The York Energy Demonstration Project

Final Report

by
Malcolm Bell and Bob Lowe

LEEDS METROPOLITAN UNIVERSITY

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To the staff at York City Council and to all council tenants in York.

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Executive summary

The York Energy Demonstration Project was conceived in 1991 as part of the Department of Environment's Greenhouse Programme. The purpose of the Greenhouse Programme was to support a number of energy efficiency projects in local authority housing, which would serve as models for future housing modernisation and refurbishment schemes. York was chosen as a flagship scheme in the Northern region. In total some £1.5 million was allocated to York City Council to fund energy demonstration work which involved improvements to over 230 dwellings. The impact of the energy efficiency improvements was monitored by a team of York’s technical staff, supervised by Malcolm Bell and Robert Lowe from Leeds Metropolitan University. The purpose of this report is to present the results of the monitoring work and the main findings of the project.

The York Project was based on 2-storey brick and block terraced dwellings constructed in the 1940's and 1950's. These had not been previously been refurbished, and were heated by a combination of gas fires and electric immersion heaters. The project was made up of the following three schemes:

- **The 4 House Scheme** This scheme involved insulation improvements to 4 dwellings which achieved a standard some 20% to 30% higher than the 1990 building Regulations (the then current standard). Four different heating system were installed (two gas and two electric) and the performance of each house was monitored in detail.

- **The 30 House Scheme** The objective of this scheme was to assess the impact of energy improvements at a lower standard than the 4 House Scheme within the context of York's existing modernisation programme. 30 houses from the 1992 modernisation programme were improved to an insulation standard some 10% below the 1990 building regulations level, and fitted with gas condensing boilers in place of the boilers used in York's standard modernisation scheme. The 30 houses were monitored and compared with a control group of houses, modernised at the same time, but which did not receive the additional efficiency works.

- **The Bell Farm Scheme** This scheme attempted to apply the standard achieved in the 4 House Scheme to a full modernisation scheme of around 200 houses in the Bell Farm area of York. A sample of 12 houses were monitored and in addition to comparing the results with those from the other two schemes, an attempt was made to assess the likely impact of energy advice given to the occupants.

Summary of results

4 House Scheme

The monitoring of the 4 houses indicated that the insulation and airtightness improvements made a significant impact on heat loss. The measurements of heat loss, which were made before and after the works, showed a reduction in the region of 40%. Long term monitoring demonstrated that three of the 4 houses performed largely as predicted but that one of the electric houses (the most experimental of the 4, fitted with an air-to-air heat pump) did not. This was mainly because the heat pump did not operate for long periods and the efficiency gains expected from it were not therefore realised.

It was not possible to measure energy use in these houses before the renovation. Energy consumption before renovation is based on theoretical calculations. The reductions in energy use as a result of the improvement packages were derived by comparing these calculated figures with the actual energy used after the improvements. The resulting energy saving is about 50% (some 14,000 kWh/a) representing a potential cost saving of around £500 per year. It is possible some of the benefit of the energy improvements in the 4 House Scheme were taken as higher internal temperatures, and that the actual cash saving would be less than this. A more direct comparison can be made with the results from the control group in the 30 house scheme. The difference in energy cost was £174 (about 11,000 kWh) and the additional capital cost (for the condensing boiler scheme) in the region of £1010. This gives a simple pay-back period of between 5 and 6 years.

CO_2 emissions were reduced by about 4 tonnes per year in the gas houses (from 8 to 4 tonnes) and by about 9 tonnes per year in the case of the electric house (19 to 9 tonnes). The difference between the two fuels is a function of the large CO_2 overhead associated with the conversion of primary fuel to electrical energy in power stations. In comparison with the control group in the 30 house scheme, the gas houses achieved a reduction of more than 2.4 tonnes/house/year (electricity use in the 2 gas heated houses in the 4 House Scheme was roughly half that in the 30 house, but the figure of 2.4 tonnes/house/year quoted here is based only on the reduction in gas use).

30 House Scheme

Although access difficulties and equipment failures reduced the numbers of monitored houses to 21 in the experimental group (those receiving the energy improvements) and to 11 in the control group (which received York's standard Tenants' Choice modernisation package), there is a clear, significant difference between the energy consumption in the two groups. The two groups of houses maintained similar internal temperatures over the monitoring period with the control group operating at an average winter temperature some 0.5°C below that of the experimental group. Allowing for the small temperature difference, the experimental group consumed around 5,150 kWh of gas per year less than the control group. This represents about £82 in fuel cost and was statistically significant at the 3% level. This figure was however considerably smaller than predicted by the computer model under standard conditions. Although there is a wide range of use factors which would account for this discrepancy, anecdotal evidence indicates that one of the most important factors is the installation of a gas fire in addition to the condensing boiler. Use of the gas fire for long periods could reduce overall heating efficiency by a large amount. This effect is likely to be more marked in the experimental houses since the efficiency difference between boiler and gas fire is greatest in these houses.

The average capital cost attributable to energy improvements was £1442 and the simple pay-back time was 17 years based on the measured energy use (8 years if predicted figures are used). The costs of wall insulation are largely responsible for the high capital cost since wall constructions were a mixture of cavity masonry, solid masonry and timber frame. An analysis of the most expensive house type shows that the cost of insulating the non-cavity sections of wall is very large in relation to the energy savings which result. If the non-cavity insulation was omitted from the package applied to these houses, the resulting pay back times would be between 5 and 8 Years.

A detailed analysis of the cost effectiveness of each measure is contained in chapter 3. Figure 0.1 summarises the results of that analysis. When interpreting these results it must be remembered that the effectiveness of a single measure will depend on the order in which it is applied with respect to other measures. Figure 0.1 has been calculated assuming that the measure in question is applied last. This means that the insulation measures will show their maximum saving but the improved boiler efficiency will show its lowest saving (see chapter 3 for a more detailed explanation).

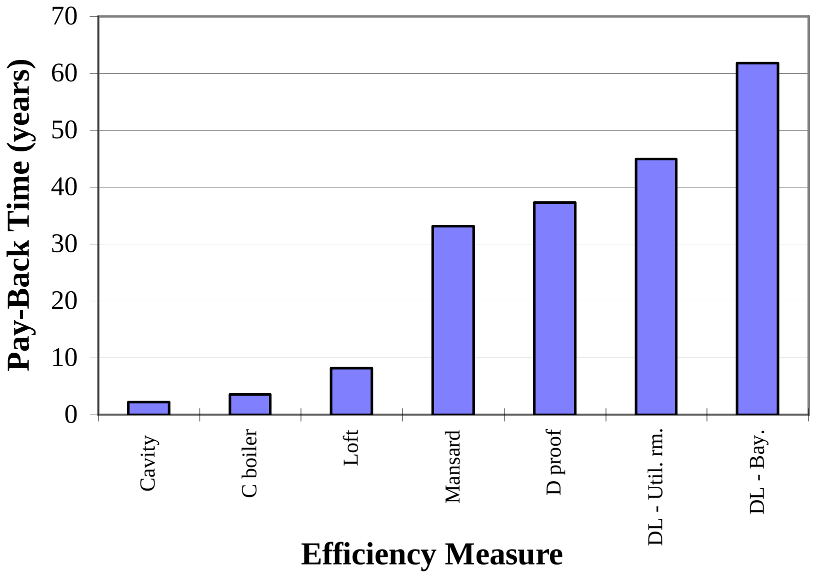

Figure 0.1 Pay-back analysis; house type C

Tenant perceptions were surveyed before and after improvements in both groups of houses. In both groups, tenants felt warmer after the modernisation and displayed greater satisfaction with their heating systems. Temperature monitoring showed that average temperatures, although slightly higher in the experimental group, were within an acceptable range in both groups of houses. The main areas of difference between the two groups were the fact that the number of tenants reporting condensation problems had reduced in the experimental group after the improvements, but did not reduce in the control group. Also the level of concern with heating bills was reduced in the experimental group but remained the same in the control group.

The Bell Farm Scheme

In terms of energy use, the Bell Farm Scheme was midway between the 4 House Scheme and the 30 House Scheme. The attempt to measure the effect of energy advice at Bell Farm was inconclusive.

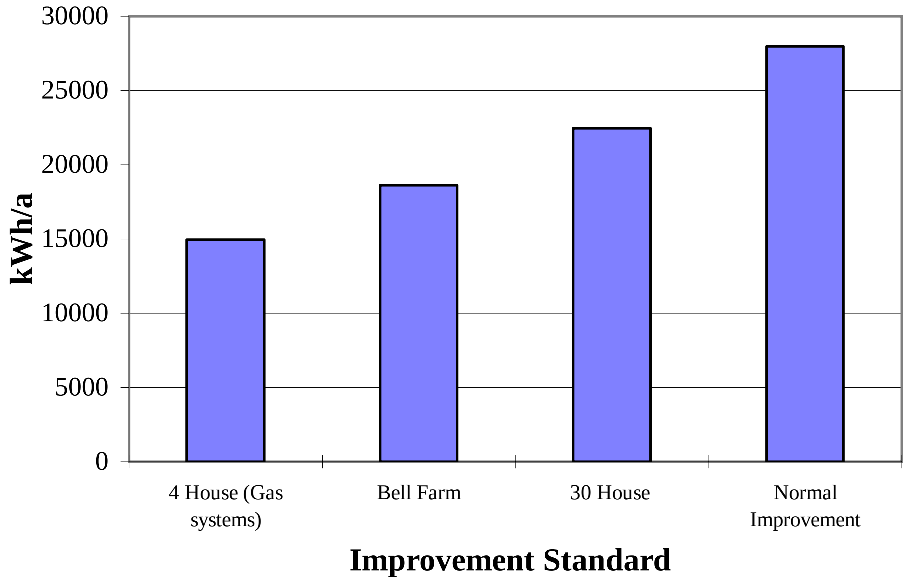

Figure 0.2 Total energy consumption; all schemes

The York project in context

Figures 0.2 and 0.3 compare the results from each of the schemes against the base line of the modernisation standard used in York at the beginning of the project. The messages which emerge from these figures are as follows:

- Given the type of low-rise, traditionally constructed housing featured in this project, the application of simple cost-effective methods of improving energy efficiency can reduce energy consumption by between 40% and 50% when compared with a modernisation standard which is typical of many local authority schemes. The additional costs are not excessive, with pay-back periods for entire packages of typically less than 10 years, and in one case as little as 2.5 years.

- The similarity in temperature across all groups indicates a desire to achieve thermal comfort, even in houses which are less well insulated. This means that efficiency improvements at York resulted in most of the benefits being taken as energy savings rather than additional warmth. In the 30 house scheme the difference in internal temperatures suggests that approximately 75% of savings were taken as a reduction in energy consumption (and expenditure).

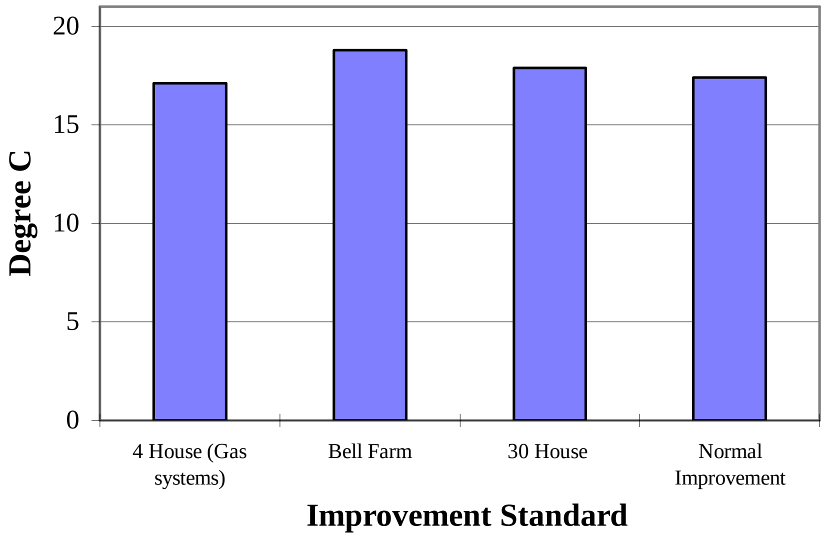

Figure 0.3 Internal winter temperatures; all schemes

Figure 0.4 compares the energy standard achieved in the 4 house scheme with the average for the UK housing stock (Shorrock & Brown 1993 and DoE 1993) and with three low energy new-build schemes - the Pennyland houses (Lowe et al. 1985), representing the best of the UK low energy projects of the 1970's and 1980's, the Longwood House (Lowe and Curwell 1996), representing one of the most energy efficient UK schemes of the 1990's, and Kranichstein (near Darmstadt in Germany) representing the best of the low energy housing projects currently being undertaken in Europe (Feist 1994). Pennyland and Longwood address the concerns of the 1970's, which were the exhaustion of fossil fuels, and security of supply. Kranichstein addresses the much more demanding agenda of the 1990's, which is the stabilisation of atmospheric CO_2 concentration.

The standard achieved in existing houses at York is well ahead of the national average and illustrates the potential which exists in the existing stock for reducing energy use and carbon emissions. Nevertheless, further reductions in energy use are technically and economically feasible, and necessary, in view of the need to reduce the environmental impact from existing housing. The likely impact of such reductions are indicated on figure 0.4 and can be achieved in the following ways:

- Glazing and external doors are areas where significant additional improvements can be achieved in the short term. Application of best available technology to these areas could reduce heat losses from the best of the houses at York by a further 20%. This would bring overall energy use close to that achieved at Pennyland in the early 80s, a level which is still rarely bettered in new housing.

- In the longer term, measures to reduce the considerable thermal bridging through the roofs of traditionally built houses (at eaves, and party and gable walls) could be undertaken in conjunction with re-roofing. This probably represents the limit to what can currently be achieved cost effectively. Further reductions in heat loss would require technologies such as external insulation of existing cavity walls, a step which would not normally be undertaken.

- Further reductions in energy use for water heating can be made by the fitting of showers, the use of aerating taps, the systematic application of thermal insulation to all pipework within the house, and by further increasing the thickness of thermal insulation applied to cylinder. These measures would reduce energy use for domestic hot water by up to 30%.

- Very significant reductions in energy use are possible by the systematic application of best available technology to lights and electrical appliances. Estimates of savings range upwards from 60% (March Consulting Group 1990; Nørgard 1989). Improvements in this area can in principle be undertaken very quickly, due to the relatively short life of most electrical appliances, but are difficult to achieve institutionally.

- The final area in which improvements can be made is in energy supply systems. Options include the use of solar hot water heating, small-scale combined heat and power, and the application of photovoltaics.

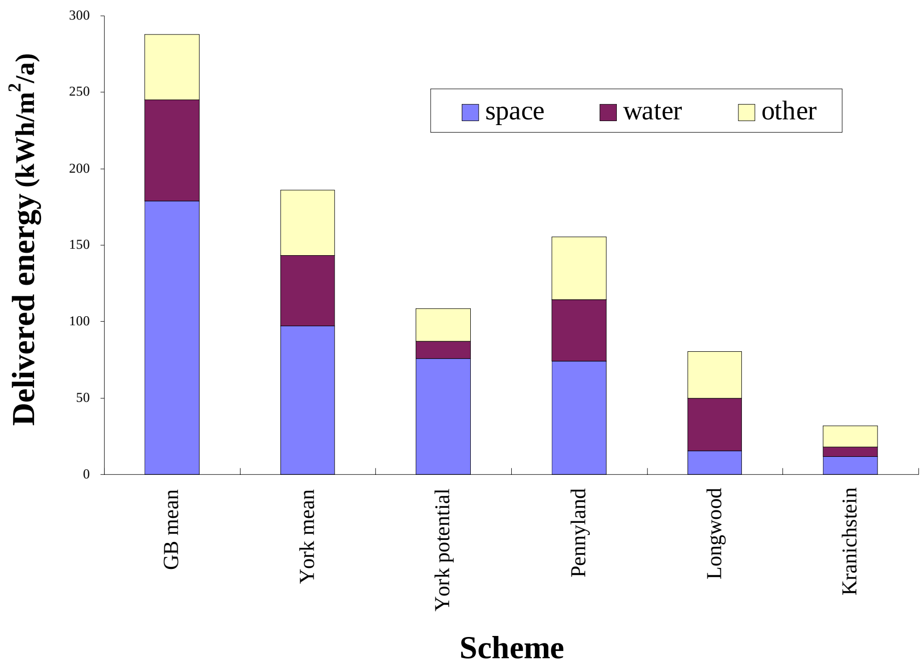

Figure 0.4 Comparison of energy standards

Our final conclusion is that although we have already almost halved energy use in existing houses at York, further significant reductions are technically and economically feasible. By applying reasonable additional measures to improve fabric performance, by applying sensible conservation measures to domestic hot water, and with the use of the most electricity efficient lights and appliances, energy use in the 4 House Scheme at York could be brought down to around 130 kWh/m²/a. Application of solar water heating could bring this down to 110 kWh/m²/a, a level of performance that, in the UK to date, has been met by only a handful of new houses (Olivier et al. 1996).

