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ENERGY EFFICIENCY IN EXISTING HOUSING

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ABSTRACT

This paper sets out the monitoring results of the York Energy Demonstration Project (YEDP), carried out under the UK Government's Greenhouse Programme. Energy savings of up to 50% were observed as a result of incorporating energy efficiency measures into housing modernisation programmes. The project also provided insights into a number of replication issues.

1.0 INTRODUCTION

Although estimates vary as to the scale of the CO_2 emission reductions required to combat global warming, there is little doubt that they will need to be considerable. Some estimates indicate the need for reductions in the industrialised countries which could be as much as 80% [1]. The achievement of such targets will require major programmes in all sectors. The YEDP was an attempt to demonstrate reductions in energy and CO_2 through the modernisation of existing housing. The scheme was aimed at public housing but its findings are relevant to all housing sectors.

In the UK, housing is responsible for about 29% of energy consumption and a similar proportion of the production of CO_2 [2]. Although developments in the energy efficient design of new housing are important, they are unlikely, on their own, to make the necessary impact on the overall efficiency of the stock. In the UK, new housing tends to add to, rather than replace, existing dwellings and current rates of development would suggest, that by the year 2050, some 60% of the stock will have been built prior to 1990. The need to tackle existing dwellings was clearly recognised by the Greenhouse Programme and is also enshrined in UK legislation through the Home Energy Conservation Act 1995, which requires local authorities to develop strategies designed to achieve a 30% improvement in energy efficiency (and reduction in CO_2 emissions) in existing dwellings over the next 10 to 15 years.

Demonstration projects have two broad aims. Firstly, by pointing the way to large scale replication, they are part of the dissemination process. Secondly, they provide greater understanding of the issues of application which need to be tackled, if the technology demonstrated, is to become part of mainstream programmes. Monitoring of the project is crucial to achieving these aims. The purpose of this paper is to summarise the main outcomes of the York project both in terms of energy reductions and the wider issues of application [3].

2.0 THE YORK ENERGY DEMONSTRATION PROJECT.

The housing stock in York is typical, not only of much local authority housing but of a very large proportion of all UK dwellings. The houses in the studies were two storey semidetached or terraced houses with pitched roofs and masonry cavity walls. York has just under 75,000 dwellings of which about 9,500 are owned by the local authority. The project involved about 230 dwellings in three schemes. The schemes and monitoring arrangements are set out in table 1. The 4 house scheme established the highest efficiency standard and was designed to demonstrate 4 different heating systems (two gas and two electric), combined with a high level of insulation and airtightness. The 30 house scheme sought to incorporate energy efficiency improvements into an existing modernisation programme and provided an opportunity to monitor energy performance against a control group of properties taken from the same programme. This enabled comparisons to be made between energy efficient and non-energy efficient modernisation policies. Window frames were not replaced and this resulted in a lower efficiency standard than the 4 house scheme. The final scheme was an attempt to replicate the 4 house standard in a full modernisation scheme of about 200 dwellings.

Scheme	*Energy Efficiency works*	*Monitoring*
4 House scheme	*Fabric improvements* 200mm. loft insulation. cavity wall insulation[1], 20mm low emissivity double glazing in new timber frames, factory fitted draught proofing to all window and door frames. *Heating systems* 4 different systems used: Gas systems - condensing boiler central system and gas unit heater system. Electric systems - Off-peak electric boiler system and air-air heat pump with resistance heating back-up.	*Short term* co-heating tests[2] before and after improvements. Pressurisation tests before and after improvement. *Long term* internal temperatures and energy consumption - May 92 to May 93. Energy flows disaggregated.
30 House scheme	200 mm loft insulation. blown fibre cavity wall insulation[3], draught-proofing to existing windows and doors. Central heating system with gas condensing boiler.	Internal temperatures and gross energy consumption for the period Nov. 1992 to March 1994.
200 house scheme	Fabric improvements as the 4 house scheme and most houses were fitted with gas boilers (a mixture of condensing and non condensing boilers). Some houses had one non-cavity wall which was not insulated.	Internal temperatures and gross energy consumption were monitored in a sample of 10 houses.

