#2043

ENERGY CONSERVATION IN BUILDINGS

S J Leach

Building Services and Energy Division,
Building Research Establishment,
Garston, Watford, WD2 7JR

'Building services' accounts for some 40 — 50% of the UK's consumption of primary energy. The potential for energy saving through the adoption of such schemes as district heating, combined heat and power, heat pumps and solar energy could make a major contribution to the country's energy balance

All physicists are of course aware that energy is always conserved! However, throughout this article the term 'energy conservation' will be used in the way now widespread to mean a reduction in the energy required for a given purpose, for example a reduction in the energy required to produce comfortable temperatures in buildings.

Forecasts of energy consumption for the UK given by the Department of Energy in evidence to the Select Committee on Science and Technology (Energy Resources Sub-Committee 1975) explore the future possibilities implied by a growth rate of 2·7 to 3·3 % *per annum* and are shown in figure 1. The mix of primary fuels varies considerably and the underlying assumptions which produce this variability are described in the evidence. It can be seen that there is a wide range of flexibility and uncertainty over this time scale. The energy 'crisis' is not of shortage now or in the immediate future. However, the recent increases in costs of energy in real terms (that is, above general inflation) in the UK and in most nations emphasizes the need to optimize the use of resources in a new way. Energy can now be used more efficiently because the value of the energy saved by a conservation measure has increased, justifying the investigation of a new range of options for energy conservation. The main aim of this article is to discuss some of these new options for energy conservation in buildings. The statistics of energy use in buildings will now be outlined and it will be shown that 'building services' is the single most important category of energy use requiring annually at least 40 %, and possibly 50 %, of the UK's consumption of primary energy. This is about three times the consumption of the transport sector.

Energy use in buildings

When discussing energy consumption it is important to distinguish between the consumption at or by the building itself (the net energy) and the consumption of the original raw material or primary fuel (the gross energy). The difference between the two can be great. For example, in the UK in 1972 only 27 % of the calorific value of the fuels entering the power stations arrived as electricity to buildings. These 'energy overheads' of the fuel industries will be discussed further below.

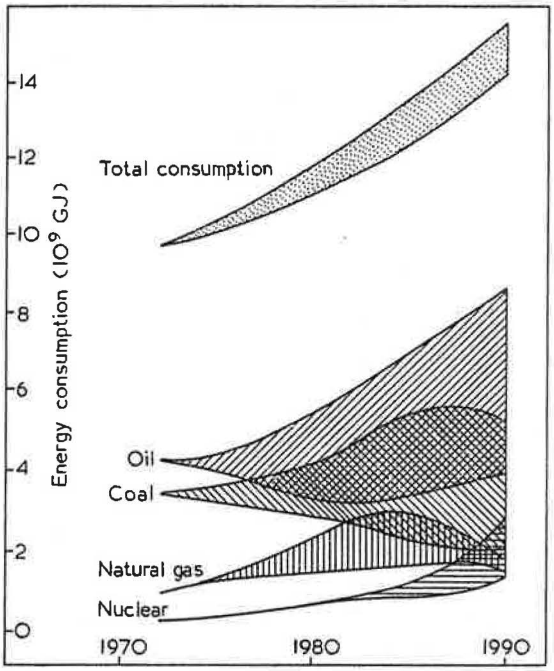
In this article the unit of energy employed is the joule (J) and its multiple the gigajoule (1 GJ = 10^9 J). 1 GJ is approximately equal to 278 kW h or 9·5 therms.

The following discussion is based on 1972 figures to avoid any distortions from difficulties of supply

Table 1 *Ratio of gross energy input to net energy delivered to users: UK fuel industries,* 1972

Coal	1·03
Oil	1·09
Natural gas	1·07
Town gas	1·42
Electricity	3·82
Other manufactured fuels	1·38

Figure 1 *Envelopes of Department of Energy energy consumption forecasts* (*Evidence to Select Committee Science and Technology* 1975)



in the period which immediately followed that year or the effect of price increases now being passed on to consumers. Primary energy consumption of the UK was $8{\cdot}9\times10^9$ GJ and energy delivered to final users was $6{\cdot}1\times10^9$ GJ, the difference representing losses in conversion and distribution by the fuel producers (figure 2). The difference between the gross energy input and net energy output of the electricity industry is almost equal to that delivered to the whole of the industry sector. The relationship between the gross energy used and the net energy delivered for UK fuel industries is given in table 1.