1 Introduction

1.1. Objective

The objective of the York Energy Demonstration Project (YEDP) was to demonstrate the potential impact of energy efficiency measures on the modernisation and improvement of existing low-rise housing. This project is one of a number of demonstration projects set up under the UK Government's Greenhouse Programme (DoE 1994) which was designed to provide energy efficiency models for the future modernisation and improvement of local authority and other social rented housing. In common with other Greenhouse demonstration projects the York Project concentrates on well tried and tested methods of improving energy efficiency, the emphasis being on replication of well understood technology. The only exception to this is a heat-pump heating and ventilation system in one of the houses in the 4 house scheme. Three individual schemes make up the project each with a different emphasis and these are outlined in section 1.4 below.

In order to identify and disseminate the lessons from the project, each scheme was monitored over a one to two year period. This report sets out the results of the monitoring and draws conclusions on the wider application of energy efficiency in housing modernisation and maintenance.

1.2. Importance of energy efficiency

Improving energy efficiency is now a fundamental requirement of the design, construction and modernisation of buildings. This is so for a number of important reasons, any one of which would provide sound justification for continued emphasis in this area. At an environmental level, the emission of CO_2 into the atmosphere which results from the burning of fossil fuels is a major cause of climate change. Reducing the current level of emissions is crucial if the consequences of increased global temperatures are to be avoided. On a social level, the ability of the poor and vulnerable sections of society to afford the levels of warmth required for health and comfort is heavily influenced by the efficiency of the dwelling in which they live. In national economic terms, the long term availability of energy and security of supply are also of crucial importance.

1.3. Importance of existing housing

In 1990, housing accounted for 27% of national energy consumption and a similar fraction of CO_2 production. Given this fraction, it is clearly important that housing modernisation policies take account of the need to improve energy efficiency. Many projects over the last 20 to 30 years have concentrated on developing the design of new housing and improving building regulations (see for example. DoE 1981, Everett et al 1985). However, in the UK dwellings have a long physical life. Since 1970, demolition rates have declined and are probably running at about 20,000 per year, about 0.1% of stock. The long term annual rate of new construction is around

200,000 or 0.9% of stock (DoE 1991). Dwellings built after 1990 will probably constitute about 8% of the total by the year 2000, and less than 40% by 2050. To a large extent, new construction adds to the existing dwelling stock, rather than replacing it. Reductions in total domestic energy consumption will therefore only come about if radical improvements in the performance of new dwellings are coupled with similar improvements in the performance of the existing stock.

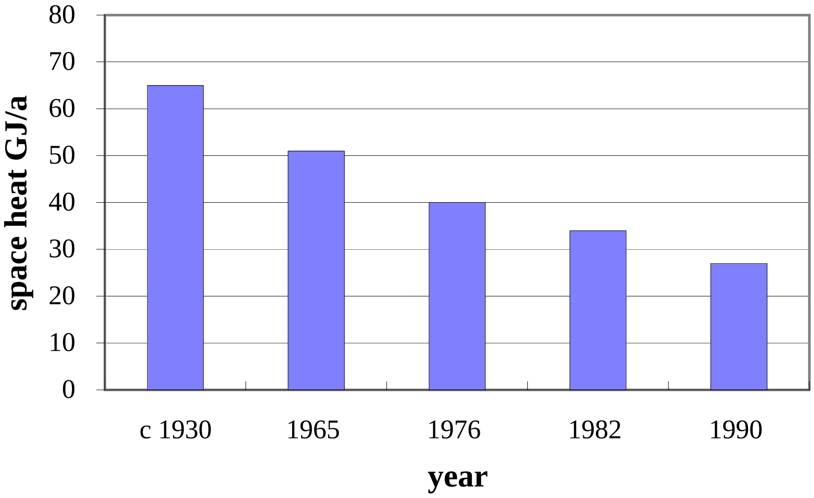

Figure 1.1 Impact of Building Regulations on Energy Use (semi with well controlled central heating)
Source: Anderson 1988, crown copyright.

Figure 1.1 illustrates the considerable variation of energy efficiency standards which exist within the British housing stock[1]. Although such an analysis, based on age, is crude it, nevertheless, provides a broad indication of the potential which exists in the existing stock. Attempts over the last 20 years to improve the efficiency of the national housing stock have concentrated with success on loft insulation and lagging of hot water storage cylinders. By 1991 some 90% of accessible lofts had been insulated with an average depth in the region of 85mm and over 90% of hot water cylinders lagged. Other important areas, notably masonry cavity walls and windows have also seen some improvement. Cavity wall insulation has lagged behind double glazing with only about 22% of cavities insulated by 1991 compared with 51% of dwellings having some windows double glazed (Shorrock et.al 1992 and Shorrock & Brown 1993). This apparently high figure is, however, not a true reflection of the extent to which the potential for glazing improvement has been realised. Only 46% of double glazed dwellings have all rooms treated, with the average percentage of rooms treated standing at 65%. In addition, very few houses are likely to be fitted with high performance double glazing units which have almost double the insulation performance of older units. Given the above analysis, the potential for further improvement in glazing (with existing commercially available technology) is more likely to be in the region of 85%.

The York Energy Demonstration Project addresses the energy conservation opportunities which present themselves in housing modernisation programmes. The results from the project suggest

[1] The analysis in figure 1.1 predates the 1995 building regulations. However the energy rating attained in a similar house in the York project (gas houses - 4 house scheme) approximates to the 1995 regulations and gives a figure of around 20 GJ/a for space heat.

that this approach can unlock a large potential within the existing stock for reductions in energy consumption and CO_2 emissions.

1.4. The York housing stock and design of schemes

The Local Authority housing stock in York consists mainly of two storey semidetached and terraced housing of traditional construction based on brick cavity walls and pitched tile and slate roofs. The City Council own some 9,500 dwellings, which makes up about 15% of the total dwelling stock in the local authority area[2]. Around 75% (7,280) of council owned dwellings were built prior to 1964. Although the data in figure 1 would suggest that there is much which could be done to property of all ages, the project has concentrated on the pre 1964 stock, particularly those constructed in the 40s and 50s (around 3,500 dwellings) which form York's current modernisation target group. Notwithstanding the local authority focus of the project, many of the measures adopted have application in both public and private sectors.

The assessment of energy conservation options, and the design of coherent packages of measures was carried out using the National Home Energy Rating programs produced by the National Energy Foundation (for discussion of a precursor to these programs, see Chapman, 1990). These in turn are based upon the BREDEM algorithm developed by the Building Research Establishment (Anderson et. al. 1985 and Anderson 1985). They provide energy and cost estimates based on standard use patterns. For the YEDP, all assessments assumed a dwelling occupied by 2 adults and 2 children, maintaining a living room temperature of 21°C for 9 hours per day. The NEF programs provide both an energy cost rating index (NHER) and a building energy performance index (BEPI). The NHER index is based on the total cost of energy for all end uses, and rates a house on a scale of 0 to 10 - the lower the score the less energy efficient the house is and the more costly it is to run. A dwelling built to 1990 building regulations achieves a BEPI of 100, and an NHER rating between 5 and 7.5, depending mainly on heating system.

The demonstration project consisted of 3 individual improvement schemes which are outlined below.

1.4.1. The 4 house scheme.

This scheme was designed to investigate a small number of properties in detail. It involved insulation improvements to a standard some 20% to 30% higher than the 1990 building regulations (the standard at the time the schemes were constructed) and explored 4 different heating strategies, two gas systems and two electric. The insulation measures consisted of cavity wall insulation, loft insulation (200mm) and replacement timber windows with low-emissivity double glazing and draught seals. Works to improve the airtightness of the houses were also carried out where appropriate. Monitoring of this scheme was done in two stages. Stage one was done on a before-and-after basis in order to provide a measure of the effectiveness of the improvements. This involved the direct measurement of the heat loss characteristics of the house fabric. Stage two consisted of long term monitoring designed to assess the performance of the houses during occupation. Internal and external temperatures and energy consumption were monitored over a twelve month period after the works and in some cases energy consumption

[2] In 1996 the City of York became a unitary authority and its boundaries were extended to take in a number of urban fringe areas and small rural settlements. The current authority has a population of 174,000 living in just under 75,000 houses. At the time the demonstration project was carried out the pre-1996 authority contained some 44,000 houses 22% of which were owned by the Local Authority.

was disaggregated to enable the effectiveness of heating systems to be understood in more detail. The effects of the measures were estimated by comparing measured energy use after improvements with predictions (based on the NHER/BREDEM model) for the houses before improvement.

1.4.2. The 30 house scheme

The objective of this scheme was to demonstrate the implementation of energy efficiency within an existing modernisation programme. Improvements consisted of wall insulation, loft insulation (200mm) and draught proofing to existing doors and windows. No glazing improvements were carried out. The level of insulation achieved was some 10% below 1990 building regulations levels. Gas wet central heating and hot water systems were installed using a condensing boiler (an improvement in efficiency of around 20% over the type of boiler installed on standard modernisation). Monitoring of this scheme was designed to test the difference between existing modernisation standards and the enhanced standard achieved in the 30 houses. In order to do this a control group of 20 houses was to be established which were drawn from the same modernisation scheme but improved to the normal modernisation standard used in York at the time. This standard provided for the refitting of kitchens and bathrooms together with minor alterations and repairs, but did not include any energy efficiency works other than the installation of a central heating system with a conventional boiler. This scheme presented a good opportunity to obtain a statistically convincing result based on actual consumption data. Monitoring consisted of internal temperature monitoring and gross energy consumption in each house.

1.4.3. The Bell Farm scheme

This scheme was carried out some twelve months after the 4 and 30 house schemes and sought to apply the 4 house standard to a full modernisation scheme of about 200 houses. The scheme was monitored using a sample of 12 houses in which internal temperatures and energy consumption were recorded over a 12 month period. In addition to being able to assess the performance of these houses against the other schemes, an attempt was made to assess the impact of simple advice to tenants covering a number of aspects of energy efficiency in the home. Halfway through the 1994/95 winter a simple advice sheet was given to the occupants of 8 out of the 12 monitored properties backed up by a personal visit from a member of the monitoring team. Energy monitoring then continued to the end of the winter and the results assessed.

1.5. Progress of works and funding

The project as a whole received over £1.5M from the Greenhouse Programme which provided £60m nationally for a range of Local Authority demonstration projects. The 4 and 30 house schemes received funding of around £327,000. Works on the 4 house scheme were completed in March 1992 and long term monitoring took place from October 1992 to mid 1994. Works on the 30 house scheme were completed in the summer of 1992 and monitored from November 1992 to March 1994. Funding for the Bell Farm scheme amounted to about £1.2M and the works to all properties were completed by April 1993. Monitoring took place from April 1993 to March 1995. In total, some 230 dwellings were improved to a standard close to or greater than 1990 building regulations standard and all schemes demonstrated significant energy and CO_2 savings. The detailed results of each scheme are presented in the following chapters.

2 The 4 house scheme

2.1. Rationale

The 4 House Scheme was set up to pursue three main objectives:

- to demonstrate a relatively high level of energy efficiency in a small number of houses;
- to explore a number of specific issues that required a more detailed level of energy monitoring;
- to provide the York Energy Demonstration Project with a focus for public education.

York City Council could not afford to pursue these objectives in all houses in the York Energy Demonstration Project. The reasons for this were partly financial, but also included practical considerations. The 4 House Scheme required that the houses be unoccupied for a period of some three months to allow direct measurement of the effect of the insulation package that was applied, and it would have been impossible to have found 50 empty dwellings in the York stock. It was also felt that the level of tenant participation, which is an essential part of York City Council's Tenant's Choice refurbishment scheme, would have been incompatible with the need to formulate and carry out a clear programme of energy related work in these houses.

The 4 House Scheme was based on two houses in the Chapel Fields estate on the western edge of York, and two houses on the Bell Farm estate, to the north of the city centre. Photographs of all houses are shown in figure 2.1. The monitoring plan for these houses envisaged two stages of monitoring, house calibration, and long term monitoring. The objective of house calibration is to measure the physical characteristics of the house which directly affect space heat demand, namely, the heat loss coefficient and air tightness. House calibration would involve fan pressurisation testing and co-heating tests, which would be carried out before and after dwelling improvements, with the houses unoccupied. The occasion of the co-heating tests was also used for an infra-red thermography survey.

The purpose of long term monitoring is to measure the combined performance of house envelope and heating system with real occupants in order to provide a clear demonstration under typical use conditions. Long term monitoring began in October 1992, and continued until late 1993 in the case of the Chapel Fields houses and mid 1994 in the case of the Bell Farm houses. The monitoring level was chosen to provide direct measurements of whole house temperatures and a fairly high level of disaggregation of energy uses in this group of 4 houses. Key variables were:

- condensing boiler efficiency in Chapel Fields A;

- on-peak/off-peak split, and MVHR heat recovery efficiency and electricity use in Bell Farm A;
- electricity use by heat pump and by back-up resistance heaters in Bell Farm B;
- disaggregation of cooking, space heating, hot water heating and electricity use for lights and appliances in all four houses.

Monitoring systems in all 4 houses were capable of recording hourly average data. Toward the end of the project, dataloggers were reset to record daily averages. This significantly reduced the amount of data recorded, and allowed the dataloggers to be left running for several months unattended. Logged data was supplemented by manual reading of utility meters.

The main design aim in these houses was to demonstrate an energy performance significantly above the level set by the then-current Building Regulations for new housing (DOE & Welsh Office 1990), within reasonable bounds of cost and practicability. This aim was translated into the objectives of achieving Building Energy Performance Indices (BEPI) of over 100 and National Home Energy Ratings (NHERs) of 8 or above in each house, with pay-back times significantly less than 20 years.

A secondary aim was to use each of the 4 houses to demonstrate a different approach to space and water heating. It was decided that two of the houses would be used to demonstrate gas heating systems, and that two would be used to demonstrate electric heating systems.

Table 2.1 Description of houses before improvement

	Chapel Fields Houses	Bell Farm Houses
House type	Two bedroom, semidetached constructed in the 1950s.	Three bedroom, semidetached constructed in the 1930s.
Construction	Load-bearing cavity brickwork with a pitched tile roof and solid concrete ground floor. Plan area 34.8m²	Load-bearing cavity brickwork with a pitched tile roof. Ground floor construction - part solid and part suspended timber. Plan area 37.5m²
Condition	No modernisation works since construction. Rewired and repaired only.	Some modernisation works in early 70s but in need of renewal. Rewired and repaired including roof renewal.
Existing Insulation	100mm loft insulation fitted within the last 5 years.	25mm loft insulation fitted in early 70s.
Heating & Hot Water	Gas fire in the lounge/dining room and hot water provided by an immersion heater fitted to a lagged cylinder.	Electric storage heaters and electric fire in the lounge, both dating from the early 1970s. Hot water provided by economy 7 cylinder with mineral fibre lagging.

Bell Farm A&B from front.
Note external temperature sensor at top left hand corner.

Bell Farm A&B from back.

Chapelfield A from front.

Chapelfield A from back.
Note boiler flue to left of kitchen window, and infra-red camera in foreground.

Chapelfield B from front.
Note flue for wall mounted heater below living room window.

Chapelfield B from back.
Note flue for wall mounted heater below living room window, and flue for multi-point water heater to left of kitchen window.
Solarimeter is mounted at eaves.

Figure 2.1 The 4 House Scheme dwellings

Given the style of houses and the fact that the existing single glazed windows were at the end of their lives and needed to be replaced, the choice of fabric improvements was relatively straightforward. The package of improvements consisted of; loft insulation improved to 200mm, cavity wall insulation (60-65 mm cavities) and 20mm low emissivity double glazing units in new softwood window frames. All new window frames incorporated draught seals and trickle ventilation units. This package gave a BEPI of 119 in the two Chapel Fields houses and a BEPI of 130 in the two Bell Farm houses. The difference is accounted for mainly by the different cavity fill systems used. Blown fibre was used in the Chapel Fields properties and CFC free polyurethane foam in the Bell Farm case. Polyurethane foam is a better insulant but is much more expensive than blown fibre. The effect of this on the capital cost and energy cost picture is discussed below. Details of the houses prior to the works are given in table 2.1. The heating systems used in each house are summarised in sections 1.1.1 and 1.1.2 below.

2.1.1. Gas heating systems

Chapel Fields A In this house a full central space and water heating system was installed, based on a gas condensing boiler, controlled by room thermostat, thermostatic radiator valves and a programmer. The objective was to demonstrate an efficient wet central heating system. The condensing boiler was expected to be around 20% more efficient than non-condensing gas boilers used in the majority of houses in York's modernisation programmes. The opportunity provided by the improved thermal insulation to reduce radiator sizes was taken. This reduced the capital cost of the radiators and minimised the amount of wall space taken up.

Chapel Fields B used a contrasting system based on three gas wall heaters and instantaneous gas water heating. The wall heaters were controlled by integral thermostats and a programmer, which also provided timed control of the water heater. The objective here was to show that standards of warmth and energy efficiency similar to Chapel Fields A could be achieved, but at lower capital cost. The problem of partial central heating (based on Parker Morris standards (Morris, 1961)) in the very poorly insulated council housing of the 1960's still looms large in the minds of local authorities, and leads to overdesign of heating systems in better insulated houses. The important issue in Chapel Fields B is therefore the extent to which the improved insulation provides adequate thermal comfort, as perceived by the tenant, with a partial heating system.

