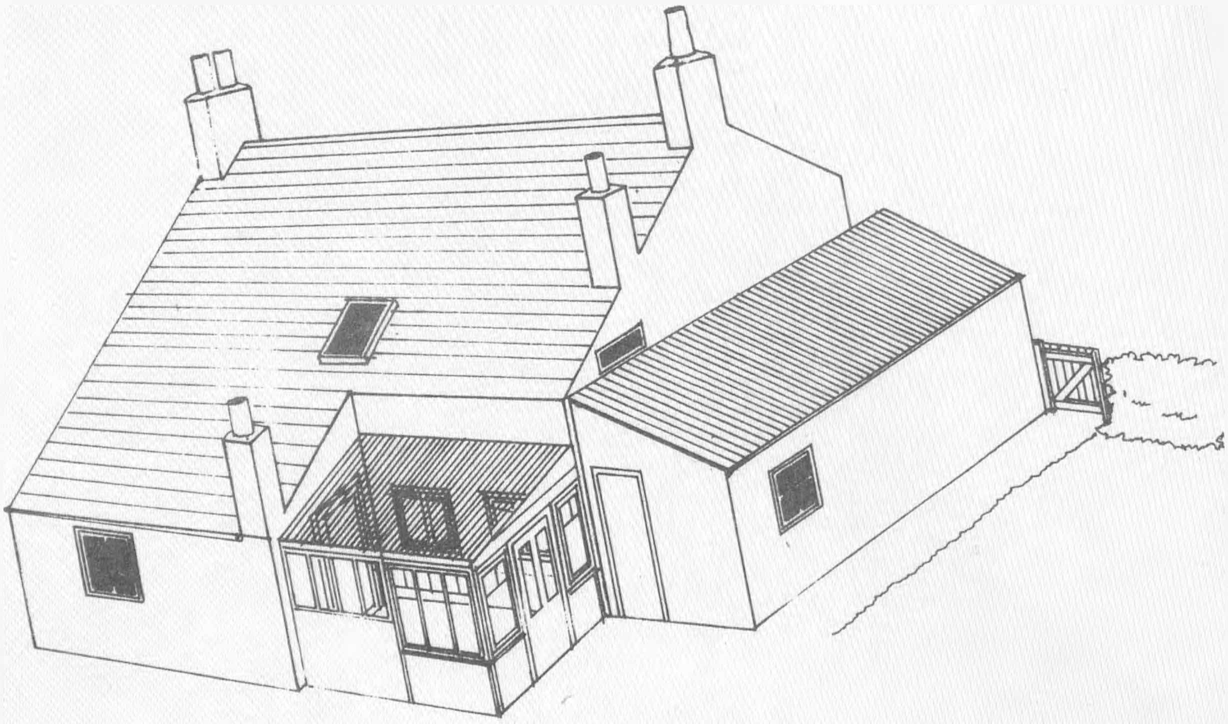
THE OPEN UNIVERSITY

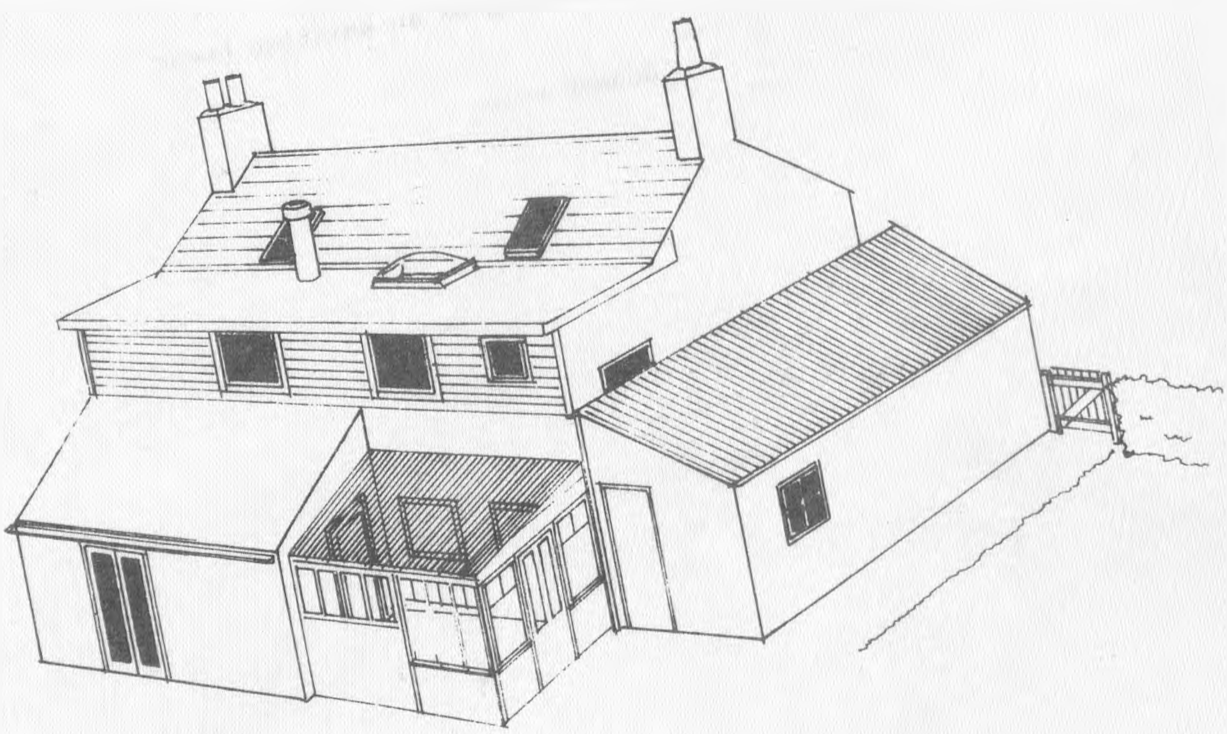
ALTERNATIVE TECHNOLOGY GROUP

Low cost thermal upgrading of an existing house

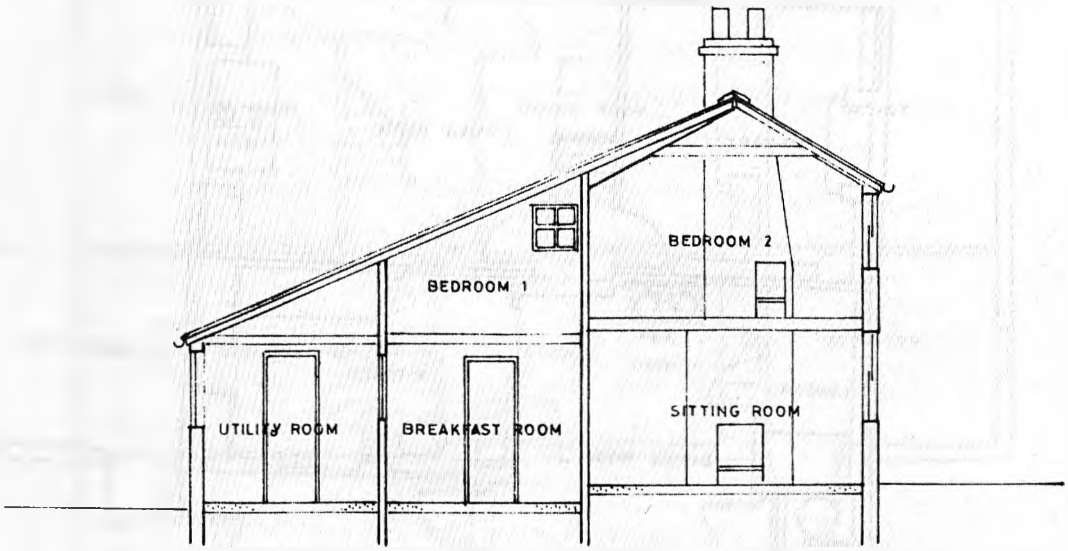
Robert Vale



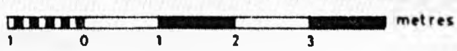
View from South East before conversion 1974

