THE PENNYLAND PROJECT
Prof. J. Chapman, Dr. R. Lowe & R. Everett
EXECUTIVE SUMMARY
ERG 054 ETSU-S-1046(S)

Energy Research Group
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This is the final report on the performance of 177 low-energy, houses at Pennyland, Milton Keynes, monitored by the Open University Energy Research Group (ERG), for the Milton Keynes Development Corporation (MKDC), under contract to the Energy Technology Support Unit (ETSU) at Harwell.

The principal authors are J. Chapman, R. Lowe and R. Everett (ERG).

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Enquiries about copyright should be addressed to:-

The Information Officer
ETSU
Building 156.3
AERE
Harwell
OX11 ORA.

Contract No: E5A/CON/1046/174/040

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THE PENNYLAND PROJECT

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INTRODUCTION

The Pennyland project has involved the design, layout, construction and monitoring of an estate of 177 low energy houses in Milton Keynes.

The project started in 1976 when there was relatively little knowledge about the performance of well insulated houses of a passive solar design in the U.K.

Milton Keynes is a new town, about 50 miles north of London (see figure S.1) and is unusual in that it has several low energy housing schemes that have been promoted by its Development Corporation (MKDC). Of special note is the companion Linford field trial involving the monitoring of 8 low energy houses in considerable detail, of a similar design to some of the Pennyland houses.

For both of these projects the Development Corporation collaborated with the Open University Energy Research Group, also based at Milton Keynes.

The large amount of new house construction in Milton Keynes has given a unique opportunity to have large numbers of experimental and control houses in close proximity, cutting out the microclimate differences that have spoilt previous trials.

The Pennyland field trial has been funded both by the Department of Environment as an extension of their large 'Better Insulated House' programme and by the Department of Energy under their Passive Solar Programme, through the Energy Technology Support Unit (ETSU). Much of the analysis work has been funded by the Science and Engineering Research Council.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

FIGURE S.2. INITIAL ESTIMATES OF COST-EFFECTIVENESS OF INSULATION

**FUEL SAVING/YR.**
(1977 GAS PRICES)

10 YEAR PAYBACK TIME

- INSULATING WINDOW SHUTTERS
- FLOOR SLAB EDGE INSULATION
- EXPAND CAVITY WALL TO 100mm AND INSULATE
- DOUBLE GLAZE (INCLUDES 0.2 AC/H AIRCHANGE RATE REDUCTION)

**INSULATE 50mm CAVITY WALL**

**INSULATE ROOF TO 150mm TOTAL THICKNESS**

1976 BLDG. REGS.
BASELINE

EXTRA CONSTRUCTION COST - 1977 PRICES

FIGURE S.3. COMPUTER ASSESSMENT OF INSULATION AND PASSIVE SOLAR MEASURES
The project began in 1976 with a number of design studies, attempting to produce a cost-effective mass-market low energy house design.

Initial calculations looked at the payback times of simple insulation measures (see figure S.2).

A computer model was used to assess the energy effects of various direct gain passive solar measures such as avoiding overshading of one house by another, correct orientation, concentrating the glazing on the south side of the house and varying the total area (see figure S.3).

These calculations showed that there were clear energy benefits from these measures, but that there was little benefit from increasing the glazing beyond 40% of the south-facing wall area.

They also showed that a southerly orientation for a house both maximised the passive solar gains and minimised the peak summer temperatures (see figure S.4).
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.5.
Percentage reduction in solar radiation through south-facing window 1.2 m from ground over period November to March.

Figure S.6. A typical Pennyland south facade. Note shadow of roofline on wall. Time 2.00 p.m. on a January afternoon.

Figure S.7. Using the shadow prints to lay out the estate.
The Pennyland estate was laid out to avoid overshading using computer generated 'shadow prints' showing the energy shadow to the north of a house caused by obstruction of the solar radiation over a heating season (see figures S.5-7).

The roof lines of the houses were lowered slightly to allow better penetration of solar radiation to the more northerly rows of houses.

As many houses as possible were laid out with orientations of south ± 45°, consistent with an attractive estate layout.

Despite a site which sloped slightly down to the north, a density of 35 houses/hectare was achieved.

The gardens were mostly on the south side of the houses with landscape mounds at the ends to maintain privacy.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.9. Dual Aspect House Type

Figure S.10. Single Aspect House Type
S4. House Design

The Pennyland estate has included a normal mixture of house sizes, but analysis has concentrated on the three-bedroom, 5-person house type. There have been two basic variants of this:

1. A normal deep plan dual aspect design with only slightly more glazing on the south facade than on the north (see figure S.9.)

2. A shallow plan single aspect house design with the main living rooms and glazing area concentrated on the south side, with very small north-facing windows (figure S.10)

The estate was split into two halves with essentially identical house shells but built to different insulation levels:

AREA 1 - Approximately equivalent to the 1982 U.K. Building Regulations standards.

Walls: 50 mm fibreglass insulation
Roof: 80 mm fibreglass insulation
Windows: Single glazed
Floor: No insulation

AREA 2 - Approximately equivalent to the Danish - BR77 standards (introduced 1979)

Walls: 100 mm fibreglass insulation
Roof: 140 mm fibreglass insulation
Windows: Double glazed
Floor: 25 mm polystyrene edge insulation

The estate, was built by John Mowlem Ltd using a poured concrete system for the inner skin, with insulation and a conventional brick outer skin being added, afterwards. The concrete mix used was fairly dense, which gave the houses the thermal mass required for the passive solar design.

Figure S.11

Pennyland Area 1 houses during construction
Intensively monitored Linford houses with weather station

South-facing Pennyland houses

East-west facing terrace at Neath Hill
In order to demonstrate the energy savings of the package of measures, the neighbouring Neath Hill estate was used as a control group. This estate was built in 1978 to relatively high standards of construction, but only insulated up to the standards required by the 1976 Building Regulations, i.e. 50 mm roof insulation, unfilled cavity walls, single glazing, etc.

20 houses on the Neath Hill estate were designated as a 'solar control group' to enable a comparison of a normal mix of randomly oriented and overshad ed houses with the south-facing unovershad ed Pennyland ones. In order to make them comparable in insulation level to Pennyland Area 1, they were given extra insulation, 50 mm of urea formaldehyde foam cavity fill for the external walls. The subsequent discovery of large differences in boiler efficiency and air leakage between Neath Hill and Pennyland eventually made the solar comparison impossible to carry out.

In addition, the Pennyland measurements have been compared with detailed measurements and experiments carried out in the neighbouring Linford project, houses. These are of a similar insulation level and layout to some of the Pennyland Area 2 houses. Where the Pennyland project has sought to demonstrate energy savings, the Linford project has tried to explain them.

