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RESEARCH

THE PENNYLAND AND LINFORD LOW ENERGY HOUSING PROJECTS

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SYNOPSIS

August 1986 saw the opening by Milton Keynes Development Corporation (M.K.D.C.) of 'Energy World', an exhibition of 50 low-energy house designs. In many ways this has been prompted by the success of two local housing field trials, Pennyland and Linford, that have clearly shown the benefits and popularity of simple energy saving measures.

Study of the Pennyland estate of 177 houses allowed comparisons of fuel bills of large numbers of houses to give a reliable demonstration of energy savings. Compared to adjacent estates this showed a halving of gas heating energy consumption, worth about £115 per year for a three-bedroom house at 1984 prices. This was achieved for an extra construction cost of £450, giving an overall payback time of under five years.

The companion eight-house Linford project allowed detailed study of the various measures involved:-

- **Insulation to Danish BR77 standards.**
- **Use of low thermal capacity gas boilers.**
- **Air-tight construction.**
- **Direct gain passive solar design.**

Detailed costings of the two projects have also given a full breakdown of their relative cost-effectiveness.

Design

The two projects in many ways sprang from a detailed appraisal of the Bradville active solar house,[1] built in Milton Keynes in 1974. Although this worked and also managed to halve heating bills, it was not cost-effective, but detailed study[2] showed that other measures could be.

In 1977, after extensive discussions between Milton Keynes Development Corporation (M.K.D.C.) architects and Open University energy researchers, and some computer modelling, a design brief for the basic experimental house was reached:

- Roof insulation approx 150 mm thickness.
- Wall insulation 100 mm thickness.
- Double glazing.
- 25 mm thick edge insulation to ground floor slab.
- Draughtstripping.
- Houses to face south within 45°.
- Houses must not be overshadowed by others to the south.
- Windows concentrated as far as possible on the south side.
- Dense concrete internal construction to store solar gains.
- High efficiency low thermal capacity gas boilers.
- Efficient heating controls.

This basic list was then used for the two housing schemes.

From an experimental point of view, the Pennyland scheme was both intended to test out passive solar design for the UK Department of Energy (D.En.) and also insulation levels for the Department of Environment (D.o.E.). The Linford scheme has been primarily a passive solar one.

Figure 1: The Pennyland Houses were laid out to face south and avoid over-shadowing. Picture shows shadows at 14.00 hours on a January afternoon.

The experimental considerations can basically be broken down into an insulation experiment and a solar one, with excursions into boiler efficiency and air infiltration. Readers who find this paper a little confusing should bear in mind that it is a digest of 1000 pages of project reports.[3-5]

The insulation experiment

The Pennyland study followed on from the D.o.E.'s '*Better Insulated House Programme*' field trials. Due to cash limitations only a half of the estate (Pennyland 2) could be insulated up to the full standard, the remainder (Pennyland 1) being insulated approximately at a level which was to become the UK 1983 Building Regulation standards, *i.e.*

- Roof insulation 80 mm (1983 standards 100 mm).
- Wall insulation 50 mm.
- Single glazing.
- No floor edge insulation.

The neighbouring estate of Neath Hill in particular acted as a control group, being built to the UK 1976 insulation standards:

- Roof insulation 50 mm.
- Unfilled cavity walls.
- Single glazing.
- No floor edge insulation.

The solar experiments

Within the Pennyland estate, two different house shapes

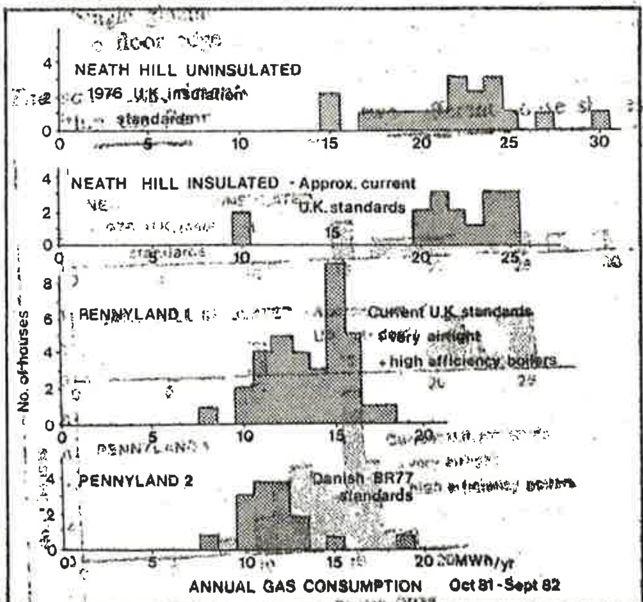

Figure 2: Histograms of annual gas consumption of the four main insulation groups.