Notes: 1. Blown fibre in gas houses, polyurethane foam in electric houses

2. Co-heating tests give an estimate of the heat loss coefficient of a dwelling - see Everett 1985 and Lowe & Gibbons 1988.

3. Dwellings in this scheme had a complex mix of cavity, solid and timber frame walls, each requiring different treatment.

Table 1: Description of schemes

3.0 RESULTS

3.1 4 House scheme

Monitoring of the 4 houses consisted of short term before and after measurements of whole house heat loss using co-heating and pressurisation tests, together with the long-term monitoring of the dwellings in occupation during the 12 months after improvement. It was not possible to monitor the occupied dwellings before the works and therefore estimates of before consumption were made using NHER evaluator (based on BREDEM [4]).

Short term monitoring of fabric improvements showed a reduction of 43% in whole house heat-loss (from 223 W/°C to 127 W/°C) and pressurisation tests revealed a reduction of 65% (from 18.1 ac/h@50Pa to 6.4 ac/h@50Pa). After improvement, the houses were among the most airtight in the UK and considerably more airtight than the UK average of 14 ac/h@50Pa [5]. Much of this improvement is likely to result from the draught proofing improvements built into door and window replacements and also reflects the intrinsic airtightness of wet plastered masonry [6]. Two of the houses (electric systems) received polyurethane foam cavity fill and this may also have contributed to the improvement.

Scheme	before improvement				after improvement			
	kWh			tonnes	kWh			tonnes
	gas	elec.	total	CO_2	gas	elec.	total	CO_2
Gas House A condensing boiler	23900	4300	28200	8.4	13160	1209	13369	3.8
Gas House B gas unit heaters	23900	4300	28200	8.4	11535	1524	12059	3.8
Elec. House A off-peak elec.	n/a	24800	24800	17.5	n/a	12225	12225	9.0
Elec. House B air-air elec. heat pump	n/a	24800	24800	17.5	n/a	12296	12296	9.0

Table 2 Energy and CO_2 - 4 House scheme

The results of long term monitoring are summarised in table 2. Three of the houses performed largely as predicted (to within 3% on average) but one of the electric houses (the most experimental of the four, which was fitted with and air-to-air heat pump) did not. Installation and user control problems resulted in the heat pump not operating effectively for much of the time and a great deal of heating was provided by direct on-peak resistance heating. The savings in delivered energy across all houses is about 14,000 kWh representing a reduction in the region of 50% on the calculated "before" consumption.

Mean internal temperatures after improvement in the gas houses (17.3°C and 16.9°C) were perhaps a little on the low side but compared well with averages of 17.9°C and 17.4°C in the two groups of the 30 houses scheme. The temperature of 19.6°C in Electric House A was high by UK standards. The temperatures achieved are broadly in line with estimates of affordable warmth requirements [7]. CO_2 emissions show a reduction of about 50% in all houses but absolute levels in the electric houses are high compared with the gas houses, reflecting the large CO_2 overhead on UK electricity generation.

3.2 30 house scheme

Reliable data was available from 21 dwellings in the experimental group (energy efficiency improvements) and 11 in the control group (modernisation only). A comparison of the energy characteristics of both groups revealed that they had almost identical energy characteristics prior to works being carried out. The groups were monitored over 17 months (Nov. 92 to March 94) which enabled data to be collated over two heating seasons. Both groups maintained similar internal temperatures with an average heating season temperature of 17.9°C in the experimental group and 17.4°C in the control group.

Group	Gas		Electricity		Totals		
	kWh	Cost £	kWh	Cost £	kWh	Cost £	CO_2 (Te)
Experimental	19313	348	3138	292	22451	640	6.5
Control*	24458	430	3529	322	27987	752	8.0
Difference	5145	82	391	30	5536	112	1.5

* Consumption in control houses has been adjusted by +1366 kWh to allow for the difference in mean internal temperature.