It was realised that providing the two Chapel Fields houses with focal point gas fires would undermine the objective of reducing energy consumption in several ways:

- the flue and air supply vents that would be necessary with such devices would increase the ventilation rates in these houses;
- without thermostatic control, the gas fire would have become the “lead” heat source in both houses, and would have displaced the more efficient condensing boiler and gas wall heaters;
- the absence of thermostatic control on the gas fire would probably have led to unnecessarily high temperatures in both houses, and thus to a greater need for space heat.

A decision was therefore taken to omit the focal point fire from these houses. This resulted in a significant capital cost saving, improved safety, and reduced energy use.

2.1.2. Electric heating systems

Although the majority of tenants in York choose to have gas central heating systems in the modernisation of their homes, it was considered important that the electric option be included in the scheme.

Bell Farm A used off-peak electric resistance heating, coupled to a conventional hydronic radiator system. Water heating was provided by an off-peak storage cylinder with 75mm of polyurethane insulation (50% more than standard). To the householder, this system was similar to the gas central heating option. Mechanical Ventilation with Heat Recovery (MVHR) was also included in an attempt to reduce ventilation heat loss and to assess the possible condensation and air quality benefits. The MVHR system, which was supplied by ADM of Bradford, was expected to lead to only marginal reductions in energy cost, as MVHR consumes on-peak to save off-peak electricity. MVHR should however reduce annual CO_2 emissions in a sufficiently airtight house (see below).

Bell Farm B was the most experimental of the 4 houses and predictions of savings were more tentative than in the other cases. A warm air heating system was used which recovered heat from the outgoing air. The system used was a Genvex GE 215 VP system. In this system, heat is extracted from outgoing air, first by a heat exchanger which pre-warms the incoming air, then by a heat pump. If further heat is required to satisfy demand, electric resistance heaters are provided in the supply ducts, together with a focal point fire. This system was chosen in an attempt to reduce the CO_2 emissions from the house by making more effective thermodynamic use of electricity. However, because it was expected to use a higher proportion of on-peak electricity than Bell Farm A, the cost savings predicted were not as great. A sketch illustrating the principle of the Genvex system is shown in figure 2.2 below:

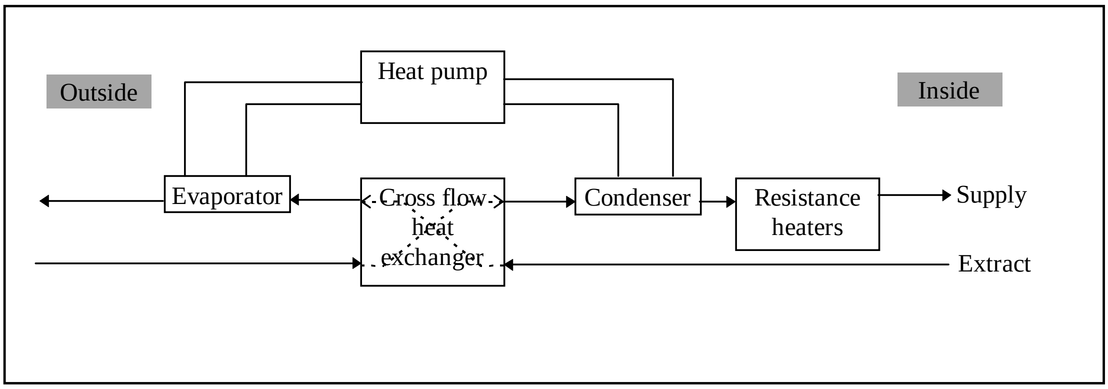

Figure 2.2 Warm air heating system used in Bell Farm B

Because both the Bell Farm houses made use of MVHR it was important that air leakage in each house be reduced to a minimum. In addition to the sealing of all windows and doors, the lounge suspended floor was sealed with thin plywood sheeting and further sealing of the structure was provided by filling the wall cavity with in-situ foamed polyurethane. Polyurethane foam costs some £1200 per house, compared with about £170 for blown fibre. Given such a large difference it is unlikely that improvements in air tightness and U value would tip the balance in favour of its use. However this type of system is used to stabilise walls which have suffered wall-tie failure. Where modernisation is to include wall-tie replacement, there may be merit in using the one material to perform 3 functions. Because of the experimental nature of this system and in order to present a more uniform picture, the cost and energy predictions presented later are based on blown fibre cavity insulation. The polyurethane foam reduces the thermal transmittance (U value) by about 0.1 W/m²°C, equivalent to a financial saving in the region of £10 per year. The reduction in air leakage, at a maximum of 2.5 ac/h at 50 Pa (see section 2.3.1 below), would be worth up to £5 per year. The two effects together would yield a pay-back time for installation of polyurethane foam instead of mineral fibre on energy saving grounds alone, of 60-70 years.

2.2. Predicted savings and capital costs

Details of capital expenditure on these houses are shown in table 2.2 below. All costs are net of the cost of general repair or improvement works. The cost of cavity wall insulation in the electric houses was based on the cost of blown fibre, despite the use in both houses of in-situ foamed polyurethane. As noted above, this was done to give a more balanced view of costs. Table 2.3 summarises predictions of annual energy use and expenditure, and CO_2 emissions for each house. These predictions were calculated using the BREDEM based NHER (Evaluator) programs, and were made before long term monitoring began. Heating and hot water costs are reduced by between 62% and 73%. This leads to a significant shift in the make-up of total energy costs, with electricity use for lights and appliances becoming more important. As with all predictions of this nature it is not clear to what extent the assumed temperatures and heating patterns in the model would be realised in practice. It is common when improvements in insulation and heating are made for part of the benefit to be taken in greater warmth rather than energy savings.

Table 2.2 Capital costs of measures

	Chapel Fields		Bell Farm	
	House A	House B	House A	House B
	(£)	(£)	(£)	(£)
loft insulation	240	240	240	240
wall insulation	160	160	170	170
low emissivity double glazing	330	330	295	295
draught sealed loft hatch	30	30	30	30
sealing of suspended ground floor	-	-	120	120
heating system	2550	1771	2945	2950
TOTAL COST	3310	2530	3800	3805

Table 2.3 also contains predicted savings in CO_2 emissions which show reductions of 55% in the case of the two gas houses and 58% to 70% (heat pump house) in the electric houses. The penalty of using electric resistance heating instead of gas is clear from the absolute difference in CO_2 emissions from the Chapel Fields A&B and Bell Farm A houses. Heat pumps can in

principle supply low temperature heat (< 100°C) with lower CO_2 emissions than gas fired heating. There are two reasons why Bell Farm B was predicted to emit more CO_2 than the gas heated houses: first, because water heating in this house is still provided by electric resistance heating; and second, because a significant part of the space heat in this house is provided by top-up resistance heating. Both of these issues will need to be addressed if electric heat pumps are to out-perform gas fired domestic heating in the UK.

Table 2.3 Energy and environmental; summary

Item	Chapel Fields			Bell Farm		
	A&B before	A after	B after	A&B before	A after	B after
Heating (£/a)	321	97	98	635	143	195
Hot water (£/a)	295	71	72	129	93	93
Other Energy Costs (£/a)	280	280	280	283	283	283
Total Energy Costs (£/a)	896	448	450	1047	519	571
Total Energy Consumption (GJ/a)	101.6	51	53.3	89.3	43.3	35.6
Carbon Dioxide (tonnes/a)	8.4	3.8	3.8	17.5	7.4	5.3
Building Energy Performance Index (BEPI)	59	119	119	57	130	130
National Home Energy Rating (NHER)	2.6*	8.3	8.3	2.4*	7.1	-
Capital Cost (£)		3310	2530		3800	3805
Simple Pay-back (years)		7.4	5.7		7.2	8

* Uncertified rating

The capital costs shown in table 2.3 are the cost of energy works net of costs relating to general improvement or repair. For example the cost of double glazing has been included, but not the cost of replacing rotten or poor quality window frames. Costs include: loft insulation, cavity wall insulation, the additional cost of low emissivity double glazing, the additional cost of a draught sealed and insulated loft hatch, sealing of suspended floors (Bell Farm houses only), and the full cost of central heating systems. With the life of the modernisation expected to be 30 years or longer, the predicted pay-back times of up to 8 years indicate a high degree of cost effectiveness for these house types. A discussion of relative cost effectiveness of individual measures is presented in chapter 5, but it is worth noting here that, for these houses, cavity wall insulation (blown fibre) is by far the most cost effective single measure with a pay-back time of between 1 and 2 years.

It should be noted that we have not included either the costs or the benefits of the MVHR system installed in Bell Farm A in the tables presented above. The benefits of MVHR include better air quality, reduced condensation and reduced energy use. The economic value of the first two is difficult to quantify. Measurements at Bell Farm were not precise enough to allow a direct quantification of the value of the energy savings due to MVHR, but it is likely to be small given the fact that the MVHR system uses unrestricted electricity (costing 7.7 p/kWh) to save heat produced by electricity at the off-peak heat rate (2 p/kWh).

2.3. Results: short-term monitoring

2.3.1. Fan pressurisation testing

Fan de-pressurisation tests were carried out before and after improvements in Chapel Fields A and Bell Farm A, and have been reported previously (Lowe et al 1994). The tests were undertaken in January 1992, before improvement work, and in March and April 1992, after improvement work. The tests were carried out using the Leeds Metropolitan University's Minneapolis blower door. Each test took roughly half a day. In January it was possible to test only two of the houses under near perfect weather conditions, while in the spring it was possible to test all three of the houses, but under adverse wind conditions. The leakage rates at 50 Pa pressure difference are shown in table 2.4 and figure 2.3 below.

Table 2.4 Air leakage rates

ac/h @ 50 Pa	before	after
Chapel Fields B	19.3±1	7.5±0.4
Bell Farm B		6.8±0.3
Bell Farm A	16.9±1	4.9±0.3

These results show a 2.5 - 3 fold improvement in air tightness in both sets of houses. This has been brought about by a combination of measures, including draughtstripped replacement windows and doors, covering of tongued and grooved floors with 3 mm plywood sheeting (not sealed around skirting boards), and repair of obvious damage to plasterwork around doors and windows.

Leakage rates before improvements were higher than the UK average, although by no means extreme (Perera & Parkins 1992, see also Warren & Webb 1980). The leakage rates after improvements are low compared with measurements made in other UK houses. The estimate for Bell Farm A is below 5 air changes per hour[1]. This figure was exceeded, in 1992, by just two in a BRE database of 385 dwellings, and it approaches the 1980 Swedish 3 ac/h standard for new housing (Anon 1980). The fact that this level was achieved without significant attention to detail or workmanship or supervision, suggests that the decision to fill the wall cavities at Bell Farm with high density polyurethane foam may be a reliable and effective way of reducing air leakage in traditionally constructed masonry houses. This result and the fact that a number of obvious construction defects were evident at the time of testing, imply the possibility of achieving air leakage rates of 3 ac/h or less in existing masonry houses, with the application of modest additional effort.

[1]In this house, after refurbishment, it was only possible to measure directly the leakage rate with the mechanical ventilation system unsealed. The effect of sealing this system was estimated from measurements on the adjoining house.

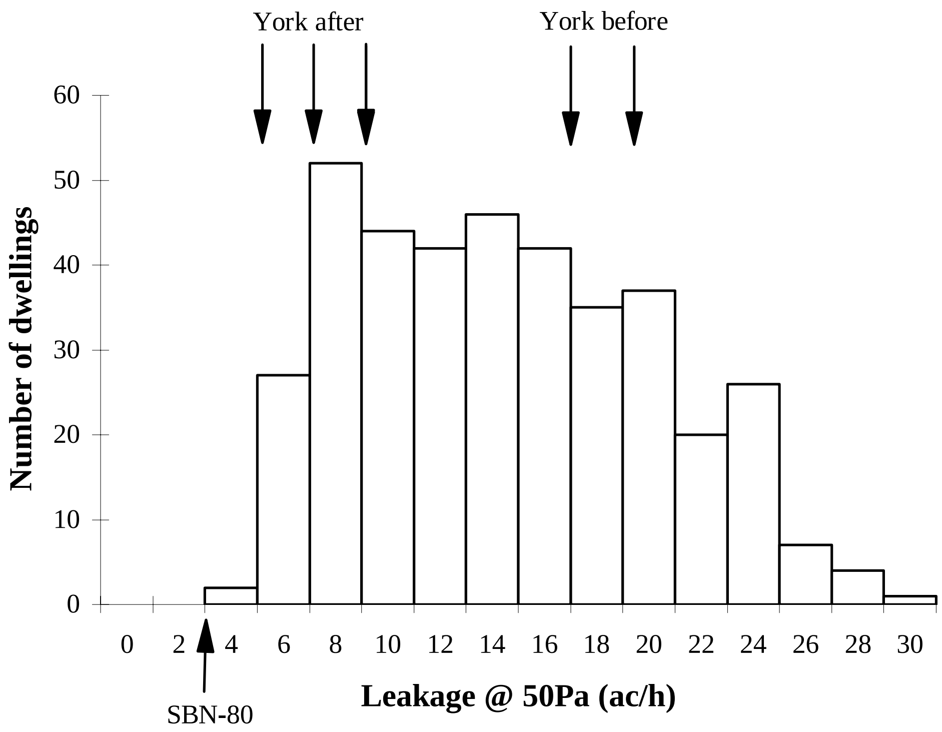

Figure 2.3 Pressurisation test data (after Perera & Parkins 1992)

2.3.2. Co-heating tests

A co-heating test involves heating a house electrically and measuring the energy input needed to maintain a constant internal temperature as the external temperature and solar radiation fluctuate. The details of the method are described in Everett (1985) and Lowe & Gibbons (1988)[2]. Co-heating tests were carried out in Chapel Fields B and Bell Farm A. The "before" tests were carried out in December 1991 and January 1992, and the "after" tests were carried out in March 1992. The coheating test rig used at Chapel Fields A is described below.

Table 2.5 Co-heating test: typical set-up

fan heaters	rating kW	controlled by
front bedroom	1	room thermostat in bedroom
bathroom	1	room thermostat in bedroom
back bedroom	2	room thermostat
lounge	2	electronic thermostat in lounge
kitchen	2	electronic thermostat in lounge
Total	9	

[2]Co-heating tests allow the estimation of both the heat loss coefficient and the effective solar aperture of a dwelling. At York, only the former was measured.

In addition to the above, a number of oscillating desk fans were used to stir the air in the houses in an effort to maintain an even distribution of temperature throughout the house. A very similar set-up was used at Bell Farm A.

Initially it was expected that data loggers would be used to log internal and external temperatures and solar radiation during the co-heating tests. For a number of reasons, including large scale theft of equipment[3], this was impossible. Instead, Differential Temperature Integrators (DTI's), supplied by Dr Bob Everett of the Open University, were used to log degree days in living room, hall and bedroom of each house tested. Solar radiation, and heat flux through the party walls was not measured. The DTI's registers and the electricity meter were read on a daily basis, normally in the morning. Internal and external temperatures were checked using a mercury in glass thermometer, and a hand-held digital thermometer.

The results of the co-heating tests are shown graphically in figures 2.4 and 2.5, and are summarised in table 2.6.

The ratios of before and after heat loss (as measured) are remarkably close to the predictions made in Autumn 1991, before any of the experimental work was carried out. The discrepancies between the measured and calculated heat loss coefficients after carrying out the works are 8 and 11% respectively. The differences between heat loss coefficients before and after the energy improvement works are highly significant, and clearly demonstrate the effects of these improvements.

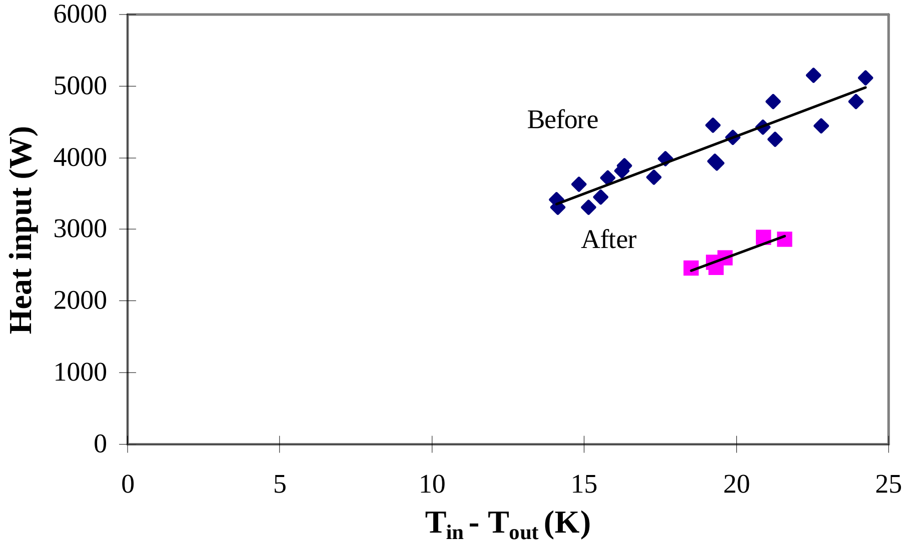

Figure 2.4 Co-heating test: Chapel Fields B

[3]This almost resulted in the co-heating tests being called off. On one occasion, the external temperature sensor from Bell Farm A was found buried, javelin-like, in the front lawn. External steel shutters had to be installed on all windows and doors in this house to keep intruders out. These had the advantage of completely excluding solar radiation and therefore of significantly simplifying the experiment and interpretation of results.