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**Figure S.13**

Neath Hill, Pennyland & Linford Comparisons

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Increasing Passive Solar Measures
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.14 Infra-red photograph of a Pennyland Area 1 house showing heat losses from window, door, floor edge and boiler flue.

Insulated windows appear darker (colder) than uninsulated glazed door.

Figure S.15 Infra-red photograph of a Pennyland Area 2 house showing effect of insulating window shutters.
### S6. Monitoring

Several kinds of monitoring of the construction and thermal performance have been used. The construction of the Pennyland houses was inspected by a team of researchers from the Building Research Establishment for 'buildability'. A brief thermographic survey was also carried out, but the main performance monitoring has involved the measurement of energy consumptions and temperatures over two heating seasons. In addition, airtightness tests were made on a sample of houses and a comprehensive social survey was carried out by MKDC.

#### Buildability

The B.R.E. researchers visited the site several times during construction. This was as part of a wider study of highly insulated houses (including Linford). They concluded that the extra insulation did not impede the building process, but the use of fibreglass batts in walls did require a little extra supervision and training.

#### Thermographic Survey

A brief infra-red survey of the exteriors of the Neath Hill and Pennyland houses showed that the insulation appeared to be correctly installed, though the effects of slight variations in the cavity width in Pennyland Area 1 could be detected.

The visible heat losses from the edge of the floor slab (see figure S.14) appear to confirm the high floor heat losses found at Linford. Also clearly visible were the effects of the Insulating shutters fitted to some houses, reducing the window heat losses (see figure S.15).

#### Airtightness

The airtightness of a sample of Pennyland and Neath Hill houses were measured by a research team from British Gas. This involved pressurising the houses using large fans and measuring the resultant air flow. These results were linked to more detailed work done on the Linford test house to show the energy savings due to reduced air infiltration (see section S.10).

#### Social Survey

Milton Keynes Development Corporation carried out a comprehensive social survey, interviewing the majority of Pennyland households with a view to establishing the level of satisfaction with the houses. The results will be found throughout this summary, but predominantly in section S.15.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.16
Electronic heat meter used for measuring space and water heating energy.

Figure S.17
The D.T.I. house temperature meter specially developed for the project.
MONITORING

Energy and Temperature Monitoring

The energy performance of all of the Pennyland houses has been monitored on a crude basis by reading the gas and electricity meters on a monthly basis.

A sample of 19 houses at Neath Hill and a further 58 in the Pennyland estate were fitted with extra equipment. An extra gas meter was fitted to measure cooking gas consumption. Electronic heat meters (see figure S.16) were fitted in the central heating system to measure actual space heating energy, and additionally in some houses, water heating consumption.

Differential Temperature Integrator (D.T.I.)

A special house temperature meter was developed for the project. This recorded the temperature in three rooms of the house, indicating the cumulative difference between each of these and an external temperature sensor, hence the name 'Differential Temperature Integrator'. This can be thought of as an attempt to record real degree-days for each house.

The extra monitoring equipment could all be read from outside the house and data was gathered by a meter reader who toured the houses once a week. This weekly average data was subsequently entered manually into a computer at the Open University for analysis.

This 'low-tech' method of data gathering has proved fairly foolproof and has presented a human face to the monitoring, since the meter reader was also able to observe the reactions and opinions of many residents.

Linford Weather Station

Weather data was recorded at the nearby Linford site, with such parameters as air temperature, solar radiation, wind speed and direction all being recorded on an hourly basis. In addition the results of the more detailed measurements on the Linford houses have proved vital in building up a full picture of the Pennyland energy savings.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.18  TOTAL ANNUAL GAS CONSUMPTIONS
October 1981 - September 1982

NEATH HILL UNINSULATED GROUP
1976 Regs. insulation standard
Conventional gas boiler
Normal air change rate

NEATH HILL INSULATED GROUP
As above but with 50mm cavity wall insulation

PENNYLAND AREA 1
Approx. 1982 Regs. insulation standard
Low thermal capacity gas boiler
Low air change rate

PENNYLAND AREA 2
Approx. Danish BR77 Regs. insulation standard
Low thermal capacity gas boiler
Low air change rate

Figure S.19  NEATH HILL INSULATED HOUSE

Figure S.20  PENNYLAND AREA 2 HOUSE
Delivered Energy
Kwh/day
GAS
ELECTRICITY

GAS
ELECTRICITY

1981 1982 1983
0 100
50

1981 1982 '83
S7. Annual Energy Consumption

The most basic results of this project have come from looking at the annual energy consumptions of the various house groups.

Figure S.18 shows the annual gas consumptions of samples of the Neath Hill and Pennyland houses, all of the same nominal size. This shows clearly that the Pennyland Area 2 houses use on average only a half of the gas used by the uninsulated Neath Hill houses. The energy consumptions of the latter group have been found to be very similar to a much larger sample of houses on other Milton Keynes estates, all equipped with similar heating systems.

Electricity consumptions of the various groups have not been found significantly different. The table below shows how gas heating costs have been reduced to below the cost of electricity for lighting and appliances.

<table>
<thead>
<tr>
<th>House Type</th>
<th>No. of Houses</th>
<th>Delivered Gas kWh/yr</th>
<th>Electricity £/yr*</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.E. 4-Estate Sample</td>
<td>150</td>
<td>22172</td>
<td>253</td>
</tr>
<tr>
<td>(75/76 Data)</td>
<td></td>
<td>2416</td>
<td>121</td>
</tr>
<tr>
<td>Neath Hill Uninsulated</td>
<td>18</td>
<td>23400</td>
<td>267</td>
</tr>
<tr>
<td>Not Measured</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neath Hill Insulated</td>
<td>14</td>
<td>22480</td>
<td>256</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3086</td>
<td>154</td>
</tr>
<tr>
<td>Pennyland 1</td>
<td>33</td>
<td>14010</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2856</td>
<td>143</td>
</tr>
<tr>
<td>Pennyland 2</td>
<td>15</td>
<td>11530</td>
<td>131</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2598</td>
<td>148</td>
</tr>
</tbody>
</table>

The wide variation in individual house gas consumptions within each group show the large effects of different occupant behaviour. This illustrates the need for large numbers of houses in each group in order to get hard answers for the average energy savings.

The large-scale house construction programme in Milton Keynes has provided a unique opportunity to do this. The resultant detected energy savings are thus probably the largest and most statistically significant found in any U.K. field trial to date.

Figures S.19 and S.20 show energy consumptions of two sample houses over the monitoring period, illustrating how improved insulation reduces the winter demand for gas.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.21
Box plots of heating season average room temperatures
Winter 1981/2

Figure S.22
Box plots of monthly whole house average internal temperatures

Figure S.23
Social Survey
Summer '82
Survey Date
Autumn '83
Ability to keep house warm enough
S8. Internal Temperatures

The recorded internal temperatures have generally been high, indicating a trend to whole house heating. They are amongst the highest in the record of post-war U.K. field trials (see table below).