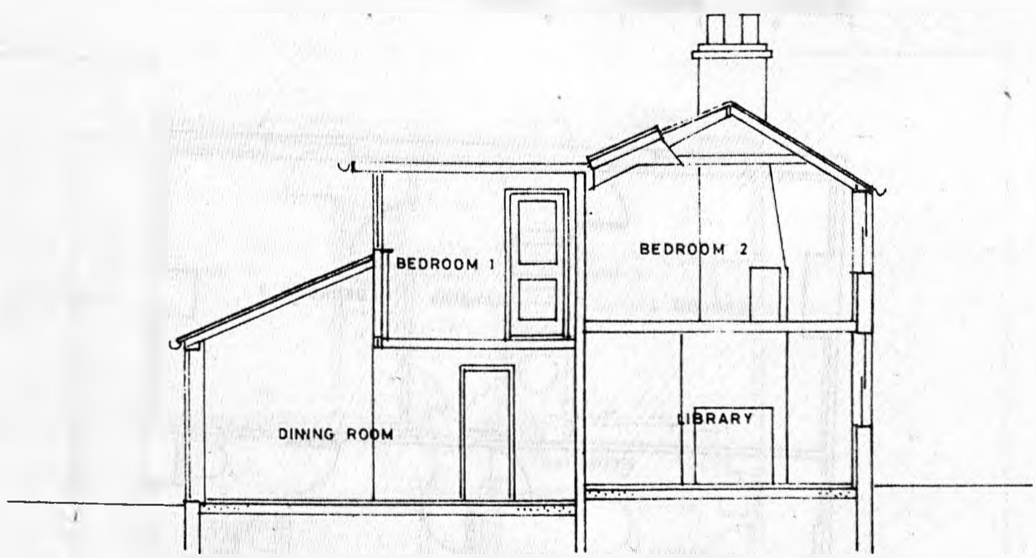


After conversion 1977



Section before conversion





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