Table 1: Estate Energy Consumptions.

	Number of houses	Delivered Energy: Gas (kWh per year)	Gas (£ per* year)	Electricity (kWh per year)	Electricity (£ per* year)
M.K. 4-estate sample (75/76 data)	150	22 172	253	2416	121
Neath Hill uninsulated	18	23 400	267	Not measured	
Neath Hill insulated	14	22 480	256	3086	154
Pennyland 1	33	14 010	160	2856	143
Pennyland 2	15	11 530	131	2598	148

* *Spring 1984 prices*

were used, a normal deep plan 'dual aspect' type, with about two thirds of the glazing on the south side of the house, and a shallow plan 'single aspect' type with more glazing on the south side. The Pennyland houses were laid out to avoid overshading (see Figure 1) and to face approximately south. A 'non-solar' control group was created on the Neath Hill estate of randomly oriented overshaded houses. These were given wall cavity foam insulation in an effort to bring them up to the Pennyland area 1 insulation standards. The fact that this group used 50% more gas than the Pennyland 1 houses turned out to be one of the most interesting features of the whole project.

Finally, the Linford houses were of an identical single aspect design, with the full insulation level. They were similar in design to the Pennyland 2 single aspect houses, though detached and with more floor area (110 m² instead of 90 m²) and with a larger amount of south-facing glazing. One of the houses was kept unoccupied and used as a test house for detailed experiments.

Construction

Building work started on the Pennyland site in 1980. The houses were built by a John Mowlem & Co. using a poured concrete technique. The inner skin was made of dense concrete cast *in-situ*, with glass-fibre insulation batts (50 mm or 100 mm according to insulation level) outside, and finally a brick outer skin built up afterwards. The inner skin was sufficiently dense to act as a vapour barrier.

The Linford houses, built by a smaller local firm, followed using more conventional construction techniques. 100 mm glass-fibre insulation batts were fitted between a dense concrete blockwork inner leaf and a brick outer skin.

Both schemes used the same type of double glazing using unframed sheets of 5 mm thick glass sliding in plastic tracks and surrounded by thick wooden frames. Roof insulation consisted of conventional rolls of glass-fibre, 80 mm thickness for Pennyland 1 and 140 mm for Pennyland 2 and Linford. 25 mm thickness of foam edge insulation was built into the floor slabs of the Linford and Pennyland 2 houses.

The first Pennyland houses were completed in early 1981 and performance monitoring was started in October 1981. The Linford houses were not all completed until late 1981 and they were mainly monitored over the winter of 1982/3.

Monitoring

The houses were monitored by the Open University Energy Research Group. Briefly, 60 Pennyland houses, 19 Neath Hill houses, and the eight Linford houses were measured in detail, though fuel bill data for a large number of other houses was also collected.

The Pennyland and Neath Hill monitoring was done on a weekly average basis. Gas and electricity meters, heat meters showing central heating output, and special house temperature meters were all read by a long-suffering meter reader.

The Linford monitoring was carried out using 15 minute data samples gathered by five data-loggers located in the test house garage. This data was recorded on magnetic tape cartridges which were read and processed in a computer at the Open University.

The main aim of the Linford monitoring was to quantify energy flows within the house. However, it also provided very valuable descriptive information about how the houses and their heating systems were used. Generally while the Pennyland experiment has *demonstrated* energy savings, the Linford houses have *explained* them.

Results

As well as physical measurements a social survey of residents' attitudes was carried out by M.K.D.C. and compared with results from other estates.

Pennyland comparisons

The clearest demonstration of energy savings is shown in Figure 2, showing spreads of annual gas consumptions for the four main Pennyland and Neath Hill insulation groups. The averages are also given in Table 1.

This clearly shows a halving of annual gas consumption, bringing heating costs below those for electricity for lighting and appliances (the differences in electricity consumption are not statistically significant).