Table 3 Energy consumption - 30 house scheme

Table 3 summarises the energy consumption in both groups. Since all houses were heated using gas, a significant difference in gas consumption was to be expected. The observed difference in gas consumption (5145 kWh) was significant at the 5% level (P=0.022) but there was no significant difference in electricity consumption (P=0.201). The observed difference in gas consumption was, however less than half the difference (11,100 kWh) predicted by theoretical modelling.

3.3 200 house scheme

Reliable energy data was available from a sample of 10 houses in this scheme and temperature data from only 5. Mean total delivered energy consumption was 18,600 kWh/a and the median heating season internal temperature was 18.8°C, a figure slightly higher than observed in the other schemes. These results place the 200 house scheme midway between the other two schemes. Although efficiency measures in the 200 house scheme aimed to emulate the 4 house standard, there were important differences which included, variations in house construction and the choice of non-condensing boilers by some tenants.

4.0 DISCUSSION

Figure 2 compares consumption and temperatures for the three schemes set against the base line of York's modernisation standard prior to the project (30 house control group). This comparison demonstrates the extent of efficiency improvements which were achieved over all schemes.

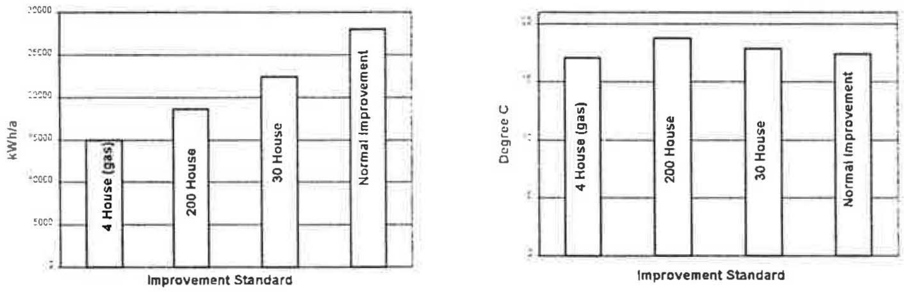

Figure 2 Comparison of energy and temperatures.

The project made an important contribution to the dissemination process in York and has resulted in major changes to York's modernisation policies. The most important of these, was a decision in 1993 to insulate all cavity walled dwellings in the Authority's stock (8,000 dwellings out of a total of 9,600). In addition, the project also provided greater insight into issues of implementation.

4.1 Cost and pay-back issues

The pay-back time in the 4 house scheme was 2 years if based on a comparison of calculated "before" and measured "after" consumption (£1000 capital cost giving a saving of £500 pa). However, this simple analysis hides the fact that some of the added befit of energy improvements would be taken as greater warmth. The likely cash benefit can be assessed by a direct comparison between the 4 house gas systems and the "normal" improvement standard established by the 30 house scheme control group. The pay-back time based on this comparison is 5.8 years for Gas House A (condensing boiler scheme - savings of £175 pa) and 1.9 years for Gas House B. The very short pay-back time for this house is the result of a heating scheme (3 unit heaters) which was £430 cheaper than the central heating scheme used in the control group, resulting in a net capital cost of only £330.

The 30 house scheme presented a much more complex pay-back picture. The pay-back period was 17.6 years if based on measured data (£1442 capital cost and savings of £82 pa) and 8 years if based on calculated energy savings. The high cost resulted from house constructions which were a mixture of cavity wall, solid wall and timber mansard wall. In some cases all three were found in the same house type. This resulted in the need for small areas of drylining and reinstatement of finishes, all of which were much more expensive than cavity wall insulation. In addition, the 30 house experimental group incurred draught stripping costs of £182 per house which were not incurred in the 4 or 200 house schemes because draught stripping was incorporated into replacement window frames. A detailed pay-back analysis of the most complex house type indicated that if drylining and draught proofing works were omitted, the pay-back time could be reduced to 8 years (4.5 years if calculated savings were applied). Although on financial grounds there would seem to be little justification for the additional wall insulation works, there are important amenity and comfort issues which should be considered.