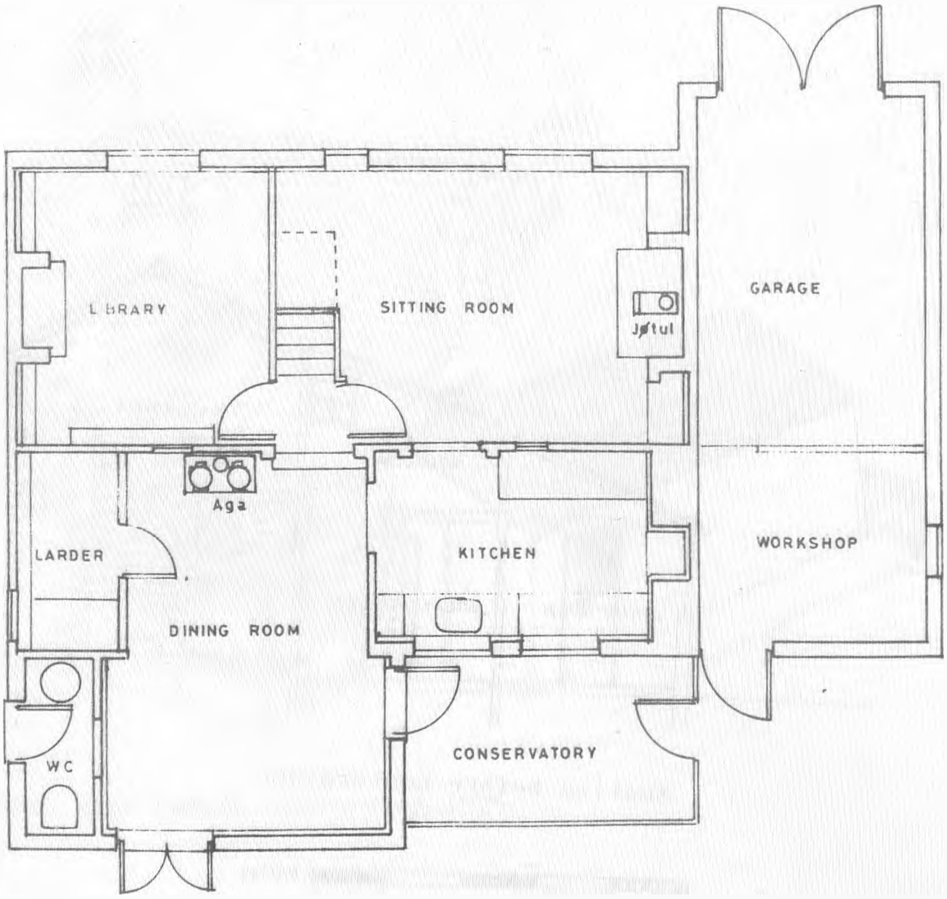
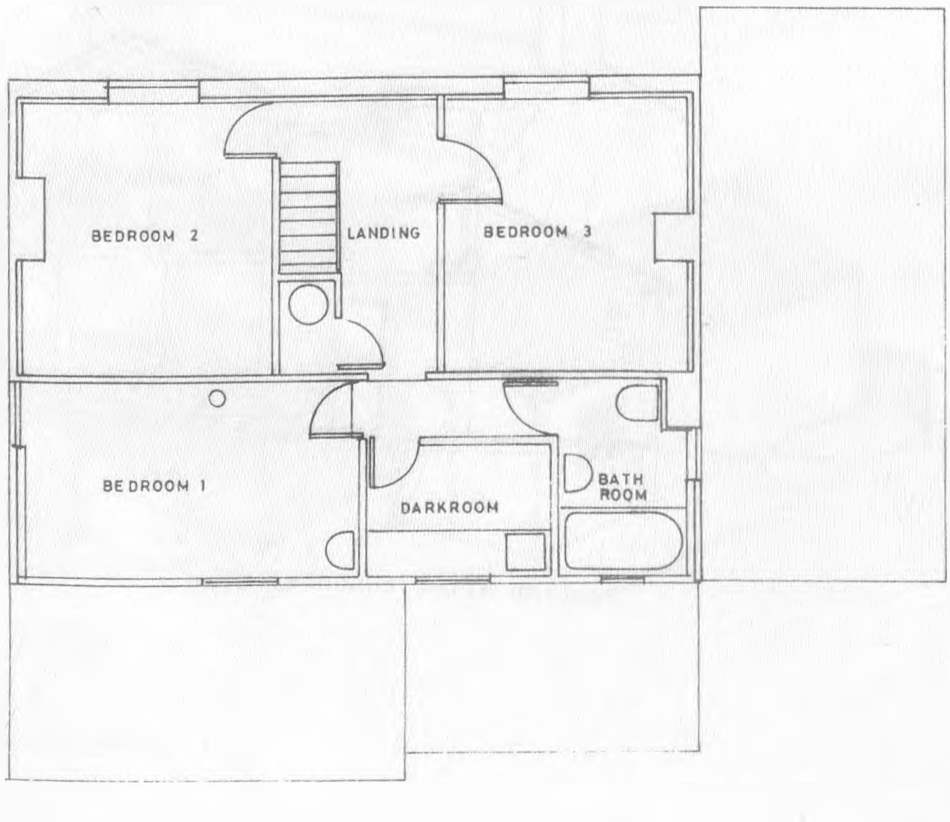
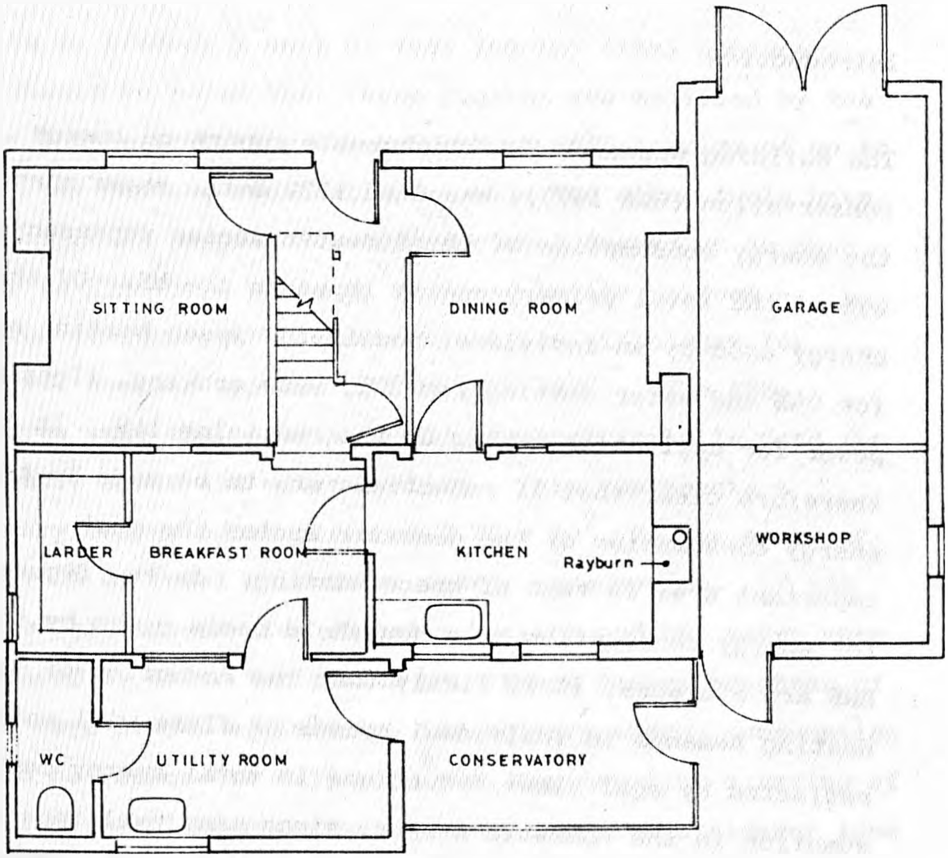