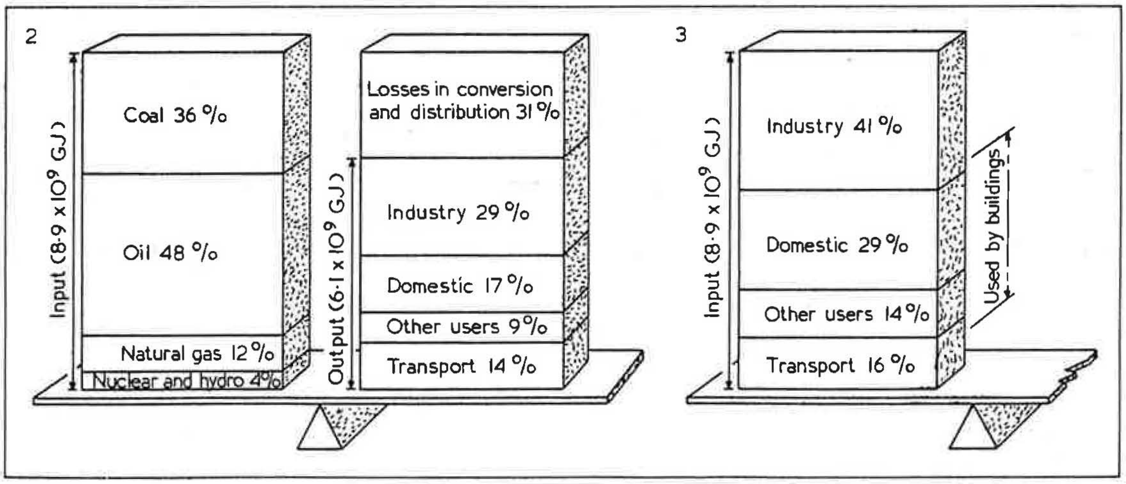
The gross energy used by various categories of final users can be derived from figure 2 by distributing the losses in conversion and distribution amongst the final users in proportion to their use of the various fuels and the result is shown in figure 3.

Nearly all the energy used by the domestic sector is used to provide heating and light within the building. This is also true of a large part of the energy used in the 'other users' sector since this sector also includes schools, hospitals and most offices. There will also be some energy used in the transport sector for building services (associated with railway and bus stations for example) and a good deal in the industry sector. Overall, at least 40 %, and possibly 50 %, of the national primary

Table 2 *Average annual domestic energy consumptions* (*GJ*)

	Net	*Gross*	*Useful (approx)*
Space heating	52	74	30
Water heating	17	30	9
Cooking	7	16	5
Lighting, TV, etc	5	18	5
Totals	81	138	49

Figure 2 *Gross energy input and net energy output of UK economy* (*left*)
Figure 3 *Gross energy used by final users* (*right*)



energy input can be associated with building services.

There were about 19 million domestic households in 1972, so the average net energy consumption in the home was about 81 GJ. This provided space heating, water heating, cooking, lighting and other sundry usages. Estimates based on field studies give the approximate usages shown in table 2.

An important feature of the UK domestic sector is the relatively large usage of electricity. It is about twice that per capita of the original six EEC member countries. Belgium and Holland provide particularly good examples as they share with the UK a maritime climate. The domestic sector per capita consumption of electricity in the UK is about 2·5 times that of Belgium and twice that of the Netherlands.

An extensive review of the possibilities for energy conservation of a wide variety of possible measures has recently been carried out (BRE 1975), with emphasis on the most important category of buildings, namely housing. This review considered the probable costs and savings of the measures as a basis for further research. The general conclusion was that the ultimate realistic potential for gross energy savings in buildings is estimated to be about 15 % of the national consumption, which is about as much as used by the entire transport sector. This total could only be achieved over a long period of time since it depends on the use of technologies which are more fitted to new constructions designed for the purpose. The estimated potential of possible measures applied in existing housing is about 6 % of total national consumption. Some of the more important measures are as follows.