Internal temperatures on the Neath Hill estate were also high, probably because of the provision of upstairs heating in some of the houses.

Of those asked, 81% of the Pennyland residents said that they could keep their house warm enough, compared to only 51% in a wider Milton Keynes survey (see figure S.23). This is all the more encouraging since the winter of 1981/82 prior to the social survey contained some of the coldest weather this century, with a minimum temperature of -17°C being recorded at Linford.

Only 3% of the Pennyland residents said that they could not afford to keep their houses warm enough, compared to 28% in a wider Milton Keynes survey.

Despite the high internal temperatures recorded at Neath Hill, only 40% felt that they could keep their houses warm enough. This may be due to the higher levels of air infiltration.

### HISTORY OF HOUSE AVERAGE INTERNAL WINTER TEMPERATURES IN POST-WAR FIELD TRIALS

<table>
<thead>
<tr>
<th>Year</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
<th>No of Houses</th>
<th>Insulation Level</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>48-49</td>
<td>12.2-16.3</td>
<td>12.0-17.5</td>
<td>36</td>
<td>Low</td>
<td>B.R.E.</td>
</tr>
<tr>
<td>2</td>
<td>49-50</td>
<td>12.4</td>
<td>13.2</td>
<td>36</td>
<td>Low</td>
<td>B.R.E.</td>
</tr>
<tr>
<td>5</td>
<td>71</td>
<td>18.0-19.0</td>
<td>14.2</td>
<td>60</td>
<td>Med-High</td>
<td>Elec. Council</td>
</tr>
<tr>
<td>6</td>
<td>74</td>
<td>16.3-16.7</td>
<td>14.0</td>
<td>25</td>
<td>Med-High</td>
<td>B.R.E.</td>
</tr>
<tr>
<td>7</td>
<td>77</td>
<td>15.6</td>
<td>14.6</td>
<td>11</td>
<td>High</td>
<td>I.E.E.</td>
</tr>
<tr>
<td>8</td>
<td>78</td>
<td>14.6</td>
<td>17.1</td>
<td>24</td>
<td>V. High</td>
<td>I.E.E.</td>
</tr>
<tr>
<td>9</td>
<td>77</td>
<td>12.7</td>
<td>19.1</td>
<td>12</td>
<td>V. High</td>
<td>I.E.E.</td>
</tr>
<tr>
<td>10</td>
<td>81/82</td>
<td>14.6</td>
<td>17.1</td>
<td>17</td>
<td>Med-High</td>
<td>Neath Hill</td>
</tr>
<tr>
<td>11</td>
<td>81/82</td>
<td>14.6</td>
<td>17.1</td>
<td>37</td>
<td>High</td>
<td>Pennyland 1</td>
</tr>
<tr>
<td>12</td>
<td>81/82</td>
<td>14.6</td>
<td>17.1</td>
<td>18</td>
<td>V. High</td>
<td>Pennyland 2</td>
</tr>
<tr>
<td>13</td>
<td>82/83</td>
<td>16.3</td>
<td>20.1</td>
<td>6</td>
<td>V. High</td>
<td>Linford</td>
</tr>
</tbody>
</table>
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.24

Living Room Stat. Programmer/Controller

T.R.V. Kitchen 3-way valve

Radiators Pump Bypass

PENNYLAND 5-PERSON HOUSE
WET RADIATOR SYSTEM

Figure S.25

HEAT OUT WATTS

COMPARATIVE BOILER EFFICIENCIES FOR PENNYLAND AND NEATH HILL

GAS INPUT WATTS

Figure S.26

SOCIAL SURVEY:
COMPARISON OF HEATING SYSTEM WITH THAT IN PREVIOUS HOUSE
S9. Auxiliary Heating

The majority of the Pennyland houses were equipped with a conventional wet radiator system. A Chaffoteaux low thermal capacity balanced flue boiler rated at 8.2 kW was used. This is more than adequate for the 4-5 kW design heat loss of the Pennyland houses. Heating was only installed in the downstairs rooms and the bathroom. The system was controlled by a conventional programmer timeclock conspicuously located in the kitchen. A thermostat for the space heating was located in the living room and water heating was controlled by a thermostat on the hot water cylinder (see figure S.24). The kitchen radiator was fitted with a thermostatic radiator valve to prevent local overheating.

The Neath Hill houses were equipped with a conventionally flued heavyweight gas boiler. This was located, together with the controls in an upstairs cupboard. Many of the Neath Hill houses had radiators in the upstairs bedrooms as well.

Energy measurements showed far higher system efficiencies in the Pennyland houses than at Neath Hill. The efficiency differences have saved an estimated £35/yr of gas for each house.

The Pennyland wet radiator systems have been well received by the occupants, with over 80% being more satisfied than with their previous system.

No instructions in the use of the controls were issued. However, 70% of the Pennyland residents said that they used the timeclock and only 13% said they did not understand it. The elderly in particular had problems in understanding and setting the timeclock.

Warm Air Systems

Some of the larger Pennyland houses were fitted with a warm air heating system also using gas. These systems have had a poor reputation in the past and the Pennyland project gave an opportunity to try them in a low energy houses design. They did not appear to be as popular as the wet radiator systems and the residents did not feel that they were making large energy savings.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.27

Comparison of pressure test leakage results for:

- Pennyland
- Neath Hill
- Linford

A B.R.E. sample of 15 U.K. houses

\(\#\) Mean of a sample of 320 Swedish houses

\(\#\) Mean of a sample of 50 Canadian houses

Air leakage at 50 pascals pressure (ac/h)

Social Survey

Figure S.28

- Pennyland Area 2
- Pennyland Area 1
- Neath Hill Insulated

Complaining of condensation

Complaining of mould growth
Pressure leakage tests on a sample of Neath Hill and Pennyland houses were carried out by British Gas. These involved pressurising the house using large fans and measuring the resultant pressure difference between the inside and outside of the house.

These tests showed the Neath Hill houses can be considered very similar to normal modern U.K. houses in leakage. The Pennyland houses are very airtight and almost up to current Canadian and Swedish standards.

The good airtightness of the Pennyland houses is likely to be largely due to the poured concrete construction, the good sealing properties of the double glazed windows, the draught-stripping, the provision of draught lobbies and the use of a balanced flue boiler. They are more airtight than the Linford houses which differ only in the use of more conventional blockwork construction.

The pressure tests roughly correspond to a seasonal air change rate of 0.3 ac/h for the Pennyland houses and 0.7 ac/h for the Neath Hill ones. The Pennyland figure would be regarded as excessively low in some circles and possibly dangerous from considerations of condensation and mould growth and (given the right ground conditions) radon gas concentration.