Ground floor

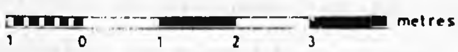


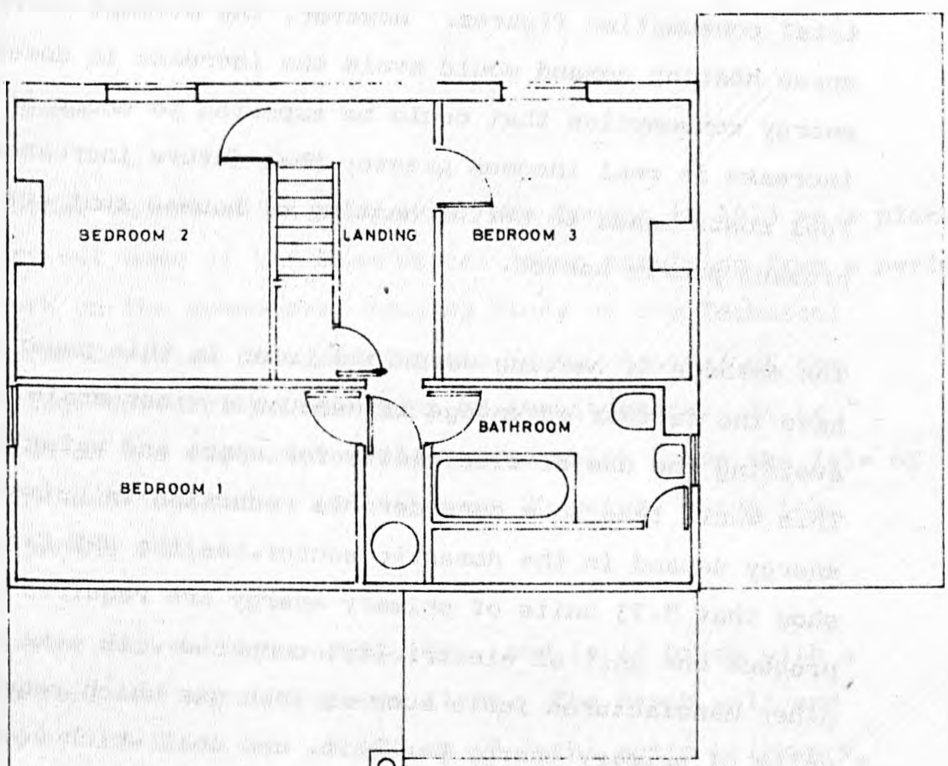
First floor

Plan after conversion



Ground floor





First floor

Plan before conversion

Introduction

The Building Research Establishment's report on energy conservation (BRE 1975), based on 1972 data, shows that the energy consumption of the domestic sector represents 29% of the total primary energy input to the UK. Of the energy used by an individual household, space heating accounts for 64% and water heating for 22%, with cooking, lighting and power for appliances making up the remaining 14%. It is therefore clear that if reductions are to be made in the energy consumption of the domestic sector the most important area is that of space heating. As the figures for energy consumption on a household basis given by the BRE are averages, it is likely that the reduction of space heating demands in individual houses or flats will not be reflected by equivalent reductions in total energy consumption in the domestic sector, since many dwellings are at present inadequately heated. In this case the reduction of space heating demand by modifications to the building fabric would simply allow a better standard of heating from the same fuel consumption, which would have no effect on total consumption figures. However, the attempt to reduce space heating demand would avoid the increase in domestic sector energy consumption that could be expected to occur if an increase in real incomes greater than future increases in fuel costs leads to better heating of houses that are at present poorly heated.

The methods of heating described later in this paper would have the further advantage, if used on a wider scale, of avoiding the use of electricity for space and water heating. This would lead to a considerable reduction in primary energy demand in the domestic sector, as the BRE figures show that 3.73 units of primary energy are required to produce one unit of electricity, compared with coke and other manufactured fuels such as town gas which require 1.4 units of primary energy per unit, and coal which uses only 1.02

units to produce a unit of fuel for the final consumer. It should be noted that these figures are modified by the fact that electricity can be used at efficiencies of up to 100% for heating applications, while the other fuels have efficiencies ranging from 25% for coal burned on an open fire to 75% for a properly designed boiler or room - heater (Bradbury 1962) with an average efficiency for central heating systems of 60% (BRE 1975). The BRE figures show that 0.19×10^9 GJ of electricity is used for domestic space and water heating. This represents a primary energy consumption of 0.71×10^9 GJ per annum or about 8% of total UK primary energy consumption. If the use of electricity for domestic heating and hot water were replaced by other fuels with an average energy overhead of 15%, used at 50% efficiency, the primary energy consumption would be reduced to 0.33×10^9 GJ, representing a saving of 4% of national primary consumption. To give a clearer idea of the magnitude of this potential saving of 0.38×10^9 GJ, it is greater than the primary energy input to the UK of the nuclear and hydro-electricity industries, which provided 0.36×10^9 GJ in 1976.

The House

The house described in this paper was bought in 1973 as a place to try out some of the theoretical ideas resulting from a period of work on the Autonomous Housing Study of the Technical Research Division (now part of the Martin Centre) at the Cambridge University Department of Architecture. It is located on the edge of the clay ridge which forms the Isle of Ely in Cambridgeshire, and is about 20 metres above the surrounding fenland.

The house was built in about 1870, and is of brick with a slate roof and a solid ground floor. The North wall and parts of the South are of 225 mm (9 inch) solid brickwork, but the remaining walls are of 110 mm (4½ inch) brick with a thin cement render externally. When acquired the house had a large area of South facing roof sloping at an angle of about 23^{o} to the horizontal from the ridge to first floor ceiling level. This has since been partly replaced with a flat roof to provide headroom in the first floor rooms on the South side. Internal non-loadbearing partitions are of timber stud construction, the older ones and the ceilings being faced with plastered reeds. Total floor area is approximately 115 m^2 excluding a lean-to garage and storage shed at the East end of the building. This compares with a mandatory gross area (excluding garage) of 76.5 m^2 for a two-storey four person Local Authority house or 114.5 m^2 for a seven person house (Fairweather and Sliva, 1969). Since all three bedrooms in the house have enough room for two beds, and there is also a study, the house could theoretically be occupied by up to seven people.

Although research carried out in the field of autonomously-serviced houses showed that it was possible to design a successful building which used no mains services, experience to dat (for example as reported by Steadman 1975, and Vale and Vale 1975) suggested that it would be very difficult and expensive to convert an existing building to total autonomy, and there would be litle point as, in this particular case, the house was connected to mains water, electricity and drainage. It was decided to concentrate on reducing the energy consumption of the house by the use of insulation and to then use a mixture of conventional and "renewable" energy sources to meet the reduced demand.