Table 2.6 Summary of heat loss coefficients from co-heating tests

Bell Farm A	before W/°C	after W/°C	after/before
measured calculated	229±4 300	121±4 132	0.53±0.03 0.44
Chapel Fields B	before W/°C	after W/°C	after/before
measured calculated	218±3 266	133±1 149	0.61±0.02 0.56

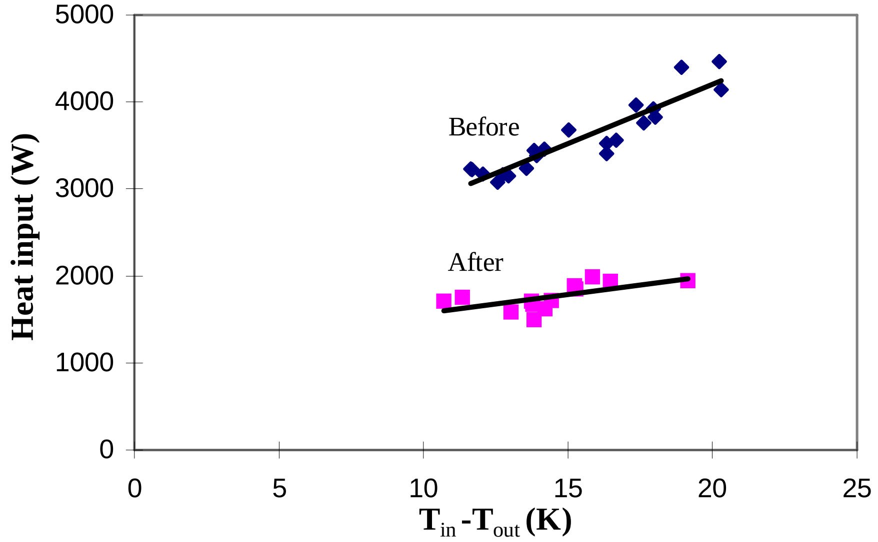

Figure 2.5 Co-heating test: Bell Farm A

Error bands quoted in table 2.6 are those that arise from the estimation of the best-fit slopes by linear regression. Total error, including possible bias errors in temperature measurements, and the effects of thermal storage, may amount to ±10%.

2.4. Results: long-term monitoring

2.4.1. Description of systems

In the Chapel Fields houses, all energy and temperature data were recorded using a data logger (a Deltalogger manufactured by Delta T Devices). These were downloaded at nominally monthly intervals to a portable computer. The Chapel Fields houses were in some ways ideally suited to this type of work. Both houses were end-of-terrace, and each had an attached brick store room at the side. This room contained the utility meters, and provided plenty of space for additional meters and the datalogger. The data logging strategy proved to be robust, and very little difficulty was encountered in these houses. The monitoring configurations in the two Chapel Fields houses are shown below:

Table 2.7 Monitoring configuration at Chapel Fields A

Meter or sensor	**Comments** All sensors except the electricity meter were read by a Deltalogger
utility gas meter	
utility electricity meter	read manually
boiler gas meter space heat meter water heat meter	These three meters together allowed measurement of the thermal efficiency of the gas boiler.
lounge temperature kitchen temperature main bedroom temperature	internal temperatures were measured with 2kW thermistor beads, supplied by Sunvic

Table 2.8 Monitoring configuration at Chapel Fields B

Meter or sensor	**Comments** All sensors except the electricity meter were read by a Deltalogger
utility electricity meter	
utility gas meter wall heater gas meter multipoint water heater gas meter	these allowed gas use to be split between cooking, hot water and space heating
lounge temperature kitchen temperature main bedroom temperature	internal temperatures were measured with 2kW thermistor beads, supplied by Sunvic
external temperature	radiation shielded thermistor, supplied by Delta T Devices, mounted below eaves on north side of house
south facing vertical surface solar radiation	Kipp en Zonen pyranometer

The picture in the Bell Farm houses was more complex. Bell Farm A was supplied with electricity on Northern Electric's “Supertariff”. Under this arrangement there are three possible prices for electricity - night rate, day rate and heat rate. Electricity use at the heat rate is “enabled” by a mains-borne signal, which operates a relay in the meter. This means that electricity at the heat rate can be made available at times to suit the Regional Electricity Company. Day and night rate electricity are available at pre-set times. In order to understand energy use in this house it was necessary to try to separate out these different classes of electricity use. In addition, internal and external temperatures were measured. The monitoring system in this house is summarised below:

Table 2.9 Monitoring configuration in Bell Farm A

Meter or sensor	Comments
Electricity meters	All electricity meters and tariffs were read by purpose-built data logger supplied by Northern Electric
utility meter	electricity use at: • day rate • night rate • heat rate
sub-meter 1	hot water at heat rate
sub-meter 2	electricity use by MVHR system hot water at day rate
sub-meter 3	space heat at day rate
Internal temperatures: • lounge temperature • bedroom temperature • kitchen temperature	Internal temperatures were measured with 2kW thermistor beads, supplied by Sunvic and read by Deltalogger housed in pantry in Bell Farm A
External temperature	Measured using a radiation shielded thermistor, supplied by Delta T Devices, mounted below eaves on north side of house and read by Deltalogger housed in Bell Farm A
Temperature and humidity of extract air	Measured between 26/4/94 and 22/6/94 only

The Supertariff meter has an optical output, which enables the contents of 4 registers to be downloaded to a suitable datalogger. The Deltalogger was not capable of triggering and reading the output from the Supertariff meter, and an alternative was sought. Northern Electric supplied a datalogger for this purpose, which was capable of storing meter readings in steps of 10 kWh.

Bell Farm B was supplied with electricity on the conventional off-peak tariff, which distinguishes between day and night use. Space heat in this house could be supplied by the ventilation heat recovery unit, or by direct resistance heating. This results in a total of at least 4 prices for heat, ranging from perhaps as low as 0.4 p/kWh for heat from the Genvex unit running on night rate electricity, to 8.1 p/kWh for resistance heaters run on day time electricity. This is a very complex picture, to which we were not, in the end, able to do justice.

Table 2.10 Monitoring configuration in Bell Farm B

Meter or sensor	Comments
utility meter electricity use at day rate electricity use at night rate	read manually
Sub-meters 4 and 5 sub-meter 4 sub-meter 5	read by purpose-built datalogger supplied by Northern Electric Genvex total non-Genvex space heat and hot water at day rate.
Sub-meters 6 and 7 sub-meter 6 sub-meter 7	Did not function hot water at night rate electricity used by compressor
Internal temperatures lounge temperature bedroom temperature kitchen temperature	Internal temperatures were measured with 2kW thermistor beads, supplied by Sunvic and read by Deltalogger housed in pantry in Bell Farm A
External temperature	As Bell Farm A (table 2.9)
Temperature and humidity of extract air	Measured between 26/4/94 and 22/6/94 only

2.4.2. Summary of results

Measured and predicted energy use in these houses for the period May 1992 to May 1993, are shown in figures 2.6 to 2. 8 and tables 2.11 and 2.12 below. Energy use in the Chapel Fields houses has been split between gas and electricity.

These figures illustrate a number of points. The first is that predicted and measured energy use after improvements are in close agreement - the exception is Bell Farm B, where efficiency gains expected from the use of a heat pump did not materialise. The second is that if predictions of energy use before improvements are to be believed, delivered energy use in these houses has been reduced by between 49 and 54%, and CO_2 emissions by 55% in Chapel Fields A&B and 49% and 48% in Bell Farm A&B. Although we have no measurements of energy use for these houses before the energy improvement work, we consider our estimates to be robust, and that large savings in energy use and CO_2 have therefore been achieved[4].

[4]Estimates of energy use from the houses before modernisation were made using the NHER program. The figures presented here for the electric houses differ from those presented earlier, due to changes in assumptions about wall U values and cooking method. The after-modernisation figures for Bell Farm B are extrapolated from approximately 11 months data.

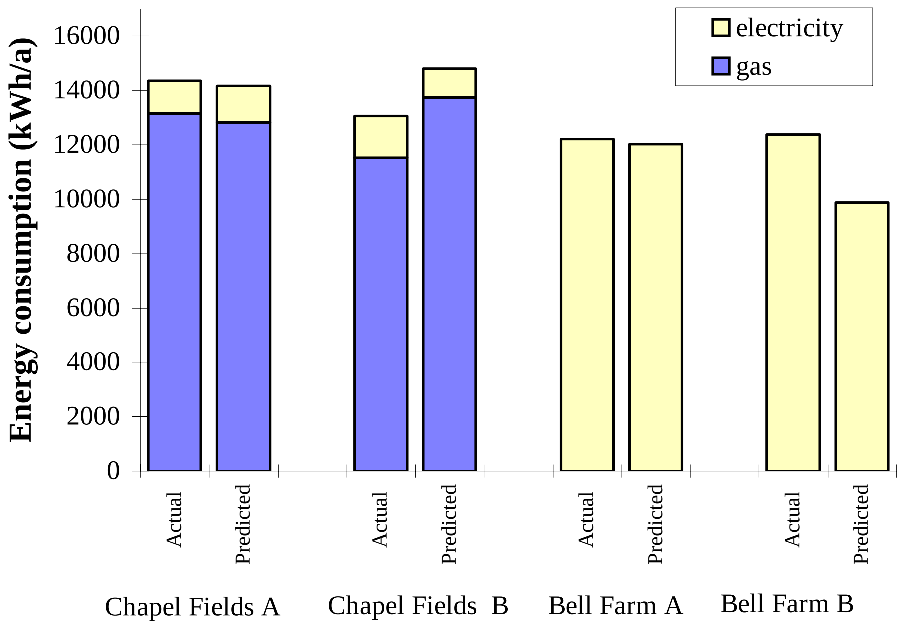

Figure 2.6 Gas and electricity use after improvement: actual & predicted

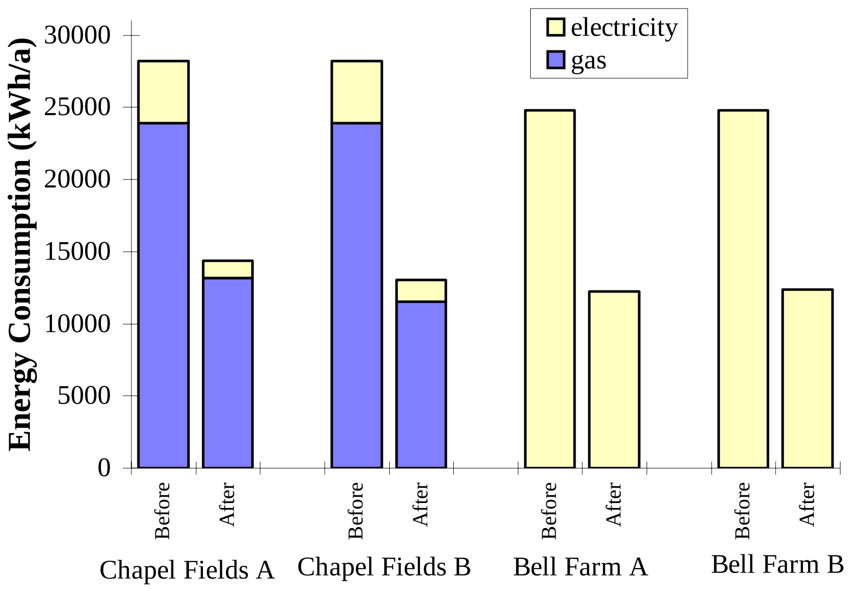

Figure 2.7 Gas and electricity use before and after improvements.

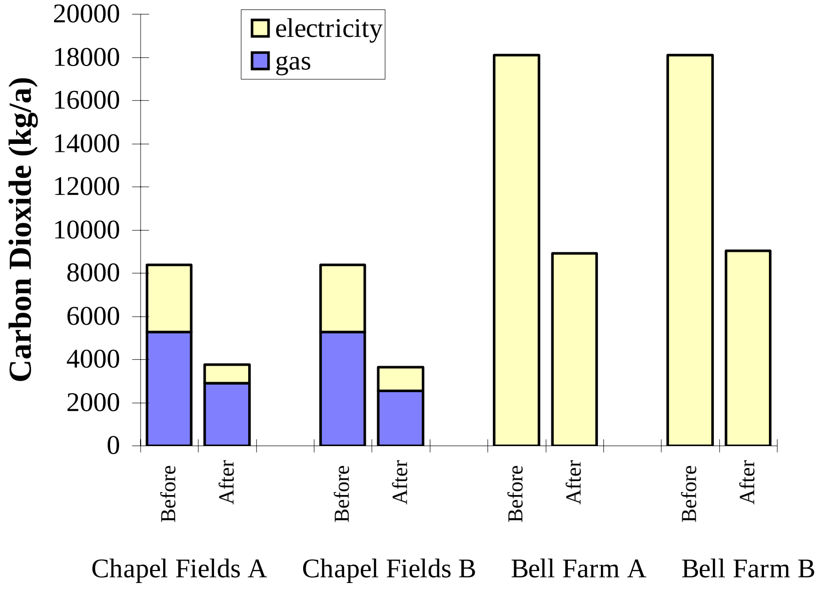

Figure 2.8 Carbon dioxide emissions before and after improvements.

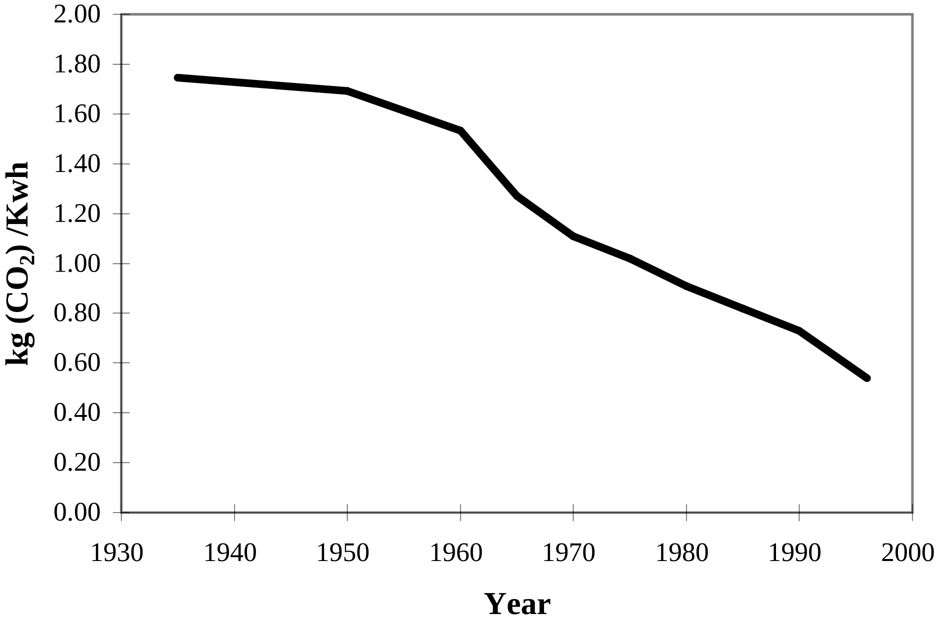

Figure 2.9 Carbon coefficient of electricity.

Comparison of the figures shows the importance of electricity consumption, even in gas heated houses. A large part of the carbon dioxide savings in the Chapel Fields houses has been achieved by fuel switching. Before the improvements, hot water was heated by on-peak electricity in these houses, and it is likely that electricity would have been used to supplement the gas fire for space heating. Reductions in demand for gas and electricity contribute roughly equally to the overall reduction in carbon dioxide emissions from these houses. The importance of electricity in the fuel mix is due to its comparatively large carbon coefficient. Throughout this report we have used the 1990 carbon coefficient for electricity (0.73

kg(CO_2)/kWh, compared with 0.22 kg(CO_2)/kWh for natural gas). However, as shown in figure 2.9 below, the carbon coefficient for electricity has fallen by about a factor of 3 since 1950, as the technology used for electricity generation has changed. In 1994, the carbon coefficient for electricity was 0.58 kg(CO_2)/kWh (Sterlini 1996), and further reductions are to be expected. Given that the most efficient combined cycle gas fired power stations currently generate electricity with a thermal efficiency in excess of 50%, there is no technical reason why the carbon coefficient for electricity could not ultimately fall to below 0.4 kg(CO_2)/kWh.