Measures aimed at reducing energy use

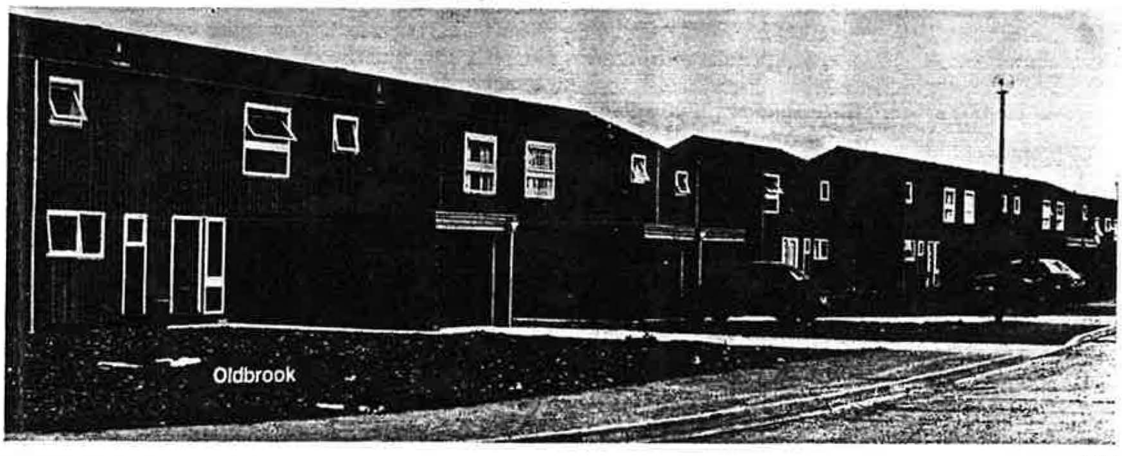
(i) District heating and combined heat and power

The analysis of energy consumption above showed that power stations account for about one-third of the primary energy used, but only about 27 % of this energy reaches consumers in the form of electricity. Because of the UK practice of generating electricity as efficiently as possible, which in the generating station implies condensing the steam after passage through the turbines at as low a temperature as possible, the heat available in the condensate is at a temperature of about 30°C. This is useless for most purposes, including heating of buildings when conventional heating systems are employed. It is quite feasible to obtain this heat at a higher and more useful temperature by increasing the pressure at the discharge end of the turbine, but less electricity will be generated for every unit of primary energy input to the power station.

Using the rejected heat is an established practice in several European countries. The BRE (1975) estimation of the energy saving potential is about 10 % of the national consumption. The feasibility and costs of combined heating and power in UK conditions is a complex issue not yet resolved.

An assessment has begun at BRE of the economics of 'long distance' transmission of heat from coal- or oil-fired power stations. A major feature of the systems considered is the use of heat storage in the form of tanks of hot water. With this storage, heat can be obtained from the power stations (using 'intermediate take-off condensing' turbines) at times of below-peak demand for electricity; in addition utilization of the pipeline linking the power station to the district heating scheme would be improved. District heating from a central boiler house may save some energy by comparison with individual heating systems in the buildings served, but the savings are not likely to be great. The average efficiency of a large industrial boiler, as used in district heating schemes, will be higher than that of a small domestic appliance, but some heat will be lost from the network of underground mains, although this loss should be limited with modern techniques to less than 10 % of the heat supplied. There is, however, very little published information to aid the design of district heating and combined

Figure 4 *These houses at Peterborough may not look particularly revolutionary in design, but they are part of the BRE's experimental low-energy housing programme and are instrumented to measure heat, water, gas and electricity consumption*