Insulation

The existing UK housing stock is about 19 million dwellings (BRE 1975). Of these, 8 million have cavity walls and 4 million, largely the cavity walled dwellings, have central heating systems. This leaves roughly 11 million solid walled dwellings which are uninsulated and probably poorly heated. Lucas (1976) quotes a figure of 5.5 million pre 1919 terraced houses, and 4 million "detached, flats, etc." with a total figure of 18 million, but does not give details of solid and cavity walls. The BRE figures have been used in this paper. At the 1972 rate of house building of 330,000 dwellings per annum (Government Statistical Service 1973) it would take over thirty years to replace the existing stock of solid walled houses with new buildings. Apart from the high cost of replacing buildings which may well be in perfectly sound condition, the experience of comprehensive redevelopment of central city areas in the 1960s indicates that a move to pull down and replace all existing solid walled dwellings, in order to replace them with better-insulated buildings, might come up against considerable opposition on grounds of social and environmental disruption.

The Advisory Board for the Research Councils (1974) has called for more research to be carried out on the insulation of existing buildings to reduce space heating demands. The insulation of cavity walled buildings is now a straightforward process, with various commercially available techniques approved by the Agrément Board (urea formaldehyde foam, polyurethane foam, injected mineral wool fibres), and the energy reductions achieved by filling the cavities of existing buildings have been well documented (Whiteside 1974). Less work is being carried out on the insulation of solid walled buildings, in spite of the fact that these represent the majority of the housing stock. There are probably two reasons for the lack of commercial interest on the scale of the cavity insulation boom; the first is that the people who live in solid walled buildings are less likely to be able to afford insulation, since older buildings other than picturesque country cottages, are generally regarded as inferior to modern houses on a new estate, and tend to be lived in by those owner occupiers who cannot afford a new house. This view seems to be confirmed by the prices asked by estate agents for older and newer houses. The second reason is that the insulation of a solid walled building is not as simple a process as the filling of a cavity wall, where the major difference between one house and another is the quantity of foam or other filling required. The insulation of a solid walled building has to be tailored to the individual building and is more allied to traditional building methods than cavity filling needs to be. As it tends to take a longer time and involve more disruption to the occupants it is understandably less commercially attractive than the simpler, cleaner and quicker process of cavity filling, in which a technique, once devised, can be easily applied to a large number of buildings.

Work on methods for insulating solid walls is being done at the Electricity Council Research Centre at Capenhurst, and at the Scottish Building Research Station in East Kilbride. The work of the latter group has not yet been published, but both are concentrating on the application of various types of insulating materials to the external face of buildings (Siviour and Mould, 1974; Southern 1976). External insulation has the following advantages:

1. The insulation can be fitted without disturbing the occupants of the building and with no disturbance of internal fittings and finishes.

2. The external insulation layer allows the solid masonry to act as a thermal store to even out temperature fluctuations within the building and to store short term thermal gains from solar radiation and other sources such as the occupants, electric lights and cooking. An example of this approach, used in a new building rather than an existing one, is Morgan's well known school at Wallasey, where heat gains from the sun, the lights and the pupils are stored in a massive masonry and concrete structure with external insulation. The storage capacity, combined with low rates of ventilation, means that it is up to a week before external temperature changes are reflected by changes within the building

(Davies et al. 1971). Anderson (1976) also gives examples of houses in the USA which use this approach to heat storage.

3. External insulation reduces the likelihood of interstitial condensation within the insulating material, since the brickwork effectively reduces the passage of moisture vapour from the interior of the building.

Externally applied insulation also suffers from the following disadvantages:

1. It changes the appearance of the building to a greater or lesser extent, according to the type of external weatherproof cladding that is specified. This may cause problems with planning permission, depending on the location of the building concerned.

2. There are considerable difficulties in detailing the insulation and cladding to achieve a satisfactory watertight fit at window and door openings, cills, eaves and verges. These problems are complicated by the presence of any string courses, cornices or mouldings on the face of the building, which prevent it being treated as a flat surface.

3. The need to provide a completely new waterproof external skin to the building increases the cost of the insulation installation. Examples of materials which have been used as claddings for external insulation include timber boarding, rendering on metal lath, tiles on battens , polymer-based rendering applied direct to the insulating material, and insulated light aggregate rendering. The cladding must throw off rainwater and resist impact damage and cracking. Southern (1976) of BRE East Kilbride, suggests that external insulation would only be used as a last resort in the upgrading of buildings because of the high cost. If the external weatherproofing of the building had

failed the application of insulation and a new cladding would be justified, but simply for insulation purposes the first choice would be cavity filling, and, if that were not possible, internal insulation.

The use of external insulation to upgrade an existing building to standards far in excess of those demanded by current regulations has been demonstrated by the Granada Television house in Macclesfield. Granada Television decided to produce a series of programmes which would show viewers how to apply some of the techniques of alternative technology to their existing houses. A Victorian coach house in Macclesfield was bought as a basis for the series which was broadcast in 1976 under the title "A House for the Future", and a booklet about the project has also been published (McLaughlin, 1976). The building has 335 mm (13½") solid brick external walls which have been externally covered with a 100mm thickness of several different insulating materials, including resin bonded glass fibre, mineral wool and expanded polystyrene. The external cladding is preservative treated softwood boarding. The modified wall has a thermal transmittance (U value) of about 0.27 W/m^2 deg C, compared with about 2.0 W/m^2 deg C for the original brickwork.

The alternative position for wall insulation in solid masonry walls is on the internal face. This seems to have received little attention from research establishments, although a number of commercial companies offer insulated internal lining systems for use in the refurbishing of existing buildings (I.C.I., British Gypsum, Cape Insulation). The advantages of internally applied insulation are as follows:

1. It leaves the external appearance of the building unchanged, which may be an important consideration in conservation areas and similar situations (for example where the traditional material for houses is stone) where restrictions might be placed on modifications to elevations.

2. By having the insulation on the inside of the masonry, a room will heat up quickly when heat is supplied since there is little thermal mass. This factor may be balanced or outweighed by the corresponding lack of storage for thermal gains from lights, occupants and solar radiation through windows.

