more dramatically in new house designs. In the experimental 'houses' almost all the potentially practicable measures for reducing energy will be investigated.

Four different systems are under test:
1 Heat reclaim
2 Solar heating
3 Heat pumps using air warmed by the sun
4 Under floor heating using heat pumps.

These are compared with a standard and a well-insulated house.

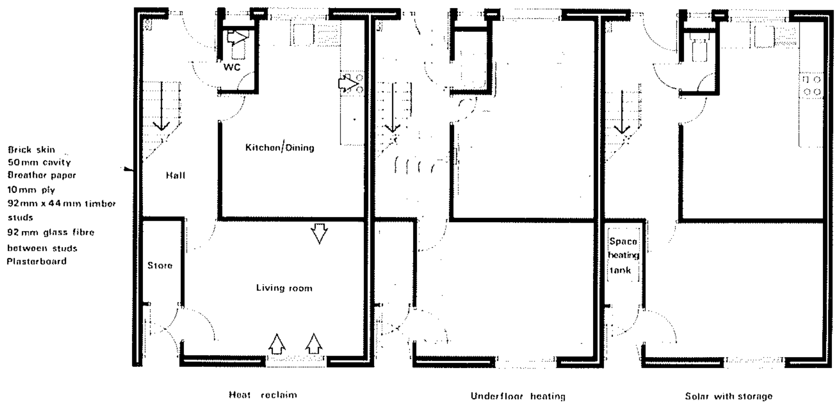
The results of the theoretical calculations of the amount of primary energy required to operate these houses (under certain regimes of use) are described below. These show that the primary energy consumption may be half to a third that of similar accommodation built to today's standards using conventional heating equipment.

The cost-effectiveness of the various novel features will be examined when firm experimental results are available. However, some factors may be noted — increasing levels of insulation show diminishing returns and, because insulation above a certain thickness may require modifications to building techniques, it was decided to adopt the particular values described here, the heating equipment used in these houses is mostly of novel design and has been constructed on a one-off basis. It is not possible therefore, to categorically state that any of these untried methods would be cost effective, but, depending on the levels of fuel and equipment costs, it is likely that some of these methods of heating will become so in the future.

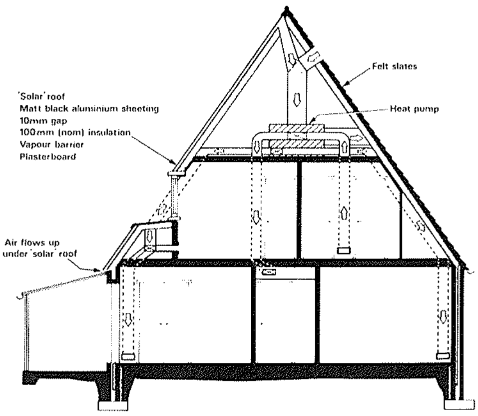
These facilities will help to avoid too rapid an application of untried technology. The successful cost-effective measures developed during the research will be further tested in field trials.

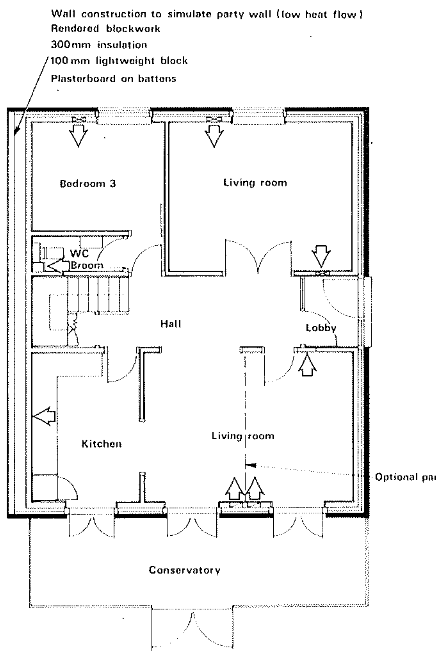
Although these BRE facilities look like houses, they are laboratories. During their operation many changes will be made to the devices they contain. The laboratories have cost about £40,000 to construct but associated with them will be instrumentation costing in total about £60,000. Several of the conservation measures are also being studied in separate BRE laboratory experiments, and the purpose of including them in the experimental facility is to investigate their operation when associated with other energy conserving measures. It is necessary to look at the integrated performance of the conservation measures because many of the measures interact.

The laboratories were designed to be operated under conditions of simulated occupancy. To obtain reliable data on the performance of energy saving measures it is necessary to be able to reproduce particular use patterns and to introduce new ones quickly. (Field studies currently being made by BRE of hot water and heat use in houses show wide variations in demand due to the intermittent use and varying comfort requirements of individual families.)



Ground floor plan





Ground floor plan

Construction

A timber framed building system was chosen for the terrace because the techniques are established and it is easy to increase thermal insulation. These are largely copied from public sector houses of this kind at Bretton, Peterborough, which were already familiar through BRE studies of district heating. They are five-person, two-storey houses.

The timber structure is prefabricated and the exterior cladding is of brick and weatherboarding. Insulation in roof and external wall panels is increased to 92mm thickness giving a 'U' value of about 0.35w/m²°C (compared with 1.0 currently required). The windows are openable and may be double glazed later. The roofs are pitched at 42° to provide a satisfactory inclination for a solar collector.

The detached laboratory design is different, being of a 'chalet' type with a 54.5° roof, having a relatively small envelope for its habitable volume. It has brick and block walls with cavity, rigid plastics foam insulation and foam-backed plasterboard dry lining, giving a 'U' volume similar to that of the timber houses; its end wall is massively insulated to simulate thermally the party wall of a semi-detached pair. In order to achieve the 'U' value, the cavity is wider than permitted under current codes. The windows are small in area except on the ground floor, south side where French doors open into a conservatory. The southern slope of the roof is covered with black painted corrugated aluminium which forms a simple solar collector through which air passes on its way to the heat pumps, which will be placed in the roof apex.

Simulated Occupants lit up after dinner.

Heat Pump House at left, with terrace containing Heat Reclaim, Underfloor heating and Solar House at right.

The Heat Reclaim House
This house has a mechanical ventilation system, but separate from the space heating, which is by radiators: extract is from kitchen, toilet and bathroom, and input to living room and bedrooms. An 'Aldes' ventilation kit (of French manufacture) is used. This has fans on both input and extract and the two air-streams pass through a heat exchanger for energy reclaim. About 0.8 air-change per hour is supplied, the inputs being through ducts of a standard size (~100 mm dia), three being used for the living-room and two for the principal bedroom. The heat-exchanger efficiency has been measured at approximately 70%, so the air at the input register is cooler than room temperature; to avoid cold draughts, the registers are sited behind the radiators.

The ventilation system has diverter valves by which extract can be concentrated in the kitchen, or input in the living-room when desired. Both these valves are controlled by time switches so that these 'boost' settings are not left on indefinitely. There is also a summer by-pass which directs the extract air directly to atmosphere rather than through the heat exchanger. Additional natural ventilation for summer conditions is also intended.

The space heating uses conventional water-filled radiators, with individual thermostatic valves, supplied from a small wall-hung balanced-flue gas boiler. The low heat requirements mean that the radiators themselves are unusually small, and some novel problems arise through both the thermostatic valves and the boiler having to operate right at the bottom end of their flow range.

A 600W heat pump operates a heat-reclaim system for the domestic hot water. Outgoing warm waste water passes into a 350 litre catch tank whose outlet to drain is via a syphon so that it is always full. Immersed in the top layer of water is the evaporator of the heat pump, while the condenser (and incidentally the hermetic compressor) are in the hot cylinder. Only bath and washing machine wastes pass to the catch tank; it is considered that sink and hand-basin wastes have too low an average temperature, and too high a grease and scum content, to be worth trapping.

The reclaim installation is expected to supply about 70% of the hot water requirement. The remainder would come from the boiler through a pumped primary coil. For experimental convenience, duplicate hot water cylinders are installed, the second one having electric immersion heating instead of the heat pump. Comparisons can then be made by alternating the tanks.

The Solar House
This house has a patent-glazed opening in its south-facing roof slope, 5 m x 4 m. Solar collector panels are mounted immediately under the glass on hinged frames which can be lowered to permit maintenance or changing of the collectors. There is 100 mm of fibreglass insulation under the panels.

Inhibited water-glycol mixture is circulated through the panels, and the energy collected is transferred to a thermal store. This store consists of a 40 m^3 (4 x 4 x 2.5 m) tank, surrounded with 0.5 m of foamed polystyrene insulation and housed (partly below ground level) in a separate structure alongside the house to the East; it contains corrosion-inhibited water. When the store temperature is low, the collected solar energy enters through a copper-tube heat exchanger. When the tank is hotter, and the collector would have a low efficiency if it were to be operated at tank temperature, a 1 kw heat-pump (HP 1) can operate as the energy transfer device.

Energy for space and water heating in the house comes from the store. In each case, the energy can pass directly, via heat exchange loops within the store tank, when the store is at a high enough temperature. The space-heating radiators are of the extended-surface type sized to provide adequate heating when the water temperature is only 40°C.

When the store temperature is insufficient for direct supply, the space and water heating are serviced from secondary storage tanks — 2,200 litres and 300 litres respectively, representing one day's supply. These tanks are heated by Heat Pump HP2 (2 kw) and HP3 (1 kw) which use the store as their energy source and operate on off-peak electricity.

Heat Pump House
This house has a warm-air heating system which incorporates mechanical ventilation. About 55% of the air flow is recirculated, via return grilles in living rooms and bedrooms: the remaining 40% is extracted from kitchen (cooker hood) toilet and bathroom.

The blackened aluminium covering the south-facing roof slope will collect solar radiation, and warm the air which is drawn up its underside. Part of this air forms the ventilation input: from the roof apex it is ducted down to pass through the condenser of an air/air heat pump. The evaporator of this heat pump is in the extract air stream, so that the outgoing air is cooled and its energy transferred to the incoming air. This heat pump is rated at 600w electrical input (including fans) and, even if no allowance is made for any solar radiation, it can furnish all the space heating energy needed at external air temperatures of 7°C or more, and it should be immune to frosting problems.

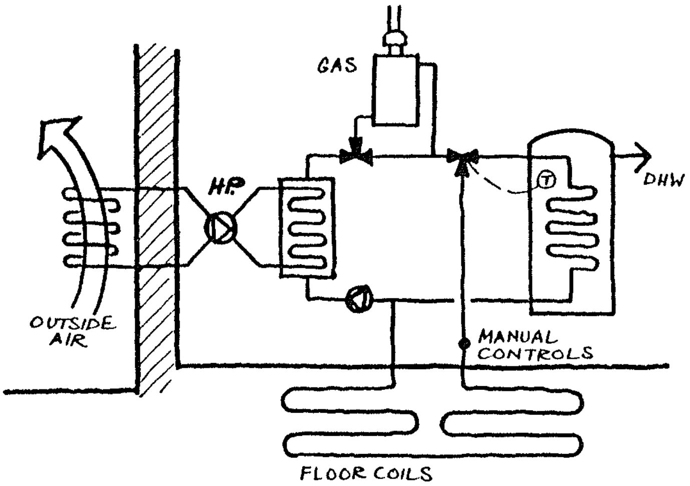
When the external temperature is between +7 and -1°C, the remainder of the space heating requirement is provided by a second air/air heat pump. This machine, rated at 900W input, has its evaporator in a duct carrying all the air flow from the solar roof which has not been taken for ventilation. Its condenser is in the main warm air supply duct, heating both the ventilation air (coming off the condenser of the ventilation-heat-recovery pump) and the recirculated air. This mixed warm air flow is ducted to all habitable rooms.

A small LPG-fired heater will be used for boost heating if necessary at temperatures below -1°C.

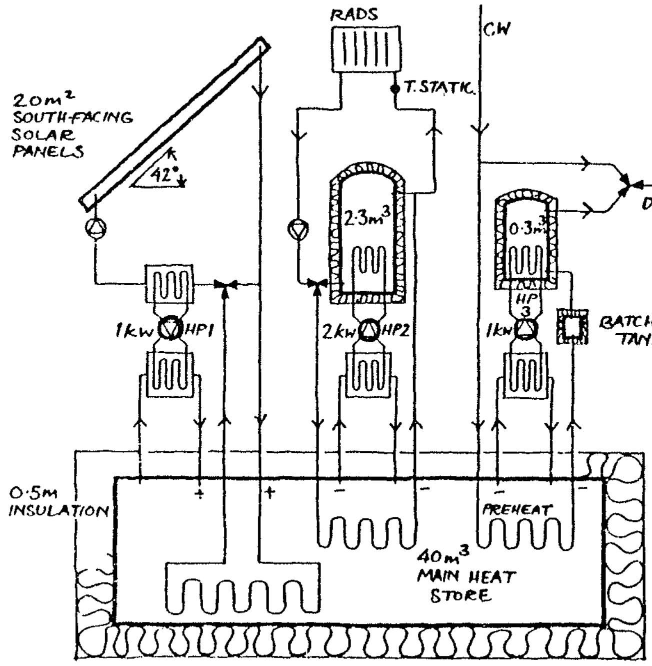
The hot water is supplied by a separate 600W air/water heat pump, whose evaporator is in the same air-stream as that of the space-heating pump. The feed water on its way to the hot cylinder passes through a heat-exchange coil also in the air-stream. This is intended for summer use, when the air coming from the solar roof will sometimes be hot enough to make a useful contribution to the water-heating. The space-heating and ventilation reclaim heat pumps do not of course run in the summer, but the mechanical ventilation system does, drawing fresh air from an alternative inlet on the north slope of the roof. It is expected that natural ventilation, by opening windows, will still be necessary in very hot weather.

Underfloor Heating House, Centre Terrace
A low temperature system employing underfloor heating is installed in this house. It consists of plastic pipes (20 mm diameter) containing warm water at 40 to 45°C. These are buried in a ground floor screed and in a sandwich-type of construction on the upper floor. The water is heated by an air-source heat pump which is electrically powered. The low water temperature should ensure the best possible performance from the heat pump. Supplementary heating is provided by a gas heater, controlled by the heat pump and operating into the same water distribution system. Domestic hot water heating takes priority over space heating and a heat exchanger in the d.h.w. tank is fed with water from the heat pump via an electrically operated 3-way valve. Delivery temperature is about 55°C.

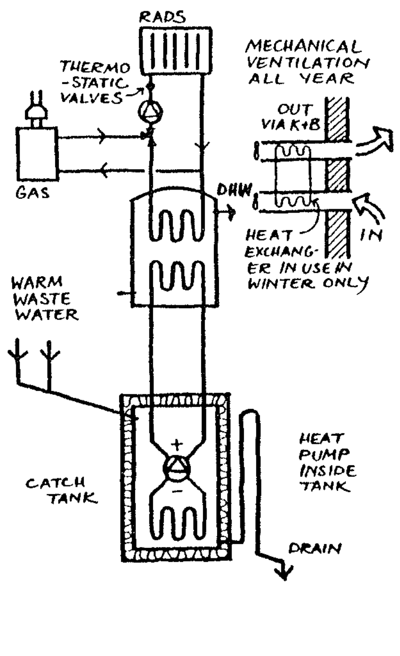
In our case the evaporator is mounted outside but it could be mounted in either attic or cellar if available. Other than this all components are contained in the cabinet, here sited in the kitchen, including the water pump, sealed expansion vessel and controls.



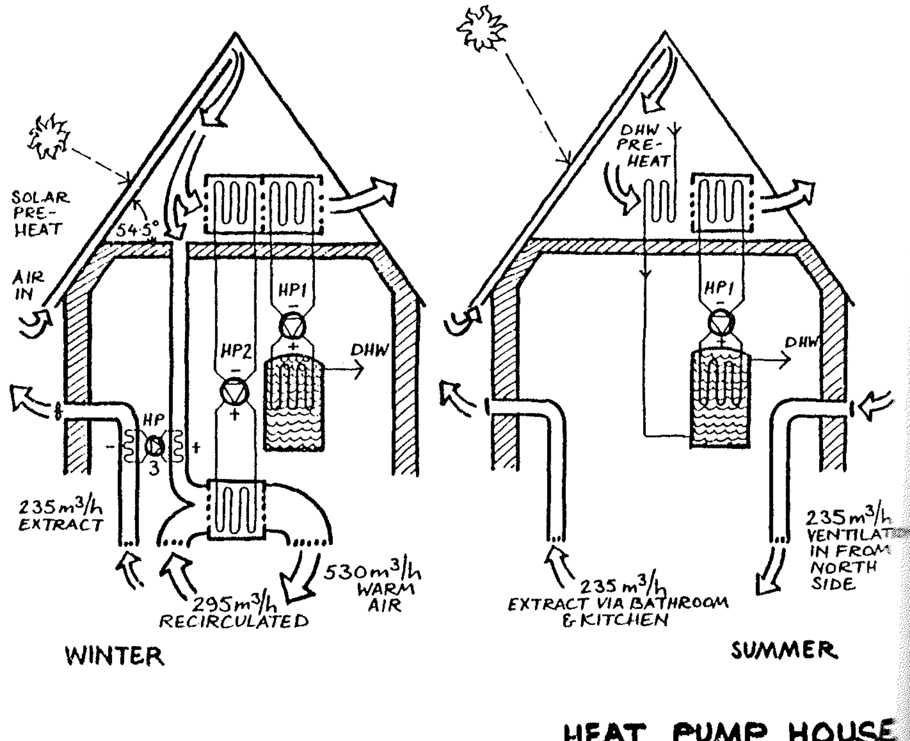
UNDERFLOOR HEATING HOUSE



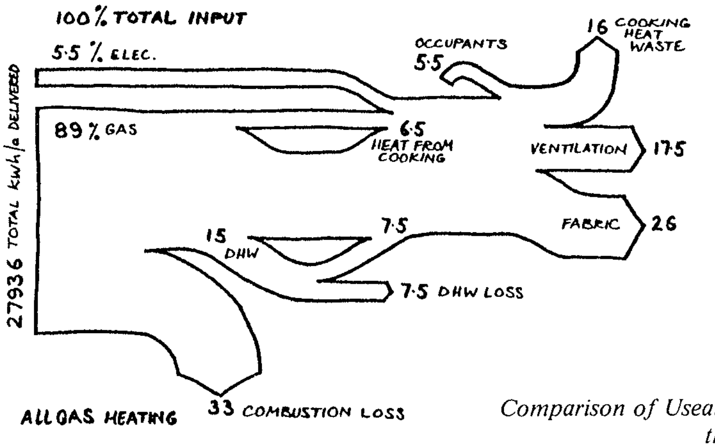
SOLAR HOUSE

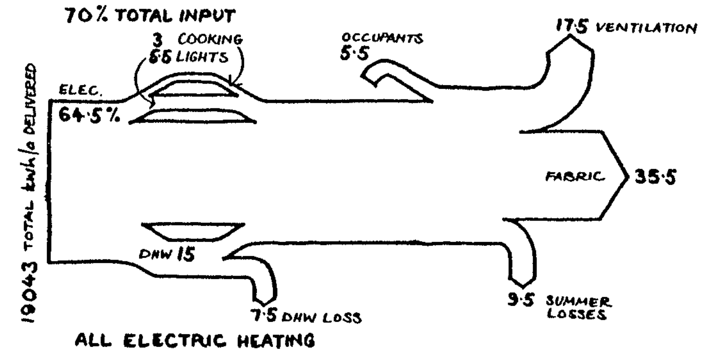


HEAT RECLAIM HOUSE

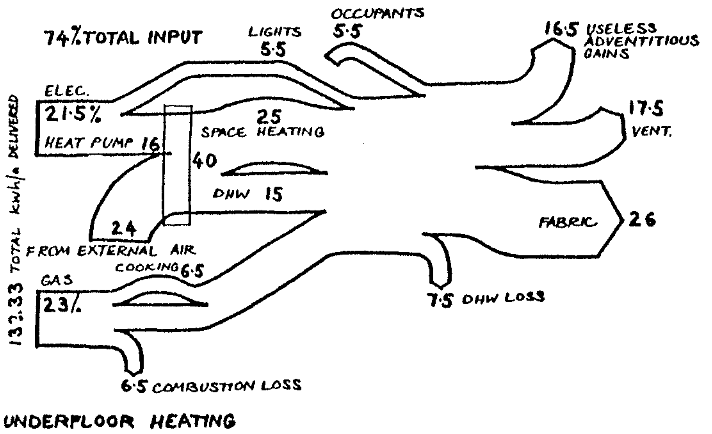


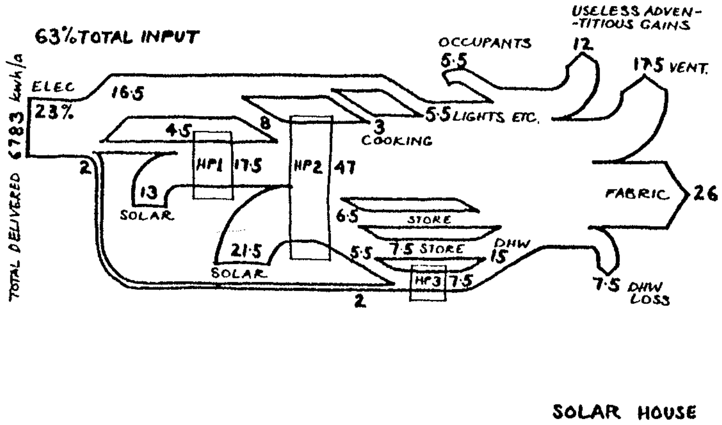
HEAT PUMP HOUSE

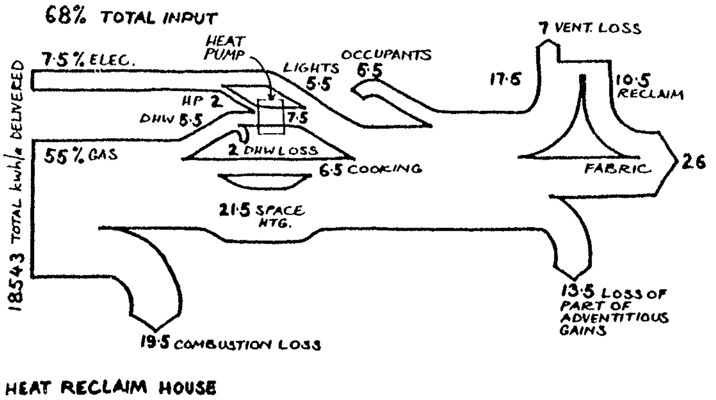


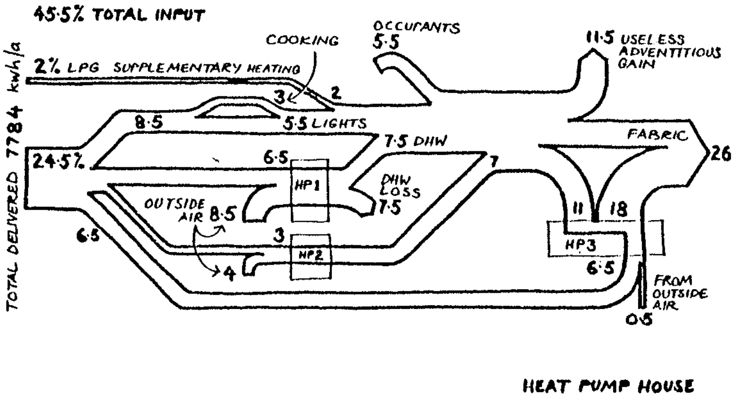


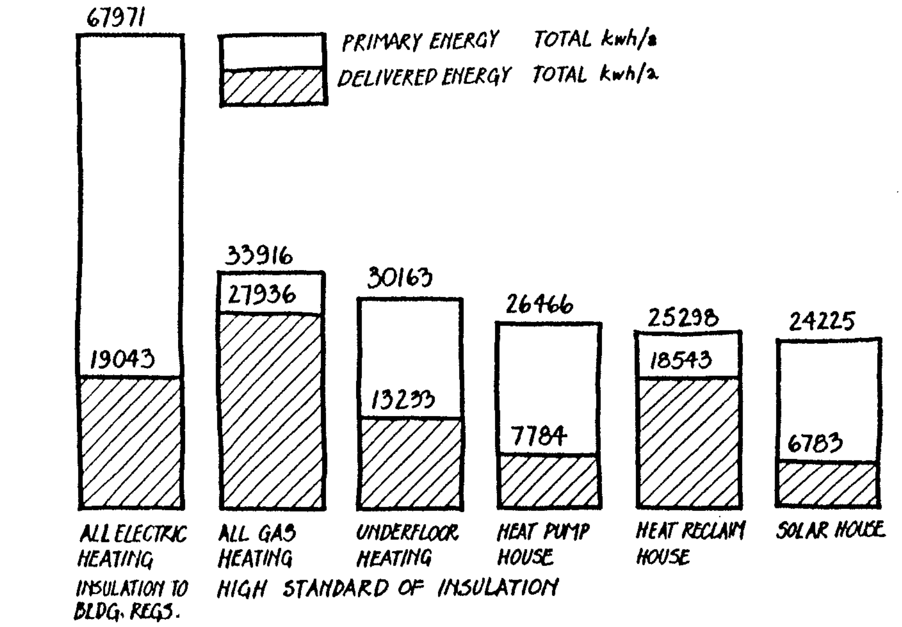
Comparison of Useable energy flows of the six houses analysed on a percentage basis, with the All Gas heated house having 100% input, including occupant gains.











Comparison of Primary and Delivered energy for the four Test houses and two Control houses. Totals include all ancillary uses such as lighting and cooking.

Performance

The figures in the table are based on calculation, using the best predictions for the performance of the novel components.

All energy inputs, including heat from the occupants' cooking, water heating lighting and domestic appliances, have been allowed for.

BRS Low Energy House Laboratories	
Date of completion	1979
Occupancy is BRE simulated occupancy pattern for a family. In practice there will be a choice between light and heavy duty: 2 or 4 persons	
No of persons	5
	m²
Usable area	88
Delivered annual energy consumption Estimated using degree day method. Figures include ancillary uses; cooking, lighting, etc. See Sankey Diagrams.	

For Visits contact
Mrs. P. Rowley

Address
Building Research Station, Garston, Watford
Telephone: 09273 74040

Monitoring Organisation
Building Research Establishment

Wilson House
Hampshire

28 This largely owner-built house represents an attempt to reduce energy consumption and increase comfort standards. The assumption was made that all energy prices would rise relative to other commodities and that alternative energy systems would not be available for some time.

It was decided that heat pump technology, using as it does a significant proportion of ambient (solar) energy, was the best immediate prospect for domestic use. It was also assumed that in the future at least a proportion of alternative energy collection would be converted to electricity through the grid (eg Wave power, wind power etc.). The design arose out of work previously carried out for the CDA competition and subsequently for the Anglo-German house in London.

The house was insulated to better than normal standards in order to minimise plant size and make the house more comfortable at a lower ambient temperature. Insulation Standards:

Walls	0.28 w/m² °C
Roof (150mm fibreglass)	0.276 w/m² °C
Double glazed windows	3.28 w/m² °C

The building, essentially low in thermal capacity in other respects, has a very high thermal capacity taking into account the thermal stores. By heat exchange this is useful not only in winter but also in controlling temperature rise in the summer, an important consideration where high insulation and an air tight building is achieved.

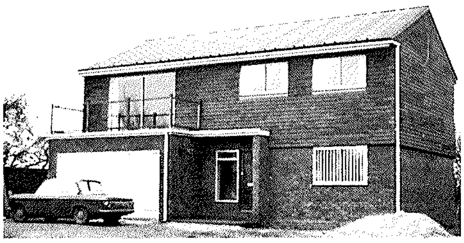
Since a significant fraction of solar energy collected via the entry of ambient air to the roof was to be from diffuse sun, the orientation was not significant and was determined entirely by normal considerations of view, privacy etc. The design had in fact been determined before the heating system was decided on and the fenestration was not altered.

The design, however, did require a small modification (an additional set of tiling battens), so as to permit ambient air to be drawn under the tiles before reaching the heat pump. The thermal store consisting of water contained in a plastic liner, required modification on the ground floor so as to permit a 600mm depth throughout the ground floor living area. Neither of these affected the external form of the building in any visible way.