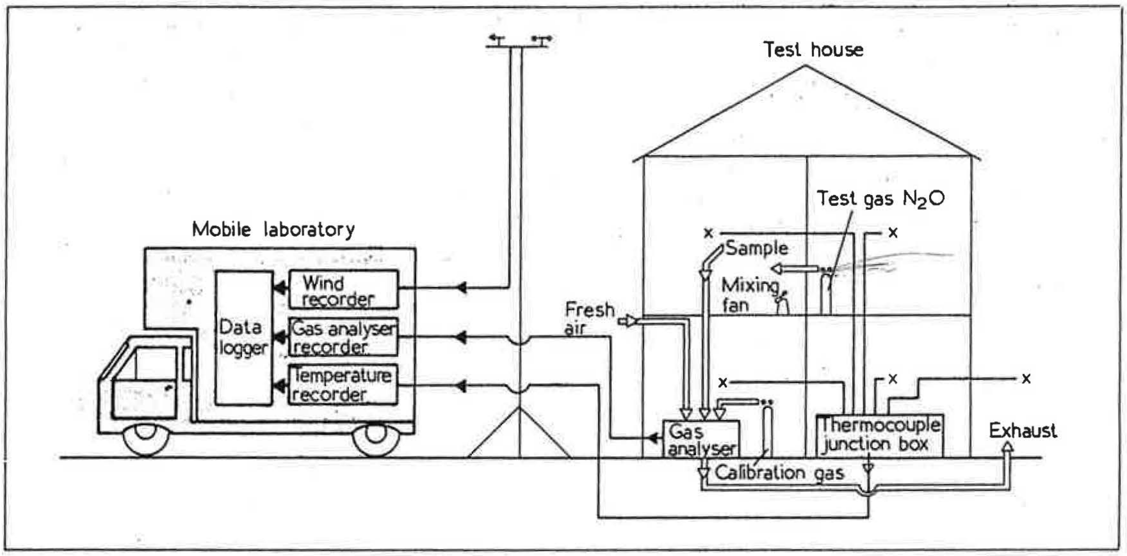


Figure 5 *Mobile laboratory for the measurement of natural ventilation*

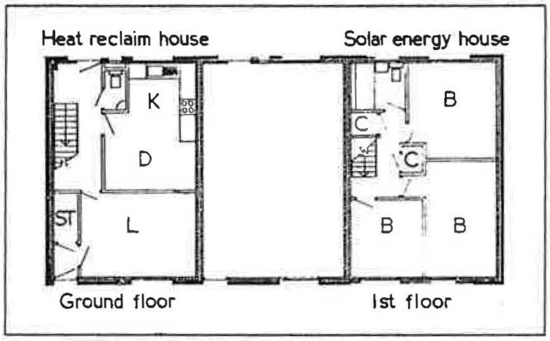


Figure 6 *Plans of heat reclaim and solar energy houses*

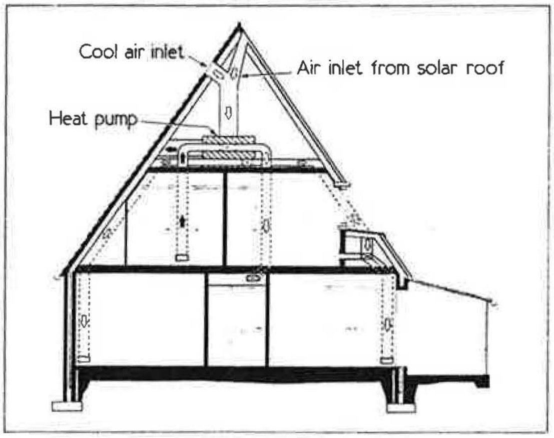


Figure 7 *Heat pump house*

heat and power systems and the main aim of the current BRE research is to provide such information.

Not all the buildings served by hot-water mains will require heat at the same time. Consequently, the boiler and mains capacity installed can be less than the total connected heating load in the scheme. The ratio between the expected peak demand and the total installed load is known as the 'diversity factor' of the scheme. If each section of a system is to be correctly sized, the appropriate diversity factor must be employed.

An extensive data collection project has been initiated at Bretton, Peterborough, to obtain information on the load patterns experienced in the district heating of houses. As well as providing data to aid the design of future district heating schemes these studies also link with the development of new low-energy designs based on the construction method used at Peterborough (figure 4) as will be described later.