3. The main advantage is that internal insulation is cheaper than external because there is no need for weatherproof cladding, and the usual internal skin of plasterboard can provide perfectly satisfactory impact resistance.

Internal insulation has two disadvantages, the first is relatively minor, but the other is a technical difficulty which must be overcome if the insulation is to function satisfactorily for the life of the building. The disadvantages are as follows:

1. Installation of internal insulation will obviously disrupt the finishes and fixtures (such as skirtings and window frames) inside the building, and for this reason it is probably best used as part of a programme of general renovation which would also include damp-proofing, rewiring etc. prior to the occupation of a house.

2. Placing the insulation on the inner face of the wall makes it liable to suffer from interstitial condensation. If no precautions are taken this will occur when temperature and humidity are low externally and high internally, (see, for example, BRE, 1969). The resulting vapour pressure will cause water vapour in the room to diffuse through the wall until it condenses at a point where the temperature within the wall is low enough. Because the masonry is insulated from the warm room it will tend to be at

external temperature and the dew point will occur within the thickness of the insulating material rather than in the brickwork. Once the insulation becomes saturated with water it will no longer have an insulating effect, and the moisture may also cause rotting of timber battens supporting the internal lining. Interstitial condensation can be reduced or prevented by the use of a vapour barrier on the warm side of the insulation to prevent vapour penetrating the wall. Materials such as polythene sheet or foil-backed plasterboard can be used to form the vapour barrier, but they must be imperforate to function correctly. The best technique for internal insulation would be to have a cavity, ventilated to the outside air, between the brickwork and the insulation. This would allow moisture to evaporate from the insulation, and would also prevent saturation of the insulation by rain penetrating the brickwork. If the insulation is fitted tightly against the brickwork, the only escape for moisture is through the brickwork to the outside air, or back into the room through the vapour barrier which should have prevented its ingress in the first place. Much of the existing information on condensation derives from work carried out at BRE Princes Risborough on the occurrence of condensation in timber framed buildings insulated to conventional standards.

Insulation of the house:

The aim of the conversion of the house was to produce a highly insulated shell with a heat source at its centre; to dispense with all heat distribution systems, and to rely on natural convection to distribute heat through the building. The choice of a method for insulating the building caused considerable difficulty, but the final decision was to insulate internally. This was done because of the difficulty of detailing external insulation round existing windows with minimal cill projection (it would have been necessary to extend the cills or replace the windows), the problem of flush eaves and verges (which would have meant extending the roof to cover the top of the new insulation layer), and the high cost of the new external cladding that would have been necessary for external insulation. The choice of insulating material was a compromise between cost, K value (conductivity, a measure of the insulation value of materials) and thickness, which had to be limited to avoid an excessive reduction in the area of the already small rooms. The final decision was to use 50 mm of glass fibre faced with a proprietary board consisting of 9.5 mm gypsum plasterboard bonded to 12.5 mm expanded polyurethane, with a vapour barrier built in between the plasterboard and the polyurethane. Expanded polyurethane is the most effective insulant per unit thickness with a K value of 0.023 W/m^2 deg C (I.C.I. Ltd.) compared with 0.040 W/m^2 deg C for glass fibre (Harrison 1976).

The construction of the wall lining was carried out by first facing the existing wall with polythene sheet. Then 50 mm x 50 mm studs of softwood, vacuum impregnated with preservative, were screwed vertically to the brickwork at 600 mm centres. Glass fibre 50 mm thick was placed between the studs, the whole was then faced with a sheet of polythene, and finally the plasterboard/ polyurethane laminate was nailed over the studs and given a skim coat of plaster and three coats of semi-matt vinyl paint. The operation was simple and no problems were encountered with this method of construction. The use of a sheet of polythene next to the brick was to prevent rainwater which had penetrated the wall, particularly in cases where the thickness is only 110 mm (half a brick), from saturating the insulation. A better solution would have been a ventilated cavity as described earlier, but this would have reduced the floor area of the rooms to an excessive extent. A cavity was used, however, on the South side of the ground floor in order to accommodate existing water pipes. The use of polythene on the cold side of the insulation, could, under some conditions give rise to interstitial condensation by trapping moisture within the insulation. The decision to use the polythene was taken with regard to the fact that rain penetration of the brickwork had occurred in the past, and this was judged to be the more severe of the two possible sources of moisture.

Now that all the insulation is in place tests will be made to determine its moisture content at critical times, such as when external temperature is low and internal humidity high, and to see whether the amount of condensation, if any, forming within the wall is sufficient to cause concern. If interstitial condensation proved to be a serious problem it could be remedied by insulating the external face of the wall to raise the temperature gradient across the brickwork to a point where the dew point would occur within the brick itself rather than in the insulation.

A further problem may arise from the fact that there is no vapour barrier behind the ground floor ceiling or under the first floor floorboards. The ends of the floor joists are built directly into the external brick walls and the wall insulation stops at floor and ceiling, leaving uninsulated brickwork within the thickness of the floor. In theory, moisture vapour could enter the floor space and condense on the exposed brickwork, saturating the joist ends which would then rot away and cause the floor to collapse. A recent (1976) visual inspection showed that the joists appeared perfectly dry, and it seems likely that if they have survived a hundred years of rain soaking through the wall into which they are built, they will not suffer harm from possible condensation. All the joists and floorboards have been treated with preservative to discourage rot, and readings of moisture levels in the wood will be taken as part of the programme of monitoring the performance of the house.