The social survey concluded that almost three quarters of the Pennyland houses had some condensation; mainly on the windows and in particular between the panes of the double glazing. None of the residents regarded it as serious. Modifications to the design of the double glazing could alleviate some of the problems. Condensation levels at Neath Hill did not appear to be significantly different.

Over a half of the Pennyland houses had some mould growth, but again none of the residents regarded it as serious. Levels of mould growth at Neath Hill were much lower. This perhaps suggests that more attention to deliberate ventilation in kitchens, bathrooms and W.C.'s should be made in future low energy house designs.

Dampness measurements in the roof timbers proved entirely satisfactory.
REGRESSION METHODS USED TO DETERMINE SOLAR GAINS

Figure S.29

Solar Radiation
Temp. Difference

Figure S.30

Correlation of space heating (Q) with temperature difference (ΔT) and solar radiation (S), to give house heat loss (ΣU.A+C_v) and solar aperture (R).
SOLAR GAINS

S11. Solar Gains

Three of the aims of the Pennyland project have been to test the acceptability of the passive solar design, make sure that summer overheating was not a problem and, if possible, to quantify the energy savings due to the solar measures.

The estate and house design has proved very popular with the residents, though with certain reservations about the privacy considerations of the large south-facing windows.

Summer Overheating

Two surveys of midsummer internal temperatures were carried out on hot July days. Both were entirely satisfactory. They showed no significant differences between any of the groups and suggest that the extra thermal mass of the Pennyland design is not really necessary, normal medium-weight construction, as used at Neath Hill, being adequate.

Absolute Solar Gains

It was not clear at the outset of the project whether the solar gains could be quantified at all, since no previous work of this kind had produced clear answers. Indeed, the answers of this project are by no means clear-cut.

The difficulty in determining the solar gains will be appreciated considering that they are effectively space heating energy that has not been used, rather than some positive measureable quantity. This means that every other source of energy and heat loss in the house must be thoroughly understood.

Regression techniques developed during work on the Linford test house have allowed the solar gains there to be quantified within 10%. These techniques have been applied to the Pennyland data, allowing the solar gains to be similarly quantified, but at a lower level of accuracy (see figs. S.29 & S.30).

Generally levels of solar gains have been lower than expected, because of the almost universal use of white net curtains throughout the estate and the habit of drawing blinds and shutters on sunny winter days, thus reducing solar absorption.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Neath Hill Insulated House
Adjusted Gross Heat Loss 16,500 kWh/yr

Pennyland Area 1 Single Aspect
Adjusted Gross Heat Loss 14,500 kWh/yr

Pennyland Area 2 Single Aspect
Adjusted Gross Heat Loss 12,900 kWh/yr

Figure S.31 ANNUAL ENERGY BALANCES

kWh/day

Neath Hill Insulated
Aux. Space Heat
Solar
Free Heat

Pennyland Area 2 Single Aspect
Aux. Space Heat
Solar
Free Heat

Figure S.32 MONTHLY ENERGY BALANCES

--- Balance for measured internal temps.
--- Summer balance for 20°C internal temp.
ENERGY BALANCES

S12. Energy Balances

Monthly and annual energy balances have been drawn up for 'average' houses in each of the groups equipped with detailed monitoring. These show how the total heat loss of the house is offset by solar gains, 'free heat' from cooking, lights, etc., and by actual space heating energy from the heating system itself.

The annual energy balances for three house types are shown in figure S.31. This illustrates that as the insulation level is improved, the house becomes predominantly heated by free heat and solar gains, with the space heating system simply topping up the energy balance.

Figures S.32 and S.33 show the monthly energy balances over the year. This shows how the improved insulation both reduces the midwinter heating demand and also reduces the length of the heating season, allowing the house to be heated just by solar gains and free heat for a longer portion of the year.

The Pennyland single aspect houses have a high level of solar gains (most noticeable at the ends of the heating season). Their total space heating demand is not reduced compared to the dual aspect type, though, because of their higher heat loss.
Delivered Energy
kWh/yr

NEATH HILL INSULATED

Figure S.34 Delivered Energy Breakdowns

PENNYLAND 1

PENNYLAND 2
ENERGY BALANCES

End Fuel Use

Analysis of the houses with detailed monitoring has shown the various end uses of the energy supplied. Figure S.34 opposite and the table below show the energy breakdowns into space and water heating, cooking and boiler losses.

<table>
<thead>
<tr>
<th>House Group</th>
<th>No. of Houses</th>
<th>DELIVERED ENERGY</th>
<th>USEFUL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total Boiler Gas</td>
<td>Electricity $</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kWh/yr</td>
<td>kWh/yr</td>
</tr>
<tr>
<td>Neath Hill Insulated</td>
<td>14</td>
<td>22480</td>
<td>7670</td>
</tr>
<tr>
<td>Pennyland 1</td>
<td>33</td>
<td>14010</td>
<td>3700</td>
</tr>
<tr>
<td>Pennyland 2</td>
<td>15</td>
<td>11530</td>
<td>3220</td>
</tr>
</tbody>
</table>

*Average for houses with gas cooking
$ Average for all houses.

These clearly show the energy savings, especially in boiler losses, due to the use of a low thermal capacity gas boiler.

The considerable difference in hot water consumption between Neath Hill and Pennyland is thought to be due to slight demographic differences between the estate populations. This illustrates the difficulties in separating out the house performance from the occupants' behaviour.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Total heating energy
kWh/day

Neath Hill

Slope = \sum (U \cdot A) + C_v

Pennyland Area 1

Pennyland Area 2

FIGURE S.35 'ENERGY SIGNATURES' FOR THREE SEPARATE HOUSES - TOTAL HEAT IN VS. \Delta T

FIGURE S.36 CALCULATED TOTAL HEAT LOSSES & PROPORTIONS FOR MAIN HOUSE TYPES.
ENERGY BALANCES

Heat Losses

The project measurements have not been detailed enough to produce hard estimates (±10%) of the heat losses of individual houses. For this the more intensive monitoring as used for the Linford houses is necessary. However, simple plots of total heat into a house against inside-outside temperature difference have proved sufficiently good to distinguish houses at the three basic insulation levels with detailed monitoring (see figure S.35). These results suggest that the fabric losses are broadly in line with their theoretical values.

This has proved to be the case in the companion Linford project, with the exception of the floor heat loss, which was about double that expected.

Figure S.36 shows breakdowns of heat losses for the four main insulation levels using theoretical U-values and air infiltration rates estimated from pressure tests.