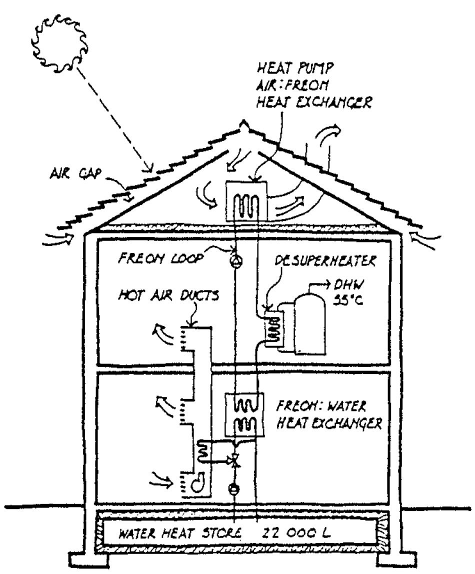
The system has normal automatic controls, but in particular it should be emphasised that the heat pump delivers heat to the building by an independent circuit. Thus the primary heating source works entirely through its own automatic controls while the control of heat output can be altered at will by the user in the normal way. The owners are aware of the system functioning and the effect of bad weather conditions on the amount of heat available in the store.

The ventilation system operates by a continuous low velocity air movement, thus ensuring that all those parts of the building being heated operate as a whole. Thus the thermostat will call for more heat and an increase in air flow rate via a graduated speed controller, avoiding rapid cycling and noise problems. Also, lighting and incidental gains from cooking, people etc. are incorporated within the system and interact in a useful way.

Monitoring arrangements were made by Aston University with the Science Research Council and the monitoring programme had already been through one heating season. The most important result so far is that the contribution of ambient energy is greater than calculated and approximately 15% of total energy use. It is important to emphasise



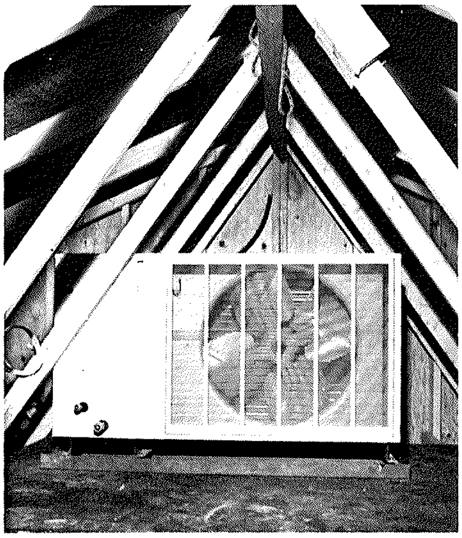
that when using an electric heat pump one of the main bodies to benefit is, in fact, the CEGB, which is supplying electricity out of peak conditions and not during the coldest weather or peak hours. Since no tariff is offered to recognise this benefit, the extra capital cost of providing the thermal store, which makes this possible, is not directly beneficial to the owner. In use, the main fan operating the heat pump proved to be unnecessarily noisy and was modified by Lennox to the instructions of Helix to improve performance as well as reduce noise.



The heat loss from the store through the ground was found to be considerably greater than expected. Edge insulation was used, and insulation between the top of the store and the house. It is therefore suggested that:

(a) The store is insulated all round with 150mm polystyrene or equivalent.
(b) Tanking is necessary to prevent evaporative loss through evaporation of ground water.

Warm air was chosen as the distribution system. It is recommended, however, that very low temperature (35/40°C) flow systems should be used instead. This will help the COP(H) of the heat pump considerably. This system would be combined with a fresh air input/extract and extract system such as those used by BRE in their test houses.



Wilson House, Hampshire		
Date of completion		December 1976
Capital cost		£1 450 above an oil system
Occupancy Normal domestic occupancy		
No. of persons		3
Persons per m²		0.021
		m²
Usable area		143.1
		m³
Usable volume		353.92
Delivered annual energy consumption Measured		
		kwh
Total	min	11 760
	max	15 680
per m²	min	82.2
	max	109.6
per m³	min	33.2
	max	44.3
per person	min	3 930
	max	5 226
Primary annual energy per m²		365

Client
Mr. Brian Wilson

Address
Bramleys, Floyle Lane, Long Sutton, Hampshire

Architects (for modification only)
Helix, Multi-professional services

M & E Engineers
Helix, Multi-professional services & Lennox Industries

Monitoring Organisation
Aston University

Solid Fuel Homes Pontypool

29

The layout of these houses is intended to make solid fuel heating attractive once again to those who presently favour the easy automation of other fuels. Therefore, the kitchen/living room contains the main heat source and the loading of coal and removal of ash are confined to a utility lobby which is separated from the living spaces. Also the design facilitates easy fuel delivery and ash collection from the front of the house.

The designers questioned the apparently widespread assumption that children can be banished to their bedrooms to do homework — or father to practice his violin — while others watch T.V. Therefore a parlour/study/living room which is separated from the cooking/living area by the open stairway was included. The circulation area is confined to the small front entrance lobby which also acts as an air-lock to minimise heat loss through the front door.

The solid fuel room heater provides a most enjoyable form of radiant heat in addition to general space and water heating. Unlike gas or electricity, solid fuel is purchased prior to use and it is easy to see from the fuel store how fast you are burning your money. The heating unit required for the NBA house is a front openable (to make toast) room heater/boiler. The fuelling and de-ashing processes are restricted to the utility lobby behind the boiler. An appliance suitable for use in the NBA house-type is currently under development by Trianco Redfyre Limited sponsored by the National Coal Board. The prototype room heater is an adaptation of the existing 'Housemaster' model which has a total heat output of 10.26kw. However, the output can be modulated to suit the lower heating demands generated by the standards of insulation and ventilation control envisaged by NBA.

The modifications to the 'Housemaster' include a backfed hopper, rear flue cleaning facility and reciprocating chrome iron grate bars, which avoid the need to open the fire door for fire-bed cleaning.

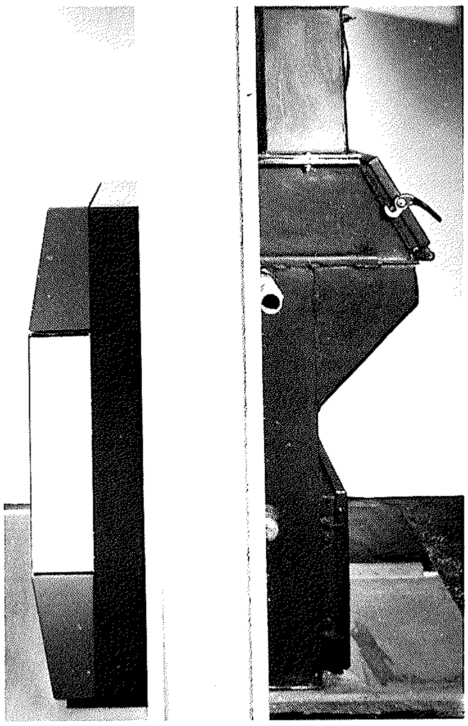
Two variations on the plan are possible:

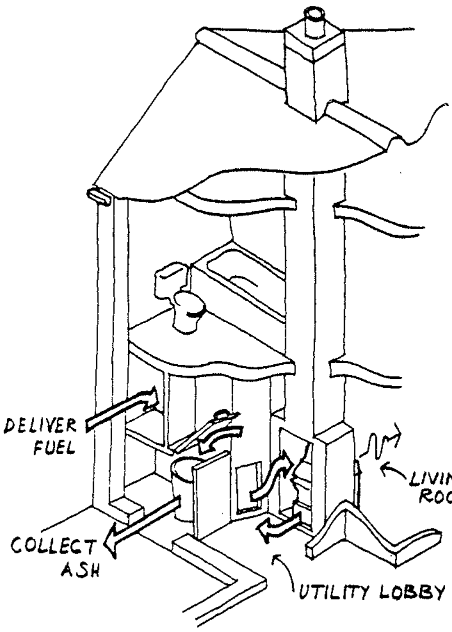
1 A free standing room heater in the open living/kitchen heats domestic hot water and central heating radiators as well as direct heat. The dwelling is well insulated and radiators may be omitted in bedrooms. In this case, background heat will percolate up the stairway and 'leak' from the flue. The flue is centrally located to make full use of the heat it stores and it is brought out through the ridge line, to avoid the need for a back gutter. A cooker head and extraction system will prevent unwanted cooking smells drifting upstairs (although nothing stimulates the lazy to rise in the morning like the smell of frying bacon!) However, a partition can be erected to provide an enclosed kitchen.

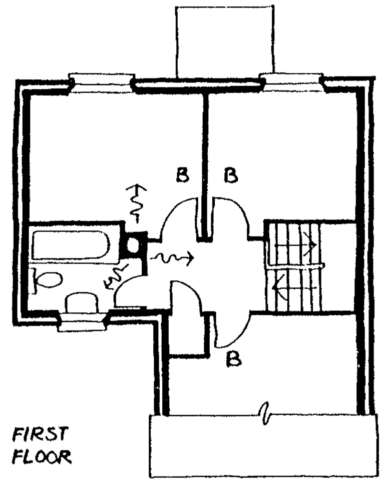
2 A second alternative, suitable for rural areas, would use a solid fuel cooker in place of the free standing room heater.

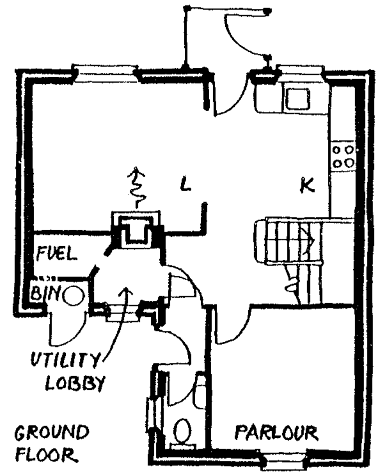
The internal 'air-lock' porch at the front is complimented by a glazed air-lock at the rear of the house. This could be extended with standard greenhouse units to provide a 'lean-to' conservatory.

The hot water storage tank is situated in the airing cupboard on the first floor with an immersion heater for summer hot water. Solar water heating panels can be located either on the roof or back porch or on the roof below the window to the single bedroom. These lower levels will prevent thermo syphonage and ease maintenance.









The houses will be built by traditional techniques with a good standard of insulation.

Ground floor:
150mm concrete ground slab insulated at perimeter.
Walls: U = 0.55 w/m²°C.
Roof: U = 0.3 w/m²°C
Windows: U = 4.3 w/m²°C.

Solid Fuel Homes, Pontypool	
Date of completion	1981
Occupancy	
Normal domestic occupancy	
No of persons	5
Persons per m²	0.058
	m²
Usable area	86
	m³
Usable volume	205
Delivered annual energy consumption	
Estimated according to the CIBS guide	
	kwh
Total	25 800
Per m²	301.4
Per m³	121.01
Per person	5160
Primary annual energy per m²	310

Client
Tor Faen Borough Council

Address
Usk Road, Pontypool

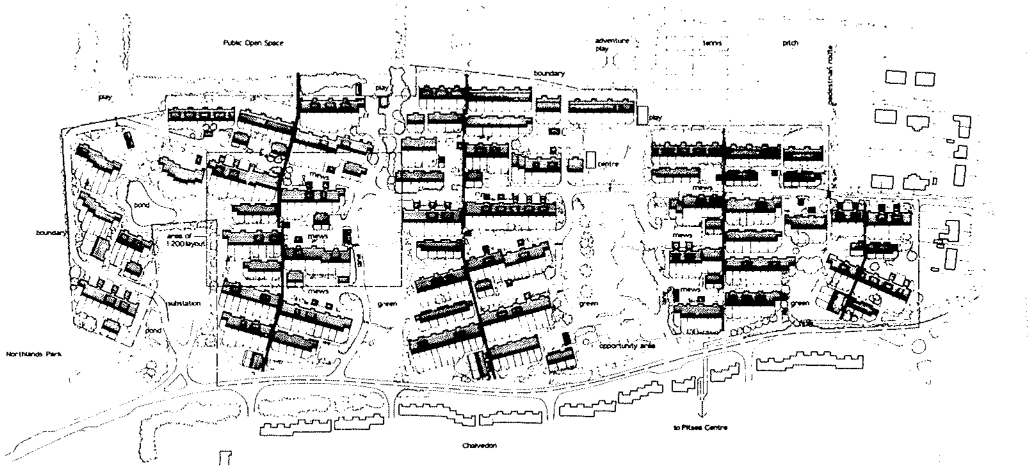
Architects
National Building Agency (Wales)

M & E Engineers
National Coal Board & Ove Arup and Partners

Quantity Surveyors
National Building Agency

Monitoring Organisation
National Coal Board

Felmore Housing Basildon



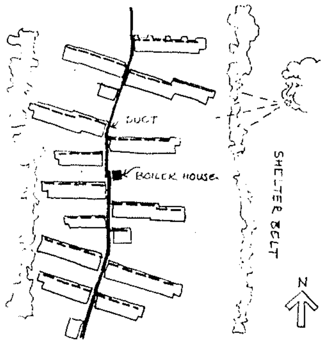
30 In this scheme for 430 houses, energy conservation was considered as a major parameter from the inception of the design. Reductions in energy demand were attempted for three reasons: to reduce running costs, improve environmental conditions and make the houses resilient to the effects of a breakdown of fuel supply. The cost of the houses is within the DOE yardstick. Primary emphasis was placed on all those measures which contribute to making the houses habitable, independent of the use of engineering systems; i.e. their layout in relation to microclimate and isolation, their internal planning and construction properties (see Fig. 1).

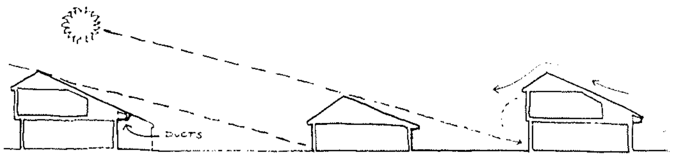
To maximise solar gain, a layout was developed in which all houses face within 22° of south and overshadowing is avoided from one terrace to the next by careful spacing.

This orientation was also best in relation to microclimatic considerations, as the prevailing winds run along the terraces and are reduced by shelter belts running north/south, planted between groups of houses. Pitched roofs, with deep eaves, are used to reduce wind turbulence and overshadowing between houses. Surface areas have been kept to a minimum and terraces of over seven houses were planned wherever possible.

Larger windows (40% of wall area) are confined to the south side. Bedrooms and bathrooms have windows as small as the Building Regulations allow. The construction is of brick with timber frames on the upper floors. Insulation values are 0.55 to 0.6w/m²°C in walls and floors and 0.54 in the roof. More insulation would have been cost effective.

An attempt has been made to reduce ventilation to 1 ac/h. Condensation risk is minimised by providing a separate utility room for clothes washing and by good





Diagrams of site layout and spacing between terrace based on maximum solar penetration and economic district heating runs.

kitchen extract ventilation. Shutters could not be afforded, though tenants have been advised to use aluminium curtains.

Because of the low heating loads, despite whole house heating (3.5kw), individual gas boilers were found to be too large and thus too inefficient. Electricity was discounted as being too wasteful of primary energy and therefore various district heating schemes were investigated. The system chosen uses three coal fired boiler houses, serving three independent groups of about 120 houses each. Group heating was chosen not only because of cheapness but because it allows for easy fuel substitution. Low pressure, hot water radiators with thermostatic valves are used in the houses. Site distribution mains are located in an overhead duct which also houses other services and have been kept to a minimum by virtue of careful design of the layout, thus allowing the use of district heating on moderately low density housing.

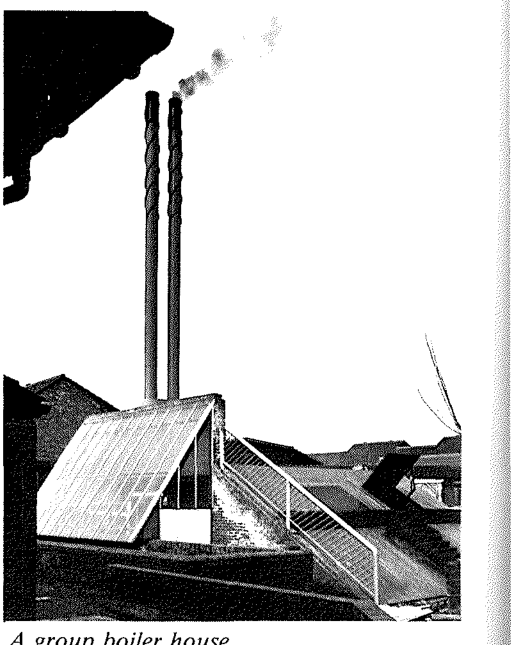
It is very difficult to produce energy conserving buildings by traditional methods. If the designer's intentions are to be realised in practice, new ways of supervising thermal insulation and airtightness are essential.

Thermal insulation tends to be hidden from view in cavity walls and lofts, and visual inspection is inadequate. For instance, it is difficult to check that the loft insulation has been tucked in or that cavity walls are completely filled.

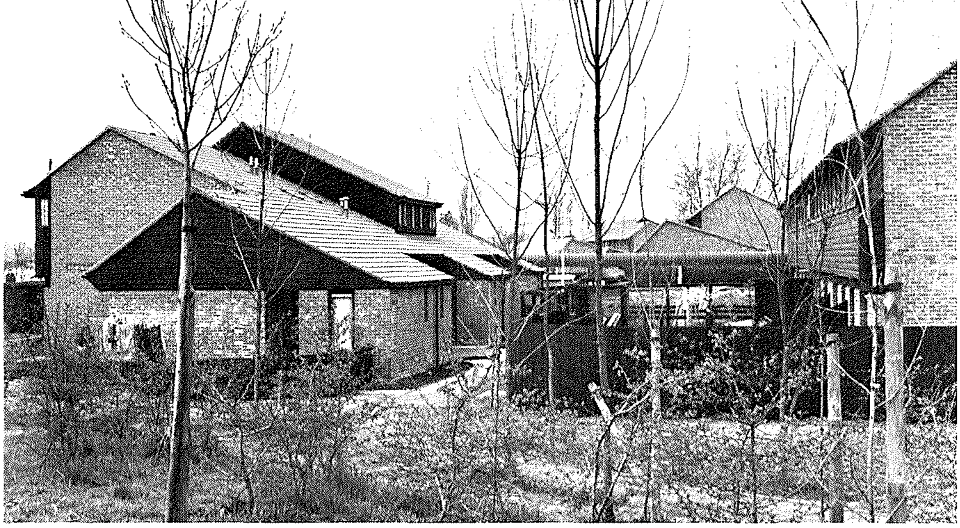
Infra red photography was used at Felmore to check insulation standards. A heat picture of the internal surfaces shows temperature variations greater than ½°C. Colder areas show up as darker patches and indicate that the insulation is either missing or is below standard. The main shortcoming of this system is the need for a minimum temperature differential of 10°C between inside and outside, effectively limiting the test to winter. The cost of the survey is about £15 to £20 per house.

	Saving per item	Saving per group
A Avoid waste		
① Improve layout and orientation	5-15 / 10	
② Improve shape (surface area)	5-30 / 10	
③ Reduce glazing area	10-30 / 15	30
4 Double glaze	2-10 / 5	
⑤ Improve insulation (med-low U)	20-30 / 25	
⑥ Reduce ventilation (1½-1 ac/h)	15-20 / 15	45
7 Use shutters on windows	5-15 / 10	10
B Reduce standards		
1 Reduce int. temp. 18-15·5°C	30	30
2 Reduce int. temp. 18-11°C	75	
C Increase efficiency of plant		
① Improve responsiveness	5-25 / 15	
② Improve boiler efficiency	5-20 / 10	25
D Use most efficient fuel Assuming a cumulative saving in A, B, C of 75%		
① Coal conversion efficiency 50% = 50 units total	25 wasted	useful 25 / 75
2 Gas conversion efficiency 42% = 60 units total	35	25 / 75

Figure 1: Four aspects of energy conservation showing approximate savings. The main design effort was placed on items marked by a circle.



A group boiler house



View of typical houses showing lower roofs at north side to allow sun penetration to the south side of the houses behind. High level duct with walkway under shows in the background.

Faults were discovered due to the following causes:
(**a**) Contractor's omissions
(**b**) Design omissions
(**c**) Disturbance due to following trades, particularly noticeable in the loft when the electricians had finished their second fixing.

The majority of the faults however were due to the contractor's omissions or following trades. Nevertheless several were due to design problems such as cold bridges and these were corrected at the earliest opportunity.

Ventilation or infiltration is less easily quantified. To date, no UK standards exist to define the airtightness of a standard house, although standards have been applied in countries like Sweden for many years. Fortunately, the British Research Establishment are currently undertaking a measurement programme of typical UK housing and two Felmore houses were included in their programme.

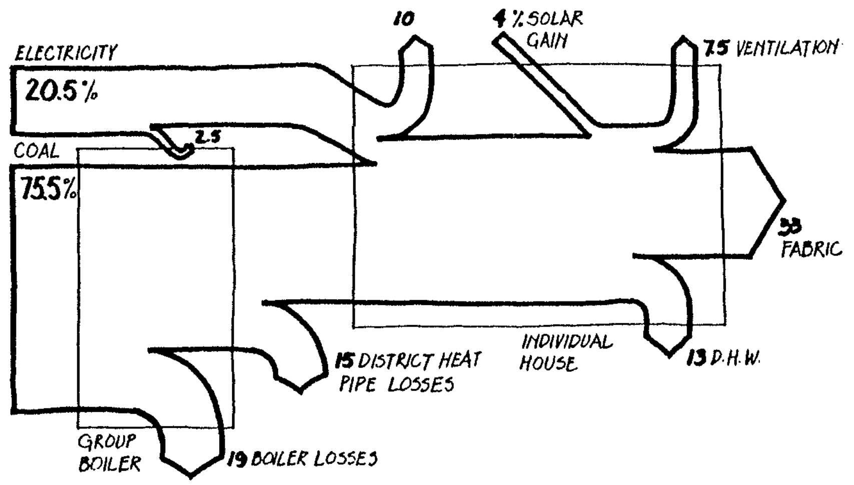
This method of testing involves pumping up the house to a pressure of 50 Pa and measuring the leakage. Pressure is then reversed to 50 Pa and the leakage again recorded. Leakage paths are identified by taping up components like windows, doors etc. and deducting those from the total. Unfortunately, it was impossible to tape up every component — for instance, skirting boards, floor boards etc. — and a high proportion of the ventilation losses were unaccounted for.

Faults and omissions discovered by this test were far more pronounced than those discovered by the infra red test. For example, sleeves on inlets were poorly packed, there were gaps below beams, draught stripping was missing from loft hatches and, most serious of all, central pipe ducts were left open to the roof void, producing a high risk of condensation from warm moist bathroom air.

The results of these tests has led to stricter supervision procedures to ensure the high standard of construction which is needed for 'energy efficient' buildings.

A tenant's handbook has been produced, showing how to derive the maximum benefit from the house, while consuming the minimum energy. This is supplemented by a demonstration house where various problems of control of the house can be explained; how the heat meter and time clock control operate, the way in which the thermostatic radiator valves work and their optimum settings, how to use curtains effectively to retain the heat and the principles of ventilation control.

The Building Research Establishment are using twelve houses to monitor a small District Heat Pump system, with solar heating for domestic water. Simple experiments with shutters and conservatories are also in projects, the results of which are being applied to subsequent housing schemes.



Total fuel use per annum Primary 38.4 × 10^3 kwh **Delivered** 24.3 × 10^3 kwh **(Primary: Delivered Ratio 1.6:1)**

Felmore Housing, Basildon	
Date of completion	From January 1979
Capital cost	£4 621 433 (tender)
Occupancy	
Normal domestic occupancy	
No of persons	5
Persons per m²	0.056
	m²
Usable area	89
	m³
Usable volume	200
Delivered annual energy consumption	
Estimated using Ove Arup computer programme HVAC1 with modified radiation data	
	kwh
Total	24 270
Per m²	272
Per m³	121
Per person	4850
Primary annual energy per m²	431

Client
Basildon Development Corporation

Address
Felmore, Basildon, Essex

Architects
Ahrends, Burton and Koralek

M & E Engineers
Ove Arup & Partners with Professor Alex Hardy and George Kasabov

Quantity Surveyors
E.C. Harris & Partners

Structural Engineers
Ove Arup & Partners

Monitoring Organisation
Building Research Establishment

Solar Housing for the Elderly

31 The scheme consists of 14 houses. There are two blocks of five terraced houses, one with solar walls and a high standard of insulation, the other without solar walls and built to the 1976 building regulations standard. Two further semi-detached houses face south-east and two south-west, all having solar walls.

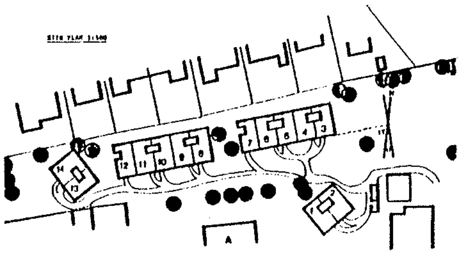
With the 21 °C inside design temperature for elderly people, an outside design temperature of -1 °C and two ac/h, heat loss calculations showed the following: Conservation/Solar houses 3.30 kw and the Traditional Control houses 4.90 kw.

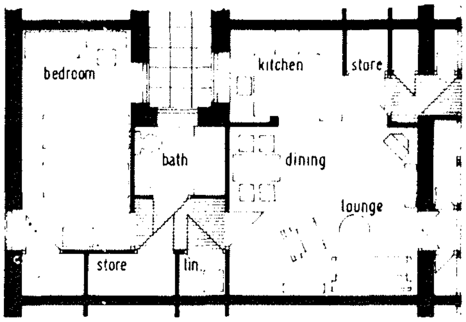
The design is based on a total environmental concept that uses solar radiation to a maximum for the energy requirements of a house. This is achieved by an integral relationship between its design, construction and other essential features.

The objective of the scheme is to provide an economical solution for the provision of space heating by means of solar radiation and which can be applied to housing generally.

The main aim in designing the experiment — the layout, design and construction of the houses, was to monitor and compare the thermal performance of the solar houses with the traditionally designed houses of the same plan form.

The houses have been designed with the particular residents in mind to prevent any feeling of isolation. There is a small internal patio where the tenants can sit out and use for the greater part of the year; this also serves as a link with the next house for companionship or in case of emergency. There is a view from the kitchen to the walkway outside and across the patio to the bedroom in case of illness.





The cost is within normal housing corporation limits, with an additional 15% for solar and conservation design of the test houses.