Data from the houses with detailed monitoring equipment has been analysed to correct for minor differences in internal temperature, number of occupants, and within-group differences in heat loss (some houses are centre-terrace, others end-of-terrace) in order to bring out the energy differences between different house designs. This has allowed some apportioning of the savings to the different measures involved.

In addition to calculating energy savings by direct comparison of house groups, the design computer model (a cut-down version of the American NBSLD response factor model) was updated, mainly from detailed test data from the Linford project. It allowed a very detailed costings, payback times for each one. it also served as a useful 'go-between' for the various sets of experimental data.

However, some of the most interesting results are not about the physics of the houses themselves, but about the occupants and their attitudes to them as revealed in the social survey.

Occupant satisfaction

The internal temperatures in all the houses measured, Neath Hill, Pennyland, and Linford were high, averaging 18 — 19°C over the winter. These are amongst the highest recorded in UK post-war field trials.

The social survey showed good satisfaction. Some 81% of the Pennyland residents said that they could keep their house warm enough, compared to only 51% in a wider Milton Keynes survey. This was all the more encouraging since the winter of 1981/82 prior to the social survey contained some of the coldest weather in Britain this century, with a minimum temperature of −17°C measured at Linford. More important only 3% of Pennyland residents said they could not *afford* to keep their house warm enough, compared to 28% in a wider M.K. survey.

Insulation

The energy comparisons of the two halves of the Pennyland estate suggest that adopting the Danish BR77 insulation standards will save between 1400 and 1900 kWh per year of useful space heating energy for a typical three-bedroom house. Computed estimates were slightly higher.

Spot measurements on wall and roof heat losses were carried out in the Linford test house, indicating a wall *U*-value of about 0.3 W m^{-2} °C^{-1} and a roof *U*-value of about 0.2 W m^{-2} °C^{-1}, as expected. The roof insulation could have been installed better and future houses should really have two layers of loft insulation, one between the joists and another at right angles over the top covering them.

Floor heat loss

Measurements in the floor of the Linford test house showed heat losses about double that expected. The floor slab was provided with 25 mm thickness of edge insulation tucked in under the slab and extending one metre in from the perimeter. Infra-red camera observations showed large heat flows out from the building around the foundations. These were also visible on some of the Pennyland houses. There did not appear to be any particular fault with the insulation, rather there simply wasn't enough of it to cope with conduction through the damp clay soil. There is a serious need for further research in this area and given the project results, it is probably wise to insulate completely under a building with at least 50 mm thickness.

Boiler efficiency and controls

Surprisingly, the insulated Neath Hill houses used 50% more gas than the Pennyland 1 houses, despite almost identical insulation standards. This was mainly due to differences in air-tightness and boiler efficiency.

The Neath Hill houses had been equipped with a conventional gas boiler with a heavy cast-iron heat exchanger. The Pennyland houses used a Chaffoteaux low thermal capacity boiler with a lightweight heat exchanger and a balanced flue construction. The Linford houses had a similar, but larger model. Analysis showed that the heavyweight type had almost twice the 'standing losses' (pilot flame and some cycling losses) of the lightweight type.

The fuel bill savings due to the improved boiler efficiency at Pennyland amount to about £35 per year per house, and for no extra capital cost. The Pennyland boilers had maximum efficiencies of around 83%, although average seasonal efficiencies were below 70%. Maximum efficiencies for the Neath Hill type were only about 73%. Even these boilers should now be considered obsolete, as new designs of condensing gas boilers with peak efficiencies of over 90%, are introduced.

The wet radiator heating systems seemed popular, over 80% of Pennyland residents being more satisfied than with the heating in their previous home. No instructions were issued on the heating controls, but 70% said that they used their time clock, and only 13% said they didn't understand it. The elderly in particular needed instruction in its use.

Some houses were fitted with warm air heating systems. These were not as popular and although they weren't monitored in detail, the occupants didn't feel they were making energy savings.

Air-tightness

Air-tight construction of houses is a mixed blessing. On the one hand reducing the air infiltration rate cuts heat losses, reduces internal draughts, and increases comfort. On the other, low air change rates mean increased condensation and mould growth.

The Linford and Pennyland houses were surprisingly air-tight. Fan pressurisation tests were carried out by British Gas and actual air infiltration rate measurements were made over long periods in the Linford test house.