It was originally expected that air infiltration losses would dominate at the highest insulation levels, but the excellent airtightness of the Pennyland houses has shown this not to be the case.
Figure S.37

Energy saving features assessed for the Pennyland houses

Figure S.38

Computed breakdown of energy savings using project results
ENERGY SAVINGS

S13. Energy Savings

The detailed energy savings of the various measures incorporated in this project have been estimated in two ways:

A. Directly from the measured fuel consumptions and internal temperatures, with the minimum of theoretical assumptions. This produces perhaps the most convincing results, but clouded by statistical uncertainty because of the wide variations in individual occupant behaviour.

B. By using data from this project and the companion Linford trial to adjust the design computer model. This can then be used to generate very detailed breakdowns of the energy savings. The effects of the solar measures, for instance, can only be estimated in this way.

Computed savings

Figure S.38 opposite shows the overall halving in delivered energy consumption broken down into the individual contributions from each measure. This clearly shows that there is no one simple method to produce a low energy house design, rather it is achieved by the combination of many measures, each saving a small amount of energy. Insulation and improved heating efficiency account for over 80% of the saving, with air infiltration reduction and solar gains making up the remainder.
Figure S.39  Refined estimates of space heating corrected to 18°C average internal temperature.
Figure S.18 has shown the statistical problems associated with the wide variations in occupant behaviour. The variations in gas consumptions within each group can be ascribed to:

1. Slight differences in house design (mid-terrace, end-of-terrace, etc.)

2. Differences in average internal temperature.

3. Different numbers of occupants (this principally affects hot water use)

By taking these into account using multivariate statistical techniques and incorporating the measured boiler efficiencies, it is possible to refine the estimates of differences in space heating consumption between groups, in particular in order to bring out any possible solar differences.

This has been done by correcting the data so that all groups are assumed to contain only end-of-terrace houses, with the same number of occupants. It is also necessary to make some assumptions about internal temperatures. The 'refined' distributions of space heating consumption shown in figure S.39 assume the same heating season average internal temperature for all groups, largely because there seems little difference in measured internal temperatures between the Neath Hill houses and the Pennyland Area 2 houses.

This assumption possibly gives optimistic values for the energy savings, since the higher temperatures in the better insulated houses may not have been 100% useful.
SUMMARY/ CONCLUSIONS & RECOMMENDATIONS

Figure S.40 Absolute and Marginal Solar Gains

Every house is to some extent solar heated with absolute solar gains. What really matters is the difference in annual energy use between a solar and non-solar design. This is the marginal solar gain.

Figure S.41

The need for the direct-gain passive solar house to have unimpeded access for the sun to the interior is in conflict with the occupants' need for privacy. The almost universal use of white net curtains has considerably reduced the potential solar savings.
Passive Solar Savings

The next few pages will deal with the marginal passive solar savings which can be obtained by design changes to a house. These savings are not the same as the absolute solar gains into a house, since every house is to a certain extent solar heated. What we are concerned with is actual reductions in space heating demand as a result of estate layout and house design (see figure S.40).

Because of the statistical problems of comparing the energy consumptions of different groups of houses, these savings cannot be determined accurately from the actual project fuel consumptions. Instead, they have been calculated by computer modelling incorporating the results of measurements on the Linford test house.

Window obstructions and privacy

The calculations have been made using observed levels of window clutter (net curtains, etc.) at Pennyland. Less than 10% of south-facing windows had no obstruction and 35% of Pennyland residents said that they drew blinds or shutters on sunny winter days.

The high level of use of net curtains is likely to be related to the perceived privacy of the housing layout. Their use was much lower in the Linford houses which are not overlooked from the south. Residents felt that better garden fencing would have improved the privacy problem.

Passive solar comparisons

The main steps in direct gain design that have been carried out in this project are:-

1. Correct orientation, avoiding overshading in a normal dual aspect deep plan house plus the transference of about 1.4 m² of glazing from the north to the south facade to give the Pennyland 1 dual aspect type house.

2. Adopting a shallow plan single aspect house design, allowing 6 m² more glazing to be added to the south facade and the north-facing glazing reduced by a further 0.8 m².

The original estimates of the energy savings due to these changes were:- 1. 700 kWh/yr  2. 200 kWh/yr (see figure S.4).
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

NEATH HILL
'Normal' deep-plan house, oversubscribed & randomly oriented. 12 m² total window area, net curtains.

- Face south, avoid overshadowing
- Transfer some glazing from north to south facades without increasing total area or changing house shape.

PENNYLAND DUAL ASPECT
Add thermal mass - medium weight to heavyweight construction

- Rearrange house to shallow plan. Concentrate glazing on south side without increasing total area.

PENNYLAND SINGLE ASPECT
Increase south-facing glazing area

PASSIVE SOLAR DESIGN STEPS

Figure S.42

<table>
<thead>
<tr>
<th>BENEFITS:</th>
<th>Energy saving ≥ 200 kWh/yr (useful)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISBENEFITS:</td>
<td>Constrains estate layout</td>
</tr>
<tr>
<td>RATING:</td>
<td>Good, likely to be popular</td>
</tr>
</tbody>
</table>

| BENEFITS: | Energy saving 50-80 kWh/yr² per m² of glazing transferred. Sunny south-facing rooms Cost probably zero |
| DISBENEFITS: | Darker north-facing rooms |
| RATING: | Good, sunny rooms likely to be popular |

| BENEFITS: | Reduced summer overheating Good soundproofing |
| DISBENEFITS: | Poorer wall U-values 3-700 kWh/yr extra space heating Extra construction cost ≥ £100 |
| RATING: | Unnecessary, medium weight construction should be adequate. |

| BENEFITS: | Most rooms are sunny Mixtures of deep and shallow plan houses add variety to estate. |
| DISBENEFITS: | Featureless north facade Extra cost due to increased ratio of external to party wall approximately £150 |
| RATING: | Moderate, not cost-effective but may be more popular design. |

| BENEFITS: | South-facing rooms sunnier. |
| DISBENEFITS: | Privacy problems Risk of overheating Increased energy consumption with single glazing. Extra costs due to £60/m² difference between windows and insulated wall |
| RATING: | Poor |
ENERGY SAVINGS

Correct orientation and avoiding overshading

It was originally intended that the energy savings for step 1 would be determined by comparing the performance of the Neath Hill insulated houses with the Pennyland Area 1 dual aspect houses. The discovery of the large differences in air infiltration rate and boiler efficiency made this impossible to carry out. Computed estimates, in the light of experimental results suggest a lower figure around 200 kWh/yr. This reduction is due to:

A. Results of a survey of the Cambridge housing stock, showing that overshading levels are not as bad as first thought.

B. The high level of window clutter.

Transferring glazing from north to south facades

Calculations suggest that energy savings of 50-80 kWh/yr can be achieved for each square metre of glazing transferred from the north to the south facades. Given that this need not incur any extra construction cost, this is a highly cost-effective way of saving energy.