The construction uses heavyweight materials insulated externally; the solar wall acting as a generator of warm air which is ducted to different rooms in the house. Windows and doors are designed to puncture the solar wall and take advantage of direct gains. As the internal heat gains in this type of building are low, it requires an auxillary heating system which can:

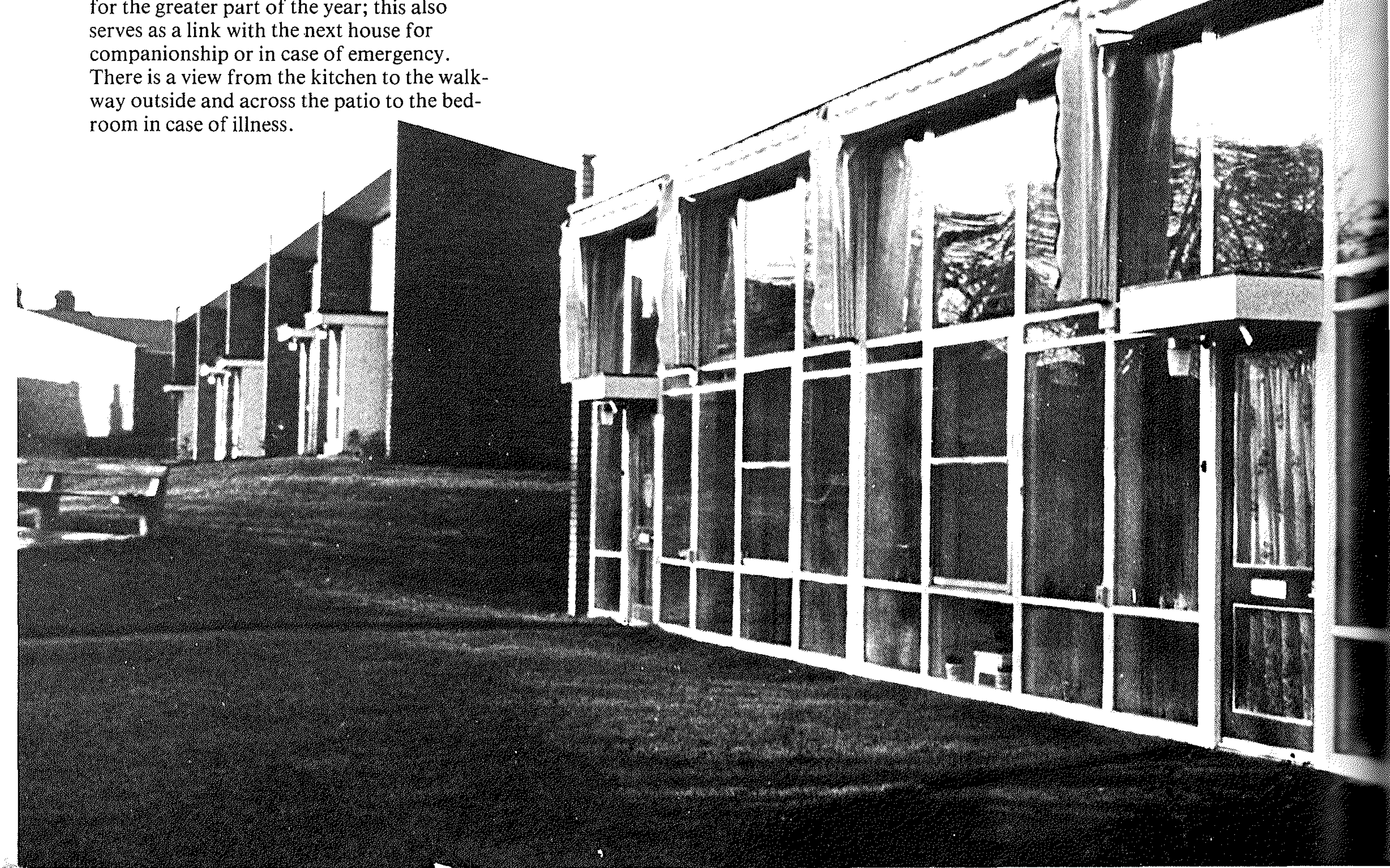
1 back-up the natural system when it needs topping-up and operate with the same fluid-warm air;

2 because of 24 hour occupancy, the heating also needs to be topped-up in the evening during early spring and late autumn when the structure may not yet have stored up enough heat for the whole night.

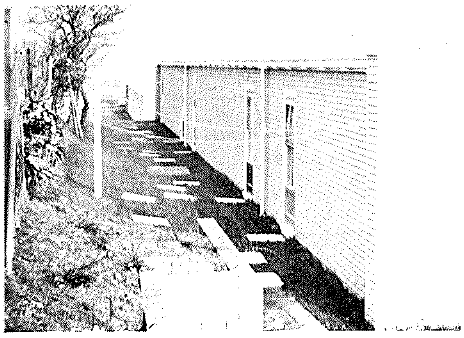
The solar warm air heating is backed-up by off-peak electricity using storage heaters. These are strategically positioned so that the warm air output will integrate with the solar warm air return flow from the bedroom to the solar cavity. The economy 7 tariff operates between 0030 hours and 0730 hours Greenwich Mean Time — 0130 and 0830 hours British Summer Time — and between these hours any appliance in the house — not only the storage heaters — operates on the cheap tariff. Thus, the 1.5kw convector heater in the bedroom and the 0.5kw one in the hall are controlled by a time clock so that they can be set to clock on and off in the early morning to pre-heat the bedroom and hall at off-peak rate, before the occupants get up. To operate the same heaters during the day on the full-rate tariff, the time clock has to be over-ridden by the tenant.

The residents control the warm air heating by opening or closing ventilators, blinds and fans as necessary. This soon becomes routine.

The choice of auxillary heating was between electricity, oil and solid fuel as there was no gas available on the site. Criteria for selection were, easy control, integration with the solar warm air system, cleanliness and — reasonable 'cheapness'. Of the three fuels considered, solid fuel was the cheapest but was ruled out on the grounds of dirt and inconvenience. Oil was not chosen because of



cost and because boilers would be oversized for the small demand of the houses. Electricity fulfilled all the criteria if mainly used 'off-peak'.



The total concept for the design of the houses is based on six principles:

a Orientation of the dwelling to receive maximum solar radiation.

b The solar heated houses have one outer wall covered by a double glazed outer skin. Solar radiation is absorbed by the high density black brick wall and re-radiates heat into the house on the storage heater principle.

c Warm air heated by the high density wall is circulated throughout the house by natural convection through a system of ducts. This is a result of the use of a double module in depth.

d A highly insulated structure, including double glazing, minimises heat loss.

e The geometry of the building allows the roof volume to be used as an extra source of warm air, to assist the natural circulation during spring and autumn.

f To avoid overheating, there are four integrated systems. The first is external shading, the second involves removing the warm air produced by the solar wall, the third is natural ventilation and the fourth is the use of a fan to assist ventilation.

A comprehensive monitoring scheme is to be carried out for two years and will cover all aspects which affect the performance of the dwellings. The areas to be monitored include:

1 meteorological data: radiation — direct and diffuse, wind — velocity and direction, air temperature, relative humidity and precipitation.

2 internal environmental temperatures.

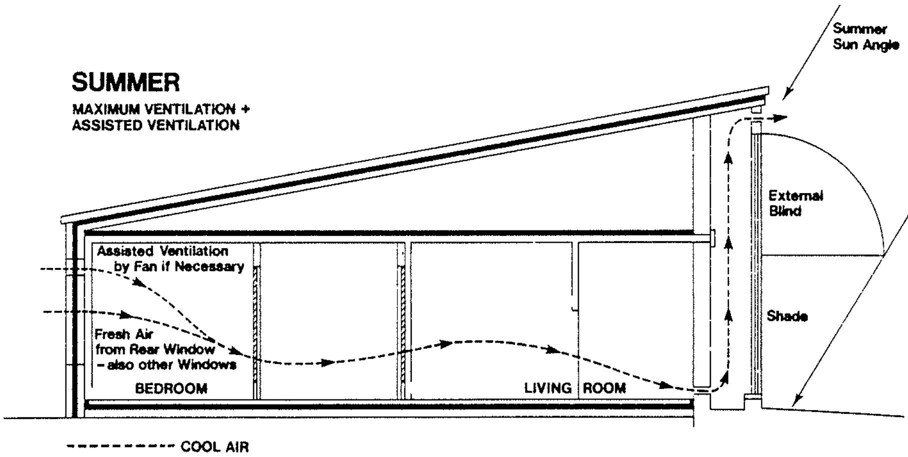
3 thermal performance of the structural elements in both the solar and the traditional control houses.

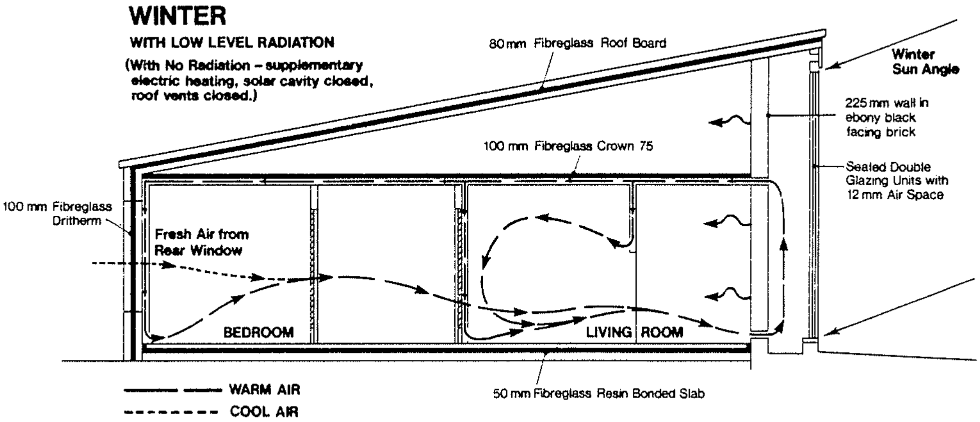
4 performance of the solar wall/heating system, and

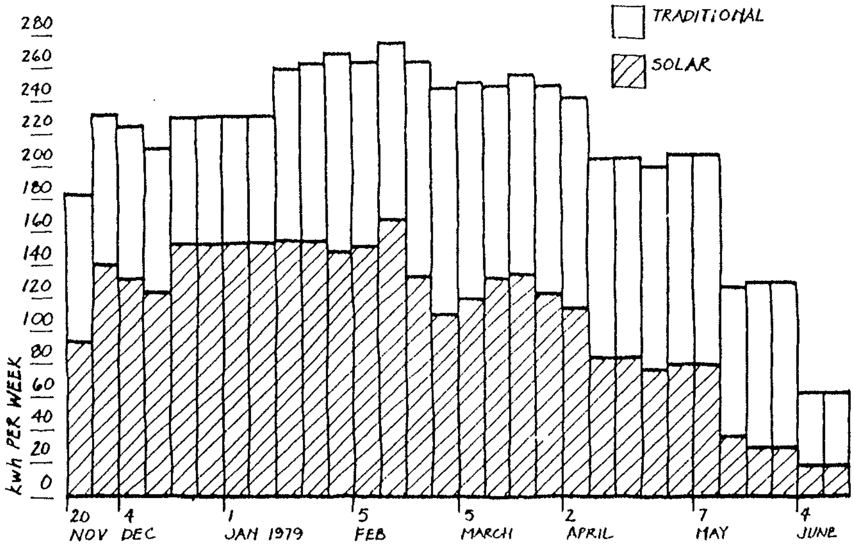
5 energy consumption/cost in both the solar and the traditional control houses.

Preliminary measurements made by the whole monitoring team from November 1978 to June 1979 show that the solar system makes a noticeable contribution to the space heating demand, particularly in the spring. A comparison, made by Peter Greenwood, of the electricity accounts for 52 weeks, of the two solar houses, and one traditional house, has shown a considerable saving.

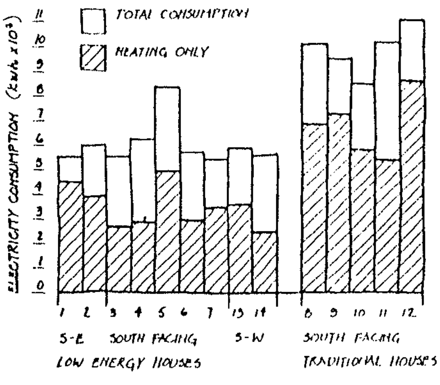
However, a clear assessment of the effectiveness and cost benefit of the system will have to wait until the monitoring programme is complete and the results can be analysed, taking into account the difference between the test and control houses.







Weekly electricity consumption for heating, showing considerable solar heat gain in the spring period. The design heat loss of solar houses is approximately 2/3 of the control houses.



Electricity consumption for the fourteen houses, from 20 November 1978 to 3 September 1979.

Solar Housing for the Elderly	
Date of completion	July 1978
Capital cost	£190 000 for 14 houses
Occupancy	Normal domestic occupancy
No of persons	2
Persons per m²	0.04
Usable area	50
Usable volume	118

Client
Merseyside Improved Houses

Address
Acorn Close, Wirral, Merseyside

Architects
Peter Greenwood & Howard Ward in association with Paterson, Macauly & Owens

Quantity Surveyor
Tweed, Atkinson, Lewis & Partners

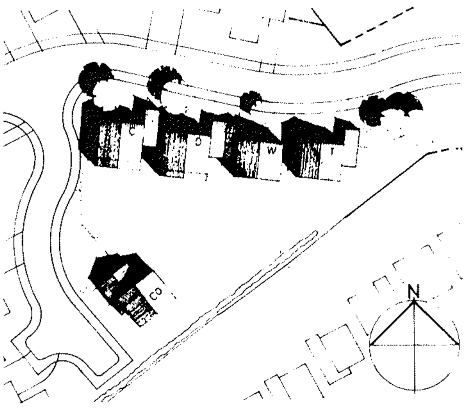
Monitoring Organisation
Merseyside Improved Houses, The Designers, Pilkington Brothers Ltd. & The Department of Energy

Solar Housing Aylesbury

32 Five of the houses on a typical small estate will form an experiment in passive solar design. The brief to the designers called for:
1 A demonstration that passive solar houses can be built in the UK at minimal extra cost
2 A quantification of the energy available from passive gains
3 Recommendations for future passive solar architecture.

The control house is a standard Taylor Woodrow 4-bedroom detached house with high levels of wall insulation.

Each of the other four houses employs variations in glazing and distribution of thermal mass.



Direct Gain House
A large south facing glazing area is used with night insulation, and horizontal shading elements to control summer gains. The building mass can be adjusted to vary performance.

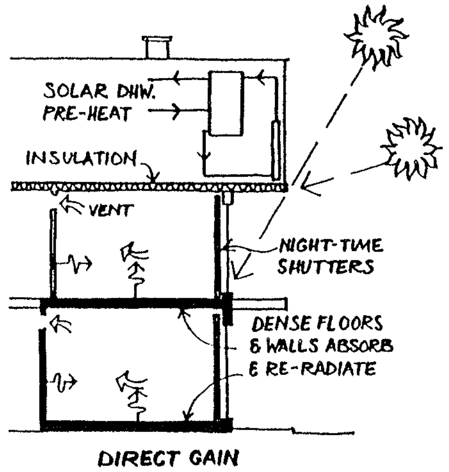
Conservatory House
This house incorporates a conservatory on approximately two-thirds of the south facing wall. The conservatory air temperature is not critical to the comfort of the house and gives control of solar gains. Thermo-circulation of conservatory air and night insulation provide additional control.

Trombe Wall
The south side consists of a heavy wall with external glazing. This absorbs heat and re-radiates it inwards at night. Night insulation and possibly selective surfaces will be employed to maximise solar gain.

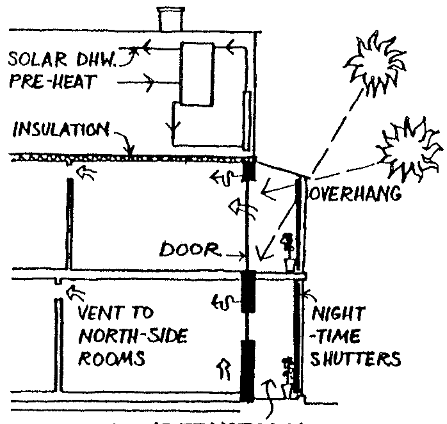
Water Wall
Cylindrical containers of water will absorb most of the solar gain transmitted through extensive glazing. Night insulation and possibly selective surfaces will be used to improve performance.

The thermal performance of the houses will be extensively monitored for one heating season with simulated occupancy. The 'live-ability' of the houses will be assessed during the three years of occupancy, with reduced monitoring.

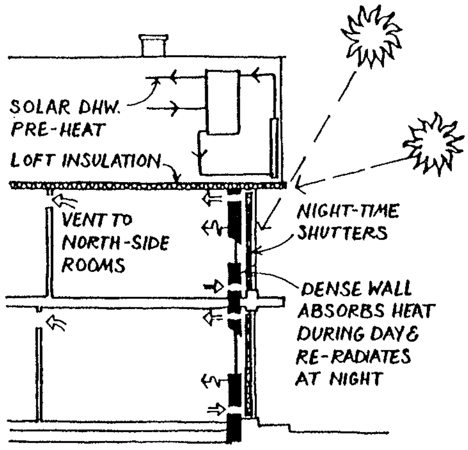
The scheme is partly financed by the EEC.



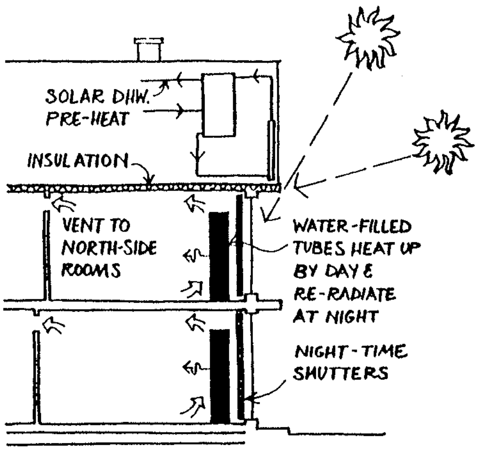
DIRECT GAIN



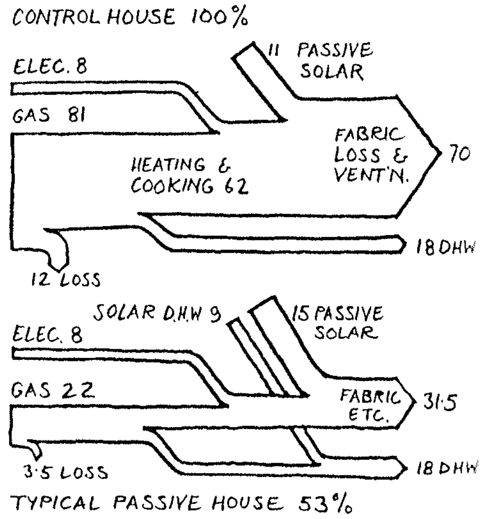
CONSERVATORY

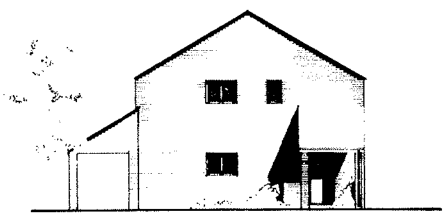


TROMBE WALL

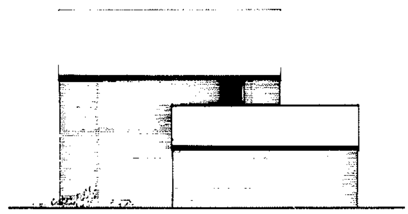


WATER WALL

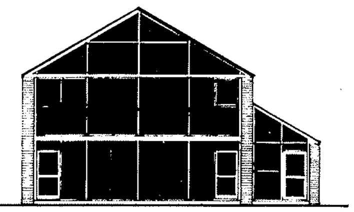




NORTH



EAST



SOUTH

Solar Housing, Aylesbury		
Date of completion	Summer 1980	
Capital cost	£200 000	
Occupancy		
Normal domestic occupancy after 1 year's monitoring		
No of persons	5	
Persons per m²	0.046	
	m²	
Usable area	109	
	m³	
Usable volume	250	
Delivered annual energy consumption		
Estimated by degree days and BALCOMB passive solar monthly performance method for south mass walls. (A) control house (B) passive house. Insulation levels for A and B are different.		
	kwh (A)	kwh (B)
Total	23 500	12 470
Per m²	218	114
Per m³	98	50
Per person	4 700	1 945
Primary annual energy per m²	412 inc. 23 solar	364 inc. 26 solar

Client and Contractor
Taylor Woodrow Homes Ltd.

Address
2 Furlong Lane, Foxhills, Aylesbury, Bucks.

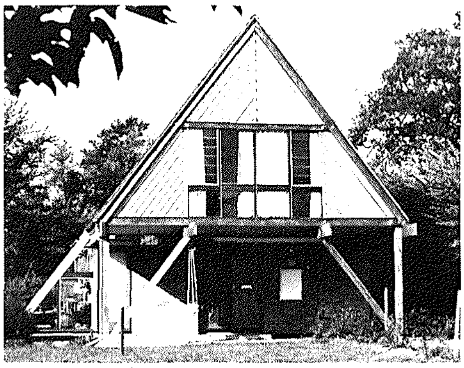
Architects
Solar Energy Developments

M & E Engineers, Quantity Surveyors, Structural Engineers
Taylor Woodrow Homes Ltd.

Monitoring Organisation
Taylor Woodrow Research Laboratories

The Delta House

33

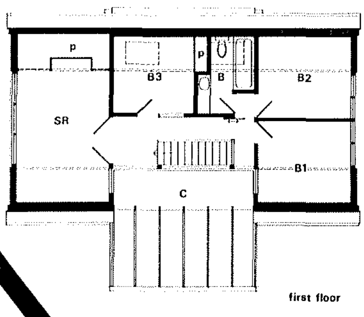


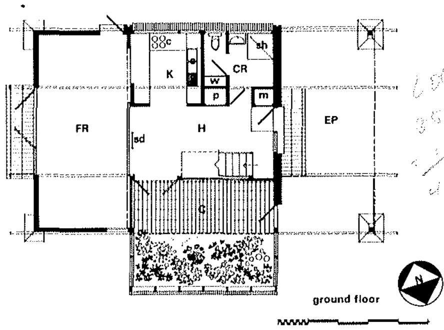
The Suffolk 'Delta' house was designed in 1973 and evaluated in 1975 with the help of the University of Sheffield. It is a timber framed highly insulated structure with a steep pitched roof and a two storey conservatory on the south side. The thermal storage is in the black tiled concrete ground floor and concrete block walls around the service rooms in the core. The sun shines through the conservatory to warm the interiors directly, and at night heavy curtains with reflective linings reduce the heat loss through the conservatory. Air warmed in the conservatory space is convected through the house, returning down the stairwell in the centre of

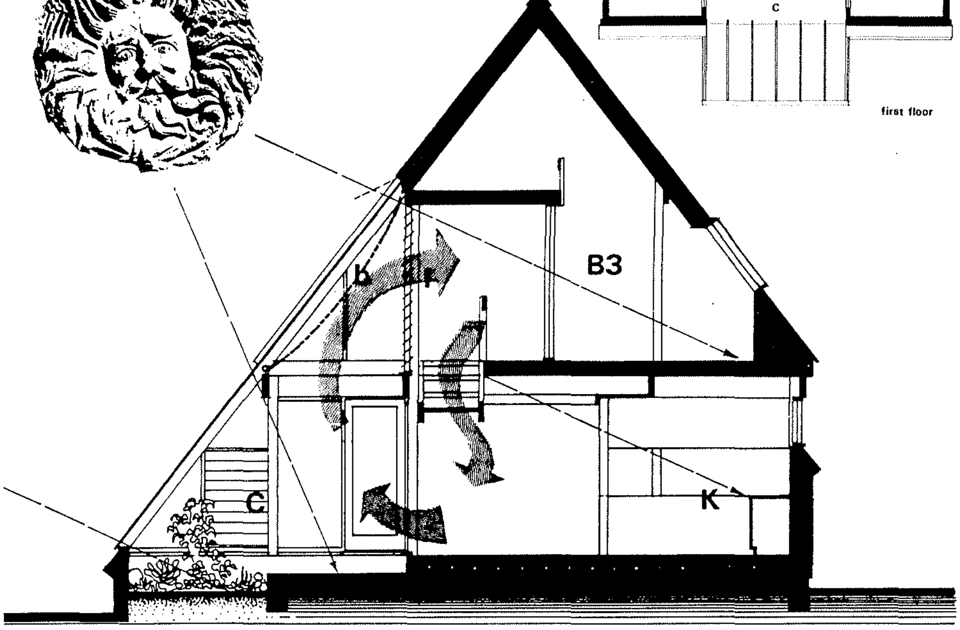
South Elevation showing two storey conservatory glazing.

the plan. Evaluation from January to April 1975 showed that 43% of the heating of the whole house, including the conservatory, was provided by the sun. However, if one considered the conservatory just as a solar collector, then the sun provided 23% of the heating needed. But the daytime usefulness of the conservatory as a room justifies considering the solar gain that it uses itself as part of the total. Thus, the whole house working as an integrated collector and storage system, performed that year with an efficiency of 69%.

The house was occasionally too warm upstairs during the day because of rising warm air from the conservatory, and too warm downstairs at night because of stored heat in the slab and the off-peak electric floor warming back-up system. During a very sunny day in autumn or spring the conservatory tended to overheat because the rate of transfer to thermal storage was too slow.







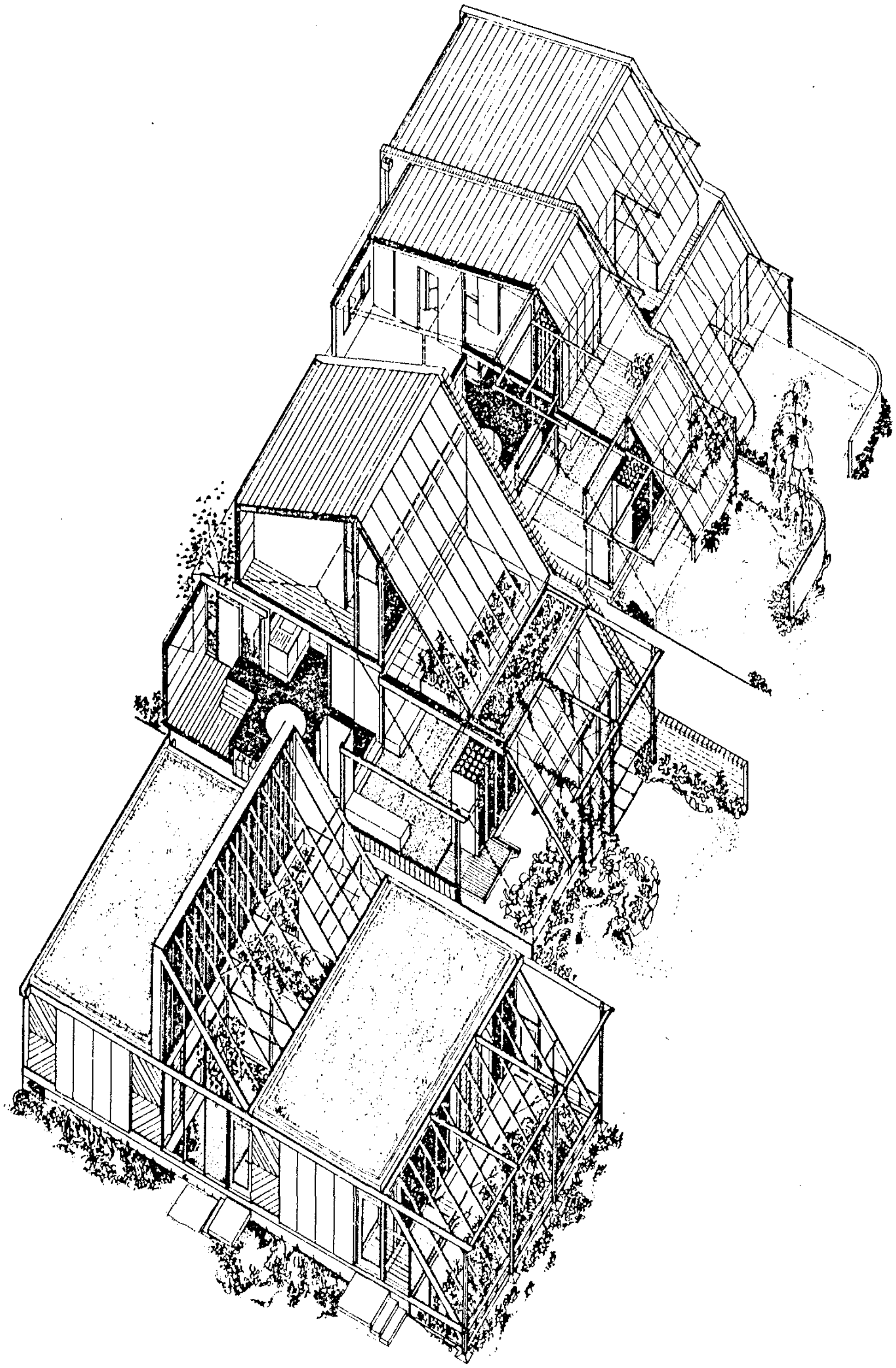
The Delta House	
Date of completion	1974
Capital cost	£11 000
	m²
Usable area	98.2 excl. cons.
Delivered energy consumption from December to April 1975 for heating only, measured	
	kwh (before)
Total	9754
Per m²	99.3
Primary annual energy per m²	377.4 (plus 29.7 solar)

Client
Cedric and Margaret Green

Address
Charsfield, Suffolk

Architects, Monitoring Organisation
Cedric and Margaret Green

SHED Project Sheffield

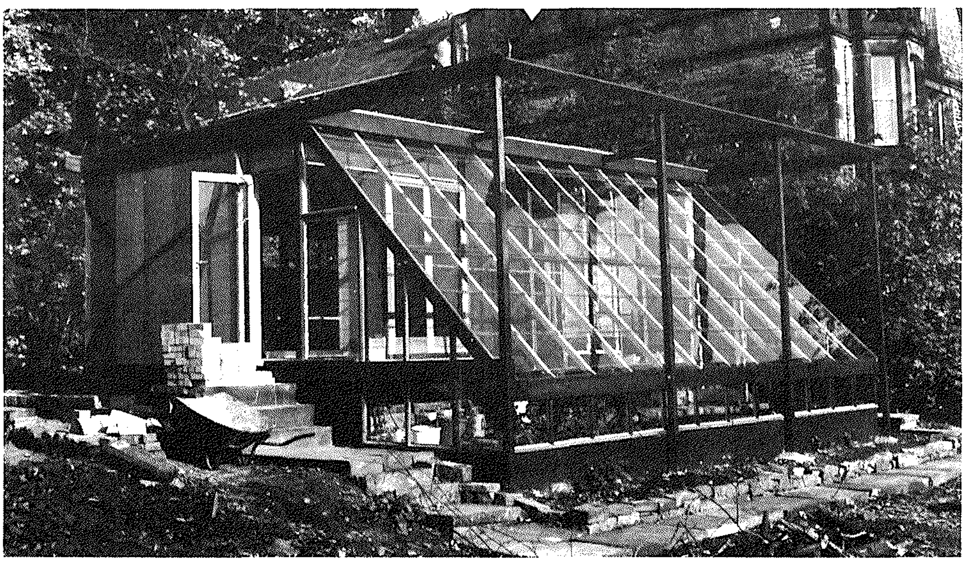


34 The SHED was designed to improve on the performance of Delta, the main difference being in the thermal storage mass. To achieve a significant increase in the amount of solar collection the ratio of south facing glazing to floor areas was increased from 1:3 to 1:1.