Insulation has also been added to the roof in the form of 150 mm glass fibre laid in the attic space, and between the rafters in areas where the ceiling is fixed directly to the rafters. The existing concrete ground floor, which seemed to lack an effective damp proof membrane, was painted with a bituminous latex emulsion which was carried up the brickwork to the level of the injected silicon damp proof course. On top of the bituminous waterproofing a layer of 12.5 mm thick expanded polystyrene was laid, a greater thickness could not be used because of the lack of headroom. The polystyrene was covered with 19 mm thick tongued and grooved sheets of flooring grade chipboard, glued together to form a continuous layer on top of the insulation. Conventional floor coverings were laid on top of the chipboard. The existing timber sash windows on the North elevation have been double-glazed with a do-it-yourself system using aluminium sections. This was largely to reduce excessive ventilation heat losses through the sash windows which are very difficult to draught seal. The other windows in the house have been replaced with low cost double windows, in which panes of glass with polished edges and no frames slide horizontally in vinyl tracks let into a softwood frame. On the first floor an extension has been built onto the South side of the house. This has not increased the floor area, but gives headroom and allows sunlight into the rooms on this side. The extension is of conventional timber stud construction clad externally with 19 mm thick softwood boarding. All timber has been vacuum treated with a preservative. The extension has 100 mm of glass fibre in the wall and 125 mm in the roof, plus, in both cases, 12.5 mm of expanded polyurethane.

To give a comparison, the calculated U values of the various elements of the building before and after insulation are set out in Table 1. The values for the elements before insulation are taken from Fairweather and Sliva (1969), and BRE (1972) the values following insulation are calculated from values given in the above mentioned publications.

Table 1

Element	Original U value	New U value
Walls	2.5 W/m^2 deg C	0.42 W/m^2 deg C
Roof	3.18 "	0.25 "
Floor	0.76 "	0.54 "
Windows	5.7 "	2.8 "

Table 2 compares the U values achieved in the insulated house with the mandatory values laid down in the Building Regulations Second Amendment, 1974, and with the values required before 1974:

Table 2

Element	New U value	Current regulations	Pre 1974
Walls	0.42 W/m^2 deg C	1.0 W/m^2 deg C	1.7 W/m^2 deg C
Roof	0.25 "	0.6 "	1.13 "
Floor	0.54 "	0.76* "	0.76* "
Windows	2.8 "	**	5.7 "

*The Regulations have no mandatory values for solid ground floors; the value given is from BRE Digest 145, for solid floors of dimensions 7.5 metres x 7.5 metres in contact with the earth.

** The current Regulations lay down requirements for overall U values of external walling which effectively control the area of glazing. If the overall value is not to exceed 1.8 W/m^2 deg C in a detached house, when the U value of the solid part of the wall is kept to the mandatory maximum of 1.0 W/m^2 deg C, the area of single glazing must not exceed 17% of the total wall area, and double glazing must not exceed 44.4% (Elder 1976). The insulated house has an area of glazing, including roof lights and glazed doors, which is 11% of the total external wall area.

Ventilation:

As structural insulation levels are increased, the heat lost through ventilation as warm internal air is replaced by cold external air, represents an increasingly large proportion of the total heat loss. Ventilation rates are typically taken as 1 or 2 air changes per hour, although it is interesting to note that BRE have measured rates in recently built houses with conventional (i.e. not weatherstripped)windows, and have found rates as low as 0.3 air changes per hour on windless days. Rates as low as this are perfectly satisfactory to provide air for breathing, and for combustion appliances if correctly installed. Gay (1974) estimates that a wood burning 'airtight' stove producing 4.7 kW requires 8.5 m^3 of air per hour. This figure assumes that half the air passing through the stove is not used for combustion, and compares with the ASHRAE standard of 6.8 m^3 per person per hour. Assuming a typical house volume of 210 m^3 and six people, the stove and the people will need only 0.25 air changes per hour. In the house under discussion in this paper, ventilation rates have been reduced by double glazing, as described above, by draught stripping all windows and doors, and by bricking up the original front door to reduce the possibility of a through flow of air. For the purpose of calculating heat losses the ventilation rate in the insulated house has been assumed to be 0.5 air changes per hour.

Heating:

The space heating in the house was planned to come from two sources, and it was considered important as part of an 'alternative' approach to the project that the heating system should be very simple and designed for a long life. At the beginning and end of the seven month heating season all space heating comes from a solid fuel "Aga" thermal storage cooker, which also provides domestic hot water. It is located roughly in the centre of the house and connected to a prefabricated insulated chimney, as there was no existing chimney in this position. The cooker is controlled by a simple mechanical thermostat which measures the temperature of the hotter of the two ovens and controls the draught to keep both ovens and cooking surfaces at the correct temperatures for use. The heat produced is stored in the 500 kg of steel within the cooker, and heat loss is reduced by vermiculite insulation and by hinged insulated covers over the two hotplates. The combination of thermal storage and thermostatic control allows the cooker to operate under constant load conditions, and consequently the efficiency is higher than a cooker in which the rate of combustion has to be varied to achieve the required cooking temperatures. Over the heating season the Aga uses about 2 tonnes of coke with a calorific value of about 28 MJ/kg, (Bradbury 1962) which represents a heat output of slightly less than 39 GJ (11,000 kWh) assuming that the appliance burns with an efficiency of 70%. Taking the figures from BRE (1975) for domestic water heating, 18 GJ per annum (5000 kWh), and cooking, 8 GJ per annum (2225 kWh), and assuming that 65% of hot water use and cooking occur in the heating season (on a time basis the heating season represents only $\frac{7}{12}$ or 58% of the year, but it seems a reasonable assumption that more cooking and hot water use will occur during the colder months of the year) means that 18 GJ (5000 kWh) is available from the Aga over the heating season. Over the 210 day period this represents a continuous heat output of 1 kW, which does not vary, because of the thermostatic control. This figure accords exactly with the makers' estimate of heat output, as quoted by the Aga sales office in Cambridge. It should be noted that the heat is given off directly from the surface of the appliance, it does not operate radiators.