Single Aspect - Dual Aspect comparison

Post project computer estimates for this step and simple measured fuel comparisons agree in showing no energy savings, though there is a high level of statistical uncertainty. The single aspect houses do appear to be warmer, though. If this increased internal temperature is taken to be 'useful' rather than 'overheating', it is equivalent to an energy saving of 700 kWh/yr.

Reducing the levels of window obstruction could increase the marginal passive solar gains by 200-300 kWh/yr, but this would require more research on privacy problems.

Overall performance

The design changes in this project not only affect the house energy consumption, but also construction costs, summer overheating and likely popularity. Indeed, the sun in the living rooms has been greatly appreciated by the occupants (see section S.15). Figure S.42 opposite lists the various benefits and disbenefits of the design steps.

All of the solar energy savings presented here are subject to large uncertainties. Further experimental results and more detailed modelling could change the answers significantly.

Also, these conclusions are only for direct gain design with single and double glazed windows. Conclusions for systems using conservatories or advanced window designs might be quite different.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

<table>
<thead>
<tr>
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<th></th>
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<th></th>
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<td>NEATH HILL UNINSULATED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 mm wall insulation</td>
<td>2642</td>
<td>30.1</td>
<td>224</td>
<td>26</td>
<td>198</td>
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<tr>
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<tr>
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<td>5.5</td>
<td>25</td>
<td>5</td>
<td>20</td>
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<tr>
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<td>32.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Add thermal mass</td>
<td>-695</td>
<td>-6.1</td>
<td>93</td>
<td>0</td>
<td>93</td>
</tr>
<tr>
<td>Reduce vent. rate</td>
<td>1319</td>
<td>15.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>283</td>
<td>3.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>PENNYLAND AREA 1</td>
<td></td>
<td></td>
<td></td>
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<td>Roof ins. 75-150 mm</td>
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<td>7.5</td>
<td>45</td>
<td>5</td>
<td>40</td>
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<tr>
<td>Wall ins. 50-100 mm</td>
<td>1351</td>
<td>15.4</td>
<td>81</td>
<td>13</td>
<td>68</td>
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<td>Double Glaze</td>
<td>729</td>
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<td>0</td>
<td>13</td>
<td>-13</td>
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<td>Floor insulation</td>
<td>348</td>
<td>4.0</td>
<td>39</td>
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<td>34</td>
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<td>PENNYLAND AREA 2</td>
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<tr>
<td>OVERALL N.H.U. to</td>
<td>10016</td>
<td>114.2</td>
<td>507</td>
<td>67</td>
<td>440</td>
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<tr>
<td>N.H.I. to PENNYLAND 1</td>
<td>4254</td>
<td>48.5</td>
<td>118</td>
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<td>113</td>
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<td>PENNYLAND 1 to</td>
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<td>35.2</td>
<td>165</td>
<td>36</td>
<td>129</td>
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<td>PENNYLAND 2</td>
<td></td>
<td></td>
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Figure S.43
Cost-Effectiveness From Computed Energy Savings

<table>
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<th></th>
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<td>NEATH HILL UNINSULATED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50mm foam cavity ins.</td>
<td>1850</td>
<td>2500</td>
<td>28.5</td>
<td>224</td>
<td>26</td>
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<td>NEATH HILL INSULATED</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved Boiler</td>
<td>-</td>
<td>3400</td>
<td>38.8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Add thermal mass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof ins., Reduced vent. Solar &amp; Mass</td>
<td>1500</td>
<td>2027</td>
<td>23.1</td>
<td>118</td>
<td>5</td>
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<tr>
<td>PENNYLAND 1 Insulation</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>PENNYLAND 2</td>
<td>1900</td>
<td>2235</td>
<td>25.5</td>
<td>165</td>
<td>36</td>
</tr>
<tr>
<td>Overall N.H.U. to</td>
<td>-</td>
<td>10162</td>
<td>115.8</td>
<td>507</td>
<td>67</td>
</tr>
<tr>
<td>PENNYLAND 2</td>
<td>N.H.I. to PENNYLAND 1</td>
<td>-</td>
<td>5427</td>
<td>61.9</td>
<td>118</td>
</tr>
</tbody>
</table>
Whether the energy saving measures are worth implementing depends on the cost of the measure and the value of the energy saved.

The extra construction costs are not easy to assess, since they do represent a tiny fraction of the total construction cost of the house. They have been estimated by a leading firm of chartered quantity surveyors, as if the houses were to be built using traditional construction methods in the spring of 1984.

For the insulation measures, extra construction costs can be partially offset with savings resulting from a reduced heating system size, including a smaller and cheaper boiler.

The cost-effectiveness has been assessed in terms of a flat-rate payback time. The two tables opposite show the payback times of the various measures and the overall payback time of the steps between each house group. Broadly, the two calculation methods show similar results.

Compared to the uninsulated Neath Hill houses, the Pennyland Area 2 houses show an overall saving of about £115/yr, with a payback time of about four years. The improvement in insulation between the two halves of the Pennyland estate shows an energy saving of about £30/yr with a similar payback time.

Some costs have been surprisingly low. The Sashless double glazing is estimated not to cost any more than conventional single glazing. The unframed thick sheets of glass allow a simpler construction, saving on costs.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

COMPARISON OF PRE-PROJECT AND POST-PROJECT ESTIMATES OF COST-EFFECTIVENESS

FUEL SAVING

Marginal passive solar gains

Add thermal mass

1977 £ 1984 £

£/yr.

50 100

10 YEAR PAYBACK

Improved gas boiler

Insulating window shutters

Floor slab edge insulation

Expand cavity wall & insulate to 100 mm

Double glaze + ventilation rate reduction

20 YEAR PAYBACK

Insulate 50 mm cavity wall

Insulate roof to 150 mm from 50 mm

EXTRA CONSTRUCTION COST 1984 £

1977 £

400 800 1200 1600 2000

0 200 400 600 800 1000

Figure S.45
Comparisons with original estimates

Figure S.45 opposite shows the original estimates of cost-effectiveness from figure S.2 compared with those based on the project results and costings for 1984. Conveniently inflation has reduced the value of the pound by almost exactly a factor of two over this period.

While the energy savings are similar for both plots, the costs of insulation at the higher levels have fallen dramatically since 1977. The low costs of the double glazing and the cavity wall insulation and the added bonus of a large boiler efficiency saving for no extra cost have dramatically improved the overall payback time of the package of measures.

The original design aim was a package of measures to pay for itself in 10-15 years. The project results are nearer five years. This is four times better than the Treasury 5% discount rate criterion used for energy projects (building power stations, etc.) represented in figure S.45 by the 20 year payback line, assuming an investment lifetime of 60 years or more, i.e. the life expectancy of the house.