It is being built in two phases — the first, completed in October 1978, consists of about half the final floor area, designed as a demountable 'laboratory' to try different arrangements of heat store, ducting and controls. The second is a complete house including a low energy and water-conserving bathroom. The first stage was built by students with the aid of grants from the Manpower Services Commission. Materials were donated and it is hoped that the second phase will be financed in the same way.

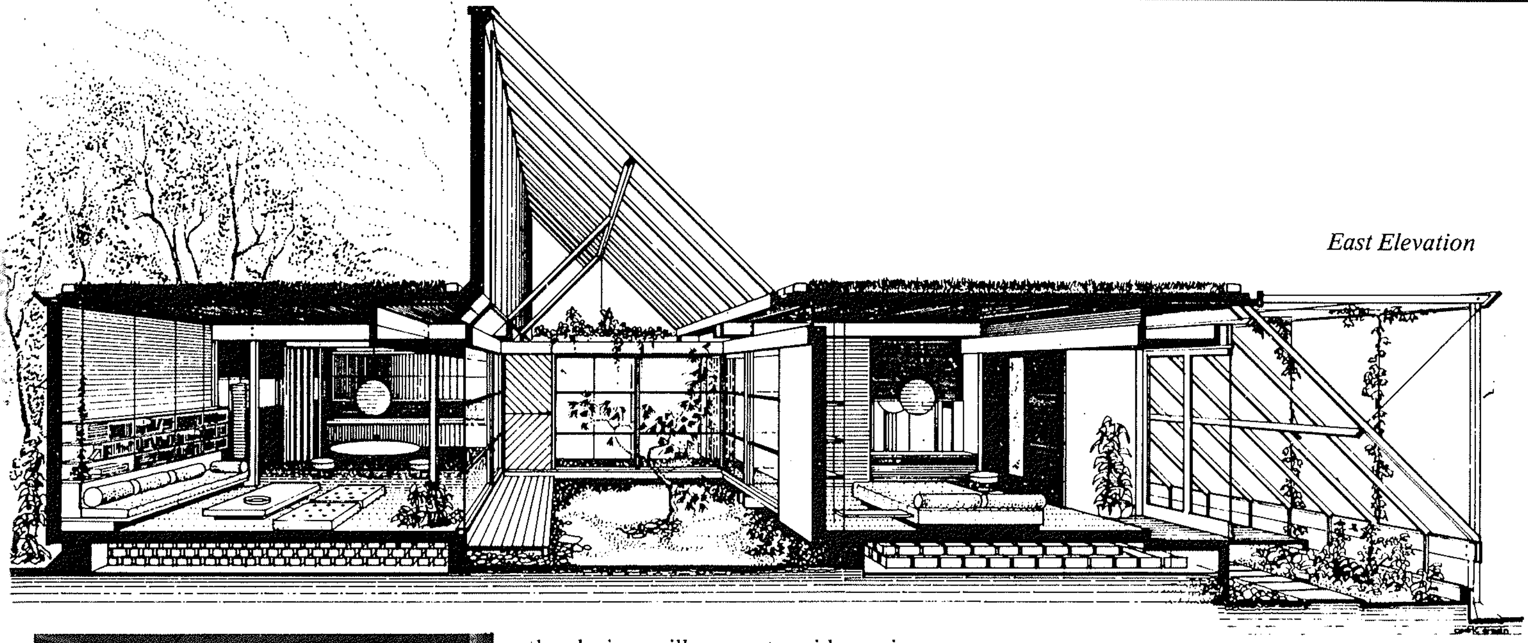
The test SHED consists of a highly insulated room with a conservatory running the full length of the south side. Half the separating wall is glazed and the other half consists of vertical air type solar collectors. Three types are being tried: first, a natural thermo-siphoning collector with hollow heat store directly behind it, second, a Trombe wall, and third, an underfloor 'hypocaust' heat store. This last heat store is divided into three sections, each of which has a different geometry and one of which contains sealed bottles of water. Distribution of heat horizontally is in each case in ducts under the main mass, and heat transfer is passive, although fan experiments will be undertaken.

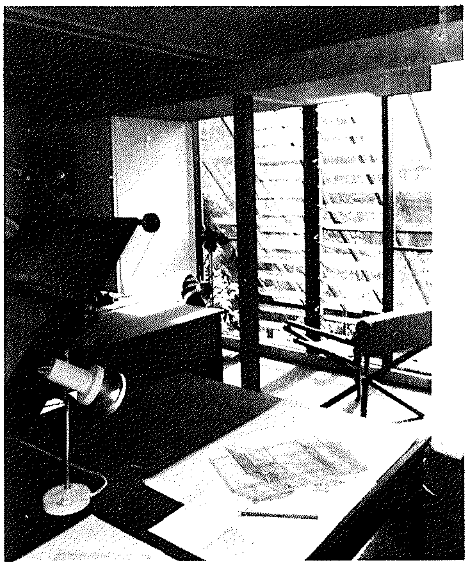
Evaluation has not been completed, but since November 1978 a thermostatically controlled back-up electric heater has been keeping a steady temperature for eighteen hours a day. Instruments are recording the temperature and humidity in the room and the conservatory, and daily power consumption. Over a period of extreme weather and negligible sunshine the mean daily energy input of the back-up heater was 25kwh. When the weather returned to the seasonal norm for late February, the consumption dropped to 10kwh per day, with not much fluctuation from day to day



despite variable amounts of sunshine, showing that the heat store was smoothing the heat fluctuations and storing a useful amount of heat. Certain problems have been noticed. The demountable timber construction has left air leaks that take time to find and seal. The geometry of the vertical heat store of perforated fireclay bricks had to be changed to allow easier air flow. The increase in cost of double glazing the conservatory would only have been £50 using horticultural glass in standard panes, which might have saved some of the plants during the very cold weather, as well as reducing electrical consumption.

With such a large ratio of glazing, heat gain in summer could become a problem so the design includes, in the first phase, a timber frame over the conservatory, which in addition to providing tension supports for

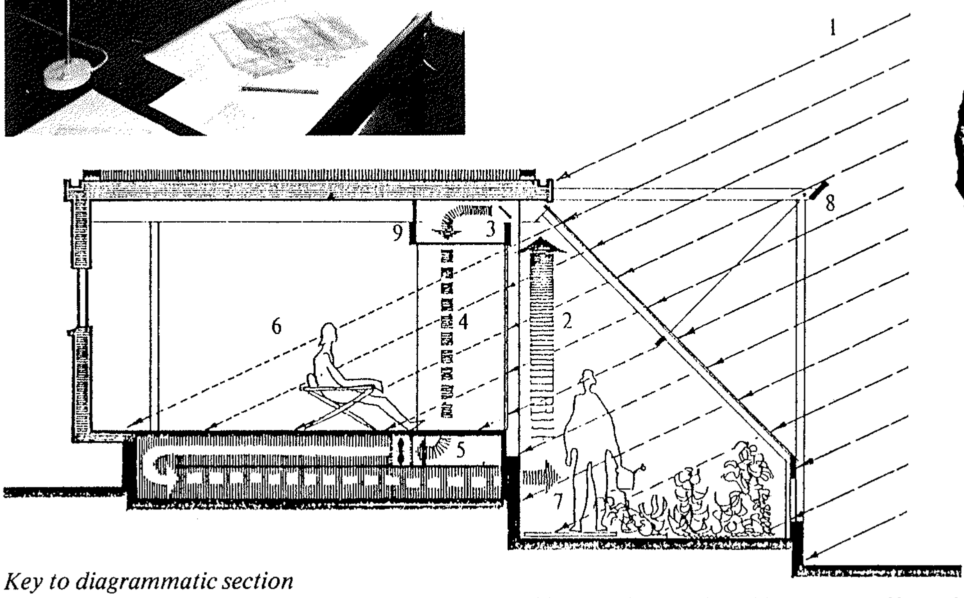




the glazing, will support rapid growing climbing plants like vines, hops or beans which will put out a canopy of shading leaves in summer. Inside the conservatory, as well as providing food, plants will act as filters by carbon dioxide absorption and oxygen production and add significantly to the amount of heat transfer to the air.

The tentative design for the final house puts another 40m² of double glazing in a south facing roof over an inner court, and on the inside facing south a vertical air collector whose heat will have to be transferred by fan to the horizontal heat store. With the price of photovoltaic cells falling very fast, the designers are intending to use solar power to drive the fans. This would eliminate the need for variable control, moving the heat away at the rate it is produced. Studies have been done of the applicability of the design to housing at various scales.

These studies and the experimental SHED were entered for the 6th Misawa Homes International Design Competition in Japan and were awarded third prize.



Key to diagrammatic section

1 Autumn and Spring direct solar radiation on glazed plane. (Approx 40% of total radiation is diffuse.)

2 Air warmed by greenhouse effect in conservatory rises.

3 Damper opens as fan is turned on by thermostat in conservatory, warm air is drawn into horizontal duct.

4 Vertical stores at intervals along wall, with warm air drawn down through them warming fireclay bricks.

5 Fan and horizontal heatstore under floor drawing warm air through 'hypocaust' of bricks + water bottles.

6 Room space warmed by some direct radiation through windows to conservatory, and heating load reduced by passive effect of thermal storage.

7 Cool air returns to conservatory — in summer heat store can work in reverse, extracting heat from room and warming conservatory at night.

8 Timber frame supporting conservatory glazing and summer climbing plants to provide external shading.

9 User controlled vent for release of warm air from vertical heat store or for extract of warm air from room in summer.

The earlier Delta house revealed the importance of separating the thermal storage from the mass of the structure, hence the underfloor storage in SHED to allow heat retrieval when it is needed.

SHED (Solar Heated Experimental Dwelling) Project, Sheffield

Date of completion		December 1978 (Phase One)	
Capital cost		£6 677	
Occupancy			
Normal domestic occupancy			
No of persons		3 (Phase 2)	
Persons per m²		0.1	
		m² (Phase 1)	**m² (Phase 2)**
Usable area (excl. cons.)		30	80
		m³ (Phase 1)	**m³ (Phase 2)**
Usable volume (excl. cons.)		69	184

Delivered annual energy consumption
Measured for Phase One during winter of 1978-79. Estimated for Phase Two, using SPIEL (solar passive integrated energy language). Figures for Heating only

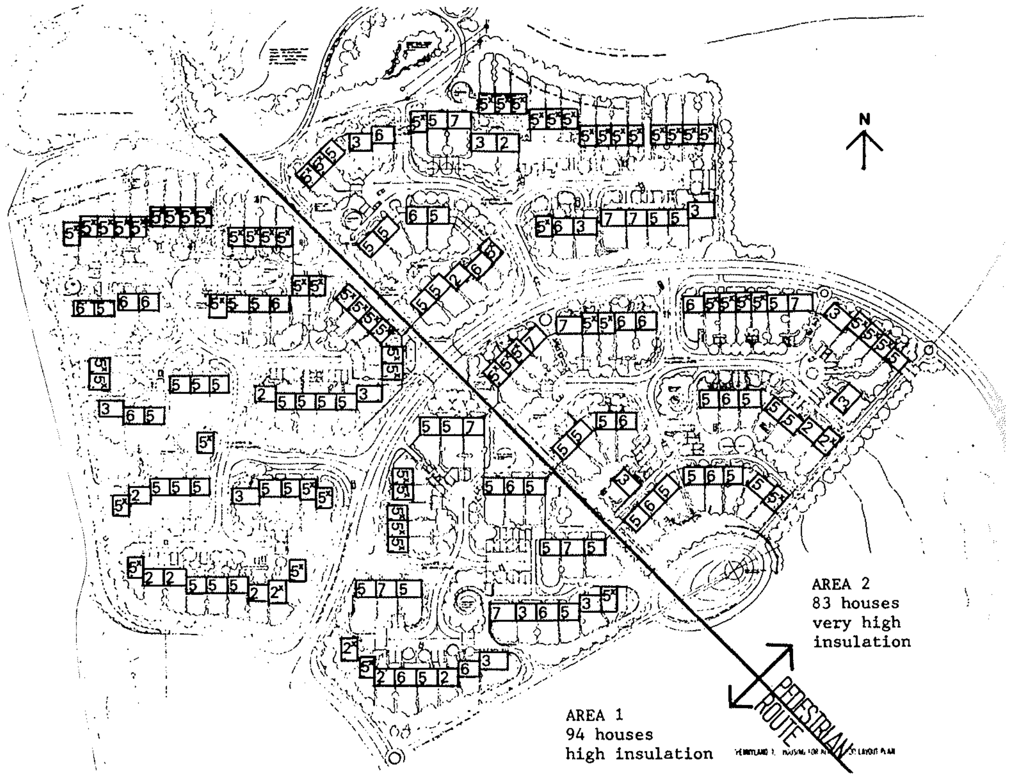
		kwh (Phase 1)	kwh (Phase 2)
Total	min	1400	2700
	max		3600
Per m²	min	46.6	33
	max		45
Per m³	min	20.2	14.6
	max		19.5
Per person	min	–	900
	max		1200
Primary annual energy per m²		178	149

Client
University of Sheffield

Address
Sunbury Court, Westbourne Road, Sheffield 10

Architects, Quantity Surveyors, Structural Engineers, Monitoring Organisation
Cedric Green and Project Team from Dept. of Architecture, University of Sheffield

Pennyland Housing Milton Keynes



35 Pennyland One is 177 houses which will be rented. They are in two groups, one highly insulated, one very highly insulated. All are designed to take advantage of passive solar gains. They will demonstrate the cost-effectiveness of a package of energy conserving measures.

The measures were chosen on the basis that they would not produce the risk of building failures due to untried detailing, and that they would be cost effective.

Cost-effectiveness can be judged in several ways. A pay-back time of less than ten years was used as the private sector criterion. For the public sector, the Test Discount Rate Technique was used, in which future costs are given a current value. This method allows future fuel price increases to be taken into account. Two likely futures were chosen, one in which fuel prices remain constant in real terms, and a second, in which fuel prices double by the end of the century. In both cases, a measure was judged cost-effective if it exceeded a 7% real rate of return. (Fig. 1) shows capital costs and fuel savings of various measures, and the dotted lines show various financial criteria. Measures above each line are cost-effective.

For Pennyland as a whole, the total package of measures cost under £500 per house, and all financial criteria are satisfied. The construction is however not typical, using, as it does, the "Mowlem Quickbuild" method. The extra cost of upgrading standards above traditional construction was costed at £650 per house, which satisfies all but the most severe criterion. Half the estate is built to satisfy the 7%, constant fuel price line, and half to a very high standard, which satisfied the 7%, doubling fuel price line in Fig. 1.

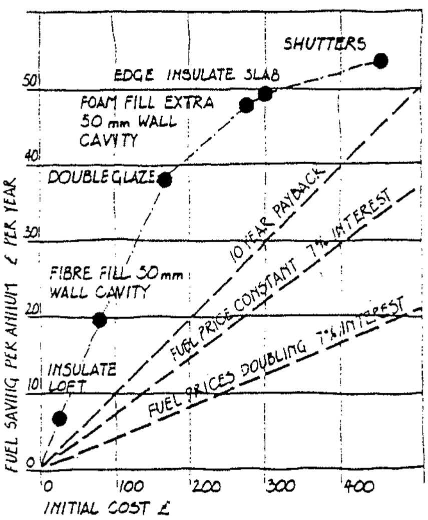
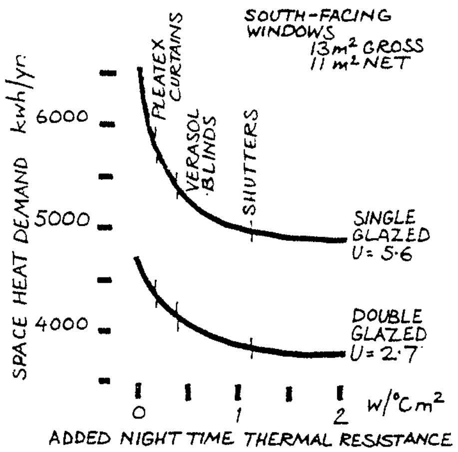


Fig 1. Cost benefit of cumulative fuel saving measures. (3 bed, 5 person end of terrace house, marginal cost 15.3p/therm, boiler efficiency 60%, 13m²south facing glazing).

For the solar component, a net benefit from windows facing south was calculated. A single aspect plan was adopted for most of the houses, and north side glazing was reduced.



The effect of window specification and night insulation on house heat demand.

The need to reduce risk of the failure of untried methods of construction ruled out some measures. Loft insulation is never more than 150mm, as there is a risk of condensation above this thickness. Cavities greater than 100mm were also ruled out, partly through condensation risk and partly because structural calculations would have been required.

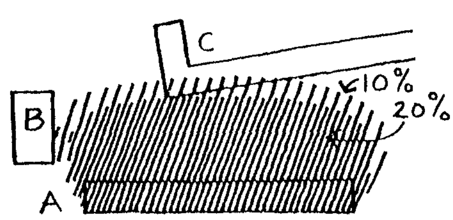
The measures adopted for the very highly insulated houses were — 100mm cavity external walls with fibre fill and 100mm dense concrete inner leaf, 150mm loft insulation, 25mm perimeter slab insulation, double glazing with internal shutters or blinds, facing the houses within 45° of south, and reducing overshading. The highly insulated houses have 50mm cavity insulation only.

Nationally, very little is known of living temperatures, ventilation rates or even installed 'U' values, all of which affect the benefits of insulation and solar gains considerably. In the absence of data several assumptions were made:

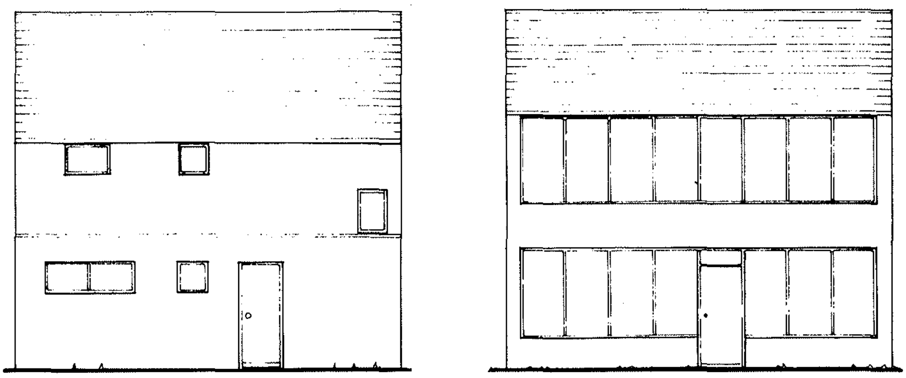
1 Intermittent occupancy, whole house thermostat set at 18°C.
2 Ventilation rate 1.0 air changes per hour.
3 Theoretical published 'U' values.
4 2400 kw hours per year for casual electric use.
5 2400 kw hours per year (useful) required for domestic hot water.
6 Boiler efficiency — 65% winter, 40% summer (this only applies to Low Thermal Capacity Boilers).

Space heating use is controlled by a room thermostat, cylinder thermostat, programmer and thermostatically-controlled radiator valves (TRVs) on all but the living room radiators. This hybrid system was first developed by British Gas to avoid overheating in south facing rooms. It avoids boiler cycling inefficiencies associated with an all-TRV system, as the boiler and pump can be shut down when both thermostats are satisfied.

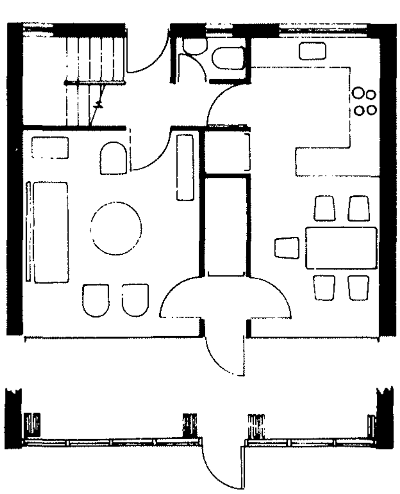
In attempting to maximise solar gains, the importance of overshadowing was known. Energy shadowprints were therefore designed which, when used as a plan overlay, show energy loss due to overshadowing. It is hard to keep overshadowing to less than 10% at densities greater than 125 persons per hectare (the normal estate density). The chosen layout reflects this. Houses can be



Solar shielding calculator. Building group A reduces solar radiation on B by less than 10% and on C by 10-20%.



Typical Pennyland house, north and south elevations.



Ground floor plan and detail showing shutters on the south side.

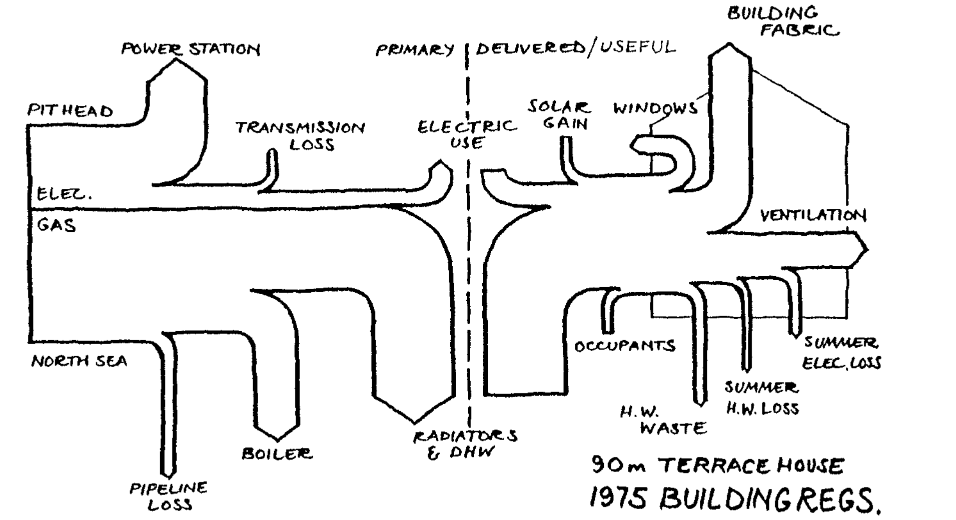
closer to each other if the southerly houses are single storey.

The effect of insulation on space heating demand was calculated using the American Bureau of Standards NBSLD Programme. This is a 'dynamic' model and takes into account both solar gains and thermal mass. It was used to evaluate a wide range of insulation measures. The chosen specification for a 3-bedroomed, end-of-terrace house, gives a specific loss, including ventilation of 160w/°C. A house built to current regulations is 315w/°C. With very good insulation heat loss through walls is very small, about 17% of the total, so the building shape is not critical. Ventilation accounts for 45% of the loss, so openings are carefully detailed.

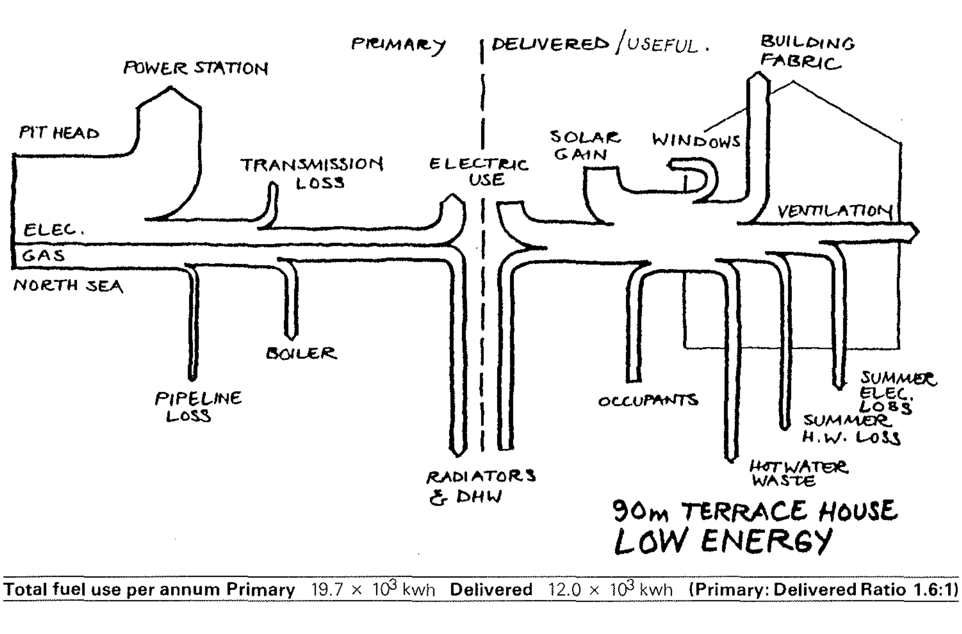
Condensation, one of the major causes of modern building failure, should also be reduced in these houses. Better insulation should decrease temperature differences inside the house and avoid saturated air condensing in cold rooms. Higher wall temperatures should reduce surface condensation, and passive gains should, to some extent, act as background heating and prevent large temperature drops with associated condensation. The high thermal mass should also help.

To establish cost-effectiveness, it is planned to monitor 60 houses in detail, with some monitoring of the rest. To find the benefits of insulation, 20 poorly insulated houses on another estate will be monitored, and compared with 20 highly insulated houses and 20 very highly insulated houses. To find the benefits of passive gain, 20 houses with random orientation will be monitored and compared.

Fuel use, space heating demand, solar intensity, average temperature difference across the house fabric and casual gains will be monitored either weekly or bi-weekly, during the critical spring and autumn periods. The monitoring is funded by the DoE (HDD) and Department of Energy (ETSU).