During the colder part of the heating season the Aga cannot heat the whole house. On the calculated heat losses it will keep the house at 20°C at a temperature difference of 4.4 deg C. The extra heat needed when external temperatures fall below about 15°C is provided by a wood burning heating stove. This is a Norwegian Jøtul and is considered by Gay (1974) to have an efficiency of 50% to 65% according to the size of fuel used and the way it is packed into the stove. This efficiency is confirmed by the U.S. importers of the stove, who claim for the model 602, which is the type installed in the house, a maximum efficiency of 69% with an output of 4.4 kW and a fuel consumption of 1.2 kg per hour. Maximum heat output is given as 7.9 kW with a consumption of 3.2 kg per hour at an efficiency of 47.5%. All tests were with seasoned wood at 20% moisture content

(Kristia Associates 1975). This information is slightly doubtful, since the heat outputs are given in Btu per hour (they have been converted to kW for the purpose of comparison above) and the maximum output of 27,000 Btu per hour is stated to be 6550 Watts, when in fact this converts to 7,900 Watts. This is the only figure given in Watts as well as Btu per hour, so no further check on accuracy can be made from the information given, which shows efficiencies and heat outputs from five different hourly rates of wood consumption. The consumption figures which are given in lbs per hour, when converted rise in multiples of 1 kg so it can be assumed that these are correct and are taken from Norwegian data. Taking the energy content of wood with 20% moisture content as 16 MJ/kh (King and Smith, 1975) and using the efficiencies given by Kristia Associates, gives the following table of results:

Table 3

Fuel consumption	Heat Output	Efficiency
1 kg per hour	3 KW	68%
1.2 "	3.7 "	69%
2 "	5.9 "	65%
3 "	6.9 "	52%
3.2 "	6.8 "	47.5%

In the 1976-1977 winter, which was the first year in which the house was sufficiently complete to give any indications of performance, the stove was not required until mid-November, as the Aga, combined with casual gains, kept the temperature at a subjectively comfortable level. Fuel consumption of the Jøtul appears to be slightly less than 20 kg per day; the moisture content of the wood used is not known, but it is stored under cover and is at least a year old. DSIR (1964) give a range of moisture contents for "thoroughly air-seasoned timber" of 17% to 25%, which would give energy contents of

15.8 kg to 17 MJ/kg using King and Smith's graph. The stove is always operated in the minimum draught setting, and as heat output can be felt to increase with an increase in draught (and hence of air supply to support combustion), it can be assumed that the output is close to the minimum figure of 3 kW. The stove is used for about 16 hours per day, but towards the end of this period it is not likely to be putting out 3 kW, as the last charge of fuel is burning away and it is not refilled. Assuming that the stove burns for 16 hours at the minimum rate of 3 kW (which would give a fuel consumption per day of 16 kg to 20 kg depending on the moisture content of the wood), it gives an output of 173 MJ (48 kWh) per day. As the stove is in use for about four months of the heating season it gives an energy input to the house of about 21 GJ (5800 kWh) with a fuel consumption of between 2 and 2.5 tonnes of air dried wood.

The fuel for the stove is slabwood, a waste product from sawmills, consisting of the bark and outer layers of wood which are removed when trees are converted into timber. An average saw log, that is a tree as it arrives at the sawmill produces up to 40% of slabwood, including bark, during conversion, although this represents only 13% of the original tree, of which 45% is left in the forest as roots, stump and branches (King and Smith 1975). Slabwood, especially that from the conversion of softwoods, is often burned in a pit at the sawmill, because its storage on site represents too great an insurance risk by reason of the fire danger. The wood is commonly sold in bundles of about a tonne for a price of £2 per bundle ex works (1976 price from Eastern Counties Timber Co., Herringswell). The wood is sold in lengths varying from 2 to 4 metres, and has to be sawn up for use in the stove; using a hand saw, enough fuel for a week can be sawn in slightly less than two hours.

The house described in this paper has a calculated heat requirement of 4.5 kW to maintain a 20 deg C temperature difference between interior and exterior. Allowing for casual gains from the occupants and electric lighting, this represents an annual space heating demand over the seven month heating season of

41 GJ (11,500 kWh). On the same basis of calculation, Table 4 shows the maximum heat load and the total demand over the heating season:

1. If the house were built to the same plan but insulated to the standards of the current Building Regulations.

2. If built prior to 1974.

3. As originally built (allowing for modification of volume caused by extending the roof on the South side).

Table 4

	Maximum load	Total
The insulated house	4.5 kW	41 GJ
1. Current Regulations	7.7 kW	77 GJ
2. Pre-1974	10 kW	101 GJ
3. As originally built	18.8 kW	189 GJ

It can be seen from the table that the heating demand is slightly over half the requirement of the same house built to the insulation standards of the current Building Regulations. If the house had been conventionally modernised and had had central heating fitted, but no extra insulation had been added, the requirement for heat would have been over four times that of the insulated house.

The heating systems installed in the house have been chosen for simplicity and long life. Both the Aga and the Jøtul are made of enamelled cast iron and have few moving parts. The hot water system requires no pump as it works by gravity circulation. The existence of many 40 year old Aga cookers which are still working satisfactorily suggests that this type of appliance is likely to outlast two or three conventional central heating systems. The Aga and Jøtul, being extremely simple, are less likely to suffer the breakdowns that can be caused in more complex systems by the malfunction of a small component.

Conclusion:

The conversion of a Victorian house described in this paper aims to demonstrate an alternative approach to the problems of cooking, hot water supply and space heating, by proposing the use of very simple heating appliances designed for a long life, and used within a heavily insulated building. This approach is in direct contrast to the generally favoured alternative of providing increasingly more "sophisticated" heating and control systems, the increased complexity of which is unlikely to contribute to a longer life or lower initial and replacement costs. Although the house feels subjectively comfortable, it is obvious that the simple system does not offer the potential for control, or maintenance of exact temperatures, that can be achieved with a more conventional system. There is also the fact that wood must be sawn, coke carried and ashes raked out, and none of these chores is necessary with gas or oil fired central heating. On the credit side, the total cost of the heating systems and insulation worked out to about £300 more than the cost of a central heating system plus a cooker (1974 prices) and has already saved more than this in reduced fuel costs. The efficiency of the two appliances combined is probably at least 65% which compares favourably with the efficiencies achieved by central heating systems. Barrett (1974) quotes efficiencies of 65% for anthracite with automatic feed, while Jones (1976) assumes 70% efficiency for gas. Finally, the simplicity of the heating appliances ensures that they will last for a considerable time and be unlikely to suffer from serious breakdowns.

Given the BRE figures (1975) that only 4 million houses in the U.K. have central heating systems, and that 11 million out of 19 million dwellings have solid walls, it seems that there is a place for simple techniques of insulation, and simple heating systems that are cheap to run. Such techniques could make a worthwhile contribution to energy conservation as well as to improving conditions in many under-heated old buildings.

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