(ii) Heat pumps

These operate on the same principles as a domestic refrigerator. They use mechanical energy to transfer heat from a free heat source (commonly the outside air) to the building and upgrade it to a higher temperature useful for space heating. Their significance is that they will always supply more heat than the energy required for the operation of the machine. It seems technically feasible to design heat pumps which would transfer three times as much heat as mechanical energy consumed. An electrical heat pump thus has a primary-energy efficiency better than that of the best modern domestic boilers. The use of heat pumps to supply heat to buildings would save about 7 % of the national primary energy consumption. (This, of course, would not be additional to the saving from district heating discussed above, but an alternative to it.) This saving may become even larger with further development of heat pumps in conjunction with ventilation heat recovery. Heat pumps lend themselves more readily to new constructions designed for the purpose but their scope in existing housing is also a subject for the BRE research programme. The possibilities for the use of heat pumps in a wide variety of ways can be seen in their use in experimental low-energy houses described later.

(iii) Improved ventilation control

The main requirement of any ventilation system is to assist in maintaining a comfortable, safe and hygienic environment within a habitable building. Heat loss to ventilating air contributes about 30 % of the space heating load in a moderately well insulated dwelling and an even higher proportion in buildings such as hospitals and schools.

Natural ventilation has the advantage that it is inexpensive but, because it depends upon the natural agencies of wind and buoyancy, it is difficult to control. To provide a basis for better design, therefore, a programme of measurements of natural ventilation rates in dwellings is currently being undertaken (figure 5). Dwellings are chosen to cover a range of parameters, particularly layout and number of external walls, likely to affect ventilation rate. Although these field measurements will be useful in themselves their main purpose will be for comparison with predictions from a computer-based theoretical model which, if sufficiently well validated, will be used for examining proposed future ventilation designs.

At each chosen site both whole house and room ventilation rates are measured using tracer gas techniques, based upon nitrous oxide and infrared gas analysis. Simultaneously with each ventilation rate measurement, wind speed, direction, internal and external temperatures are monitored and, together with tracer gas concentration, these are recorded on paper tape by data-logging equipment housed in a mobile laboratory. The subsequent analysis of the paper tape by computer allows the measurements to be rapidly analysed.

In view of the variation of wind speed and temperature it is clearly not possible to supply the required ventilation rate at all times using natural ventilation, and openings should be designed to ensure that it is exceeded for, say, 60 % of the time. In some, particularly older, houses the design ventilation rate will be exceeded for rather more than this and in these cases heat loss can be reduced by weather stripping and similar techniques. However, modern forms of construction and component design have led to 'tighter' houses. In such cases weather stripping can lead to houses which are underventilated.

Although mechanical ventilation systems have the disadvantage of additional capital and running costs when compared with natural systems, these may be offset by reduction in heat loss. This may be achieved in two ways. Firstly, mechanical systems can be designed to supply just the required amount of air when and where it is needed. Secondly, if a full input/extract system is used a heat exchanger can be incorporated to reclaim heat from the outgoing air and transfer it to the incoming air. A number of such heat recuperation systems are feasible and several will be studied in the experimental low-energy housing and one in the mechanical ventilation system of a new office block to be built on site at BRE. On a smaller scale, small heat exchangers for use in dwellings are being studied and an exchanger based upon the heat pipe principle is being investigated.

Experimental low-energy housing at BRE

Some of the many possible ways of reducing energy consumption in buildings being researched at BRE have been described above. In addition, the application of solar energy to existing buildings, the use of improved controls for heating systems and the problems associated with changing from electric heating to direct fossil-fuelled heating in existing houses are also being studied. However, incorporating energy conserving techniques into new designs will lead to problems of the integration of several measures and to a need to evaluate new heating system performance to determine costs and benefits of new designs. Three different low-energy experimental houses will form built examples of some techniques which contribute to savings in energy consumption and are referred to as the 'heat-reclaim', 'solar' and 'heat-pump' houses. They will be instrumented and their behaviour observed under controlled conditions and simulated occupancy.

(i) House construction

The houses are designed not to require unfamiliar construction techniques, nor lead to major change in the inhabitants' life style and should be suitable for normal urban/suburban sites. Consequently they do not present an obviously revolutionary image and this should enhance the likelihood of adoption of their features. Their energy savings are, in fact, of major significance.