Total fuel use per annum Primary 26.2 × 10³ kwh **Delivered** 17.5 × 10³ kwh **(Primary: Delivered Ratio 1.5:1)**



Total fuel use per annum Primary 19.7 × 10³ kwh **Delivered** 12.0 × 10³ kwh **(Primary: Delivered Ratio 1.6:1)**

Pennyland Housing, Milton Keynes

Date of completion		December 1980	
Capital cost		**£2 560 000 for 177 houses**	
Occupancy Normal domestic occupancy			
No of persons		3	
Persons per m²		0.031	
		m² (before)	**m² (after)**
Usable area		90	
		m³ (before)	**m³ (after)**
Usable volume		216	
Delivered annual energy consumption Estimated by U.S. National Bureau of Standards method. Column A shows a high standard of insulation. Column B shows a very high standard of insulation			
		kwh (A)	**kwh (B)**
Total	mean	17 550	12 020
	*max	20 630	14 170
Per m²	mean	195	133
	*max	229	157
Per m³	mean	81	56
	*max	96	66
Per person	mean	6270	4290
	*max	7370	5060
Primary annual energy per m²		291	219

*Maximum values refer to increasing the whole house thermostat setting to 20°C

Client
Milton Keynes Development Corporation

Address
Pennyland 1, Milton Keynes

Architects
Milton Keynes Development Corporation

M & E Engineers
Richards, Round & Partners

Quantity Surveyors
Milton Keynes Development Corporation

Structural Engineers
W.G. Curtin & Partners

Monitoring Organisation
Open University Energy Research Group (Funded by HDD and ETSU)

Contractor
J. Molem

Linford Houses Milton Keynes

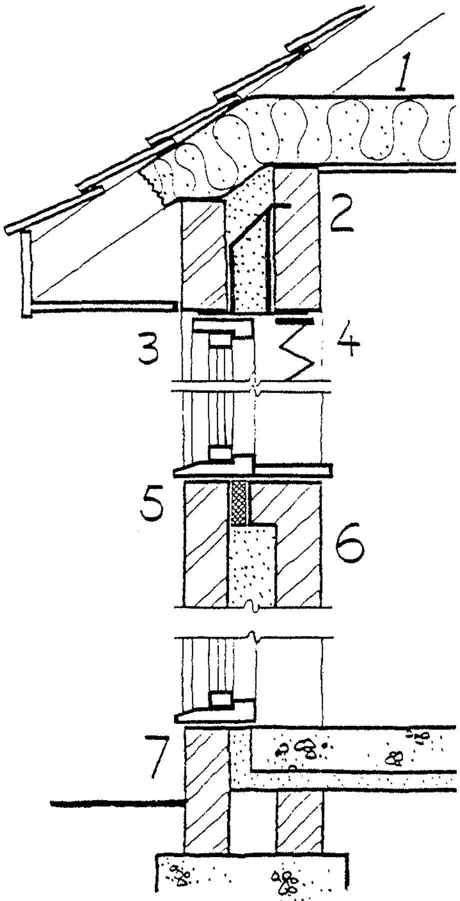
36 Linford 8B is a housing-for-sale scheme which includes eight direct-gain passive solar houses. The houses are detached and appear typical of a normal speculative development. They differ in four significant respects:

1 They have been oriented towards south to maximise solar gains and south glazing has been increased while north glazing has been minimised.

2 Insulation standards have been increased. Cavities have been widened to 100mm and fibre filled, roof insulation has been increased to 150mm, windows are double glazed and have shutters for night insulation, and the ground floor perimeter has been insulated.

3 A high-efficiency boiler with a sensitive control system has been specified.

4 Internal walls are thermally massive to act as a heat store for solar gains and prevent overheating.

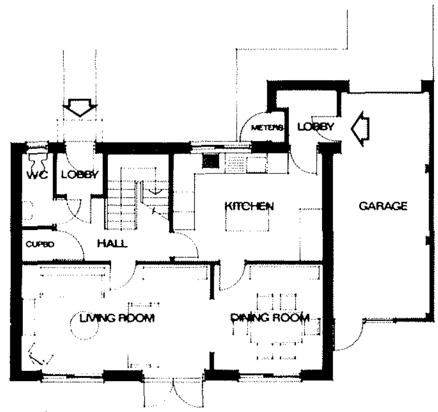


Energy conserving building details (also used at Pennyland) 1. 150mm loft insulation 2. Insulated steel lintel 3. Dual glazing 4. Blind 5. PVC cavity closer 6. 100mm cavity with insulation 7. Perimeter slab insulation

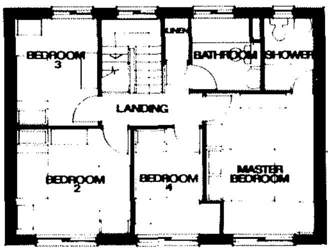
Although many of the solar and insulation measures are similar to Pennyland, some of the aims are different. These houses will be for sale, and can therefore be used to test the acceptability of insulation measures on the open market. If buyers are not prepared to pay the higher costs of installing energy saving measures, then developers won't build them in. The selling prices of energy saving houses will be checked and compared with ordinary houses to find out the price differential.

Another difference between the projects is the monitoring. At Pennyland the aim is to obtain average occupancy patterns and fuel cost savings by studying a large number of houses. At Linford the aim is to look in detail at some of the assumptions made in predicting fuel use. In predicting this, a model is made of the energy flows into and away from the house. In the past, the major effort has gone into constructing a more accurate simulation of the mechanism of energy movement, while the actual values of thermal resistance etc, have been neglected. Evidence is now emerging that major variations from published values actually occur on site. The installed 'U' values have, in some cases, been 50% poorer than predicted, ventilation rates in occupied houses are uncertain, and the fraction of casual and solar gains that usefully go towards heating a house is unknown. These make great differences to the predicted space heating demand, and must be known to make accurate prediction possible. A data logger will be installed in each meter cupboard.

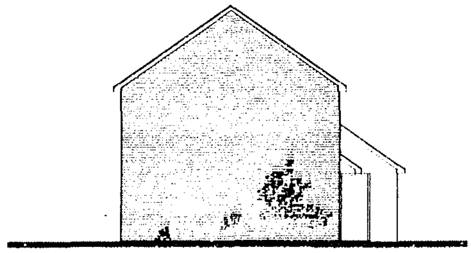
The project, funded by the Energy Technology Support Unit, will be monitored by the Energy Research Group at the Open University for three years.



GROUND FLOOR

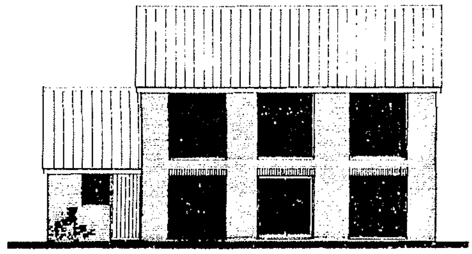


FIRST FLOOR



EAST

NORTH



SOUTH

Linford Houses, Milton Keynes		
Date of completion		June 1980
Capital cost		£84 100 for 8 houses
Occupancy Normal domestic occupancy		
No of persons		4
Persons per m²		0.035
		m²
Usable area		112
		m³
Usable volume		268
Delivered annual energy consumption Estimated by U.S. National Bureau of Standards method		
		kwh
Total	*mean	14 500
Per m²	*mean	129
Per m³	*mean	54
Per person	*mean	3 600
Primary annual energy per m²		223

*Mean values are based on a survey of similar houses already built in Milton Keynes

Client and Contractor
S and S Homes

Address
Linford 8B, St. Leger Drive, Great Linford, Milton Keynes

Architects
Charter Building Design

Quantity Surveyors
Jinks and Marshall

Monitoring Organisation
Open University Energy Research Group (Funded by ETSU)

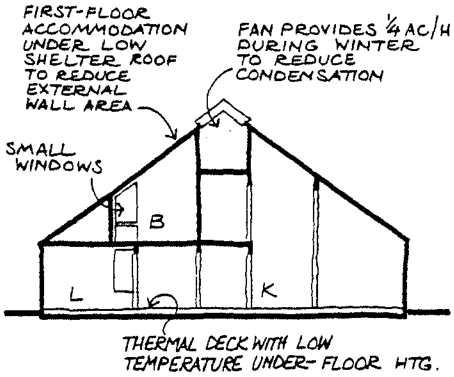
Brock House Nottinghamshire

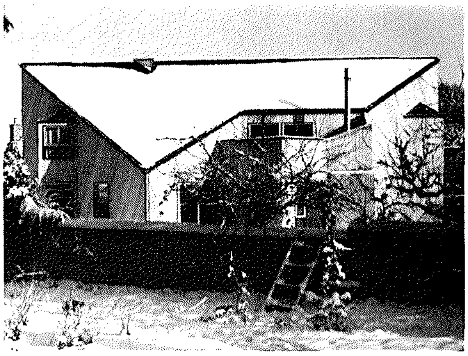
The house is a timber framed, brick core, low mass structure. The brick core acts as a wind brace and a thermal store.

The heating system consists of a 'multibeton' thermal deck using underfloor heating in plastic pipes. Water temperatures are 49°C flow and a 39°C return. There is also a wood burning stove in the living room.

The square plan and low roof reduce external wall area, with the first floor accommodation contained within the roof. Sixty per cent of the floor area is on the ground floor and forty per cent on the first floor. Windows take advantage of passive solar gains and reduce infiltration, especially in the first floor bedrooms where there is no direct heating and gains are controlled by the use of cedar blinds. High thermal and sound insulation provide an overall 'U' value of $0.33 w/m^2 {}^\circ C$. Care was taken to avoid thermal bridges by using timber frames and all openings have double gaskets and weather sealing.

The room temperature drops only 1 to 2°C overnight. Because of the high radiant temperature it is possible to reduce air temperature standards. This stable environment has proved very economical.





The normal installation costs, expected for space and water heating, proved, on completion, to have been reduced due to low heat output requirements, boiler size and speed of installation.

37

38

Brock House, Nottinghamshire	
Date of completion	January 1979
Capital cost	£29 000
Occupancy	
Normal domestic occupancy	
No of persons	5
Persons per m²	0.024
	m²
Usable area	206
	m³
Usable volume	486
Delivered annual energy consumption	
Measured	
	kwh
Total	31 459
Per m²	153
Per m³	65
Per person	6292
Primary annual energy per m²	252

Client
Mr. David Brock

Address
'Badgers', Fiskerton Road, Southwell, Nottinghamshire

Architects
David Brock

M & E Engineers
J.H. Fryer Ltd. & Multibeton Ltd.

Structural Engineers
Peter Fawcett

Monitoring Organisation
School of Architecture, University of Nottingham.

Research Laboratories, Manchester

The building is a chemical research establishment, in which hazardous chemical synthesis is sometimes carried out. This is largely conducted within fume cupboards and thus the options for servicing systems are constrained by severe functional and safety requirements.

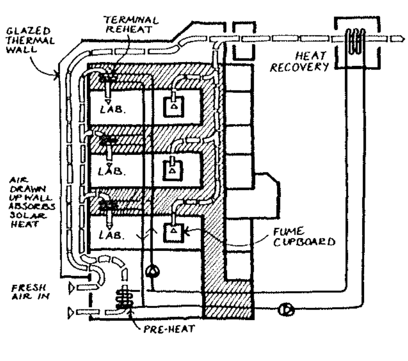
The laboratories are served by a terminal conditioning, high volumetric air system which varies in response to the operation of the fume cupboards.

Temperature is maintained at 21°C in winter and 24°C in summer. Normal ventilation rate is 64 ac/hr rising to 96 ac/hr in hazard conditions.

The building has a south facing 'thermal wall', designed to reduce the abnormally high ventilation losses. This forms a double skin to the laboratories. The inner skin is of traditional masonry and glass whilst the outer skin, (enclosing a 1.2m wide cavity the full height of the building) is of solar control glazing. This cavity also provides a service route for laboratory supply air ducting. Plant room ventilation air is passed up the 'thermal wall', picking up solar energy in summer and offsetting heat losses in the winter. The wall will have a 'tea cosy' effect on the laboratory building. The nature of the research requires that the air systems are 'once through' with no recirculation — a potentially high energy user. To ensure maximum utilization of energy, heat recovery has been used which reclaims energy from the once-through air systems. So that all available 'inherent' energy is used before further fuel is burnt.

Heat is recovered by drawing all fume cupboard exhaust air over one set of heat reclaim/rejection coils. In cold conditions, the low grade heat from these coils is distributed via a 'run-around' system to pre-heat the incoming air to the laboratories.

As the outside air temperature rises and the energy recovery via low grade heat in the run-around system loses effectiveness, the energy from the reclaim coils is routed to the central refrigeration machines and chilled, thus transferring heat to the condenser side of the machines from where it is distributed to the terminal reheat coils serving individual laboratories. In this mode the refrigeration machines are acting as 'heat pumps' and they continue to do so until the outside air temperature rises to a point where the energy requirements of the building balance. They then close down.



Section through laboratories and solar wall

On a further rise in external temperature the refrigeration machines operate as 'coolers' and excess heat is rejected to the fume cupboard exhaust air.

Reclaimed heat via the heat pumps and condensate recovery from steam process is also used to preheat domestic hot water system.

By this means, 57% of annual heat energy requirements are met from reclaimed sources.

Research Laboratories, Manchester	
Date of completion	in construction
Capital cost	£10 million (January 1979)
No of persons	350
Persons per m²	0.028
	m²
Usable area	12 055
	m³
Usable volume	60 000
Delivered annual energy consumption	
Has been calculated by CIBS, ESP and BDP programmes	
	kwh
Total	12×10^6
Per m²	1000
Per m³	200
Per person	34 300
Primary annual energy per m²	2 452

Client
Major UK Chemical Manufacturer
North Manchester

Architects, Engineers & Quantity Surveyors
Building Design Partnership

Swimming Pools

Portland

39 The scheme comprises a 25 x 13 metre swimming pool, a training hall, squash courts and other ancillary accommodation. This is a thermally efficient building in an exposed position. Infiltration losses will be reduced by the small area of windows and humidity will be controlled by a combination of heating and ventilation, with particular attention given to the pool area.

The pool water sterilizing agent will be Ozone instead of Chlorine. This allows air to be partially recirculated, the percentage of recirculation being limited only by the condensation risk which depends on the dew point temperature of the hall air and the temperature of the fabric cold bridges.

The swimming pool has its own heat recovery unit operating at a temperature differential of 28°C to -1°C. The heat transfer efficiency depends more on temperature difference than flow. Cross-plate recuperative heat exchangers are used. These avoid cross contamination. Rotary type heat exchangers were not used as they transferred too much moisture.

In the swimming pool hall, the water will be maintained at 27°C. The air DB temperature will be 28°C and RH 70 to 75%. The quantity of air will be 0.015m³ per second per m² of wet area.

To control condensation, incoming air will be blown up the hall walls and extracted at low level.

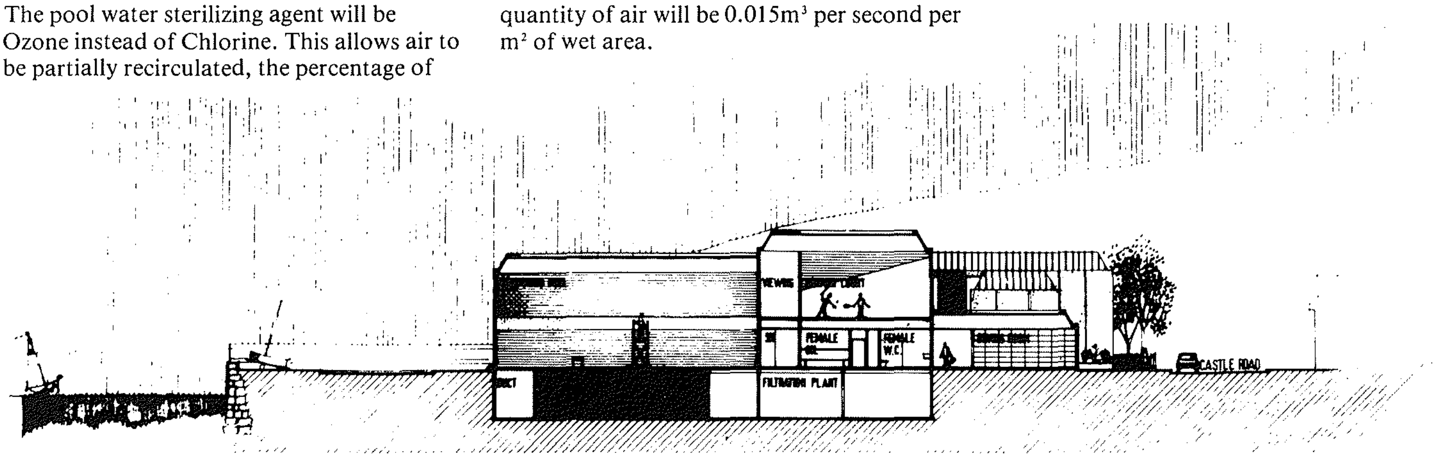
This system, compared to a conventional chlorine system without heat recovery, will save 72% of annual costs and 75% of the sensible and latent heat losses from the pool hall and had the lowest NPV when costed over fifteen years.

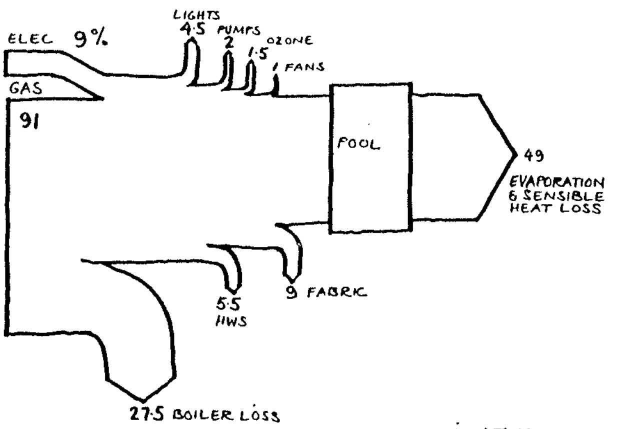
Date of completion	Autumn 1982

Client
Ministry of Defence (Navy)

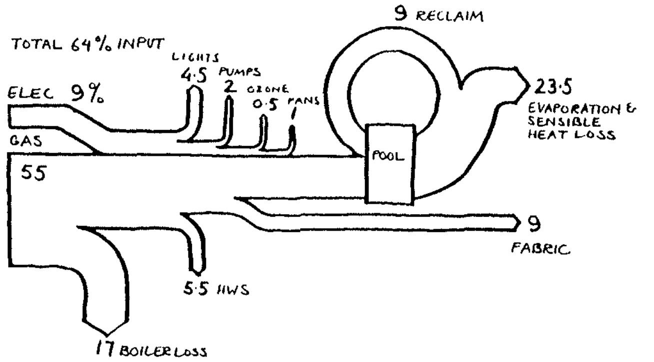
Address
HMS Osprey, Portland Naval Base

Architects, M & E Engineers, Quantity Surveyors, Structural Engineers, Monitoring Organisation
DGDS Design Office, Property Services Agency of the DOE

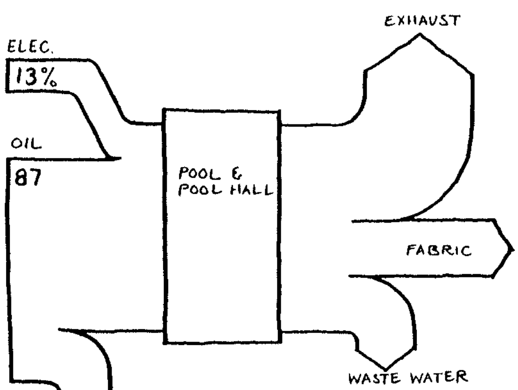




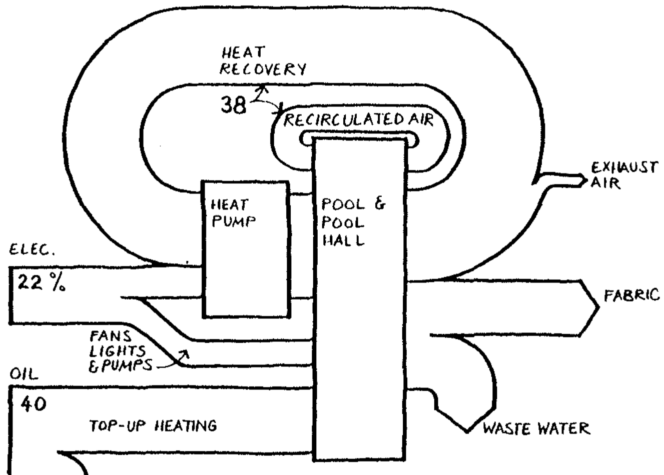
PORTLAND POOL & RTC. WITHOUT ENERGY CONSERVATION



PORTLAND POOL & RTC.
WITH ENERGY CONSERVATION (DESIGN SELECTED)
(TOTAL INPUT = 64% OF INPUT REQUIRED BY NON-ENERGY CONSERVING SCHEME)



WEST WICKHAM POOL
BEFORE
N.B. FIGURES ARE EDITOR'S APPROXIMATIONS.



WEST WICKHAM POOL
AFTER (EDITOR'S APPROXIMATIONS)

West Wickham

Indoor swimming pools consume very large quantities of heat energy, due to the high temperature of the space and the pool water, long hours of use and high ventilation rate.

This pool was opened in 1970 and provided with a straight through air system and Chlorine water treatment. The heating system was oil fired, providing low pressure hot water to convectors, radiators and heat batteries in the air distribution system.

Over the years, pool temperatures have risen. This has resulted in increasing condensation problems and large amounts of energy being wastefully released from the building by the straight through ventilation systems.

To remedy this, the following work was done:
1 Insulation of the void between the suspended ceiling and the pool hall roof.
2 Filling the cavities of external walls.
3 Providing insulation to the supply and extract ductwork.
4 High level strip heating was added inside the main pool hall to lessen condensation in the coldest weather.
5 A heat pump was introduced to reclaim heat from the exhaust air from the pool hall, recycling the heat.
6 Air recirculation.

The reclaim system operates with alternating priorities during occupancy periods. Heat is supplied for space heating with surplus energy being passed into the pool water.

The heat pump now functions as the base energy source. The existing heater batteries and pool water calorifiers are used as supplementary heating only when necessary. An advanced control system has been introduced to act at precise temperatures.

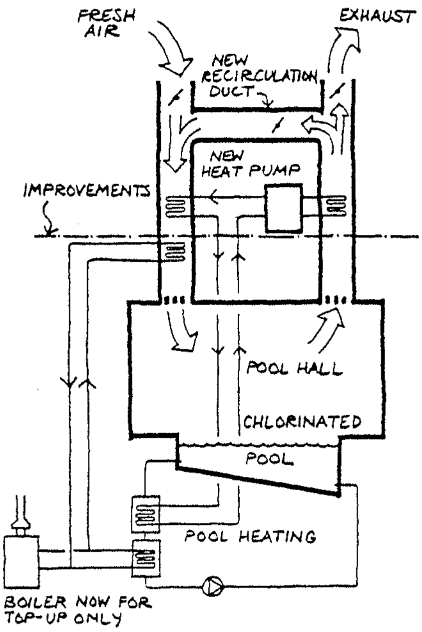
Date of completion	November 1978
Capital cost of heat reclaim	£28 500 + insulation £4 000

Client
London Borough of Bromley

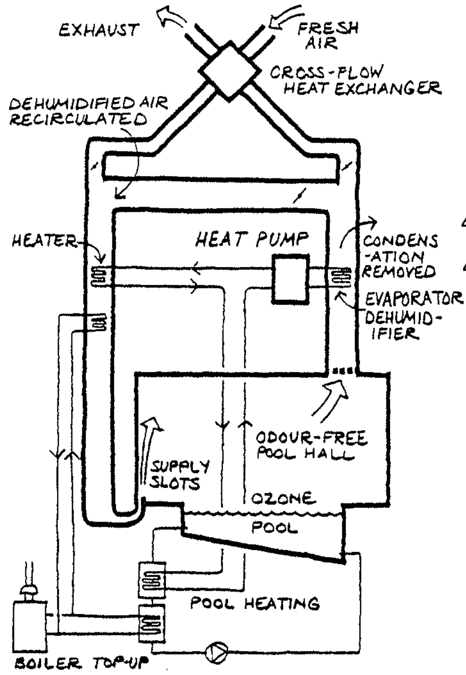
Address
Station Road, West Wickham, Kent

Architects, M & E Engineers
Dept. of Architecture, London Borough of Bromley

Monitoring Organisation
Electricity Council, with Bromley

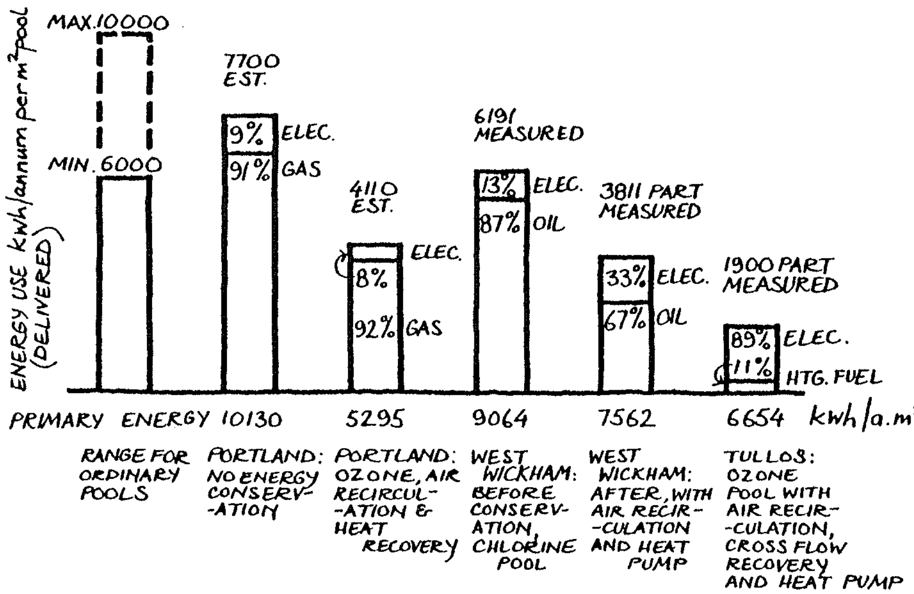


IMPROVEMENTS TO WEST WICKHAM POOL



TULLOS POOL ABERDEEN

40
41



COMPARISON OF ENERGY CONSUMPTIONS

Neston

Cheshire County Council's studies showed that heat recovery systems for swimming pools were not economic within the limitations of the County's payback policies. So, an alternative system was used, automatically varying the rate of air change according to the absorption rate of moisture into the air from the pool and the internal surface temperature of the building.

The original ventilation system provided nine air changes per hour and a space temperature 1°C above pool water, to avoid condensation, even under the worst conditions. Since these conditions do not occur at times of peak heating load, the pool's plant was handling very much more air than required.

Chart recordings showed a Pool Hall Relative Humidity of approximately 40% when the outdoor temperature approached 0°C. It was possible to tolerate a much higher relative humidity. Accordingly, the number of air changes was reduced, consequently also reducing the two major components of energy cost — heating and electrical energy for fans.

The controls were installed in one day. They include a Landis and Gyr Variopoint Control Unit which receives signals from a detector sensing the coolest indoor surface, and the absolute humidity and comparing this with a pre-set relative humidity value. This continually adjusts the fan speed.

Accurate sensing of humidity is absolutely essential in this system in order to avoid structural problems resulting from interstitial condensation.

Space temperature is maintained by an independent control system. Maximum economy is achieved when the water surface is unbroken and the fan is operating at the minimum speed. Results show that the minimum three air changes operate for most of the day.

Total cost of £5,800, including monitoring, has been recouped in fuel savings in the first ten months of use, a saving similar to heat recovery at a fraction of the cost.

Date of completion of new controls	1978
Capital costs of controls	£5 800

Client
Ellesmere Port, Neston Borough Council, Cheshire County Council

Address
Raby Park Rd., Neston, Cheshire

Architects, M & E Engineers, Monitoring Organisation
Cheshire County Council Architects Department, Energy Conservation Unit

Vimy Barracks Sportshall

42 The building will be used for physical training, organised sports competition and recreational use at selected off duty times. All indoor sports are catered for.

It will be put to hard use; 16 hours a day during weekdays and 9 hours per day over the weekends.

The sports halls will be heated to 18°C during winter. The lighting levels will be 300 lux in the sports halls, 500 lux in squash courts and 300 lux in changing areas.

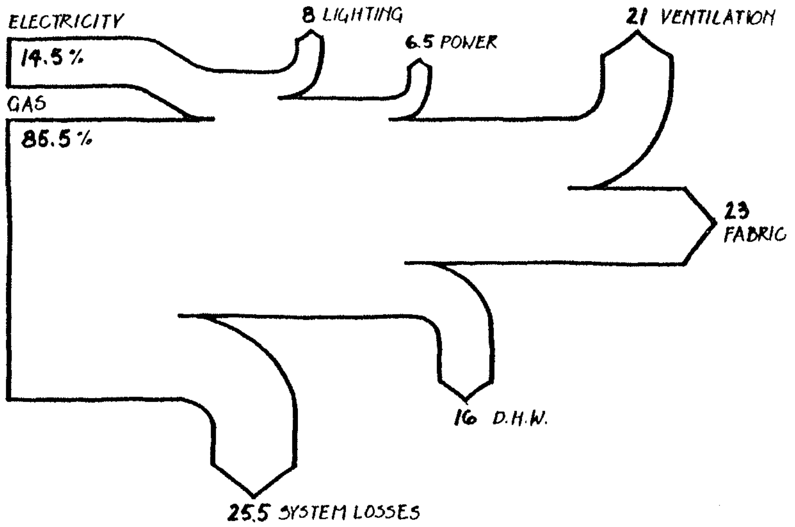
The site is characterised by cold winds, low temperatures and substantial rainfall. The windchill index is around 1,250, the driving rain index is 4m²/second, the degree days 2,298 and the exposure rating severe.