The Linford houses showed air leakages at 50 Pa, pressure of eight air changes per hour and the Pennyland ones tested only six air changes per hour. The Neath Hill control houses were closer to 14 air changes per hour, probably a fairly typical figure for current UK houses. These figures correspond

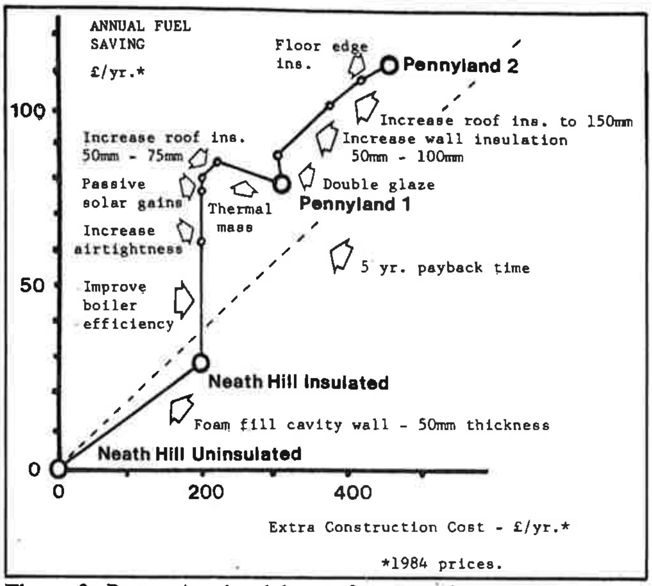

Figure 3: Post-project breakdown of computed energy savings.

to seasonal average air change rates of around 0.3 air changes per hour for Pennyland, 0.4 air changes per hour for Linford and around 0.7 air changes per hour for Neath Hill.

Since the Linford houses used fairly standard construction techniques, the low air change rates are probably due to good attention to construction detail and good draughtstripping. The Pennyland houses had the additional benefit of a poured concrete bunker construction, leaving few gaps in the walls for air to leak through.

The low air change rates may have also produced increased comfort. Despite the high internal temperatures measured in the Neath Hill houses, only 40% of occupants felt that they could keep their houses warm enough compared to 81% in Pennyland.

The reverse side of the coin was also shown up in the social survey. Inhabitants of both the Pennyland and Neath Hill control houses were asked whether they had condensation or mould growth. Equal percentages in each estate (about two-thirds) said they had condensation, but a half of the Pennyland residents said they had some mould growth, as opposed to only 15% in Neath Hill. The mould was where you would expect it, in bathrooms and toilets, and only occurred in the mid-winter period.

The Linford houses had micro-switches fitted to the windows allowing some assessment of when they were opened. Curiously, the windows needed open to stop condensation (kitchen, WCs and bathroom) were precisely the ones that they didn't open. Obviously future house designs must be both well sealed and contain purpose-built ventilation to these rooms.

The extensive measurements of air infiltration rates in the Linford test house tied up well with a theoretical model and hinted that modest energy savings could be made by aligning terraces S.W.-N.E. rather than broadside on to the prevailig South-Westerly winds.

Direct Gain Passive Solar Design

No aspect of these projects received greater attention than the direct gain passive solar system, largely because the primary source of funding was the Department of Energy Passive Solar Programme. Passive Solar is seen as 'alternative energy generation', but as is obvious from Figure 3, the benefits are a small fraction of those from 'energy conservation'. The mechanisms of direct gain solar absorption are dealt with in great detail in the Linford project report but the 'pros' and 'cons' can be briefly summarised here.

Benefits

Facing normal deep-plan Pennyland-style terrace houses south within 45°, and concentrating glazing on the south side

Table 2: Computed Cost-effectiveness of Pennyland Measures.