The decision to use familiar construction techniques led to the choice of a timber-framed building system for two of the houses. The techniques of this type of building are now well understood, and the construction readily permits an increase in thermal insulation. Studies of heat consumption are being made in timber-framed houses built at Bretton, Peterborough. Thus the plan-form of the Type 47 house from Bretton was adopted for the 'heat reclaim solar energy' houses (figures 4 and 6). These are conventional 5-person terrace houses with 5·7 m frontage, 8·6 m in depth, with dining–kitchen, living room, cloaks and a store downstairs, three bedrooms and bathroom upstairs. The two end houses of a 3-house terrace (which are effectively semi-detached) would be the experimental houses while the central one forms a thermal 'buffer' and will house all the monitoring instruments.

The timber structure is prefabricated into large panels and the only change from the standard as built at Peterborough is that the thermal insulation in the panels and roof is increased from 25 mm to 92 mm and 100 mm of glass fibre respectively. This gives a thermal transmittance (U) value (Raynham 1975) of about 0·29. The roofs, covered with slates, will be of 42° pitch; this steepening, as compared with the 22·5° at Bretton, provides a more suitable inclination for the solar collector and increases the loft space available for equipment. The windows will initially be of the same type as at Bretton, with modifications such that the opening portions will have very low infiltration rates when properly closed. Windows of higher quality, and double glazing, may be fitted later.

The heat-pump house is of chalet type with upstairs rooms accommodated within the pitched roof, and intended to be built in semidetached form (although a terrace variant is possible). The envelope area is small relative to the habitable volume (figure 7).

This house is of load-bearing cavity wall construction: the outer leaf is facing brick, with cavity, rigid plastic foam, lightweight concrete block and foil-backed plasterboard on battens as the inner dry lining providing insulation. This wall construction also has a U value of 0·29. Double-glazed opening windows will be used, and the area of glazing has been kept small, except for the ground floor on the south side where French doors open into a glazed conservatory.

The ground floor is an insulated solid slab, the first floor of timber and the internal partitions of conventional timber and plasterboard construction. The roof has a steep pitch and provides a space for the heat-pump machinery, and its south-facing slope forms a simple solar collector. Air passes through this collector on its way to the evaporator coils of the heat pump.

(ii) Heat-reclaim house

Heat reclamation is applied both to space heating and to domestic hot water. The heating system will be a small gas fired boiler.

Although openable windows are provided for summertime use, there is a mechanical system capable of handling the whole of the ventilation requirements of the house. One fan in the roof space extracts air from toilet, bathroom and kitchen – the latter via a hood over the cooker. Another fan draws fresh air from within the roof space, where it will have received some warmth from solar gain and from conduction losses through the ceiling, and feeds it through ducts to all main habitable rooms. The in and out streams pass through two sides of a heat exchanger, so that much of the heat in the outgoing air is transferred to the ingoing. Without this heat recovery the ventilation heat loss would be about 44 % of the space heating load. A heat-exchange efficiency of about 60 % is expected.

The domestic hot water reclaim system has a storage tank (1 m³) into which pass the wastes from bath, dishwasher and washing machine. Near the top of this is the evaporator coil of a small heat pump, which extracts heat from the water and returns it, via a condenser coil, to the hot-water cylinder. This is expected to supply about 70 % of the water-heating energy, the remainder coming from the gas boiler via a normal primary coil.

(iii) Solar-energy house

The energy system (figure 8) includes a solar collector of about 22 m² fitted into the south-facing pitch of the roof. In summer this should deliver more than enough energy for space and water heating. Surplus energy is stored by heating water in a large (35 m³) well insulated tank, located outside and below ground level.

Space heating is by radiators, larger than normal size so that lower water temperatures can be used. When the 35 m³ tank is hot enough, the radiators draw their heat from it. At other times they draw it from a 1 m³ insulated tank which is heated by a small off-peak electric heat pump using the 35 m³ tank as source. Inflow to the domestic hot water system passes through a heat exchanger in the 35 m³ tank and into a 0·3 m³ storage tank, sufficient for 24 h supply. This too can be topped-up by a small off-peak heat pump. Energy from the solar collector is fed into the 35 m³ tank when it is hotter than the tank, or via another heat pump (not off-peak) when it is cooler.