Microclimate considerations, together with heavy daily usage pointed to a thermally heavyweight well insulated building, with fenestration reduced to levels consistent with functional need and visual amenity.

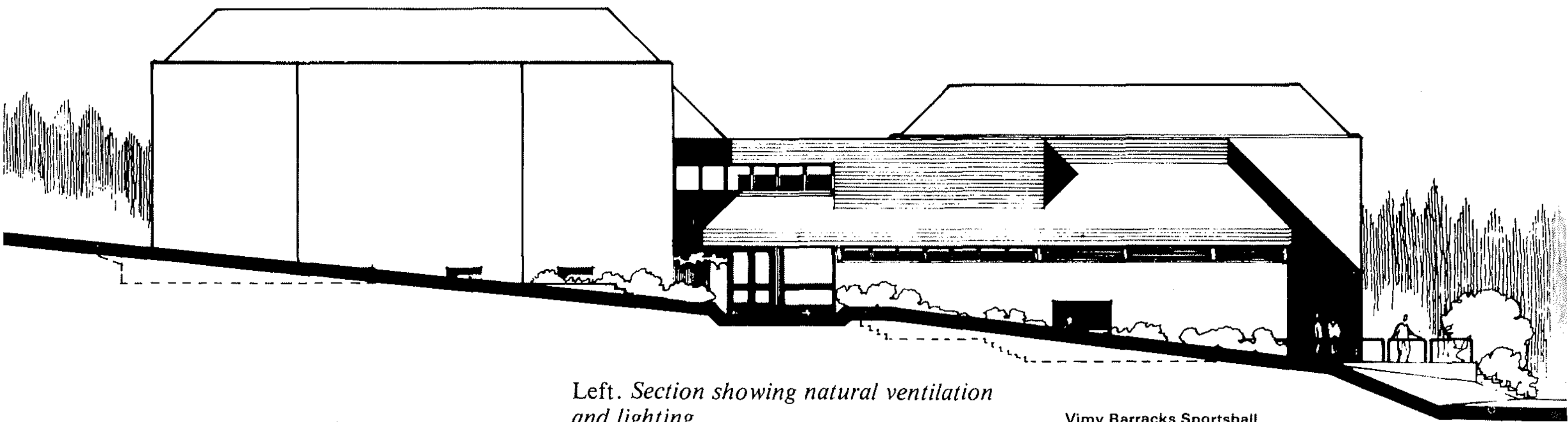
The main halls are both high, so that adequate ventilation could be provided during both summer and winter by natural buoyancy. Accordingly, the building has been set out to permit adequate openings located appropriately at low level for supply air with a series of pneumatically operated roof extract ventilators. In order to reduce ventilation heat loss, high temperature hot water radiant panels are used to produce a high environmental temperature. These are fed from an existing HTH supply at 158°C.

Natural lighting is provided for the main hall by means of the cranked roof which has been designed to cut out glare. This is sufficient for a wide range of activities to take place without recourse to artificial lighting. High pressure sodium discharge lamps are used on account of their good visual performance and high efficiency. The switching is arranged in steps so as to compensate for reductions in natural lighting.

Heating energy, hot water consumption and lighting loads can all be monitored separately.

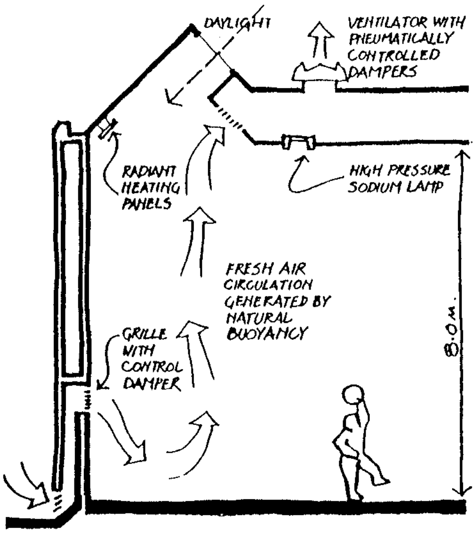


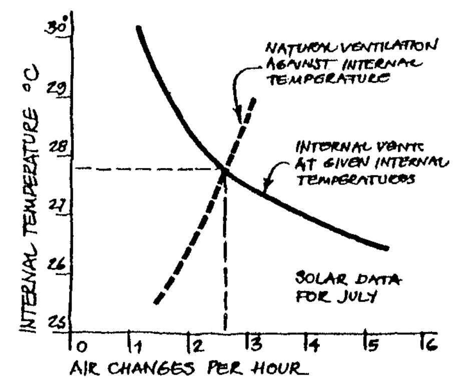
Total fuel use per annum Primary 1.6 × 10⁶ kwh **Delivered** 1.2 × 10⁶ kwh **(Primary: Delivered Ratio 1.3:1)**



Left. *Section showing natural ventilation and lighting*

Below. *Analysis of conditions that produce adequate ventilation and temperature control*





Vimy Barracks Sportshall	
Date of completion	Mid 1981
Capital cost	£900 000 (June '79)
Occupancy	
14 hours per day, 7 days, throughout the year	
	m²
Usable area	2058
	m³
Usable volume	11,352
Delivered annual energy consumption	
Calculated by CIBS method	
	kwh
Total	1 198 800
Per m²	582
Per m³	105.6
Primary annual energy per m²	756

Client
Ministry of Defence (Navy)

Address
Catterick Garrison, Yorkshire

Architects, Engineers, Quantity Surveyors & Monitoring Organisation
PSA/DGDS, Design Office

Total Energy Leeds Infirmary

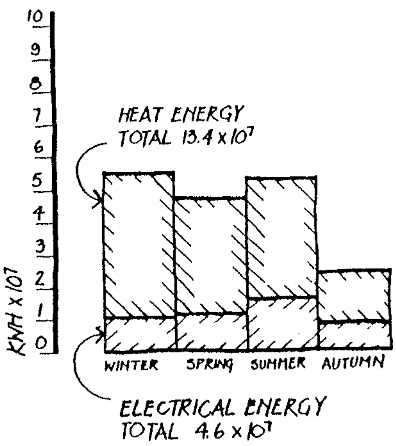
43

A Total Energy system is only suitable in circumstances where there is a fairly continuous and even demand for both heat and power at all times. Only then will fuel savings be sufficient to recover the increased capital, maintenance and staff costs.

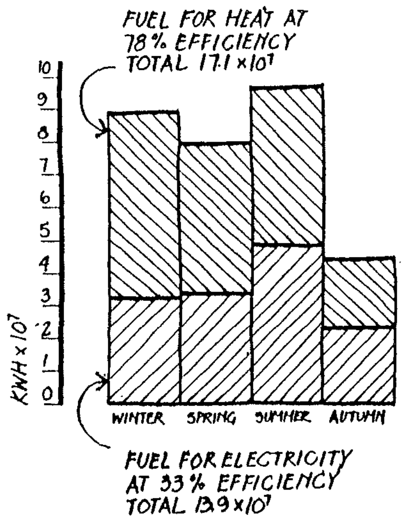
Combined heat and power generation can be achieved with several kinds of equipment producing a ratio of power to heat of between 1:1 and 1:5. Unless there are other factors, such as the need for standby generators, it is probable that an electrical load of at least three megawatts (3000 kwh) is required. Apart from the possibilities for serving whole communities, this makes the concept useful for some industrial situations and for major institutions, like hospitals.

The Leeds Generating Station Complex serves the Infirmary, Medical and Dental Schools. Two possible forms of electrical generation were analysed: gas turbines and diesel engines.

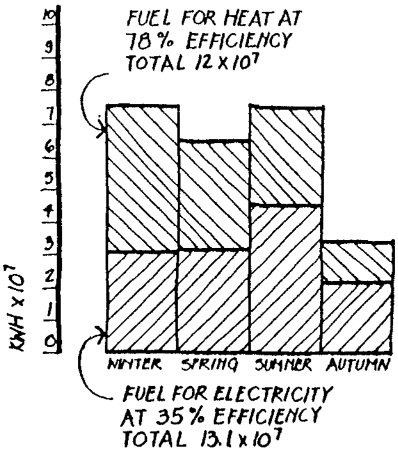
Exhaust heat is used to raise steam, while the engine jacket water and lubricating oil heat is recovered to provide low pressure hot water. Steam requirements vary seasonally and conventional boilers are provided to meet peak needs. Refrigeration needs are met by a combination of steam heat absorption and electric drive compression units. About two thirds of the energy in the fuel is thus used effectively. Financial analysis showed that the system saved 40% on annual running costs compared to the conventional approach and even though phased gave a 20% return on the additional investment required.



Energy loads for a large teaching hospital



Primary fuel consumed for conventional scheme



Primary fuel consumed for total energy scheme – only 80% of conventional scheme

A prime advantage of a total energy system is that it ensures that supply cannot be interrupted easily by external causes. This is of fundamental importance to a hospital. The system is designed with internal safeguards also: each service is 'modular' with five engine/waste heat boiler sets so far, any three of which can meet peak demands whilst the others are on maintenance and standby. The engines are dual-fuel, running normally on natural gas, but with instant switching to diesel oil if required. This guards against supply problems, lowers the gas tariff and provides about 10% extra capacity if the need arises. The control system provides automatic load sharing on all systems, starting up and shutting down elements as necessary. A back up electricity supply from the grid is also available, equivalent to one engine set, and it is possible to export power to the supply authority equivalent to two engine sets.

Total Energy, Leeds Infirmary	
Date of completion	April 1977
Capital cost	£6 500 000

Client
Yorkshire Regional Health Authority & University of Leeds

Address
Leeds General Infirmary, Leeds

Architects, M & E Engineers, Quantity Surveyors
Building Design Partnership

Marks and Spencer Energy Conservation Programme

44 1972/73 was the last year in which Marks & Spencer used energy freely, hardly counting the costs — they only represented 0.4% of the turnover.

Actual consumption has risen over the six years since then by 8%. Overall costs have risen to 260% of old costs. If energy conservation measures had not been taken, these figures would have been 60% and 400% respectively.

These cost reductions were achieved by a number of measures. The most important factor is the commitment of the Company Chairman to energy conservation, providing encouragement for all staff to be vigilant in the use of energy. The Chairman receives periodic progress reports on consumption, costs and details of technical innovations.

The energy strategy evolved in four stages. In each stage, two questions were asked:
1 Is it necessary to use energy?
2 If so, is it being used in the most efficient manner?

The four stages of the energy strategy were:
a An energy Audit
b Good housekeeping
c Improvement in efficiency
d Technical innovations.

The Energy Audit actually began the year before the Energy Crisis. The Electricity Council had carried out a year's test at Tooting store, metering energy and environmental conditions. Energy survey forms were prepared for all the 252 stores in the UK, each of which was visited within a month. All conservation measures were discussed with each manager during this visit. Details of action to be taken during summer and winter were sent by the Building Director to all store managers. A letter from the Chairman instructed the appointment of a senior member of staff in each store as Energy Conservation Officer. Periodically technical guide notes are sent to store managers. Good housekeeping has been maintained by —

1 "Switch It Off" labels over all light switches other than sales floors and emergency escape routes.
2 "Turn It Off" labels over radiator control valves — when heating is not required (thermostatic radiator valves are now installed throughout).
3 Articles in the house newspaper.
4 Competitions to maintain interest and awareness of energy conservation. The first competition was won by the suggestion to install maximum demand alarms in stores, so reducing maximum demand charges.
5 Posters.
6 Energy exhibitions.
7 Lectures to all new employees.

The Energy Audit showed:

Electricity (80% of total)	
Sales Floor Lighting	40%
Foods refrigeration	29%
Air conditioning, ventilation and electrical components of heating	18%
Other lighting and power (lifts, escalators, baling machines, floor cleaning etc.)	13%
Gas (20% of total)	
Heating, hot water supplies and staff catering.	

The most immediate and significant reductions were made in lighting. Illumination of sales areas was reduced from 1000 lux to 600 lux by using the one third/two thirds switching facility already installed for early morning cleaning and stocking. Very few customers noticed the difference. Perimeter (or pelmet) lighting was twin fluorescent tubes; this was reduced to a single tube. Nearly 60,000 feet of tubes were eliminated, achieving an annual saving in 1973 of £80,000.

A change was made to the Philips fluorescent TL84 tube. This has excellent colour rending properties and a light output 40% higher per watt than the previous natural tube. This enabled the installation of 30% fewer tubes. Despite the cost of the TL84 tube — over five times that of the natural tube — calculations show an overall saving per original 1,000 tubes of over £1,500 per annum. All existing light fittings in over 200 stores have been converted by re-spacing lampholders to give an even distribution of light. Mercury halide lamps have also been introduced in new stores — these now have equally good colour rendering.

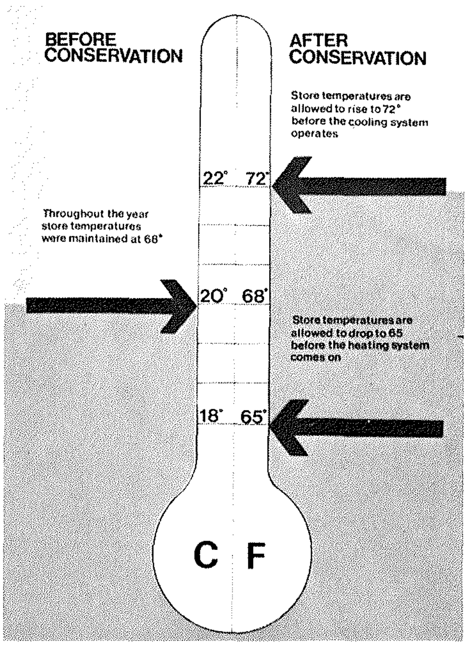
By reducing floor lighting costs by over 50%, the heaviest user of electricity is now refrigerated foods. It is difficult to produce anything like the same percentage savings, and this part of the company's business is expanding rapidly. Immediate economies were achieved by reducing displays in the early part of the week when sales are lower, switching off as much equipment as possible.

The equipment was examined for efficiency. The two most popular units were:
1 The multi-tiered 'gondola' specially developed for Marks & Spencer to provide good access and display with stringent temperature requirements.
2 The multi-tiered frozen food side counter.

Both units are operated from remote compressors. Both are expensive to run. A simple modification to the side of the 'well' of the gondola by raising it 3" has considerably reduced the spillage of cold air with only a small effect on access.

A new form of island unit has been designed, made up of units incorporating their own refrigeration compressors. By installing a mixture of island and piped units, a balance between heat loss and gain is attempted. New frozen food tub units have been developed which are less costly to install and run than the multi-tiered frozen food units. They retain their cold air and can be fitted with night covers. A new unit, which incorporates the best features of the tub and the side display, has been introduced. The side wall display section of the unit has glass doors.

Thermostats controlling air conditioning for cooling have been re-set from 20°C to 22°C. The reduction in the electrical lighting load provided a bonus on air conditioning and ventilation running costs. Lighting constituted over 30% of cooling load. It has been possible to reduce fan speed by 10%, saving 25% of motor running costs. Smaller, simpler plant is now often used in new installations.



Before conservation the store was maintained at 68°F. Winter and Summer.

It was decided to reduce heating in Winter to 65°F by setting down the thermostats, and also setting down boilers from 180°F to 170°F.

Similarly it was decided to raise the temperature at which the store is controlled in summer

Ventilation fans are now switched on as sales floor temperatures are rising above 70°F, and chillers serving air conditioning plant, as sales floor temperatures are rising above 72°F.

Tungsten lighting, which was widely used in stockrooms, offices and staff areas is being replaced by fluorescent which has over three times the efficiency. More effective switching, particularly in stockrooms, enables only those lights which are really needed to be used.

Since the Company's electricity is paid on the Maximum Demand tariff, which has such a significant effect on costs, particularly during the winter months, maximum demand alarm systems are being installed in all stores.

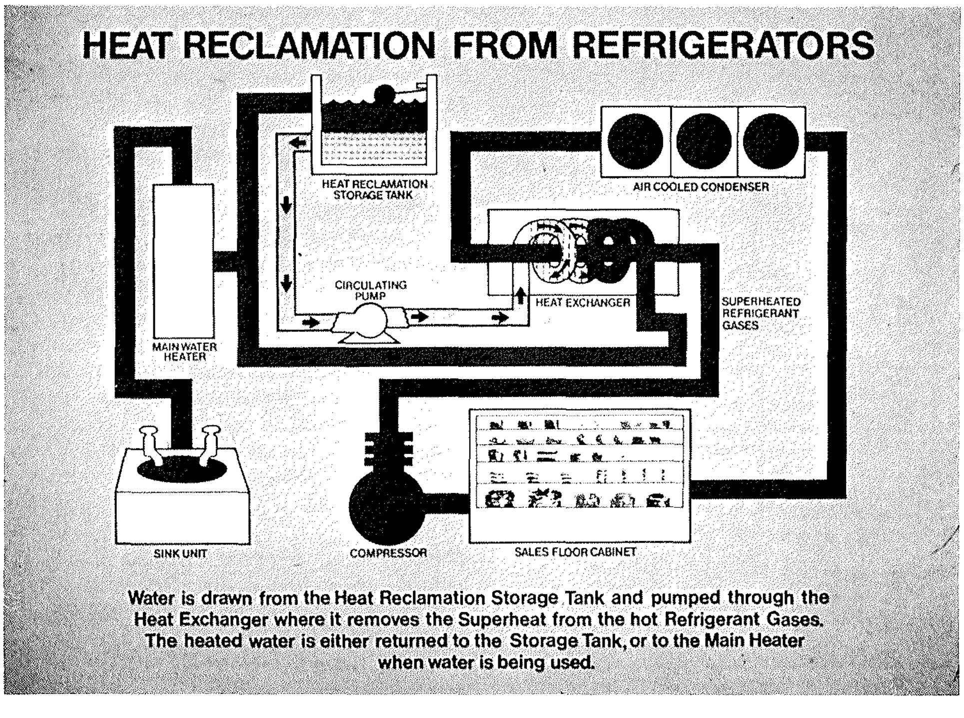
There is also a programme of installing Power Factor Correction equipment where the tariff demands it. This can save 10%.

Thermostats controlling heating have been set down from 20°C to 18°C.

In several new stores using mercury halide lighting, heat is reclaimed from the light fittings and delivered to stockrooms in winter.

Solar panels have been installed in seven stores to pre-heat domestic hot water. Savings of an average of 30% are being made in domestic water heating costs.

Plant reclaiming heat from food refrigerators has shown savings in energy consumption by domestic water heaters in excess of 80%. The capital cost of each installation is between £4,000 and £7,000 depending on size, and the pay-back period is less than four years. Plant has been installed in fifteen stores and forty-six will be operational by the end of this financial year. It is now standard for all new developments.



The new 1" diameter colour 84 tube is being evaluated. This gives a further 10% reduction in energy consumption and has been installed in several new stores. It can, at the moment, only be fitted into the new Philips flush ceiling fittings and is not yet suitable for the suspended fittings used in the majority of stores.

Much lighter, higher efficiency fittings with optical systems developed on computers are used. They can be more widely spaced and carried on the suspended ceilings, whereas the old fittings had to be carried from the slabs above. They cost the same now as the old fittings cost ten years ago.

Air conditioning installations are much reduced. Instead of 4½ to 6 tons of refrigeration per 1,000 square feet, there is now 2½ to 3 tons. Instead of 2 cubic feet of air per minute per square foot there is now 1½. In many cases, it is no longer necessary to construct plant rooms with chilers, pumps, water systems, cooling towers, large fans, filters and heat exchangers. Instead, factory built, packaged equipment can be used, sited on the roof.

High-level hot air heating is being evaluated in warehouses. Efficient modular boilers are being introduced. Cavity fill using fibreglass drytherm is standard on new construction, with roof insulation, double glazing and duct and pipe insulation. Window areas in new developments are reduced.

The company has spent £1.5 million on energy conservation since 1973. £9 million has been saved in the same period. In addition, there have been savings of well over £1 million on the reduction of capital cost of new installations due to lower energy demand of equipment.

The process of conserving energy has shown that substantial savings can be made while still maintaining and even improving standards. The essence is to avoid waste.

However, positive technical steps can largely be nullified by carelessness. The message must continually be brought home to all staff. Energy has risen less in price since 1974 than many other commodities, but the Company feels we are approaching another major acceleration which will be triggered by a growing realisation of the world's vulnerability.

E J Arnold Factory
Leeds

45 This stationery factory, including offices, was built to high standards and achieves low energy consumption, equivalent to a cost per employee of about £250 per annum, which is around 30% lower than other buildings operated by the client.

The offices are within the overall envelope of the building, to keep external walls to a minimum.

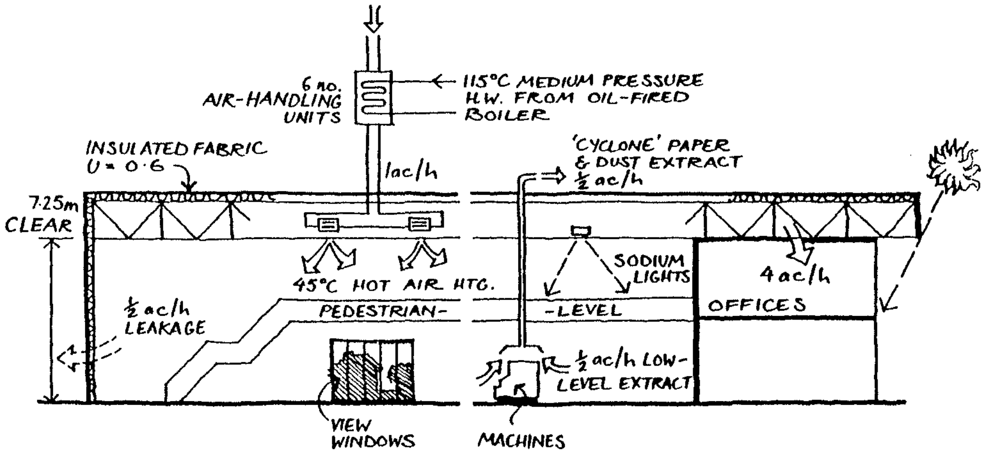
There is no roof glazing. Permanent artificial light in the production areas is provided by high-pressure sodium lights, giving 500 lux in the factory and 300 lux in the storage areas. A mock-up was built to test employees' reaction, which was favourable. The lamps are glare-free. The yellow light makes colour recognition difficult, and for some tasks, stations with fluorescent lights are provided. The sodium fittings use 25% less power than fluorescent lights, and less than half that used by mercury vapour lights.

Cost-effectiveness was investigated for roof insulation levels, and the provision of a 'U' value of 0.6w/m²°C, instead of the then statutory minimum of 1.7w/m²°C, was shown to pay-back over five years or less. The better value was adopted, and the asbestos cement sheet roof has an under-lining of foil-backed plasterboard with 60mm of glass fibre insulation, which is, however, compressed to 20mm at fixings.

Views out are provided by areas of wall patent glazing which give rise to some localised discomfort in winter.

In offices, overheating is avoided by anti-sun glazing and roof overhangs.

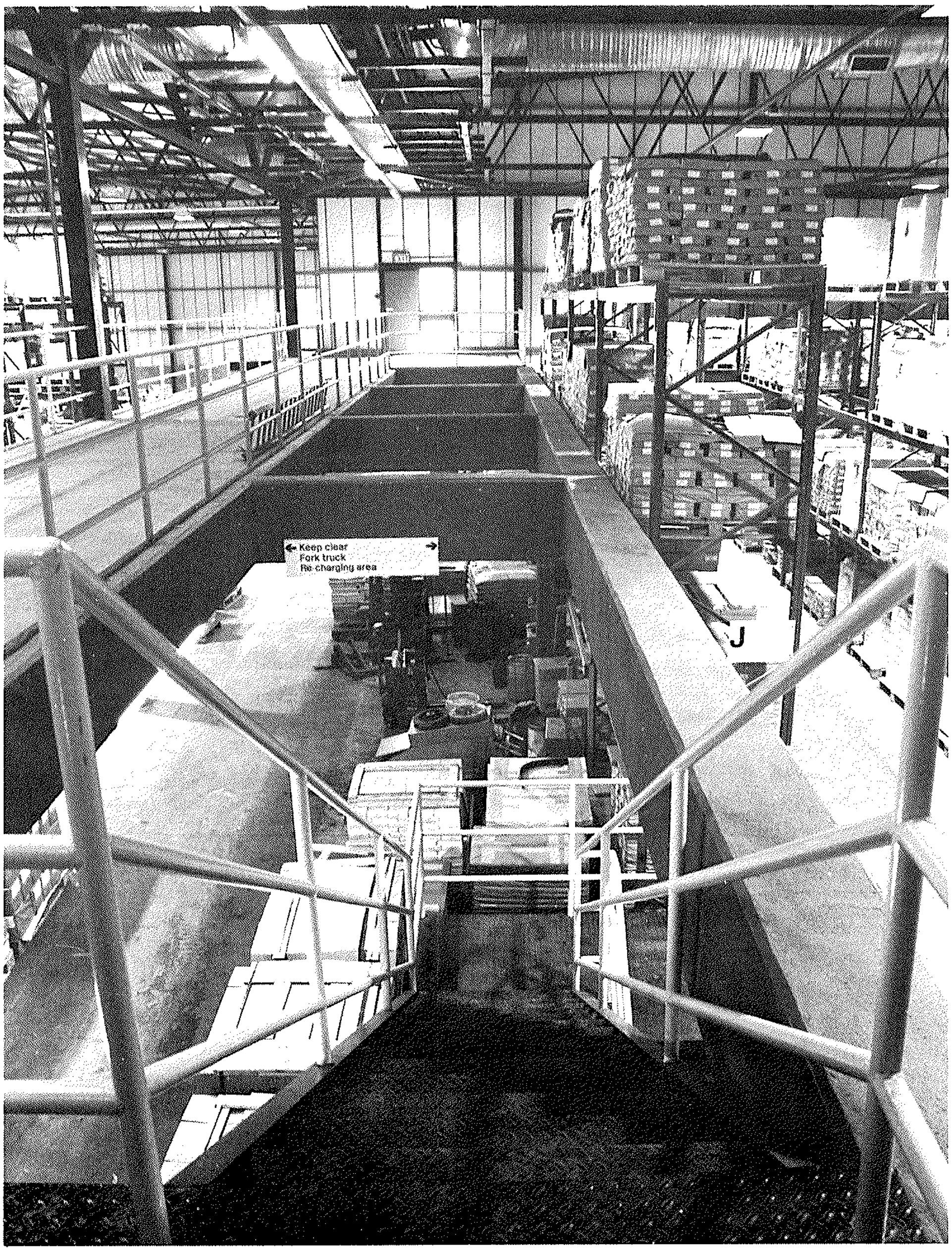
Each doorway has an airlock and secondary protection where possible, consisting of draught sealing brushes on roller shutters and vertical PVC strip-curtains on loading bays.



There are two gas/oil boilers, operating on oil obtained at favourable bulk tariff. These supply medium pressure hot water at 115°C to eight air-handling systems which in turn heat the offices and factory.

The offices' systems supply and extract about 4ac/h via ceiling diffusers. The factory is served by six air-handling systems with high level supply diffusers, which provide only 1ac/h. This is very low, but effective despite the supply diffusers being above the 7.25m clear structural height; there are no high level extract ventilators, fans or windows. Heated air can therefore reach working level. The air supply temperature is relatively low, 45°C, reducing any tendency to stratification.

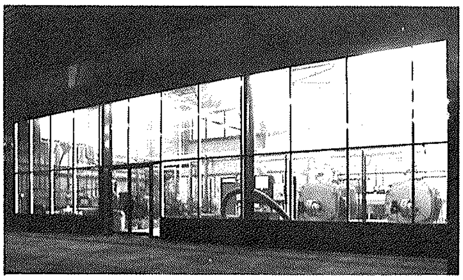
The only means of extraction other than leakage is from low level via the cyclone dust and paper extraction system. This system operates almost continuously and accounts for about ½acph. Heat recovery from the cyclone is not economic.



Spray-taps in washrooms limit hot water consumption, but the length of dead-legs on supply pipes creates a delay before warm water is delivered.