Some items have not been cost-effective. The additional thermal mass of the passive solar design has a high cost for little visible effect. The insulating window shutters fitted to some houses do not appear to have been used sufficiently to justify their installation.
COMPARISON OF COMFORT LEVELS WITH LAST HOME

Is your house warmer or colder than your previous one?

Do you make more or less use of the rooms?

ESTIMATES OF SAVINGS ON FUEL BILLS

Comparison of fuel bills with previous home

Estimate of amount saved on fuel bill
S.15. Occupants Reactions

A social survey was carried out by MKDC in 1982. 123 families on the Pennyland estate and 15 at Neath Hill were interviewed. The survey aimed to discover whether the Pennyland residents liked their houses and how they appreciated the energy saving features.

The Pennyland estate proved to be very popular, but the residents originally chose their homes not for the energy features but for the attractive layout and 'traditional' appearance and construction.

Once living in the houses, the low energy costs were seen as a major advantage that would make the houses good for purchase and easy to sell.

Generally the residents felt that their houses were warmer than their previous home and that they made more use of the rooms.

91% of the Pennyland households felt that they were making savings on their fuel bills and 67% claimed to be saving over a quarter. They were also generally well satisfied with the heating system.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.48 POPULARITY OF 22 CHARACTERISTICS OF THE PENNYLAND ESTATE

<table>
<thead>
<tr>
<th>Position of living room</th>
<th>Position of kitchen</th>
<th>Amount of greenery</th>
<th>Size of fuel bills</th>
<th>Layout of the rooms</th>
<th>Look of the house</th>
<th>Nearness to shops</th>
<th>Friendliness of your area</th>
<th>Materials of house</th>
<th>Way houses are arranged</th>
<th>Location of footpaths</th>
<th>Size/shape front windows</th>
<th>Safety from traffic</th>
<th>Size of back garden</th>
<th>Look of blinds</th>
<th>Shape of back garden</th>
<th>Size of front garden</th>
<th>Space around the house</th>
<th>View from house</th>
<th>Security from burglary</th>
<th>Car parking</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
<td>4.6</td>
<td>4.5</td>
<td>4.4</td>
<td>4.4</td>
<td>4.5</td>
<td>4.4</td>
<td>4.4</td>
<td>4.2</td>
<td>4.3</td>
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<td>3.9</td>
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<td>3.8</td>
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<td>3.6</td>
<td>3.9</td>
<td>3.7</td>
<td>3.0</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Figure S.49 Social Survey popularity of estate layouts
OCCUPANTS' REACTIONS

Layout and built form

The layout of the houses and the large south-facing windows were very popular. The appearance of the houses and the general landscaping were also considered very satisfactory.

The main problems related to the lack of adequate car parking, the privacy problems of the large south-facing windows and the garden mounding intended as a privacy barrier.

Residents were also concerned about security from burglary and complained about the adequacy of the door and window locks.

The residents were asked to compare the Pennyland estate layout with three others which they were told would involve different fuel bills. Generally a layout of semi-detached houses was as popular as the Pennyland layout, despite a slightly larger fuel bill. The slab terrace layout and a Neath Hill courtyard style estate were rather unpopular, despite the fact that the slab terrace would be cheaper to heat (see figure S.49).

The solid construction style and the double glazing at Pennyland were rated highly for soundproofing by the residents.

Room size and amount of sun

% Response

Figure S.50
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

PENNYLAND CONSTRUCTION DETAILS

Walls:
- Plaster skin
- 100 mm concrete inner skin
- 110 mm non-cavity width
- 100 mm Dritherm insulation
- 103 mm facing bricks
- Galv. steel twist strip ties
- In Abbey slots
- Lintel: galv. m.s. angle (80x100 approx)

Windows: Sashless Window Co., nailed to inner skin.

Floor:
- 160 mm r.c. slab
- 25 mm exp. polystyrene edge insulation
- 1000 gauge d.p.m.

Ground bearing slab.

Figure S.51 Area 2 insulation details - Area 1 has thinner insulation, single glazing and no floor insulation.
S16. Conclusions and Recommendations

The package of energy saving measures has worked very well, with an estimated energy saving of about £115/yr. having been demonstrated for an extra construction cost of approximately £450/house. Indeed, by the time of production of this report the measures will already have paid for themselves.

Wall insulation

50 mm of urea formaldehyde foam insulation has been successfully used in the sample of Neath Hill houses. Fuel bills and a thermographic survey have indicated that it is performing properly, though measurements have not been accurate enough to fully quantify the energy savings.

Fibreglass batt insulation has been satisfactorily incorporated into the structure of the Pennyland houses at both 50 mm and 100 mm thicknesses. The energy savings at both levels have been very cost-effective with payback times in the region of 5-7 years. The adoption of 100 mm thickness is recommended for future construction and it is possible that a 150 mm thickness would be cost-effective.

Floor insulation

The thermographic survey has indicated the presence of significant floor edge heat losses both in Area 1 (no floor insulation) and Area 2 (25 mm thickness floor edge insulation). Measurements in the Linford test house showed floor heat losses considerably higher than expected. This is a subject that is in serious need of further research, but it seems that full underfloor insulation would be desirable for future low energy houses.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.52
Condensation problem in this area due to insulation being pushed up, blocking flow of ventilating air under eaves.

Figure S.53
The frameless double glazing produced by the Sashless Window Co. has been very cost-effective.

Figure S.52
The folding insulated window shutters fitted to some houses do not seem to have been used enough to justify their high cost.
CONCLUSIONS AND RECOMMENDATIONS

Loft Insulation

Increasing loft insulation from 50 mm up to 150 mm has been very cost-effective. Increasing it further beyond 150 mm seems only marginally cost-effective unless the opportunity is taken to cut down the cold bridges of the joists. This could be done by laying the insulation in two separate layers, one between the joists and one at right angles across the top.

At these levels of insulation it is important to design in adequate ventilation in the loft space to keep roof timbers dry. The lowering of the roof line to cut solar overshading created a difficult insulation detail at the eaves and is not recommended. A condensation problem was found in one house as a consequence of this (see figure S.52).

Double Glazing

The cheap Sashless double glazing has proved extremely cost-effective. As a double glazing system it has performed well and proved to be well sealed against air infiltration. However, there has been a certain amount of user dissatisfaction, caused mainly by the detailed design of the opening and sliding mechanism. There were also problems of condensation forming between the panes. These problems could be alleviated by slightly modifying the design.

Window Shutters

Insulating window shutters of two types, a folding concertina variety (figure S.54) and a sliding blade type were fitted to some of the Pennyland Area 2 houses. Although the thermographic survey has shown that they do cut window heat loss, it seems unlikely that they have been used enough to justify their high cost.