Heat-pump house

The equipment proposed for this house comprises two heat pumps, both electrically driven, with liquid propane gas (LPG) used as a boosting fuel.

Figure 8 *Heating system for solar house*

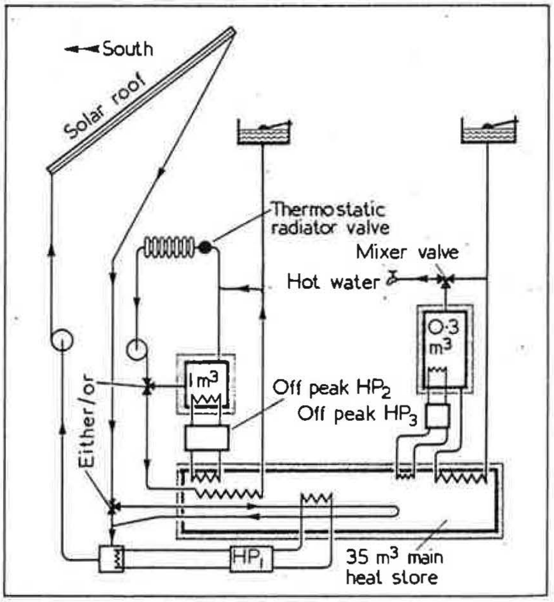


Table 3 *Estimated energy consumption (in* GJ yr^{-1}*) for the various experimental houses and comparisons*

		Net energy (GJ yr^{-1})	*Form of supply*	*Primary energy* (GJ yr^{-1})
Bretton Type 47 house to current buildings regulation	Space	54·0	Average mixture*	124·2
	Water	12·0	,,	27·6
				151·8
Bretton Type 47 house with 0·29 *U* value	Space	27·0	,,	62·1
	Water	12·0	,,	27·6
				89·7
Heat-reclaim house	Space	21·0	Gas	37·1
	Water	3·0	Electricity	11·1
	,,	3·5	Gas	6·2
				54·4
Solar-energy house	Space } Water }	13·5	Electricity	50·0
Heat-pump house	Space	8·3	Electricity	30·7
	,,	0·7	LPG	0·9
	Water	5·0	Electricity	18·5
				50·1

* Average mixture: gas, electricity and oil in the proportions in which they contribute to the national total domestic consumption; average overhead 130 %

It includes a mechanical ventilation system of similar duty to that in the heat reclaim house.

The main heat pump is an air-to-air machine. The evaporator (source heat exchanger) receives the air extracted from the kitchen, bathroom and wc so that some of the heat in this may be reclaimed. Atmospheric air fed to the evaporator has been drawn through the solar roof, so that its temperature may be appreciably above that of the outside air, and certainly not below it. The ventilation air replacing that extracted also passes, during the heating season, through the solar roof before going to the condenser (supply heat-exchanger). Return air from the warm-air-heating circulation is also blown through the condenser, and these two streams then pass into the duct system feeding the various rooms. There is provision for part of the return air to pass through the evaporator, for dehumidification, before it reaches the condenser, if this should be found desirable. In summer, a bypass duct enables the ventilation air to be drawn directly from the atmosphere on the shaded side of the building.

The domestic hot-water supply comes in a storage cylinder. Cold water on its way to the cylinder passes through one of two preheater coils: in summer a coil in the air stream from the solar roof: in winter one in the warm-air duct of the space heating system. The same two locations house alternative evaporator coils for a small heat pump, whose condenser coil is in the storage cylinder, and this heat pump is used to raise the water to the full supply temperature.

Table 3 shows the estimated energy consumptions in GJ per annum of the space and water-heating systems, for the experimental houses and two comparison houses.

The predictions for the heat pump and solar energy houses are conservative (particularly for the latter) pending the completion of more sophisticated simulation studies. In the case of the solar energy house various operational strategies are possible and these are still being evaluated, the sizes of the solar collector and the main storage tank having been determined by practical considerations rather than by optimization studies. However, each of the three houses will use one-third or less of the primary energy of current constructions.

Acknowledgment

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

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