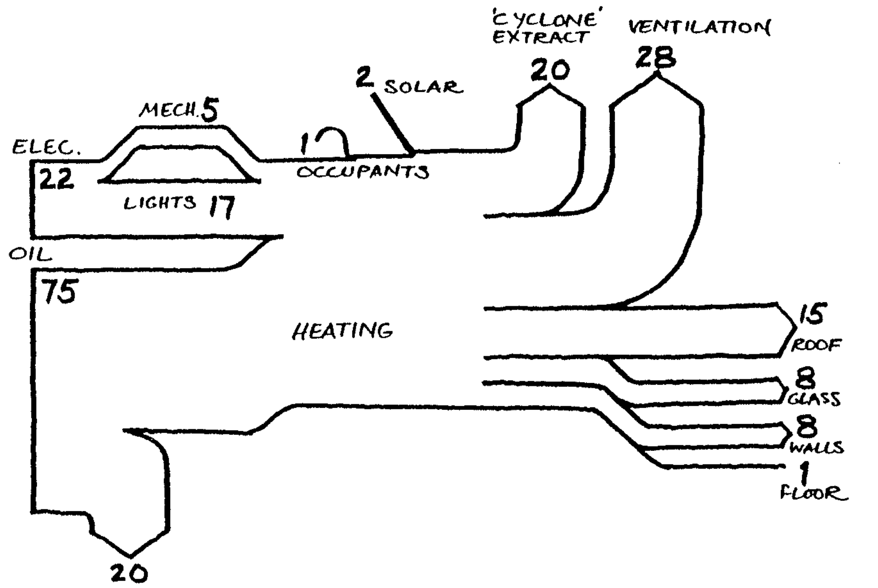
There is no automatic optimum start controller. The engineering staff review the start-up and shut-down sequence weekly.

The client decided to use in-house engineering expertise to keep systems simple and suitable for his needs. He appointed a mechanical services sub-contractor to act as a consultant, who had also worked on a previous scheme, and who provided a performance specification to tender against.



Boiler room featured on front elevation

Left. *Interior of factory showing high level pedestrian spine avoiding fork lift trucks and ventilation supply within roof space*



Total fuel use per annum Primary 6.0 × 10^6 kwh **Delivered** 2.8 × 10^6 kwh **(Primary: Delivered Ratio 2.1:1)**

E J Arnold Factory, Leeds	
Date of completion	April 1978
Capital cost	£130 363
Occupancy Two shifts, five days per week	
No of persons	150
Persons per m²	0.013
	m²
Usable area	11 476
	m³
Usable volume	107 616
Delivered annual energy consumption was measured	
	kwh
Total	2.8 × 10^6
Per m²	243
Per m³	25.8
Per person	18 567
Primary annual energy per m²	523

Client
E J Arnold & Son Limited

Address
Hunslet Road, Leeds, West Yorkshire

Architects
Abbey and Hanson Rowe and Partners

M & E Engineers
H.D.P. Mechanical Services Limited

Quantity Surveyors
Thornber and Walker

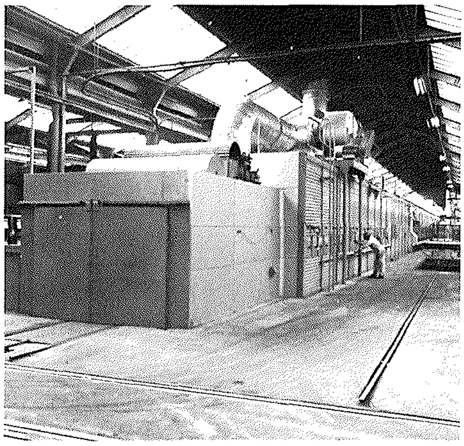
Structural Engineers
G.F. Jordan Associates

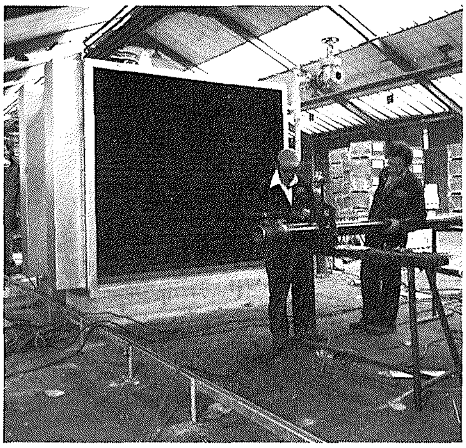
Refractory Works Nottinghamshire

46 This project provides space heating, insulation and mechanical ventilation to a 40 year old factory manufacturing refractory products. Five hundred people work in the building, in three shifts. The plant includes three continuously-fired tunnel kilns. The building had been uninsulated and had only localised heating, which was extremely ineffective. Uncomfortable conditions in winter were adversely affecting production.

The new space heating system provides an internal 16°C when the outside temperature is -2°C.

A high-pressure, high-temperature hot water distribution system is heated by either steam from the existing gas fired boiler, or, in preference, heat recovered from hot kiln gases, or both. The building is then heated by high level radiators and hot-air door curtains. Either system is capable of heating the building alone, but in practice the system operates like this: door curtains on the windward side only are manually switched on, the wind blows the hot air into the building and nearby radiators automatically switch-off. All-automatic switching is being investigated. The system is divided into 28 zones with independent temperature and time controls, and shift foremen and others are trained to operate them.

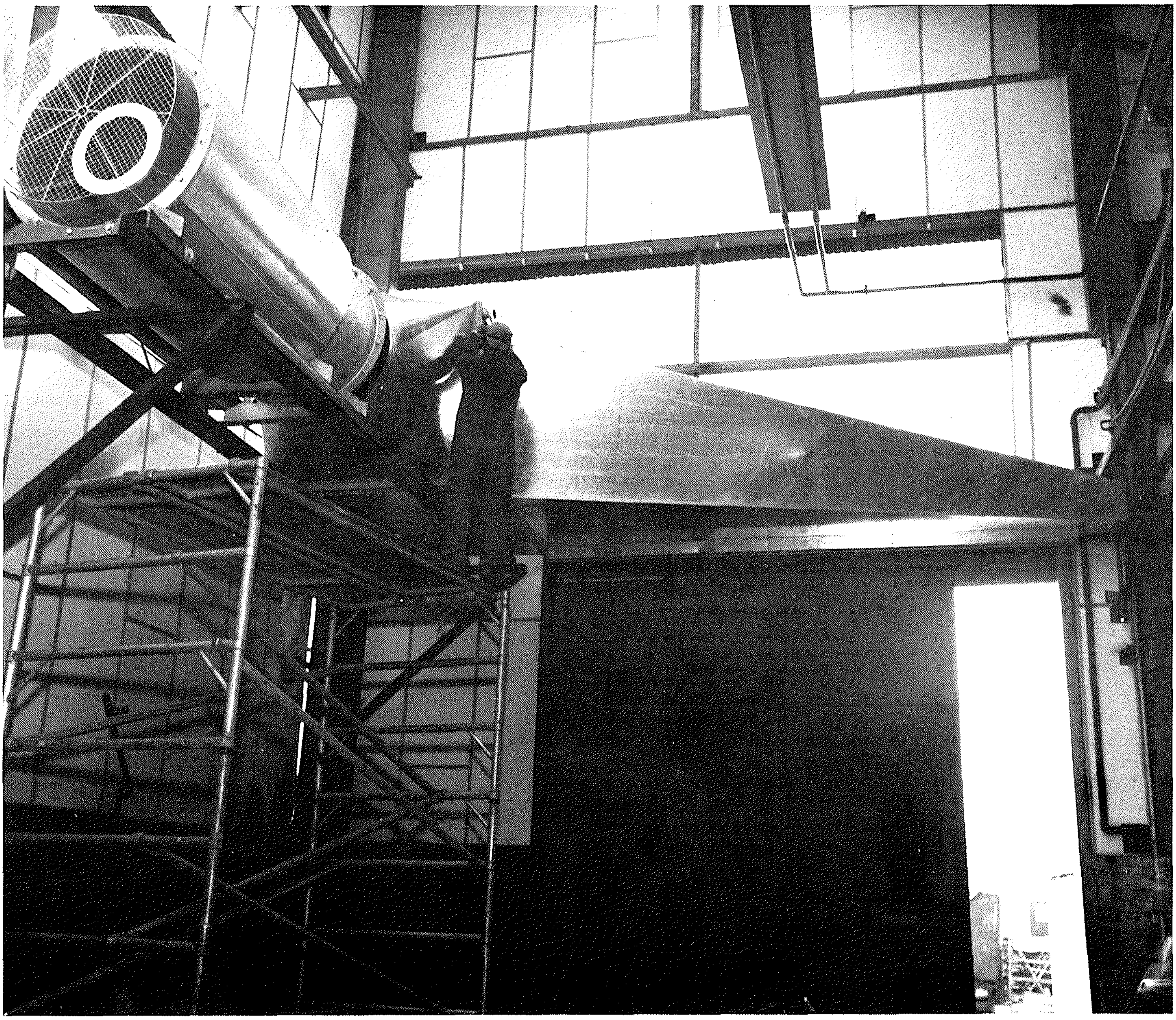




Above left. *One of the tunnel kilns showing heat recovery and flue*

Above right. *Recovery station during construction*

Below. *Hot air curtain during installation also shows high level radiator panel*



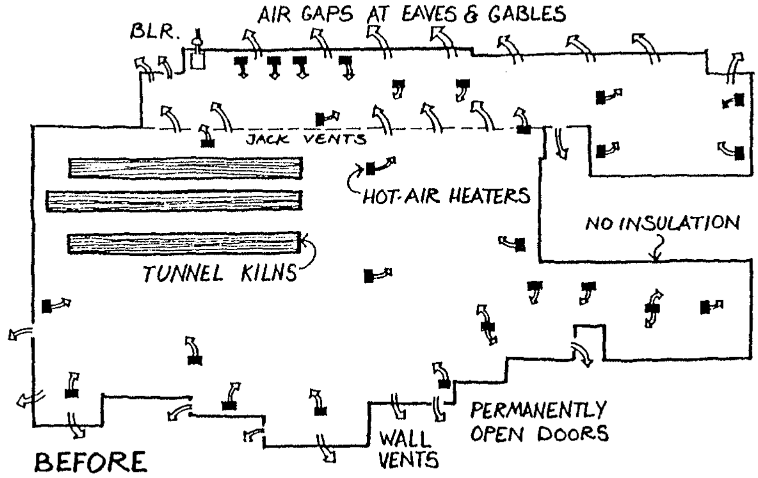
The control system is designed to minimise energy consumption by: maintaining only the minimum temperature required, providing heating only during hours of occupancy for each zone and always utilising waste heat in preference to direct supplied energy.

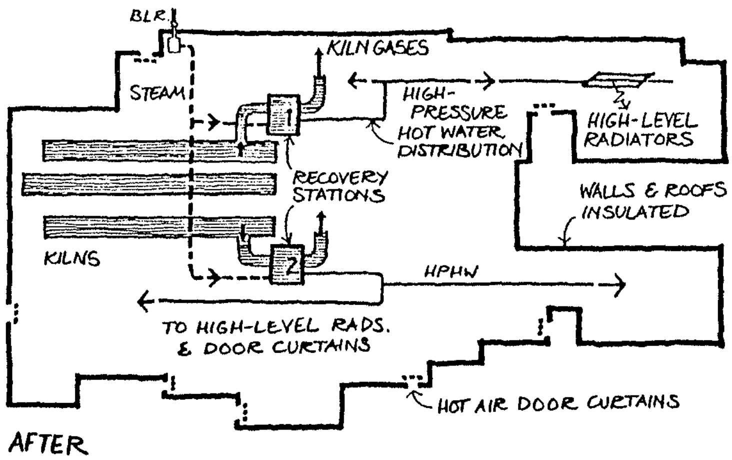
The air curtains draw in warm air from high level and eject it downwards. The curtain which is used most often is fortuitously next to the kilns, and it has been found that the air over the kilns, at 40°C, needs no further heating.

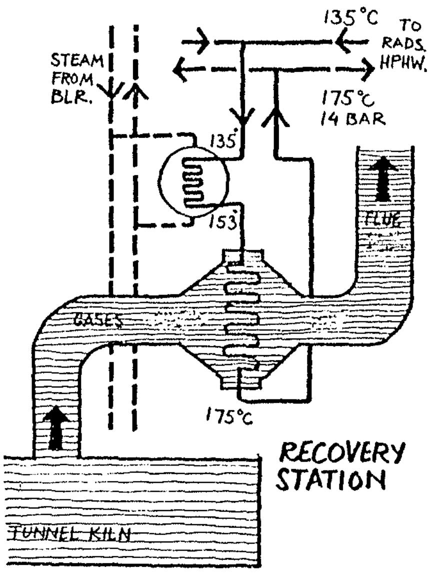
In order to use the kiln gases it was necessary to overcome problems concerning the control of the kiln vacuum, acid condensation and soot. Additional recovery from kilns so far not modified will eventually supplement the boiler.

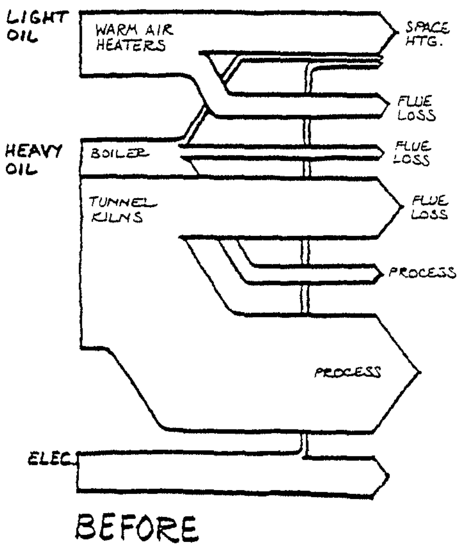
Insulation is of fibreglass and plasterboard.

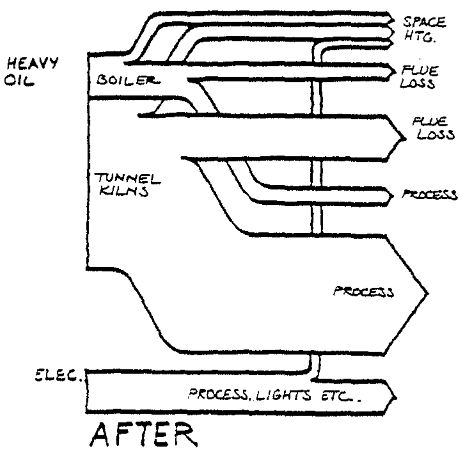
The client required no change to the shape or function of the building and no change to production processes. The object of the project was to produce a satisfactory environment with minimum running cost. No allowance was made for future increases in fuel costs. The basis of comparison was the estimated cost and energy consumption of the cheapest-to-install alternative. No allowance was made for grants.











Refractory Works, Nottinghamshire

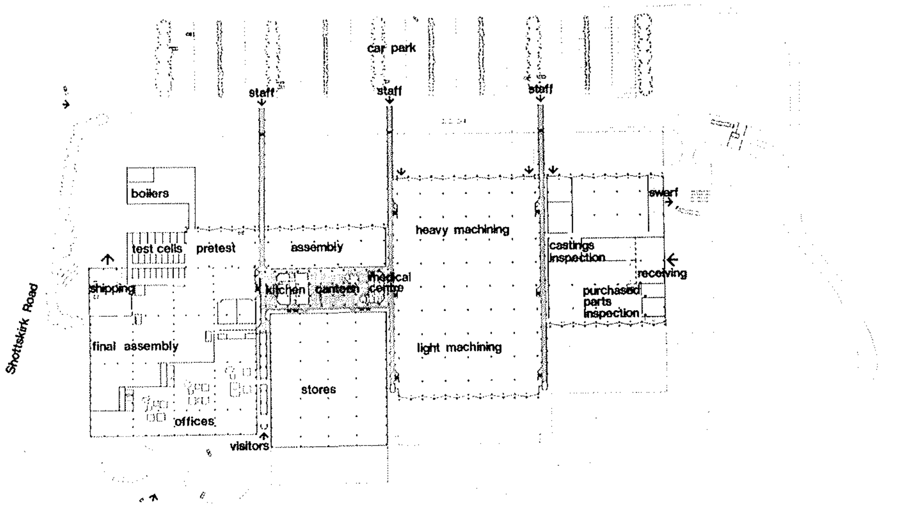
Date of completion	March 1979	
Capital cost	£440 000	
Occupancy Three shifts		
No of persons	500	
Persons per m²	**not applicable**	
	m² (before)	**m² (after)**
Usable area	30 000	unchanged
	m³ (before)	**m³ (after)**
Usable volume	180 000	unchanged
Delivered annual energy consumption Estimated using the CIBS guide		
	kwh (before)	**kwh (after)**
Total	24×10^6	4.7×10^6
Per m²	800	157
Per m³	133	26

Client
Steetley Refractories Limited

Address
Steetley, Worksop, Nottinghamshire

Architects, M & E Engineers, Structural Engineers
Hadfield, Cawkwell, Davidson & Partners

Cummins Factory Lanarkshire



47 This project will transform and extend the Cummin's diesel engine complex by 1980. The factory has been designed to achieve an annual reduction in fuel consumption of over 30% compared with a conventional building.

Such a reduction will result from careful attention to the following items:

1 Heat loss through the walls, roof and windows is much lower than usual.
2 Air handling plant are located between areas which produce too much heat and those which need it for easy heat reclamation.
3 A centralised energy management system will balance out the energy loads throughout the building and avoid unnecessary wastage.
4 Heat recovered from the engine test cells will be used to preheat engine combustion air and to provide heating for the test cell area.

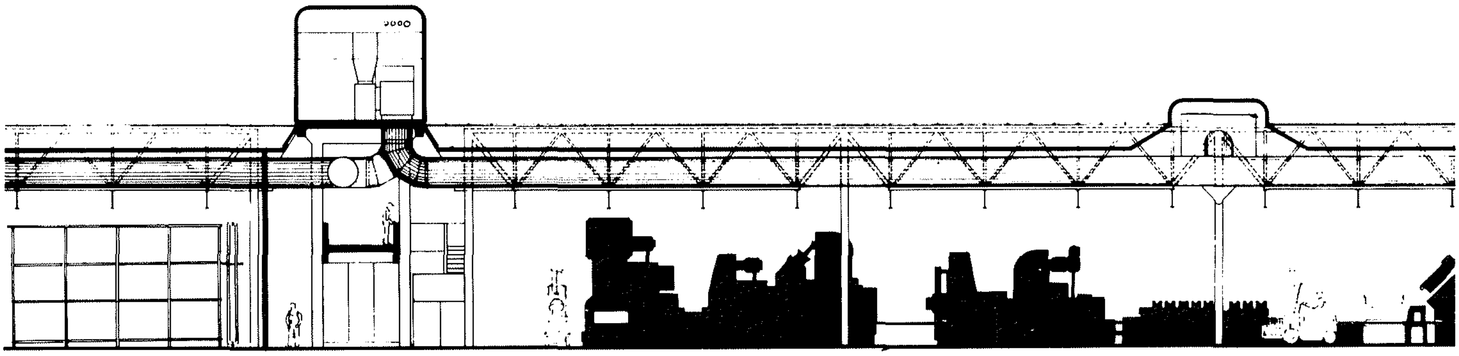
The pay-back period of these items will be about four years.

Insulation
A detailed economic analysis of insulation thicknesses was carried out using forecasts of energy costs and various discount rates. The conclusion was that at 1976 costs for energy and insulation, the 'economic' thickness was around 60mm of mineral wool. However the forecasts indicated that with increasing fuel costs the economic thickness would be closer to 100mm, which was eventually adopted for all new construction. This gives a 'U' value of approximately 0.4w/m^2°C. Most of the old parts of the building had a 'U' value of about 1.5-2.0w/m^2°C.

Heat recovery from Machine Shop
One of the client's requirements was that a

Major producers of heat are the machine shops and engine test cells. The machine shops are located so that heat can be conveniently reclaimed and used in other factory areas. Heat recovered from the test cells pre-heats combustion air for engines on test.

comprehensive dust collection system be installed in the machining area. This extracts much of the heat generated by the process machinery, and the system has been integrated with the overall ventilation system so that when surplus heat is available it can be reclaimed. 300kw of heat from the

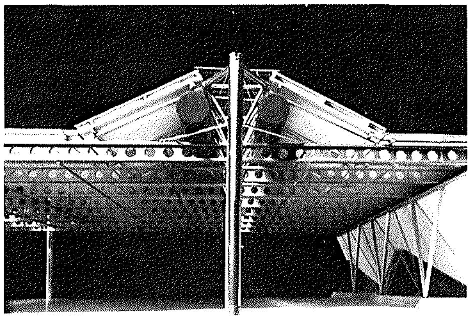


Above. *Section through machine shop showing main overhead ducts.*

machine shop will be transferred to the adjacent receiving and assembly areas. The scheme involves only additional ductwork and axial flow fans, and shows a pay-back period of approximately one year.

Energy Management System
A computerised building management system is being installed to control and maintain all the environmental systems, security and some production systems. The main features of the system are: the early detection of faults, remote indication of necessary adjustment and control, improved and easier maintenance, and energy savings via energy management.

The main features of the energy management functions are:
a reduced electrical consumption through time programme and duty cycle control of HVAC and associated mechanical equipment
b reduced electrical demand changes through peak demand forecasting and load shedding
c optimised HVAC systems start-up and shut-down based on weather conditions, building mass, HVAC system dynamic response and space temperature conditions.

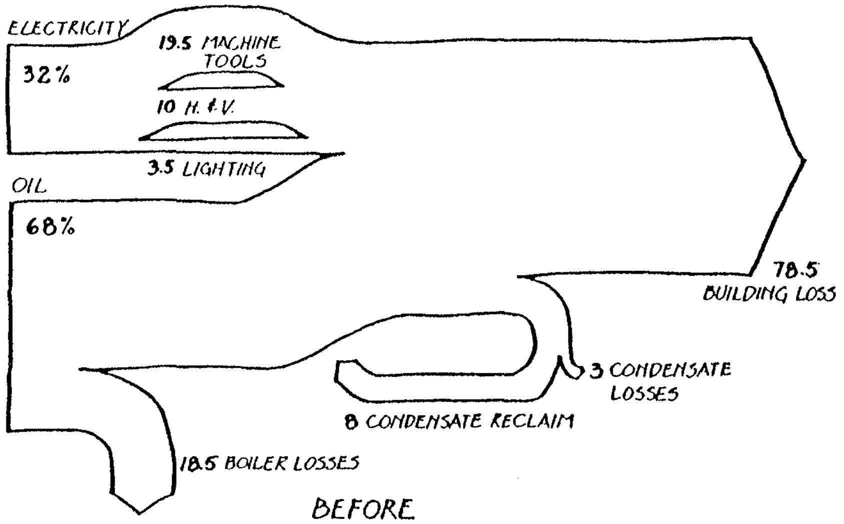


Left. *Section showing the transverse ducts under roof light, with 100mm insulation in walls and roof.*

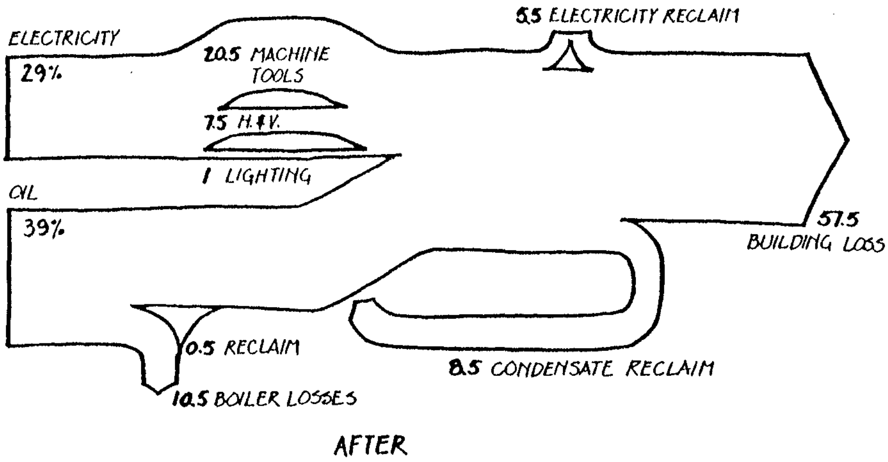
In addition, records of control actions and energy use as produced. These records are used for analysis and fine tuning of systems to take account of the building's characteristics, HVAC system responses and use patterns.

Test Cells
The engine testing procedure consumes more oil than the total heating and hot water energy requirement of the buildings. Various studies were carried out on possible recovery schemes; these included waste exhaust heat recovery, power generation from the engines, cooling water heat recovery, and radiant and convected heat recovery. The cooling water heat recovery and radiant heat recovery schemes are being installed. These schemes will recover some 25% of the test cell energy input, equivalent to approximately six million kwh per year. The heat recovered will be used to preheat the engine combustion air and the ventilation air, reducing the load on the heating and ventilation systems.

Conversion to Coal
Studies have been undertaken for conversion to coal firing. It had always been envisaged that the plant should convert to coal as the major source of energy for steam production in the middle or late 80's, and for this reason the new boiler currently being installed is dual-fired (oil/coal). Coal is currently the cheapest fuel and will be stored in a vertical steel silo with a pneumatic conveyor into the Energy Centre.



Total fuel use per annum Primary 55.0 × 10^6 kwh **Delivered** 40.0 × 10^6 kwh **(Primary: Delivered Ratio 1.4:1)**



Total fuel use per annum Primary 99.4 × 10^6 kwh **Delivered** 17.0 × 10^6 kwh **(Primary: Delivered Ratio 1.4:1)**

Cummins Factory, Lanarkshire

Date of completion	phased from 1979-1982	
Occupancy		
Daily 6.00-23.00, six days per week, throughout the year		
No of persons	1000 (before)	2000 (after)
Persons per m²	0.048 (before)	0.043 (after)
	m² (before)	**m² (after)**
Usable area	20 000	46 000
	m³ (before)	**m³ (after)**
Usable volume	103 000	242 000
Delivered annual energy consumption		
The 'before' figures have been measured, the 'after' figures are estimated by examination of load profiles		
	kwh (before)	**kwh (after)**
Total	40 × 10^6	
Per m²	2000	1540
Per m³	388	293
Per person	40 000	35 500
Primary annual energy per m²	2755 (before)	2160 (after)

Client
Cummins Engine Company

Address
Shottskirk Road, Shotts, Lanarkshire

Architects
Ahrends, Burton & Koralek

M & E Engineers
Ove Arup & Partners

Structural Engineers
Ove Arup & Partners

Warehouse in Glasgow

48 This project was to convert part of a former printing works into a warehouse, distribution centre and offices for a large ironmongery company.

The existing works, built around 1935 are a single-storey, steel-framed, pitched roofed structure, with 50% north light glazing in poor condition.

Heating was steam pipe coils fed from two obsolete boilers, one coal and one oil-fired, located some distance away from the main building. The system was very inefficient and likely to be unreliable.

A comparison of annual operating costs was made, between the existing system and a new heating and ventilating system with improved roof insulation. It indicated a two year pay-back period for a capital investment of about £120,000. The predicted performance has been achieved in practice.

The entire dilapidated glazed area was replaced with double-skin insulated cladding, retaining only 1% as rooflight using double-skin filon sheeting.

To minimise capital and operating costs of the heating and ventilation system, it was essential to minimise and control ventilation. A direct gas fired, high temperature, high velocity induction system (HTV) was installed in the warehouse. This distributes fresh air from a central unit, handling less than 0.5 air changes per hour, to local induction jet diffusers at up to 177°C (350°F) where it is mixed with recirculated air and delivered at up to 60°C (140°F).

The HTV induction system recirculates hot air accumulating at high level within the warehouse.

Gas fired plant was adopted because of the competitive tariff available. When used in a direct fired air heating unit, a combustion efficiency of 92% can be maintained.

The existing LPHW heating installations in the offices and toilet accommodation which had been served from local calorifiers were connected to new local gas fired modular boilers.