Total Fabric Performance

A major conclusion of this project is that the mere specification of U-values for a house does not fix its energy consumption. The large energy difference between the Neath Hill Insulated houses and the Pennyland Area 1 houses came as somewhat of a surprise to the researchers and demonstrates that other factors such as air infiltration and boiler efficiency are extremely important.
Figure S.55

The Pennyland landscaping in summer
CONCLUSIONS AND RECOMMENDATIONS

Heating System

The wet radiator system used in the Pennyland houses appears to have performed very well, maintaining comfort temperatures even in some of the worst weather this century (December 81). It has proved very popular with the residents. There was slight dissatisfaction with the lack of provision of upstairs heating in the Area 1 houses, but it is unlikely that it is necessary at the Area 2 insulation level.

The warm-air systems installed in some of the larger Pennyland houses have not proved so popular and cannot really be recommended.

The use of a low thermal capacity boiler with the resulting improvement in heating efficiency has been extremely cost-effective, giving a third of the project savings at no extra cost. However, it is likely that further large energy savings could be made by using the new range of condensing gas boilers with electronic ignition now being introduced.

Heating Controls

Measurements in the companion Linford project have shown that at high insulation levels the heating system must be very responsive to free heat gains from cooking as well as solar gains. The positioning of the main heating thermostat in a south-facing room will make best use of the solar gains.

Most of the Pennyland residents appear to have mastered the complexities of the timeclock and heating system programmer. Its prominent position in the kitchen is probably instrumental in this. It is recommended, though, that clear instructions are issued, if necessary with demonstrations, especially to the elderly.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.56 Large fans being used to pressurise a house to test the air leakage.

A. Slab terrace of dual aspect houses with small windows
   - cheap to build
   - cheap to heat
   - unpopular

B. Slab terrace of dual aspect houses with larger windows
   - more expensive to build than A.
   - same fuel bills as A.
   - more solar
   - possibly more popular

C. Pennyland mix of dual and single aspect houses in short terraces
   - more expensive to build than A or B.
   - more expensive to heat than A or B.
   - very popular.

Figure S.57 House design - Energy, Cost and Popularity.
CONCLUSIONS AND RECOMMENDATIONS

Air Infiltration

Infiltration in the Pennyland houses was much lower than expected. A primary reason for this is likely to be the poured concrete construction, though many other features such as the draught lobbies, window and door seals, the balanced flue boiler and the cavity insulation are likely to contribute. The resulting energy savings have been very cost-effective and do not seem to have caused serious condensation problems. It would not seem wise, though, to attempt to reduce air infiltration below this level in future projects without the use of forced mechanical ventilation.

Pressure leakage tests have been extremely useful in determining the airtightness of the houses. This simple test can be invaluable in testing the quality of construction and it is recommended that standards for air leakage are developed and testing methods introduced for new houses.

Passive Solar Design

The Pennyland project has shown that an estate of houses can be laid out to maximise direct-passive solar gains without problems, and indeed it has resulted in a well-regarded scheme, both by the occupants and by the architectural profession, winning an R.I.B.A. award.

It should not be thought, though, that the ruthless pursuit of energy cost-effectiveness in both estate and house design, will automatically result in good housing. The Pennyland estate is neither the cheapest possible layout to build or to heat (see figure S57). It is, though, very habitable.

House layout and design is primarily an aesthetic matter and each house is someone's home. Facing houses south and avoiding overshadowing should be regarded as good practice, but the energy savings will be small compared to those from proper insulation and good heating system efficiency.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure 3.58

POST-PROJECT COMPUTED SPACE HEATING CONSUMPTION AS A FUNCTION OF SOUTH-FACING WINDOW AREA - SINGLE ASPECT TYPE HOUSE

Annual Space Heating kWh/yr

6000

5000

4000

3000

2000

0 5 10 15 m²

7.4 m² Dual aspect S-facing glazing area

13.6 m² Single aspect S-facing glazing area

Net curtains

Area 1 insulation - single glazing

No Window Clutter

North-facing window area fixed at 4.7 m². Curtains assumed drawn at night.

Area 2 insulation - double glazing

South-facing gross glazing area

In houses at the Area 1 insulation level south-facing single glazing is a net energy loser - the energy optimum area is as small as possible.

At the Area 2 level space heating consumption is almost independent of S-facing window area. Excessive levels will lead to summer overheating without any energy savings.
CONCLUSIONS AND RECOMMENDATIONS

Passive Solar Design

The project has not produced clear answers as to whether single aspect houses are cheaper or more expensive to heat than dual aspect ones. In terraces, single aspect houses are certainly more expensive to build. Their justification comes in creating a mix of house designs, giving each house more individuality and marketability.

Window Area

Windows are considerably more expensive than insulated wall per square metre. Unless their thermal performance can be dramatically improved there is no energy cost-effectiveness reason for larger windows than necessary. The choice is again largely one of aesthetics.

Once the level of glazing has been chosen it seems desirable to concentrate it on the south side of the house, though not to a level that will create gloomy rooms on the north side or overheating on the south. There seems little reason to increase south-facing glazing area beyond 40% of the south-facing wall area.

It would also seem desirable that the section of the Building Regulations restricting total window area is rephrased in a way that is less punitive on south-facing glazing and more so on north facing glazing.

To make the best use of solar gains, it is essential that windows are not obstructed by net curtains, half drawn blinds, etc. This may be a problem of the perceived privacy of the site.

Thermal Mass

If the south-facing window area is kept to the levels in this project, then normal medium weight construction should be sufficient to prevent summer overheating. The provision of dense concrete blockwork can add significantly to the cost of a house.

It should not be used in the inner leaf of an external wall, especially at low insulation levels, since it worsens the U-value and adds to the house heat loss. Measurements at the Linford test house suggest that concrete ground floor slabs, once carpeted, do not add significantly to the thermal mass of a house.
SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Figure S.59  Researchers erecting the Linford weather station in arctic conditions

Figure S.60  Estate architect John Seed
Monitoring

The simple monitoring used in the project has proved adequate to determine the insulation energy savings. It has not been adequate to determine solar gains and for more detailed investigations of this type, the more intensive level of monitoring as used at Linford is needed.

Researchers on future field trials should not fall into the trap of thinking that the mere measurement of data is the whole project. In this case it has amounted to less than a half. The remainder requires the development of computer software to display, 'clean', and process the data and finally to document the project in an intelligible fashion.

Future projects should also guard against 'front end overload', where researchers who are doing essentially something rather unusual and experimental have to gallop to keep pace with builders and developers who have production schedules to meet. This creates enormous man-power and cash-flow problems..