The experience of the 30 house scheme indicates the importance of a full assessment of the needs of each house type and the importance of seeking ways to reduce capital costs. The costs of drylining were high, partly because contractors were unfamiliar with the process. Larger contracts and more experience could be expected to result in lower unit costs. Capital costs are also influenced by detailed design issues. The lack of experience with insulated houses and condensing boilers led to a tendency to over size the heating system. Although this did not have an impact on system efficiency, there was an additional capital cost. Further reductions in capital cost can also be achieved by adopting an opportunistic approach to modernisation and maintenance which seeks to incorporate energy efficiency works into mainstream programmes at marginal cost.

4.2 Use issues

Monitoring data from the 30 house scheme show a large variation between the measured difference in energy consumption and that which was predicted by the modelling program. The measured difference in gas consumption was some 54% less than that which was predicted (5145 kWh measured - 11180 kWh predicted). Such a variation is not uncommon. Other studies have reported a large variation in space heating consumption for houses with the same physical characteristics [8]. Use factors are usually cited as the principal reason for such variations. Although the monitoring of use was outside the scope of the study, an attempt was made to assess this aspect in a qualitative way and a detailed interview was carried out with the occupants of one of the experimental houses.

The house in question displayed an energy consumption about 40% above the predictions of the modelling system despite internal temperatures similar to those which were predicted. The use of the gas fire in the main living room, running independently of the central heating system, seems to have been a major factor. The fire was used for about 10 hours a day at an efficiency just below 50% (compared with the condensing boiler at about 85%) and provided almost all the living room heat. The effect of this was to reduce overall system efficiency. A crude assessment suggests that this could account for almost half of the variation. Similar fires were used in almost all modernisation schemes with most tenants (80%) using some combination of fire and central system. Although it is not possible to come to firm conclusions from a small number of dwellings, it is interesting to note that in the 4 house scheme where secondary heat sources were either not provided or not used, the variation between measured and predicted consumption after improvement was very small.

5.0 CONCLUSIONS

Figure 3 compares the energy consumption in the best of the York houses (4 house scheme) with the GB average [9] and three new-build, low energy, schemes. The Pennyland scheme [10] represents one of the best low energy schemes of the 80s, the Longwood [11] and Kranichstein schemes [12], demonstrate the levels of consumption which are likely to be required in order to stabilise atmospheric CO_2.

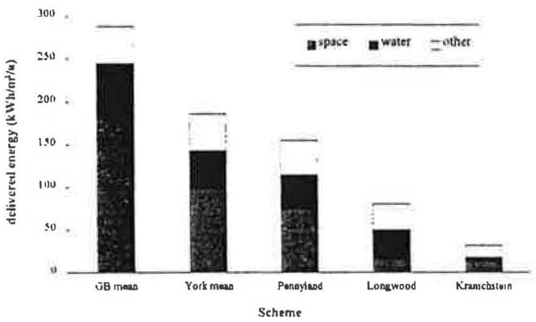

Figure 3 The York scheme in context

Despite the fact that the best York houses showed an energy consumption some 30% less than the GB average, further improvement is possible without major structural works. The use of argon filling and insulated edge spacers in glazing units could reduce overall window U values from about 2.5 W/m^{2}K to 1.5 W/m^{2}K and the addition of a further pane of glass could result in U values below 1 W/m^{2}K. The use of insulated doors would add further improvements. Such improvements to doors and windows would reduce total heat loss by about 20% compared with the level already achieved. The reduction of thermal bridging in roofs (gable and party walls and at eaves) could be achieved at marginal cost by adding external insulation during roof renewals. Further reductions in energy demand for domestic hot water could be achieved through the use of active solar water heating and water saving devices such as aerating taps. Crude estimates of the likely impact of these improvements coupled with significant improvements in domestic appliances could (using current technology) reduce energy consumption in the houses in York by a further 30% to 40% (to about 110 kWh/m^2/a). To go much further is unlikely to be realistic. Even without these additional measures, the approach adopted in York could have a major impact on energy consumption in the domestic sector if replicated effectively. Achieving the necessary replication in all housing sectors will, however, require an understanding of the social and economic aspects of design, construction and maintenance as well as the technological aspects.

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