Table 2.11 Delivered energy May 92 - May 93

Scheme	Heating system	Before (kWh)		After (kWh)	
		gas	electric	gas	electric
Chapel Fields A	condensing boiler	23900	4300	13160	1209
Chapel Fields B	gas unit heaters			11535	1524
Bell Farm A	off-peak electricity.	n/a	24800	n/a	12225
Bell Farm B	air-air el. heat pump				12296

Table 2.12 CO_2 emissions. May '92 - May '93

Scheme	Heating system	Before (te CO_2)	After (te CO_2)	
			expected	measured
Chapel Fields A	condensing boiler	8.4	3.8	3.8
Chapel Fields B	gas unit heaters		3.8	3.6
Bell Farm A	off-peak el.	17.5	8.1	9.0
Bell Farm B	air-air electric heat pump		6.8	9.0

Mean heating season internal temperatures for Chapel Fields A&B and Bell Farm A are shown below. The internal temperatures in Chapel Fields A & B (17.3° and 16.9°C respectively) are in line with data from other houses in the York Energy Demonstration Project. The temperature in Bell Farm A (19.6°C) is high by UK standards, and compares with a mean of 18.4 °C for the Pennyland houses at roughly the same level of insulation (Lowe et al. 1985). This house is occupied by a family with young children, while the other 2 houses are occupied by single mothers each with one child. Plots of monthly mean internal temperatures versus outside temperature are presented below. These all show a tendency for lower temperatures in colder weather, a characteristic of partially heated houses at modest levels of thermal insulation. However a more detailed analysis shows a difference in behaviour between the Chapel Fields houses and Bell Farm A. In Bell Farm A, lounge, kitchen and bedroom temperatures do not differ. All three temperatures fall together as the outside temperature falls. In the Chapel Fields houses, the lounge temperature does not fall as outside temperature falls, and almost all of the variation in internal environment in these two houses is confined to the bedroom and kitchen.

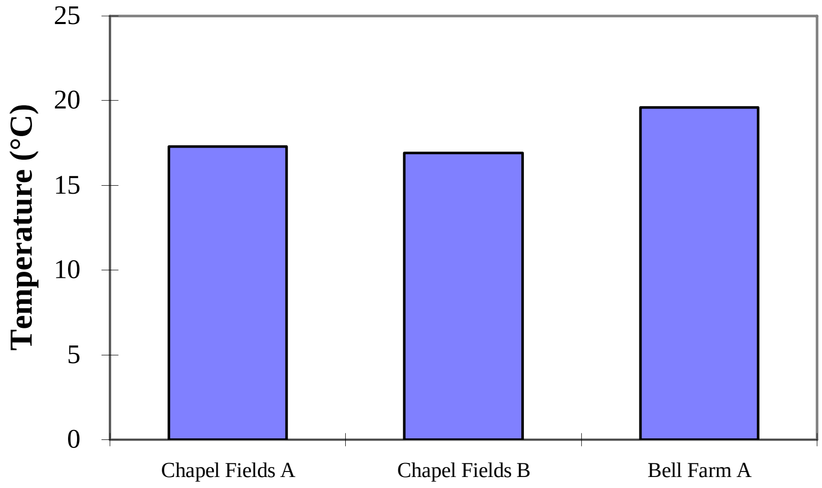

Figure 2.10 Mean internal temperatures : October to May.

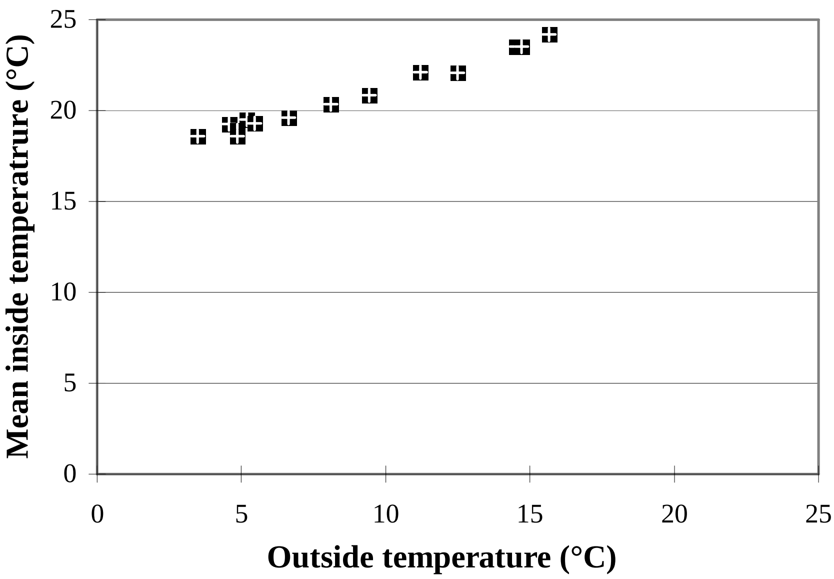

Figure 2.11 Whole house temperatures - Chapel Fields B: October 1992 to June 1994

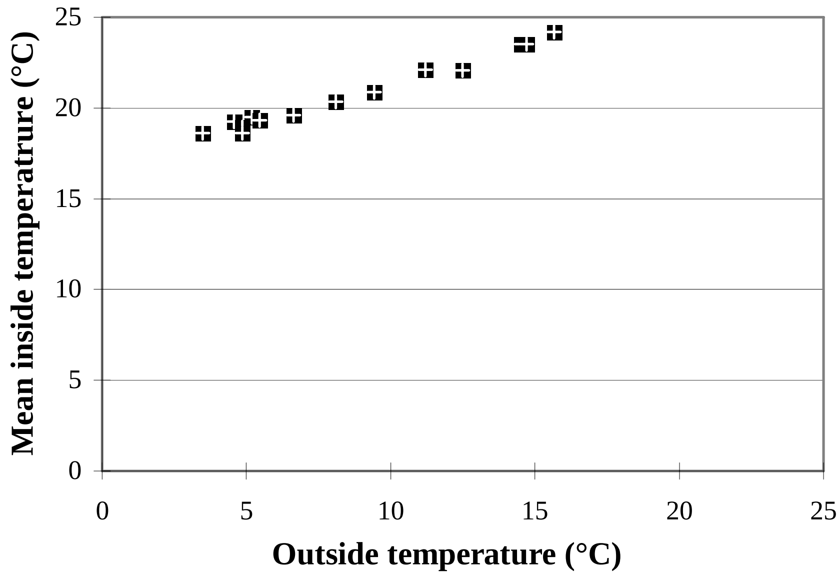

Figure 2.12 Whole house temperatures - Bell Farm A: January 1993 to February 1994

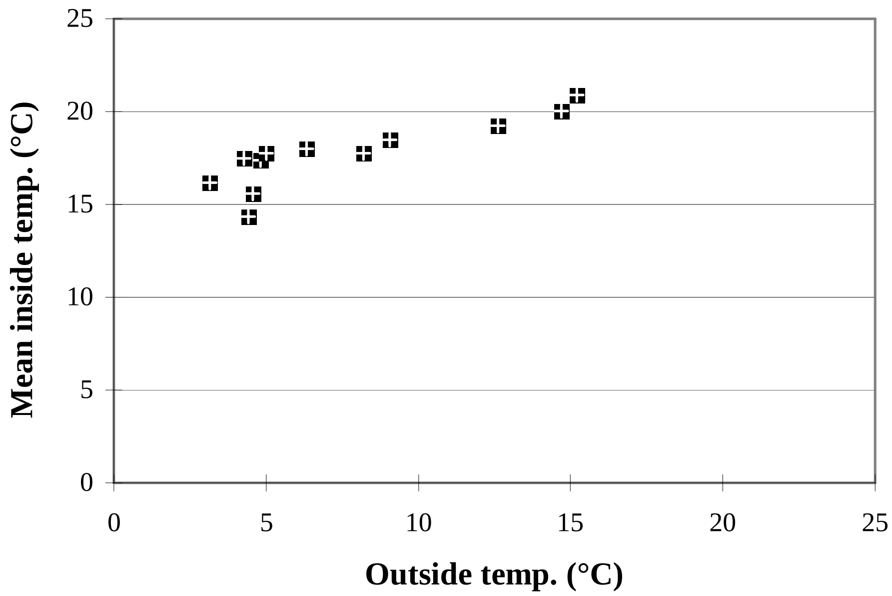

Figure 2.13 Whole house temperatures - Chapel Fields A: Dec. 1992 to Jan. 1994

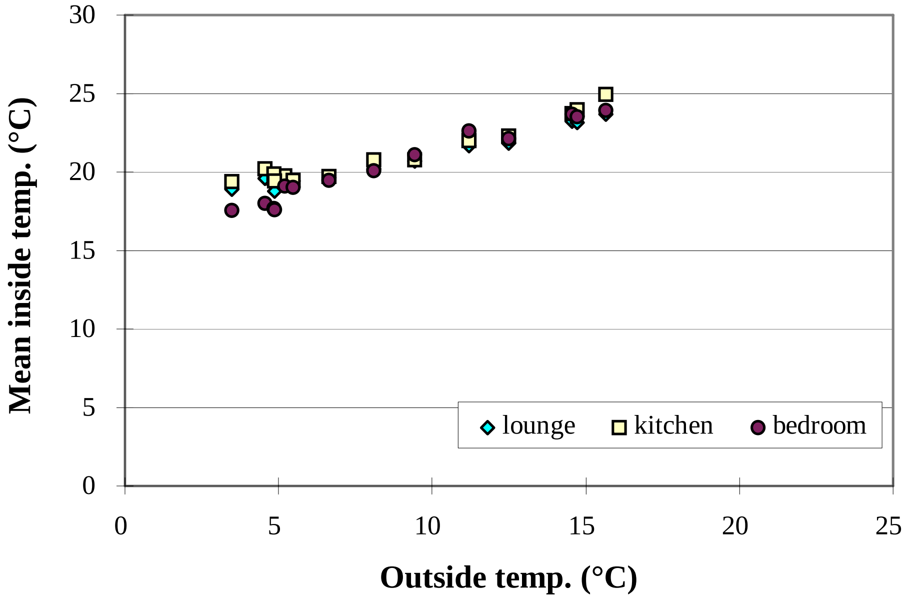

Figure 2.14 Temperatures disaggregated - Bell Farm A: Jan. 1993 to Feb. 1994

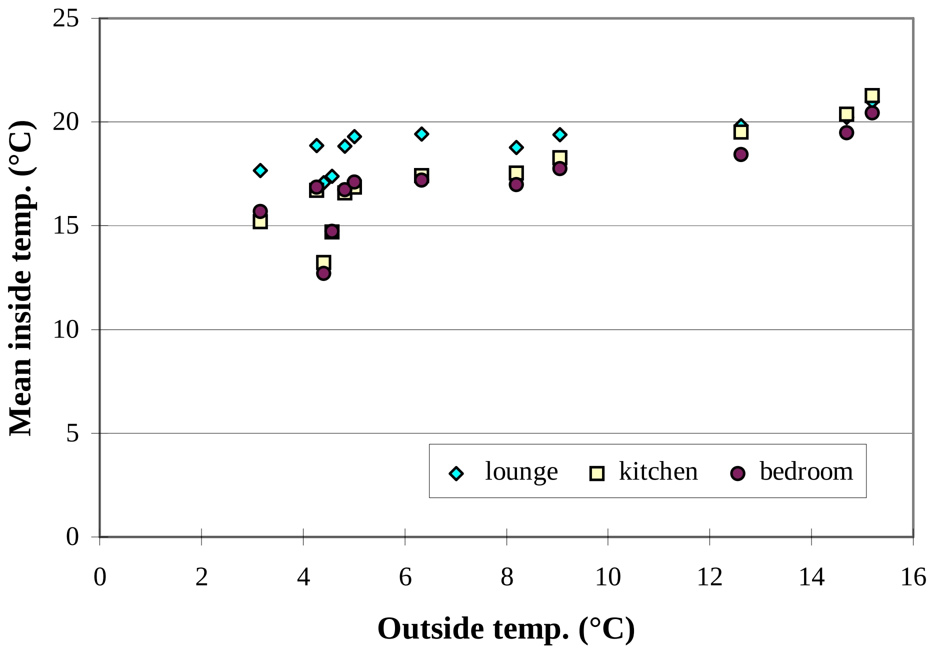

Figure 2.15 Temperatures disaggregated - Chapel Fields A: Dec. 1992 to Jan. 1994

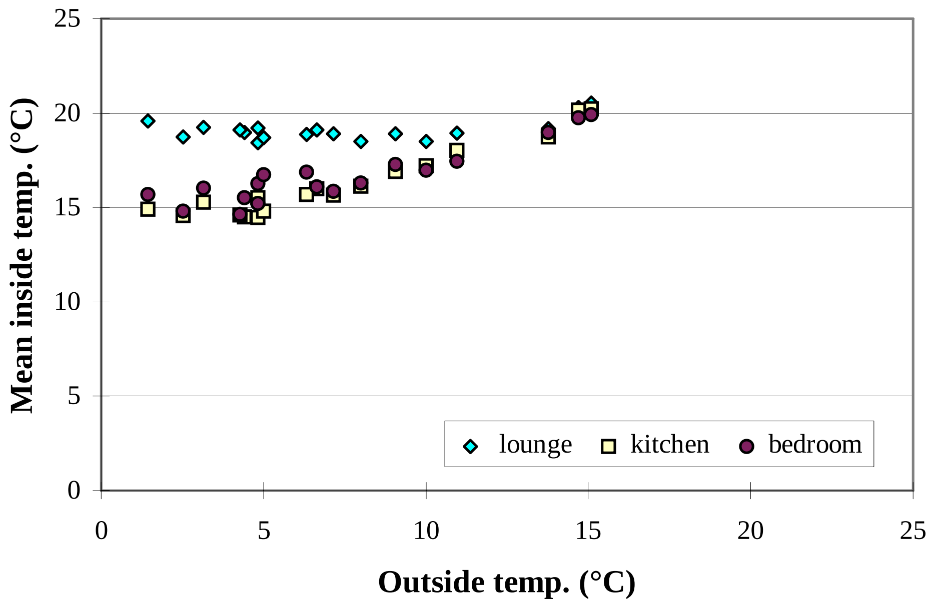

Figure 2.16 Temperatures disaggregated - Chapel Fields B: Oct. 1992 to Jun. 1994

2.5. House-by-house summaries

The final part of this chapter consists of a detailed summary of the results from monitoring of each of the 4 houses.

2.5.1. Chapel Fields A.

As stated elsewhere, this house was occupied by a mother and young child over the monitoring period. Delivered energy use from May 1992 to April 1993 is estimated at 14400 kWh. Delivered energy over the year beginning mid January 1993 (15/1/93 to 14/1/94) is slightly less at 13200 kWh. The total useful energy demand of this house over this latter period is approximately 12800 kWh. The pie chart below (figure 2.17) shows the approximate split of this figure between end uses.

Boiler efficiency.

A matter of some interest in this house is the efficiency of the boiler. This installation was one of the first condensing boiler installations in York City Council's housing stock. The figure below shows monthly mean boiler efficiencies over the whole monitoring period (December 1992 - January 1994). The mean efficiency over this period was 89% (uncertainties in gas and heat measurement amount to a total error of perhaps ±2% in this figure). A plot of mean daily boiler efficiency against load shows clearly that boiler efficiency is close to 90% regardless of mean daily load.