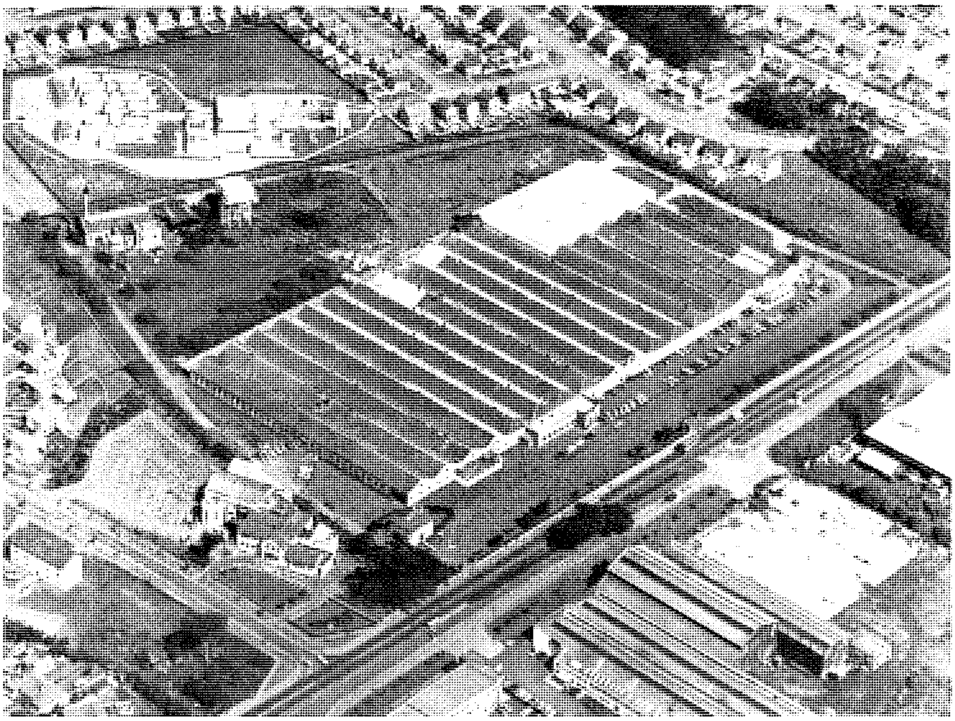
These are three temperature zones:

Offices and toilets, modulating control from boilerplant

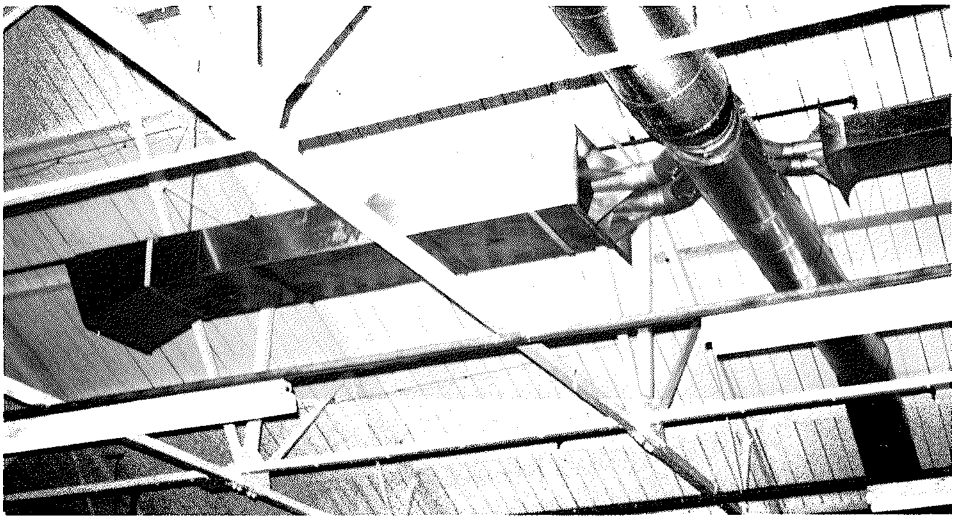
Warehouse, thermostatic control from HTV unit

Loading bay, thermostatic control from local air heaters.

The systems maintain a temperature of 18°C (65°F) at 0.5 air changes per hour. Extract ventilation is severely restricted to a leakage through a small number of fire ventilators which are normally closed, general leakage, toilet extracts and extract from an inflammable materials store.



Aerial view of warehouse before conversion

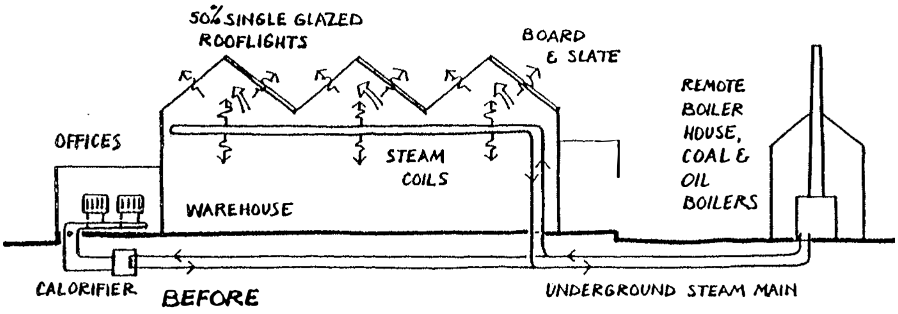


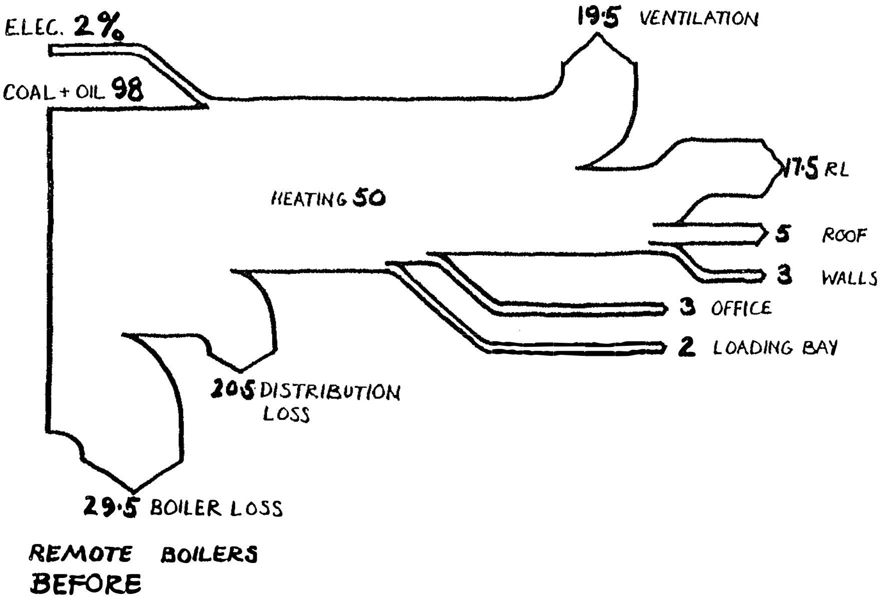
High temperature and velocity induction unit

Improvements to Reduce Fuel Consumption and Operating Costs

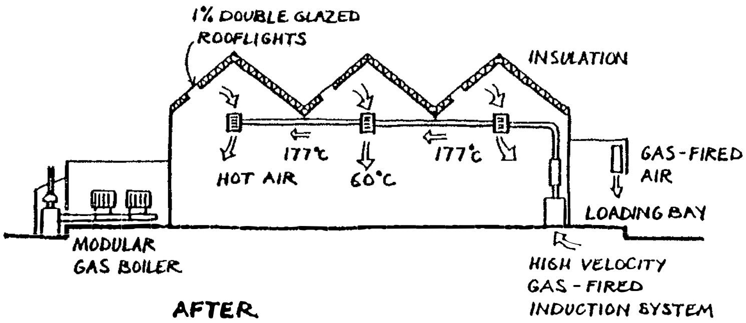
	Original Details	Heat Loss kw	Improvements Made	Heat Loss kw	Annual Savings	Capital Expen-diture	Payback* Period (mths)
Warehouse Areas Roof	Asbestos slates on timber sarking (50% of roof)	348	Asbestos sheeting with 2'' insulation on battens	99	£ 5,792	£32 000	66 months (43 mths)
	Patent glazing/trans-lucent sheeting, vents etc. (50% of roof)	1189	Double skin asbestos with 2'' insulation on battens (46.5%)	91			
			Corrugated trans-lucent sheeting	75	£23 918	£40 000	20 months (17 mths)
Walls, Floors and Windows	Cavity brickwork, single glazing etc.	187	No change	187	–	–	–
Heating and Ventilation Systems	Oil/coal fired steam boiler plant with overhead pipe coils (2 A/C)	1276	High velocity gas fired induction system (0.75 A/C)	479	£18 652 (including offices)	£60 000	39 months (31 mths)
Office Accommodation All Areas	Single storey offices adjacent warehouse area	217		219	–	–	–
Loading Bays All Areas	Single skin asbestos sheeting construction	116 (not heated)	Double skin asbestos insulated sheeting	116			
TOTALS	Original Heat Load	3334	Revised Heat Load	1264	£48 362	£132 000	33 months (26 mths)

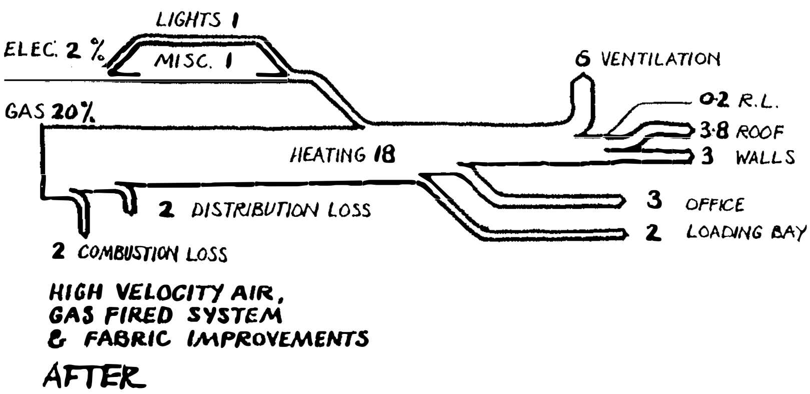
*Payback period, after interest charges taken at 10%. Payback period, excluding interest charges shown in brackets





Total fuel use per annum Primary 13.0 × 10^6 kwh **Delivered** 12.2 × 10^6 kwh **(Primary: Delivered Ratio 1.1:1)**





Total fuel use per annum Primary 4.1 × 10^6 kwh **Delivered** 3.0 × 10^6 kwh **(Primary: Delivered Ratio 1.4:1)**

Local gas fired air heaters are located in the loading bay, in addition to the main HTV system, to permit a temperature boost when necessary, or the shut down of the main system during mild weather and staggered shift working.

A lighting standard of 200 lux has been adopted in the warehousing areas, with higher standards in specific areas.

Gas and electricity consumption are metered by the supply authorities and company staff take monthly readings. Consumption figures have been analysed by Hulley and Kirkwood to evaluate actual performance during the two years after completion, and confirm that the predicted performance has been achieved.

Automatic controls comprise time clock and modulating controls for the offices with optimum start time clock control for the warehouse.

Warehouse in Glasgow			
Date of completion		August 1976	
Capital cost		Conversion	£350 000
Occupancy 8.00-18.00 plus some overtime working 5½ days per week throughout the year			
No. of persons		156	
Persons per m²		0.011	
		m² (before)	**m² (after)**
Usable area		14 300	14 300
		m³ (before)	**m³ (after)**
Usable volume		84 000	84 000
Delivered annual energy consumption Before conversion has been calculated on the basis of CIBS. procedure. Consumption after conversion shows actual measured figures.			
		kwh (before)	**kwh (after)**
Total	min		2.8 × 10^6
	max	12.2 × 10^6	3.0 × 10^6
per m²	min		195
	max	853	210
per m³	min		33.3
	max	145	35.7
per person	min		17 834
	max	77 700	19 100
Primary annual energy per m²		907	286

Client
P & R Fleming & Co Ltd

Address
Kirkintilloch Road, Bishopbriggs, Glasgow

Architects
Boswell, Mitchell & Johnston

M & E Engineers
Hulley & Kirkwood

Quantity Surveyor
Hugh A Low & Usherwood

Bore Place Dairy Unit

49 Biogas digesters have been an energy source in India and China for generations, producing methane gas bacterially from animal and plant wastes. Helix, a multi-discipline design team of architects and engineers with special interests in energy use, are about to commission a large, sophisticated farm digester system in Kent.

The radical brief requested the use of the energy and material resources of a dairy farm in a way which would tend towards self reliance and be relatively labour intensive. (For instance, at the suggestion of Fritz Schumacher just before he died, clay excavated during construction is now being made into bricks on the site.) Relatively sophisticated equipment was thought reasonable in view of the technical competence of modern farm workers and the availability of maintenance engineers.

The 50,000 gallon digester will produce all the power needed for the new dairy unit by anaerobically digesting slurry from 320 Freisians cubicled for six months a year.

Much farm equipment, in particular milking parlour and cooling equipment, is designed for electrical operation; waste slurry always has to be dealt with on a dairy farm, and study showed that sufficient heat and electrical energy could be generated from biogas from the slurry to match the needs of the dairy.

Research identified three critical technical problems:

1 Gas storage and pressurisation
2 De-scumming and removal of excess solids or matted material from the digester
3 Maintenance of optimum temperature for methanating bacteria.

The small Asian digesters successfully use cylindrical floating caps inserted into the slurry in a hole in the ground. These provided a model.

Slurry with 12-10% solids is mechanically and automatically scraped along troughs to the concrete digester tank, where it is retained for 14 days. The digested slurry is passed to lagoons, from where it is spread on the fields, completing an ecological cycle.

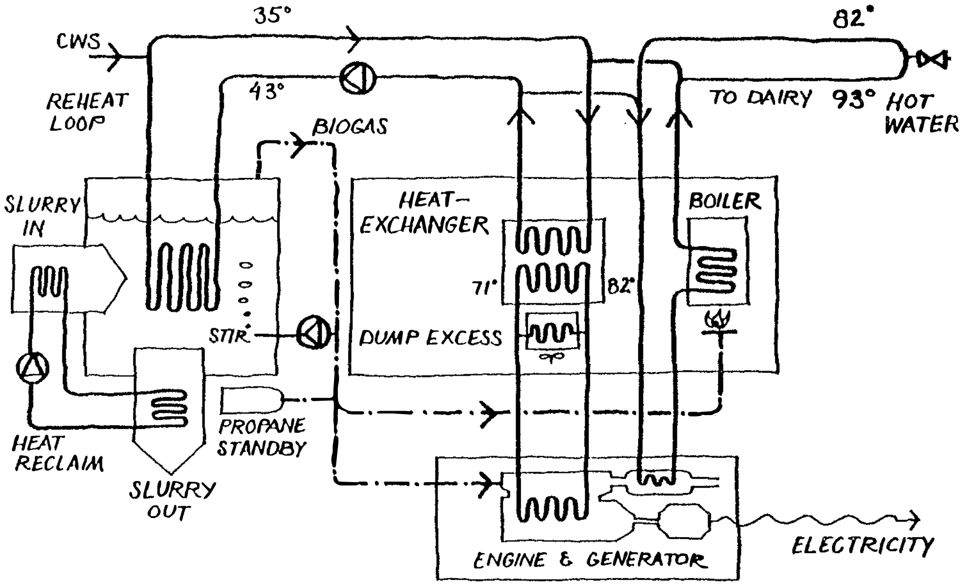
The design of the floating cap of the digester provides solutions to the three critical technical problems. Six insulated GRP modular caps, each 6m x 2m, float side-by-side to cover the surface of the slurry. Concrete T-pieces lock the modules together and provide the weight that pressurises the gas. Varying numbers of T-pieces can be used to vary gas pressure. The caps can be removed singly, to allow cleaning and de-scumming while the rest of the digester maintains 5/6 full production.

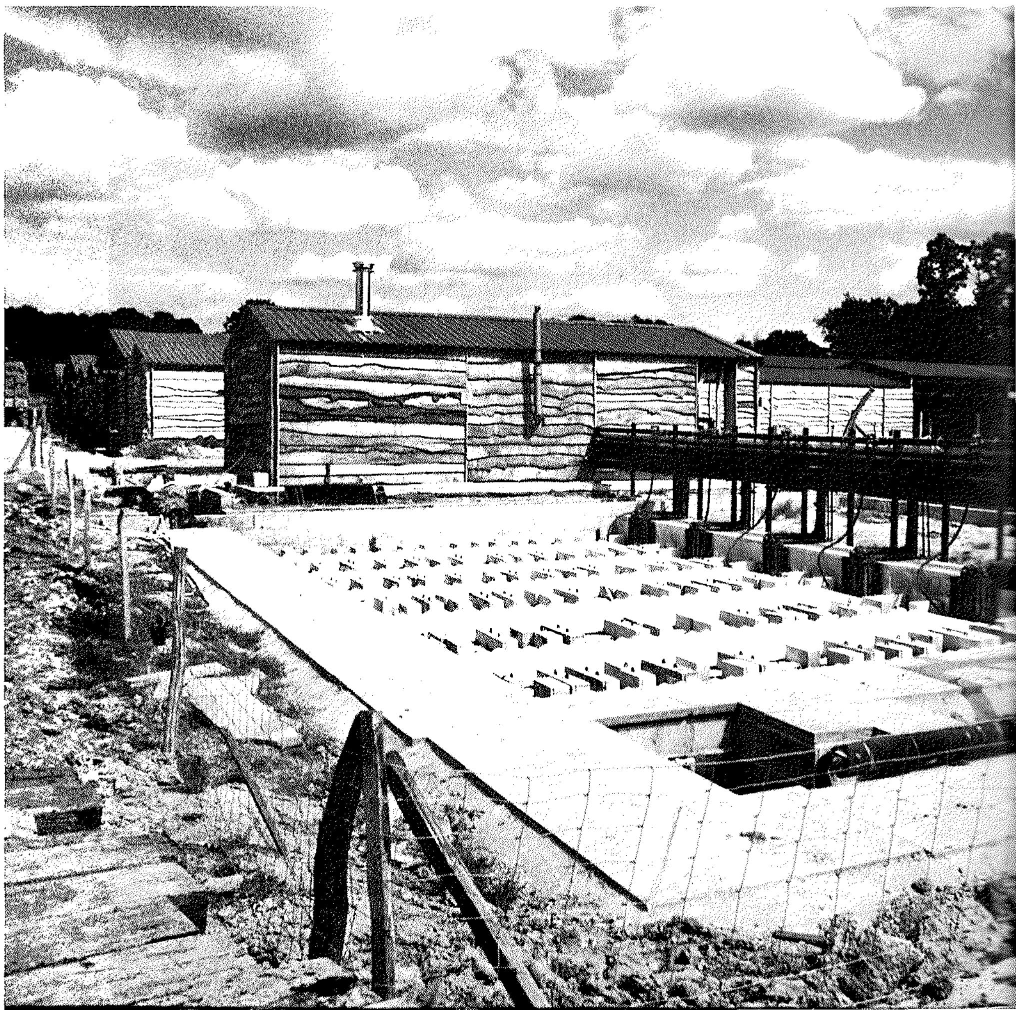
Right. *Digester, showing concrete weights holding down GRP gas collector covers, plant room and cow sheds in background*

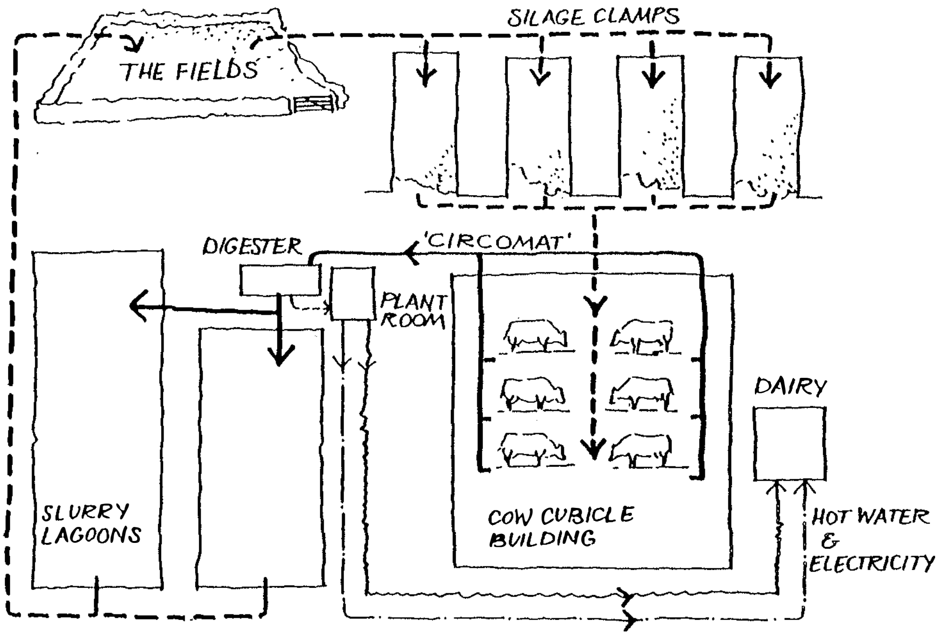
Brickmaking, using clay excavated during building works

The pre-formed polypropylene heat exchangers can be lifted from the slurry and cleaned, in sections corresponding to each module. These heat-exchangers re-invest part of the energy output to maintain the optimum 35°c temperature. Separate heat exchangers recover 60% of the heat in the outgoing slurry.

The biogas is scrubbed to remove impurities and fuels a boiler and a diesel engine modified to spark-ignition. Heat is recovered from the engine block and exhaust.





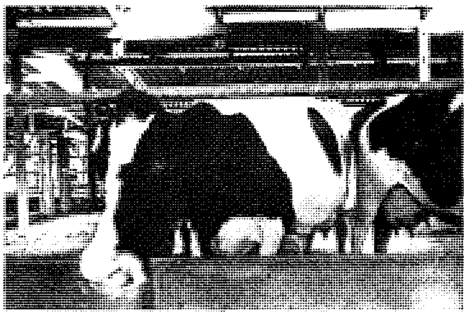


A resident manager will be responsible for controlling energy use.

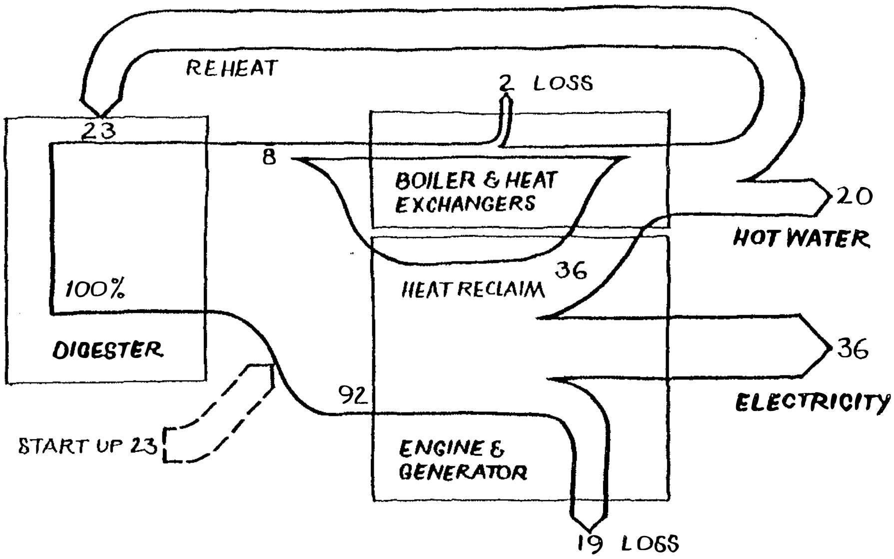
The dairy unit is planned with slurry treatment and dairy at opposite ends of the large cow cubicle building. Buildings are clad with waney elm boarding from locally felled trees.

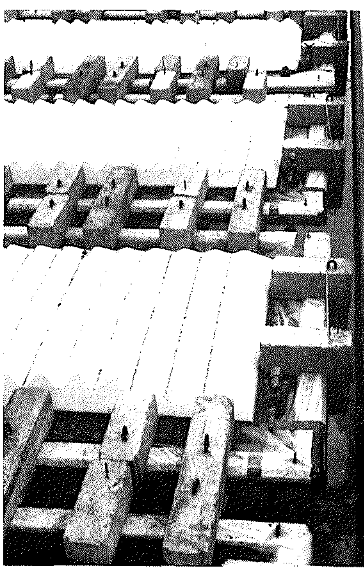
Performance will be monitored by the Ministry of Agriculture, Fisheries and Food.

Subsequent developments of the process may make use of digested slurry and surplus recovered heat in greenhouse production, or milk processing to cheese and yoghurt.



The system is designed to supply a maximum 29 kw of electrical energy and the hot water and space-heating demand of the dairy (i.e. about 2 kwh per cow day). Very considerable design time was used in analysing the patterns of equipment use. There are two daily peaks in essential energy demand, during milking. To reduce these peaks electricity is used overnight to store 'coolth' by making ice, which is then used rapidly to cool milk during milking. Slurry-scraping and other operations are also programmed to operate intermittently to smooth demand.





Digester detail

Bore Place Dairy Unit

Date of completion	August 1979
Capital cost of digester	£50 000
Occupancy	
4 hours milking, twice daily. Load pattern has to be arranged to be as even as possible	
No of cows	320
Delivered annual energy	
Produced by the unit 96 500 kwh	

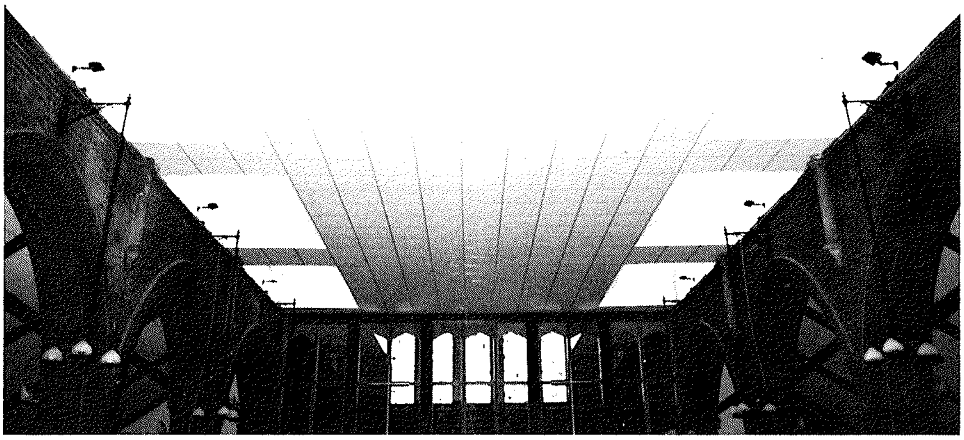
Client
Mr Ne[illegible] Wates

Address
[illegible]

Architects & Engineers
[illegible]

Monitoring Organisation
[illegible]

50



Insulated suspended ceiling and screen wall reduced the heated volume of Holy Trinity Church, Worthing by 45%
Architects Murrin and Manwaring

The cover shows an airborne thermal infrared image of an urban area. From this, areas of faulty and inadequate insulation can be readily identified because they have a higher outside surface temperature, due to the greater heat flow. In this particular image each colour represents a 1·5°C range of temperature, the order in increasing temperature being green, blue, cyan, red, yellow, purple and white.

By courtesy of the Environment and Resources Consultancy of Fairey Surveys Limited, Reform Road, Maidenhead, Berkshire, SL6 8BU Telephone: (0628) 21371

BUILDINGS-THE KEY TO ENERGY CONSERVATION

ERRATA

PAGE	ERROR	CORRECTION
17	Enegy	Energy
19	October 1978	October 1980
20	proceeding	preceding
55	no real	less
56	front	frost
68	isolation	insolation
69	projects	progress
78	section dwg. should show vent. gap above insulation	
91	17.0×10^6 kwh	71.0×10^6 kwh

There is great potential for saving energy in buildings. Once achieved, such savings can become long lasting and, as more than half of the United Kingdom's energy is used in buildings, any reduction in demand can be important as a factor in the planning of supplies.

This book, published in conjunction with a major conference and exhibition at the RIBA, explores just what is possible.

Fifty "Energy Efficient" buildings and Conservation Programmes throughout the UK are presented against a background of authoritative papers dealing with many of the central issues concerning energy conservation in buildings.

Such a collection has two complimentary objectives. First, to show policy makers who have to make decisions involving fuel supply, investment and buildings, what can be achieved, and second, to show architects, engineers and other professionals how this has been done and what effect their work can have at a national level.

Airborne thermal infra-red image by the Environment and Resources Consultancy, Fairey Surveys Limited

ISBN 0 900630 75 2