	Delivered Energy Saving (kWh per year)	Delivered Energy Saving (£ per year)	Net Extra Cost (£)	Payback Time (years)
Neath Hill uninsulated				
50 mm wall insulated	2642	30.1	198	6.6
Neath Hill insulated				
Improved boiler	2862	32.6	0	0
Reduce vent. rate	1319	15.0	0	0
Passive solar gains*	283	3.2	0	0
Roof ins. 50 mm — 75 mm	485	5.5	20	3.6
Thermal mass	–695	–6.1	93	Inf.
Pennyland 1				
Double glaze	729	8.3	–13	0
Wall ins. 50 mm — 100 mm	1351	15.4	68	4.4
Roof ins. 75 mm — 150 mm	661	7.5	40	5.3
Floor insulation	348	4.0	34	8.5
Pennyland 2				
Overall *N.H.U.—Pennyland* 2	10016	114.2	440	3.9
Pennyland 1 — 2	3120	35.2	129	3.7

* Solar gains due to avoiding overshadowing, correct orientation, and concentrating two-thirds of glazing on south side of a deep plan house.

will save about 200 — 300 kWh per year of useful space heating energy. For the larger Linford-style detached houses the figure is about 1000 kWh per year. The Pennyland residents liked the south-facing rooms and windows and the general greenery, a consequence of having the garden on the south side of the house.

Disbenefits

Over-large south-facing glazing creates privacy and security problems. The residents of Pennyland responded to the privacy problem by filling their windows with white net curtains, thus cutting the useful solar absorption.

Large glazing may also create summer overheating, although this was not a problem in the experimental houses. Heavyweight construction using dense concrete to counteract overheating can be expensive. Normal medium weight construction would have been quite adequate for the two estates.

Windows, especially double glazed ones, are far more expensive than insulated brick wall. These extra costs (at least £60 m^{-2}) cannot be justified on energy saving terms, only in the aesthetic appeal of the houses.

Wide shallow-plan terrace houses capable of having more south-facing glazing have more total surface area (and heat loss) than narrow deep-plan houses. Consequently they are more expensive to build. Again these extra costs cannot be justified in energy terms alone. The constrained estate layout to avoid overshading also led to car parking problems.

Cost-Effectiveness

Detailed costing of the various measures was done at the end of the project as if the houses were to be built using normal construction methods (*i.e.*, as Linford). The results were very encouraging, with insulation costs being much smaller than originally estimated. Figure 3 shows a plot of post-project computed energy savings against extra construction cost (net of savings due to a smaller heating system) for a Pennyland type three-bedroom deep plan end-of-terrace house. The steeper the slope, the more cost-effective. The individual payback times are also given in Table 2.

Some features have zero payback time. The high efficiency boilers save energy without extra capital cost. Amazingly, the frameless double glazing was no more expensive than normal single glazed windows. Since it allowed some reductions in heating system size it actually *reduced* total capital costs.

With the exception of the extra thermal mass, all the measures are cost-effective. It is also likely that a further increase in wall insulation to 150 mm thickness would be cost-effective.

Conclusions

These two projects have shown that low energy houses can be built in the UK cheaply and without problems. Just as the previous '*Better Insulated House Programme*' led to the improved Building Regulation insulation standards of 1983, it is to be hoped that the Pennyland 2/Linford levels will be made mandatory in the near future.

The projects have also shown that fabric *U*-values alone do not make a low-energy house. What is needed is a full 'integrated low energy house design' approach that attempts to minimise the heating cost to the consumer. This requires taking heating system efficiency and fuel type, air-tightness and passive solar features all into account.

This approach has been used for 'Energy World'. House designs submitted by developers have been analysed using a special computer model to give them a 'MKECI' rating (Milton Keynes Energy Cost Index). Designs had to be better than Pennyland and Linford to be included in the exhibition. If nothing else, this seems to have woken British developers up to what Scandinavian and Canadian builders have been doing for the past decade.

References

1 Horton, A., and Grove, S. *'Milton Keynes Solar House'*, 1979. (London: Polytechnic of Central London).

2 Barrett, M., and Everett, R. *'Cost-effectiveness of Grouped Solar Heating Schemes'*, 1977. (London: Polytechnic of Central London).

3 Everett, R., Horton, A., Doggart, J., and Willoughby, J. *'Linford Low Energy Houses'*, 1985. ERG 050 ETSU-S-1025. (Milton Keynes: Open University Energy Research Group).

4 Lowe, R., Chapman, J., and Everett, R. *'The Pennyland Project'*, 1985. ERG 053 ETSU-S-1046. (Milton Keynes: Open University Research Group).

5 Everett, R. *'Rapid Thermal Calibration of Houses'*, 1985. ERG 055. (Milton Keynes: Open University Research Group).

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