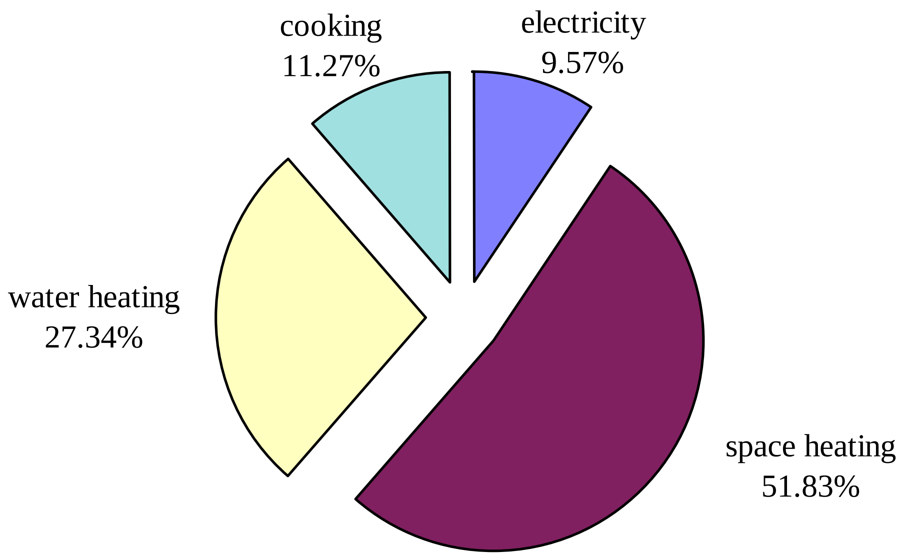

Figure 2.17 Useful energy Chapel Fields A: 15 Jan 1993 to 14 Jan 1994

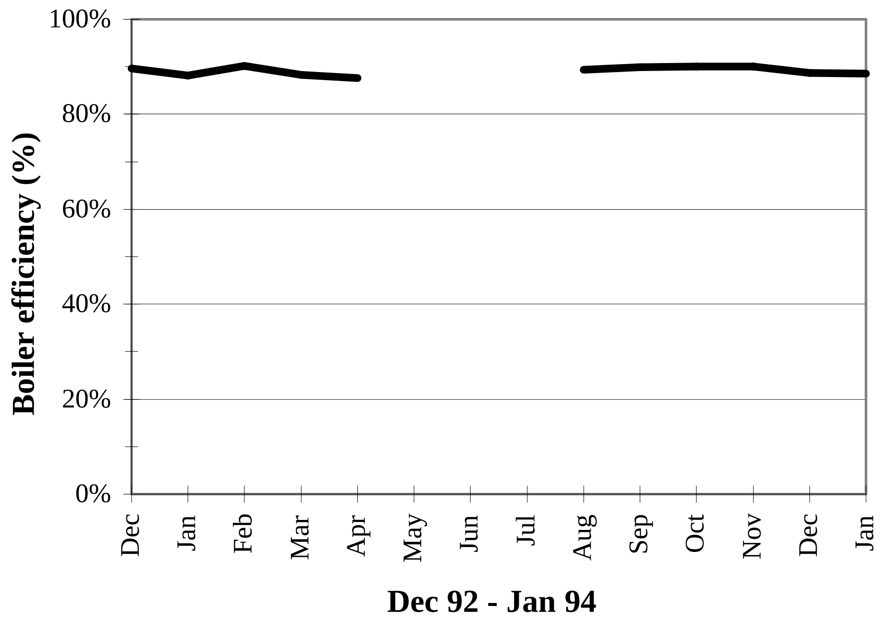

Figure 2.18 Boiler efficiency over time Chapel Fields A: Dec. 1992 to Jan. 1994

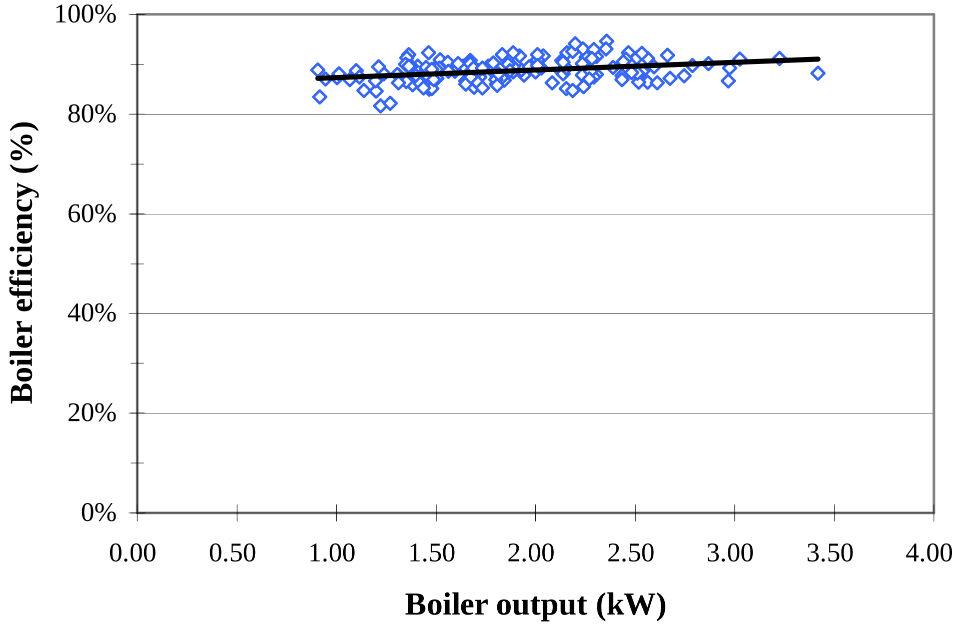

Figure 2.19 Boiler efficiency against boiler output Chapel Fields A

Boiler sizing.
There was some concern among Tenant's Choice contractors as to the appropriate size of boiler to install in the thermally upgraded houses in the York Energy Demonstration Project. Figure 2.20 shows a mean daily boiler load duration curve which shows that over a period of more than a year, daily mean boiler load did not rise above 4 kW. This figure includes domestic hot water heating. The boiler in this house was operated intermittently for about 12 hours in each 24 (see figure below). The boiler's rated output was 9.1 kW, and under this regime it was therefore operating at full capacity for a few days per year. Continuous operation of the boiler in cold weather would have allowed a significantly lower boiler rating, and hence capital cost saving.

Internal temperatures.
Figure 2.22 shows the temperatures and boiler output in this house on a typical cold winter's day. The living room temperature peaks at 20°C in the evening, with the other 2 temperatures a degree or so lower. The fall of inside temperature over the programmer “off” periods can be seen clearly. Living room temperature falls by about 4°C over the period from midnight to 9am.

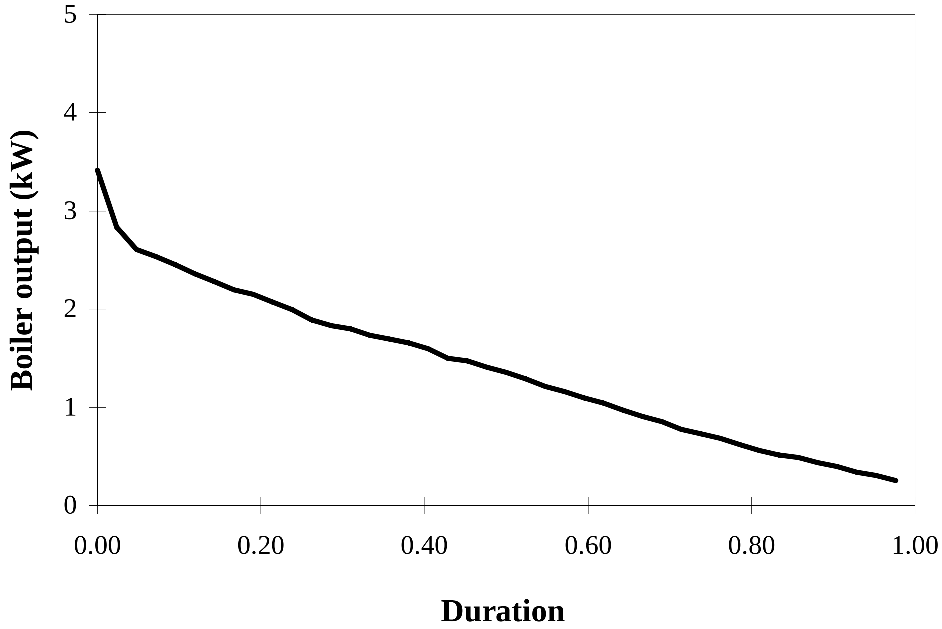

Figure 2.20 Mean daily boiler load duration curve: Chapel Fields A Nov. 1992 to Jan 1994

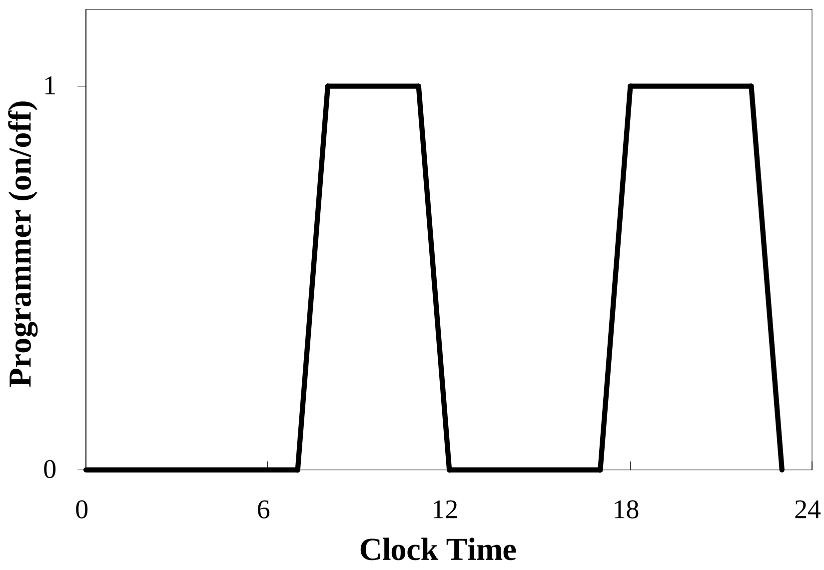

Figure 2.21 Central heating programme: Chapel Fields A

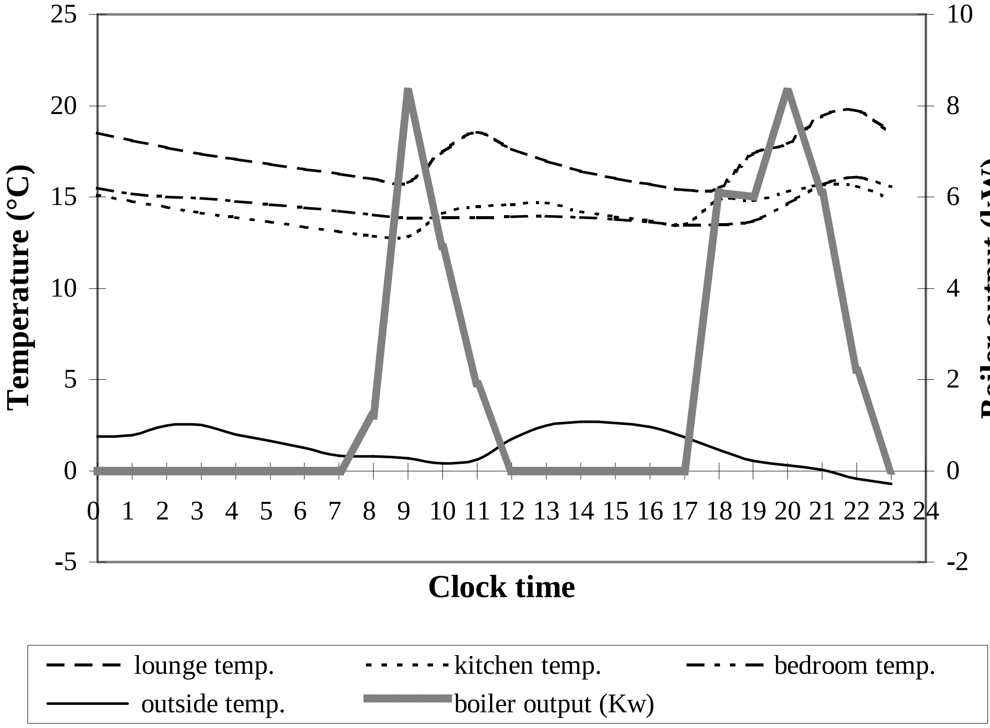

Figure 2.22 Typical hourly data (temps. & boiler output): Chapel Fields A (19 Dec 1992)

2.5.2. Chapel Fields B.

The split of delivered energy in this house is shown in figure 2.23 below.

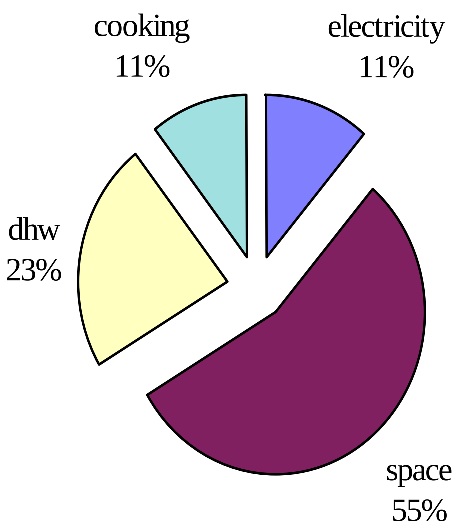

Figure 2.23 Energy end-use profile: Chapel Fields B

The occupant of this house informally provided a considerable amount of information on the way she operated her heating system, and on her perceptions about the performance of the house. In summary:

- the occupant of this house operated the space heaters like light switches - they were individually manually turned on and off, and little or no attempt was made to preheat any of the rooms in the house in advance of occupation;

- the living room is heated by just one of the wall heaters in that room (the heater at the north end of the through lounge), and peak evening temperatures are quite high; the whole house was heated by just 2 wall heaters.

- the kitchen is often very cold, and the occupant uses the gas cooker as an additional source of heat.

The occupant of the house was concerned about the costs of heating the house from the outset of the project, and said that she was initially reluctant to make much use of the space heaters, especially the one on the landing. She had never had central heating before, and lived for a long time in a house heated by an open coal fire. Her use of the system, and her anxieties, were all consistent with these statements.

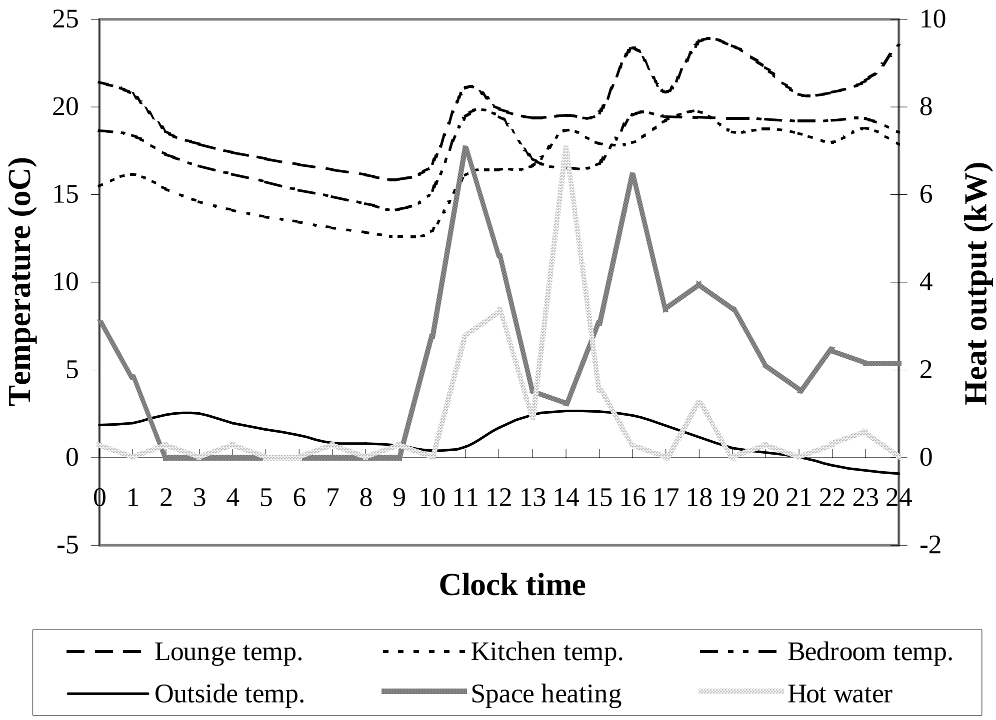

Figure 2.24 Typical hourly data (temps. & heater output): Chapel Fields B (19 Dec 1992)

Figure 2.24 shows a typical day in cold weather. External temperature on this day can be seen varying between -1 and 2.5°C. Gas consumption for space heating can be seen peaking at 11.00 and 16.00, while gas consumption for hot water peaks at 12.00, 14.00 and 18.00. Electricity consumption (not shown) is very small with a variation between 0 and 500 W over the 24 hour period.

The living room temperature peaks at about 24°C in the evening, and falls to a minimum of about 16°C overnight. There is a very rapid drop in living room temperature immediately after the unit heaters are turned off, which is probably due to the convective nature of the heat source. This soon stabilises, and the profile from about 2am is very similar to that observed in Chapel Fields A on the same day. The kitchen runs at just under 20°C throughout the evening, but falls to below 13°C by morning. The bedroom temperature is somewhere in between.

The occupant's view of the house was consistent with the measured data. She was generally happy with the house, but complained that the kitchen was hard to heat and often too cold. This can be explained by the fact that the kitchen is on the SW side of the house, and sees a large fraction of the ventilation heat load and a substantial fraction of the fabric heat load, while having no source of heat other than incidental heat gains. The tenant also complained that the hall was too cold, and that there were drafts on the stairs. The hall can be heated by leaving the living room door open, but this causes drafts in the living room. The draft on the stairs is particularly pronounced when the upstairs wall heater is turned off, and the living room door is open - this results in a large convection cell in the stair well, with cold air flowing down the stairs, and warm air rising up.

The external doors in this house were a weak point in the thermal envelope, both in terms of air-tightness and U value. One result of this was that condensation was comparatively severe on the doors, and in some cases ran down onto the floor.

Our conclusion regarding the heating system in this house is that it was a qualified success. A more even distribution of temperatures in the house would have required either:

- a higher level of thermal insulation - this could have been achieved with reduced heat losses through glazing, and better insulated, airtight doors;

or

- an additional wall heater in the kitchen - however this would have been difficult in this house due to the limited area of external wall on which a heater could have been fitted.

2.5.3. Bell Farm A.

This house was equipped with an off-peak electric wet central heating system, and mechanical ventilation with heat recovery. The house was occupied by a married couple with small child. The automatic monitoring of electricity use did not function well in this house, due to technical problems with the datalogger supplied by Northern Electric. Nevertheless, monitoring of internal temperatures was successful, and we have been able to assemble a reasonably clear picture of electricity use from manual meter readings.

The picture shown is one of a house maintained at a relatively high and remarkably uniform temperature. This is consistent with the occupants' verbal observations. Total expenditure on electricity over the period from May 1992 to April 1993 was £470. Total electricity use was 12225 kWh. A large fraction of electricity use in this house was at the heat rate as shown below. This point is considerable importance for the economics of the heating system.

The pattern of electricity use over the period May 1992 - April 1993 is shown in the two figures below. One surprise is the very small amount of electricity taken by the MVHR unit. The resolution of Northern Electric's datalogger was 10 kWh, equal to between 12 and 24 hours' consumption by the MVHR unit. This was too crude to pick up the hour-by-hour variations in electricity use by the MVHR unit, and it was therefore not possible to confirm how the unit was being used. The occupants of the house did however complain of excessive condensation.

In April 1994, a combined temperature and humidity probe was installed in the extract duct of the MVHR system, close to the MVHR unit in the loft. Purely fortuitously, this took its power supply from the MVHR unit, which ought to have been running continuously. Examination of the output from this sensor showed that it was switched off for much of the period (see figure below). The relative humidity recorded while the MVHR unit was running was not excessive, but in view of the low background leakage in this house, it is likely that the humidity would have been much higher at other times, unless windows were opened freely. It is possible that the occupants of this house were using the MVHR system intermittently in May and June, and that use had been continuous up to this date.

It does appear that Bell Farm A is sufficiently airtight to need continuous mechanical ventilation. This house maintained the highest internal temperatures of the 4 house group, with the lowest delivered energy use, which may be due in part to the combination of airtightness and the MVHR system. There is some evidence that the house is underventilated. No documentation on the commissioning of the MVHR system is available, and a final conclusion on the performance of the system is not possible without more data.

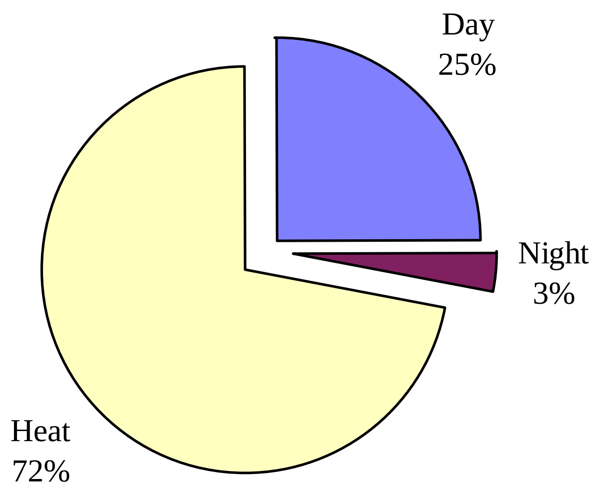

Figure 2.25 Electricity profile (May 1992 to April 1993): Bell Farm A

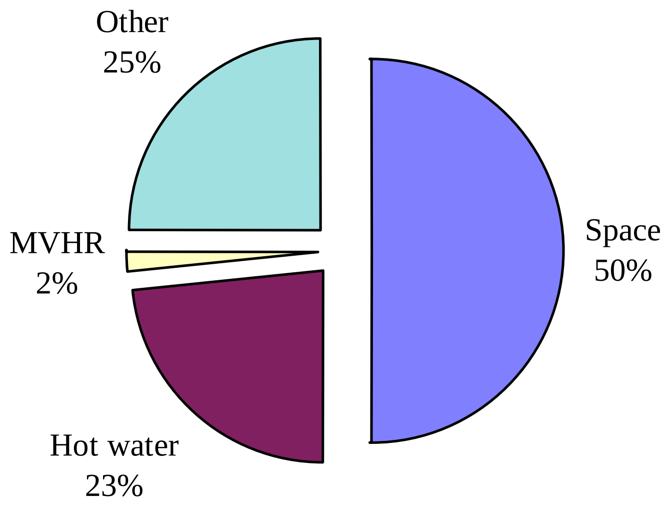

Figure 2.26 Energy end-use profile (May 1992 to April 1993): Bell Farm A

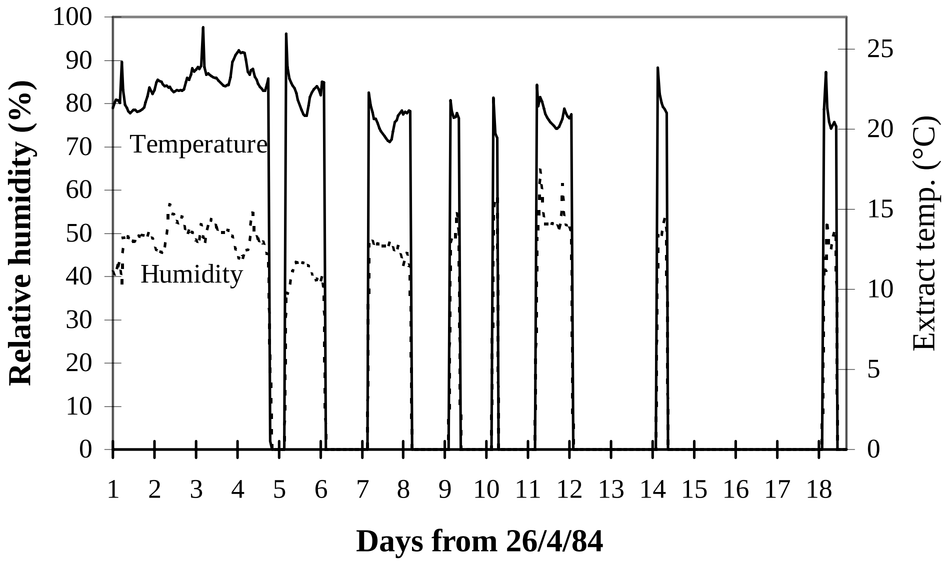

Figure 2.27 MVHR data: Bell Farm A

2.5.4. Bell Farm B.

This house was fitted with an air-to-air heat recovery heat pump, which was backed up by electric resistance duct heaters, a focal point electric fire in the living room, and an electric resistance heater in the bathroom. The warm air heating system was controlled by:

- A 2-stage electronic programmable thermostat in the hall close to the front door which was able to control duct heaters and Genvex in sequence;

- A single stage electronic programmable thermostat on the landing which switched the upstairs duct heaters.

The domestic hot water was controlled by a separate programmer in the kitchen and by immersion heater thermostats.

The house was initially occupied by a young mother and child, who moved out in the spring of 1993 to be replaced by a second similar family. Neither the heating system nor the monitoring system functioned properly in this house. The main reasons for this were:

- The experimental nature of the heating system;
- the fact that the need to sub-meter electricity use required a very clear separation of electrical circuits;
- the division of responsibilities between York City Council, Northern Electric in York and Peterlee, and Leeds Metropolitan University - this made it difficult to coordinate the commissioning of heating and monitoring systems. Nevertheless a crude picture of energy use can be assembled from a combination of logged data and manual meter readings.

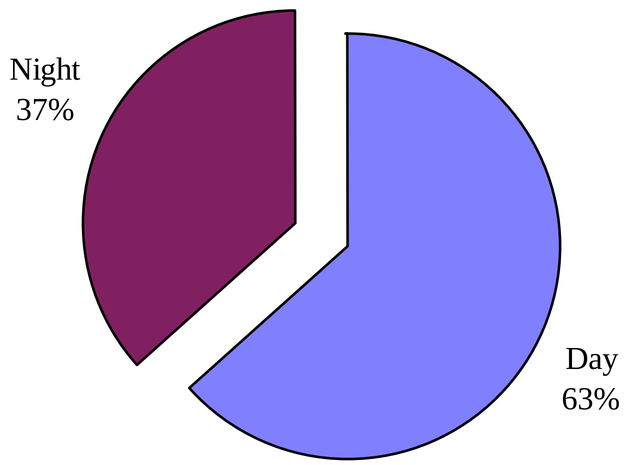

Figure 2.28 Electricity profile (May 1992 to April 1993): Bell Farm B

In this house roughly 60% of total electricity use is captured by the three sub-meters. The split between day and night rate electricity (37% night rate) is consistent with the fact that only the domestic water heating is designed to function predominantly at night. The split of energy between day and night rate, and the pattern of end uses are shown in figures 2.28 and 2.29. Estimated total delivered energy use over the year 1/5/92 to 30/4/93 is 12296 kWh or 44.3 GJ. The error on this is not likely to be greater than ±5%. Estimated total CO_2 emission over the period is 9.0 te (CO_2). This is 33% greater than the tentative prediction of 6.9 te (equivalent to 9333 kWh) made in the summer of 1992, but still 48% less than the 17.5 te predicted for the same house before the energy improvements.

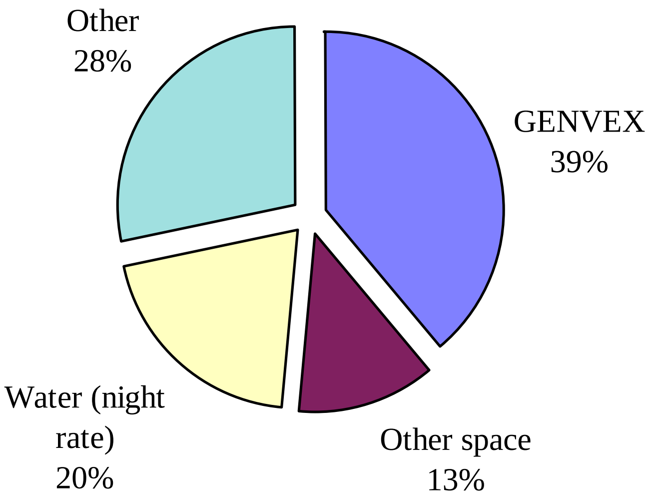

Figure 2.29 Energy end-use profile (May 1992 to April 1993): Bell Farm B

These figures suggest strongly that the space heating system in this house has not functioned as it should. This is consistent with the problems that were reported to the research team since late in 1992, the first winter of occupation. These include:

- frequent cutting-out of the heat pump due to excessive condensing temperature;
- inability of the system to maintain adequate temperatures, particularly upstairs;
- an inability on the part of the occupants of the house (and, on occasion, of the research team) to understand the very complex control system installed to control the heating system.

Comparison with Bell Farm A, and direct observation of occupant behaviour, suggest that the heat pump played a negligible part in heating this house, and that a large part of the space heating was provided by various sources of resistance heating. **The figures do not provide a reliable basis upon which to judge the performance of the Genvex system.**

3 The 30 house scheme

3.1. Introduction

The 30 house scheme was conceived with the principal aim of demonstrating the impact of energy improvements within the context of York's existing modernisation programme. This scheme differed from the 4 House scheme in that a lower energy standard was adopted and a larger number of houses and range of house types were involved. The lower standard was adopted because window replacement was not part of the modernisation and therefore the opportunity to provide double glazing was not available. The scheme provided a sound basis for comparison between houses modernised with energy improvements and those modernised to York's usual standard. Because of the numbers of houses involved this scheme provided the opportunity to produce a statistically valid comparison of the two standards of modernisation. 30 houses from York's 'Tenant's Choice modernisation programme were improved with additional energy efficiency measures. These measures consisted of 200 mm loft insulation, draught stripping to all doors and windows, wall insulation and the installation of a gas condensing boiler. These homes were then monitored along with a group of houses in the same area of York, modernised at the same time but which did not receive additional efficiency improvements. This chapter present the results of the monitoring and compares the two standards of modernisation.

3.2. Monitoring

3.2.1. Energy monitoring

The works were completed in 1992 and monitored over 18 months from November 1992 to March 1994. Monitoring consisted of energy meter readings carried out manually (supported by energy histories supplied by the fuel utilities) and the logging of internal temperatures. Meter readings were obtained from the fuel utilities for the period December 1992 to December 1994 in the case of gas and November 1992 to February 1994 in the case of electricity. Temperatures were monitored continuously at three points in each house (Lounge, Kitchen and Bedroom) using temperature loggers. External temperatures were also monitored over the same period.

Initial group sizes were to be 30 Experimental houses and 20 Control houses. These numbers were reduced as a result of:

- Unwillingness of tenants to participate in monitoring over the length of time involved. This was a particular problem in the control houses.

- Access problems to certain houses which resulted in long gaps between readings and subsequent loss of logged data as batteries failed.

The control group posed a particular problem as the drop-out from the original list meant that only 6 houses were started in November/ December 1992 to which a further 8 were added in the summer of 1993 and monitored over the 1993/94 winter. This is not ideal and apart from reducing the group size means that not all internal temperature data is from the same heating season. External temperature records indicate that the average temperatures for each heating season differed by about 0.7 °C.

Monitoring was set up in 24 experimental houses and 14 control houses. These numbers were further reduced by equipment failures in 3 experimental and 3 control houses. The analysis is based on an experimental group of 21 and a control group of 11.

3.2.2. Monitoring of tenant opinion

In order to gauge tenant opinions and perceptions a survey was carried out by an independent market research agency in November 1991 before commencing works. A follow-up survey was carried out by the same agency during March/April 1993. Both experimental and control groups were surveyed on each occasion. The time period between the surveys spanned half the 1991/92 heating season and almost all of the 1992/93 season. This provided time for tenants in both groups to get used to their new systems. Despite the changes in the control group outlined above, the social survey is based on the original control group, so as to ensure comparability between the two surveys. Details of the surveys and questionnaires used are included in appendix 5.

3.3. Description of groups and improvements

3.3.1. Description of properties

All houses in the trial were 2 storey and of traditional construction with cavity brick walls with tiled pitched roofs. Both groups contained a mix of semidetached and mid/end terraced house types. Seven distinct types were identified (allowing for mid/end terraced variants) and these are illustrated in the photographs in figure 3.1. Table 3.1 sets out the mix of each type in the two groups. House type plans and energy characteristics are set out in appendix 4 Minor type variations exist in 3 of the control houses and these were allocated to their nearest house type.

Table 3.1 House type mix in each group

House Type	Experimental group	Control Group
A - Mid Ter.	1	0
A - End Ter.	1	0
B	1	1
C	8	2
D	5	4
E - Mid Ter.	4	3
E - End Ter.	1	1
Total	21	11

Type A - mid and end terrace

Type B - semi detached

Type C - semi detached

Type D - semi detached

Type E - end terrace

Type E - mid terrace

Figure 3.1 30 House scheme house types

3.3.2. Comparison of groups

Because this project is concerned with comparing the performance of the two groups of properties it is important to establish the extent of any inherent difference in their energy consumption prior to improvements. The more alike they are in energy terms the greater the confidence that any measured difference in energy consumption is due to efficiency improvements. A comparison of the energy characteristics of each group was carried out using the National Home Energy Rating Evaluator program which is based on the Building Research Establishment's Domestic Energy Model (BREDEM). The results of this comparison are set out in table 3.2.

Table 3.2 Mean energy characteristics of study groups

Group	Before Improvement				Improvement to Tenant's Choice Standard			
	Gas	Elec.	Total	Cost	Gas	Elec.	Total	Cost
	kWh	kWh	kWh	£/yr	kWh	kWh	kWh	£/Yr
Experimental	26946	7944	34890	1135.95	27864	3246	31110	784.74
Control	26290	7818	34109	1115.66	27851	3081	30932	771.67
Difference	656	126	781	20.29	13	165	178	13.07

The two groups are remarkably similar both before improvement and assuming improvement to the normal improvement standard. All other things being equal, if both sets of houses were improved to the normal standard one would expect almost no difference in gas consumption and only a very small difference in electricity consumption. The most difficult area to control for however, is house occupancy and user behaviour. A simple occupancy comparison indicates that occupancy levels were broadly similar with an average of 3.1 persons (1.86 adults and 1.24 children) in the experimental group and 3.36 persons (2.0 adults and 1.36 children) in the control group.

3.3.3. Improvement measures

The standard improvement package in York at the time of the project consisted of a refitting of kitchen, bathroom and the provision of central heating. In addition various miscellaneous works were carried out up to a value of £500 as chosen by the tenant. All the control houses had had around 50 mm of loft insulation fitted some years previously. Repair works were also carried out depending on the needs of each property. The experimental houses received the following additional measures:

- 200 mm loft insulation (total finished thickness)
- Cavity wall insulation and/or dry-lining to provide an even coverage of wall insulation depending on house type.
- Draught stripping to all existing external doors and windows.

- A gas condensing boiler in place of the non-condensing types used in the standard improvement package.

Because of the extensive draught proofing, ventilation measures were also undertaken in the experimental houses which included fans in kitchens and bathrooms and humidity controlled trickle vents in habitable rooms. Where no roof void ventilation existed, this was also provided.

Although the house types are broadly similar in their construction there are a number of differences of detail which are important particularly with respect to the provision of wall insulation. All house types have cavity walls but in most types sections of solid or timber wall also existed. For the purposes of this demonstration it was decided to attempt to achieve similar levels of insulation in all external walls. House type C was a particular problem in this respect because of the timber mansard roof section on the front elevation. The roofs to single storey bay windows were also insulated. Most types had small sections of solid or timber wall in either the bay windows or the wall between the kitchen and an outhouse. The effect of insulating these small areas of wall was to increase construction costs well above the cost of cavity insulation but with a relatively small reduction in heat loss. This issue is discussed later in section 3.7.3 below.

3.4. Results

3.4.1. Internal and external temperatures

Energy consumption is dependant on the temperature difference between inside and outside. An important variable in establishing the difference between the two groups is the level of internal temperatures maintained. Figure 3.2 shows average internal temperatures against external temperatures for each group. The scatter of the data points indicate that there is very little to choose between the groups even when external temperatures are at their lowest. As summer temperatures are reached the scatter is reduced and internal temperatures become more a function of external temperatures rather than levels of heating.

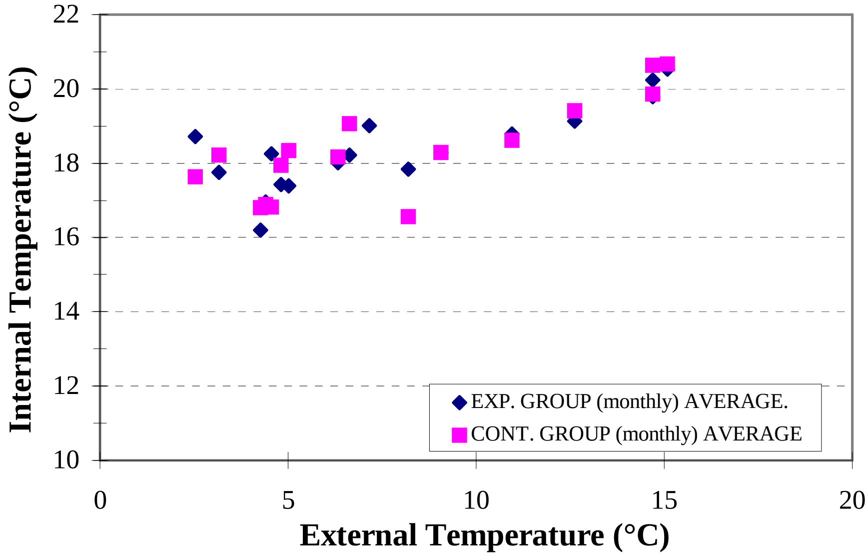

Figure 3.2 Internal and external temperatures

A small difference of about 0.5° C exists between the two groups with the control group operating at the lower temperature. The average internal winter temperature for the experimental group was 17.9°C and for the control group 17.4 °C. This difference amounts to something in the region of 1360 kWh (about £20 worth of gas) over a full heating season. On average, about 75% of the benefits of energy efficiency within the experimental group would appear to have been taken in the form of reduced energy consumption, resulting in a real reduction in fuel bills.

3.4.2. Energy consumption

The difference in average energy consumption between the two groups is set out in table 3.3. The table also includes the consumption predicted by the modelling programs under standard occupancy and use conditions.

Since all houses are heated using gas, one would expect the improved insulation and boiler to result in a reduced gas consumption. We observe such a difference which is statistically significant. The probability of this difference occurring purely by chance is less than 3% (P=0.022). The difference in electricity consumption is not significant (P=0.201). Although a significant difference in gas consumption exists it is considerably smaller (66%) than that predicted by the modelling programs, suggesting that there are many individual variations in the use of the houses which obscure the effects of the energy efficiency measures. The difference is further masked by differences in energy consumption for cooking. If all experimental houses cooked on gas and all control houses used electricity (an unlikely event) this would amount to a difference of about 1500 kWh/year.

Table 3.3 Measured and predicted annual energy consumption

Measured annual consumption						
	Gas		Elec.		Totals	
	kWh	Cost (£)	kWh	Cost (£)	kWh	Cost (£)
Experimental	19313	348	3138	292	22451	640
Control	23092	408	3529	322	26621	731
Difference	3779	60	391	30	4170	90
Temp. Adjusted Difference	5145	82	391	30	5536	112
Predicted annual consumption						
	Gas		Elec.		Totals	
	kWh	Cost (£)	kWh	Cost - £	kWh	Cost (£)
Experimental	16671	306	3104	289	19775	595
Control	27851	484	3081	288	30932	772
Difference	11180	178	-24	-1	11157	177

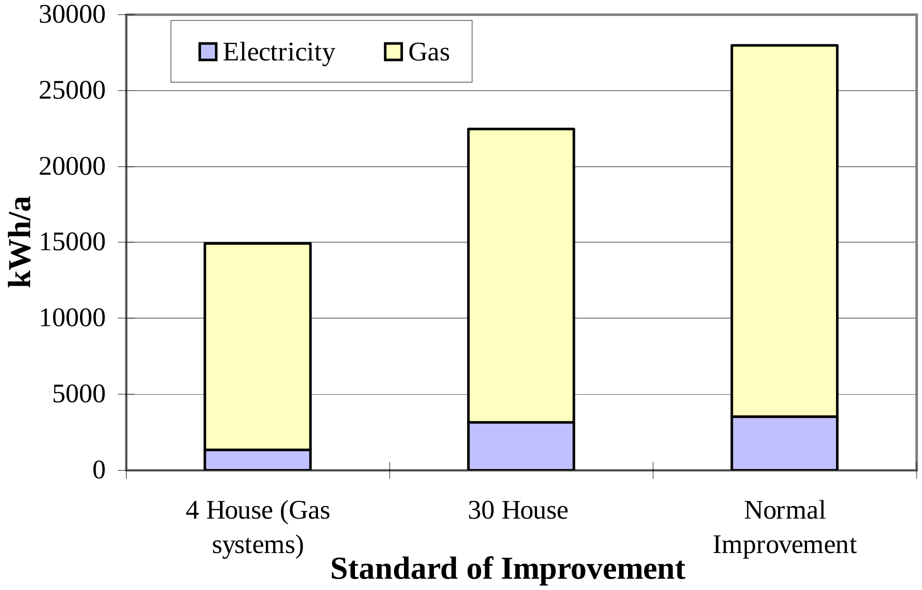

Figure 3.3 Comparison of energy consumption

Figures 3.3 compares the energy consumption data from the 30 house scheme with the gas houses in the 4 house scheme. Electricity consumption is as observed, gas consumption is temperature corrected. These figures indicate a reduction of 20% in gas consumption from the normal tenant's choice standard to the 30 house standard and a reduction of about 45% at the standard reached by the 4 house scheme. Figure 3.4 illustrates how these consumption figures would translate into fuel costs at 1996 UK prices and including standing charges and Value Added Tax at 8%.

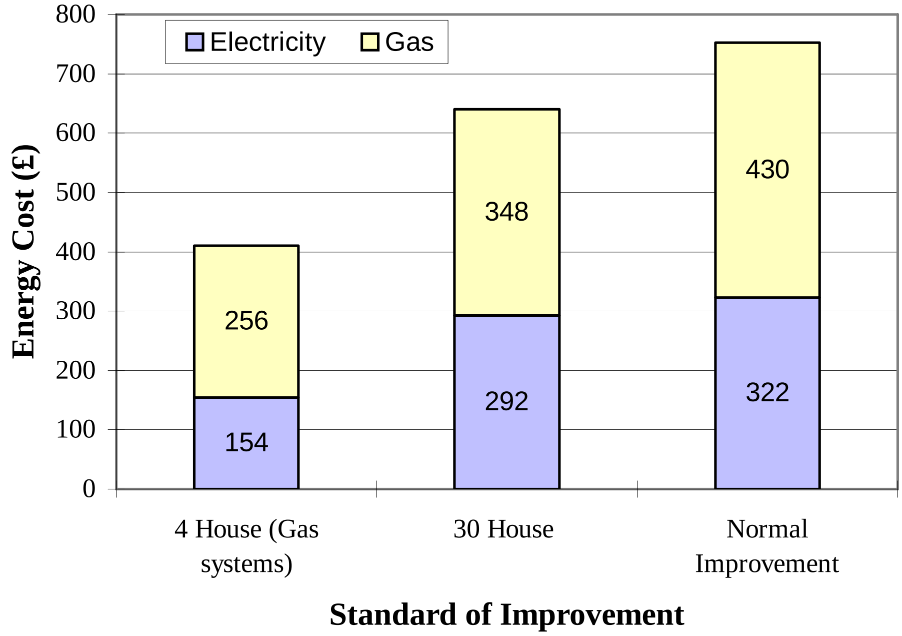

Figure 3.4 Comparison of energy cost

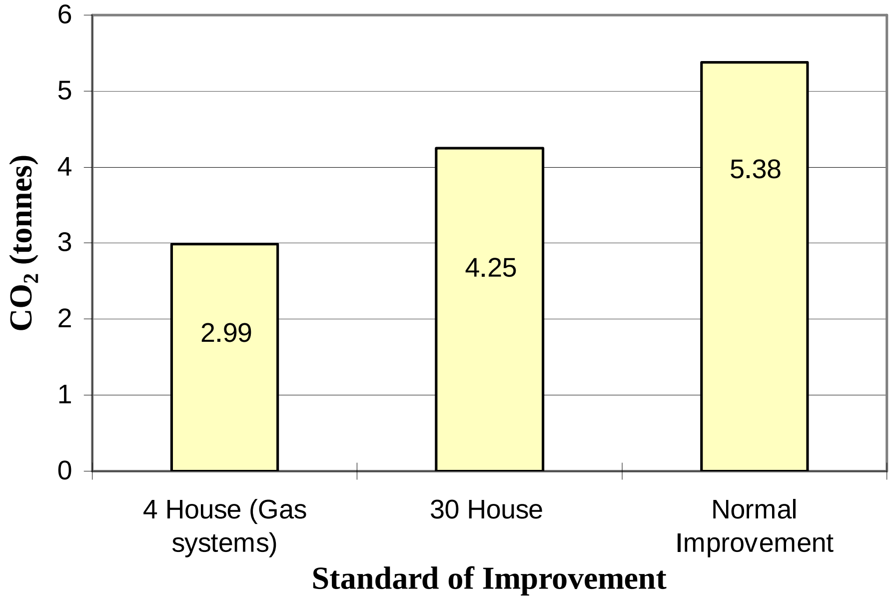

Figure 3.5 Comparison of CO_2 (gas systems)

Savings in energy also lead to reductions in the amount of CO_2 released into the atmosphere. Figure 3.5 sets out the levels of CO_2 produced for the different standards of improvement. Since gas consumption is the fuel affected in the 30 house scheme, CO_2 figures are given for gas consumption only.

3.4.3. Costs and pay-back

The extra cost of energy efficiency work on the 30 house scheme was £1442 (average), this would give a simple pay-back of about 17 years based on the measured difference (temperature corrected) between the two groups. The predicted pay-back was just under half this figure at 8 years. The costs for most of the house types in this scheme were higher than those obtained in the 4 house scheme mainly because wall constructions were a mixture of cavity, timber and solid brickwork. Each required different treatment and the dry-lining methods are more expensive than cavity filling. The 30 houses also incurred draught stripping costs of £182 per house which were not incurred in the 4 houses because draught stripping was incorporated into the window frame replacement.

The following analysis of costs for house type C (the most complex and expensive house type) will serve to illustrate the cost issues involved. Table 3.4 sets out, for each measure, the installation cost and the calculated energy saving. In interpreting these results it is important to bear in mind that the impact of a particular measure depends on the other measures which are applied and the order of application. Generally speaking, the later an insulation measure is applied, the greater its effect will be. In the case of heating system efficiency the opposite is true. Putting a condensing boiler into a poorly insulated house will save more energy than the same boiler in a well insulated house. Thus a condensing boiler will “look its best” in a poorly insulated house. Adding wall insulation will look best if applied after roof, floor and window insulation.

Table 3.4 Cost and energy analysis - house type C

Measure	Capital Cost	Energy saving	Cost saving	Cost Effectiveness	Pay-Back
	£	kWh/a	£/a	£/kWh	Years
Cavity ins.	150	4170	66.52	0.04	2
Condensing boiler	300	5282	84.26	0.06	4
Loft insulation *	210	1613	25.73	0.13	8
Mansard ins.	309	584	9.32	0.53	33
Draught proofing	182	306	4.88	0.59	37
Dry-lining - Util. rm.	339	473	7.55	0.72	45
Dry-lining - Bay.	274	278	4.43	0.99	62
Total	1764				

* this cost includes £44 for the installation of an insulated loft hatch.

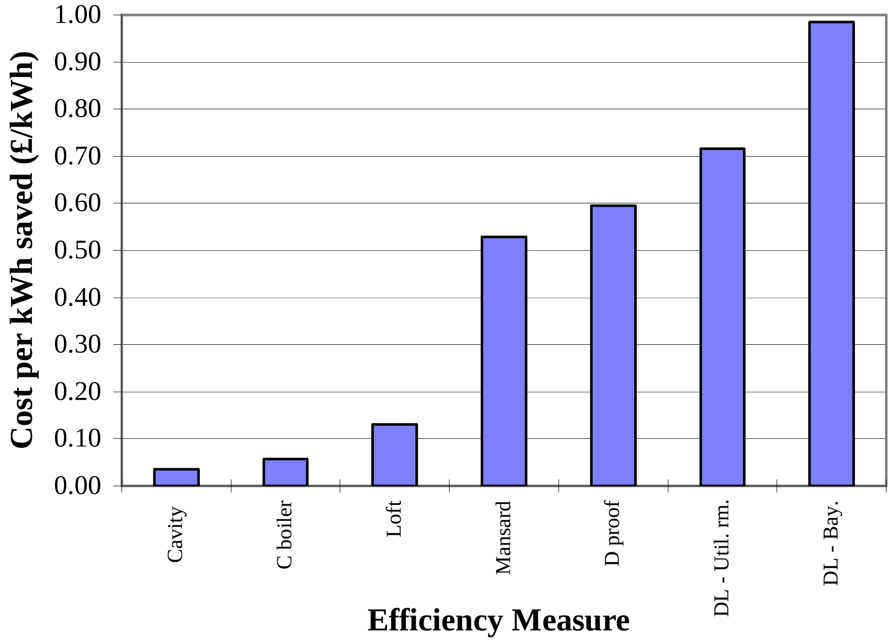

Figure 3.6 Cost and energy analysis - house type C

In this analysis, the energy saving is calculated assuming that the measure is applied last. This means that insulation measures will show their maximum saving but the condensing boiler will show a lower saving than if applied with no insulation improvements. Figure 3.6 shows the relative cost effectiveness of each measure in £s per kWh saved and figure 3.7 shows the simple pay-back of each measure. Clearly the most effective improvements are the cavity wall insulation, loft insulation and the condensing boiler. If the dry-lining and draught proofing works were omitted the calculated pay-back would be in the region of 4.5 years and if applied pro-rata to the measured difference the pay-back would be around 8 years. These figures are in line with the pay-back on the 4 house scheme where the wall insulation consisted of cavity fill only. The overall difference between the existing modernisation standard and that achieved in the 4 house scheme is some £174 at a marginal cost of around £1010. This gives a simple pay-back time of between 5 and 6 years.

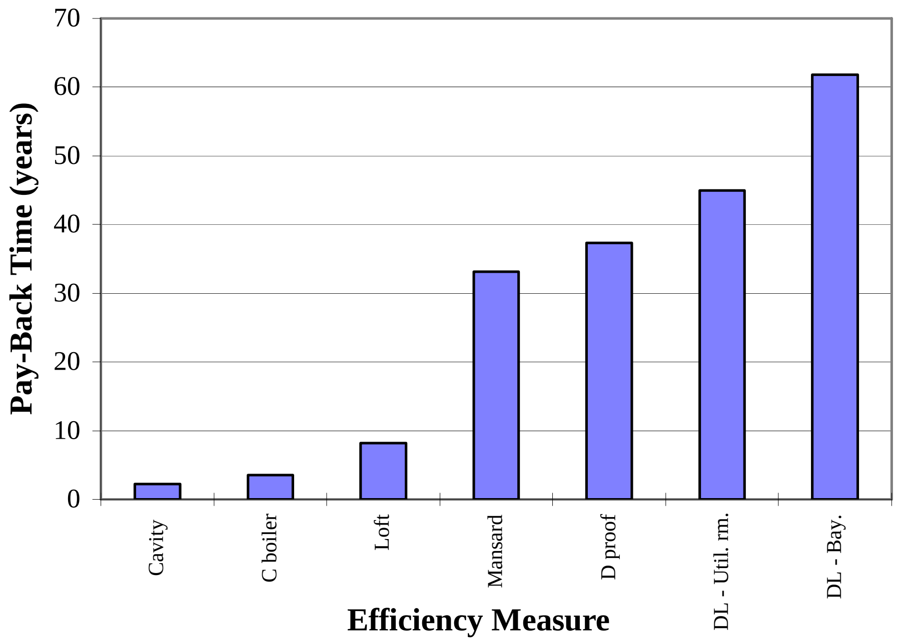

Figure 3.7 Pay-back analysis - house type C

On energy grounds alone there is little justification for the additional insulation works in some of the house types in this scheme. However there are a number of comfort and amenity issues for the tenant which should not be overlooked. Omitting insulation in some walls or parts of walls is likely to create cold spots which will be prone to condensation and reduce the feeling of warmth for anyone sitting near to the wall. The omission of draught proofing may also reduce feelings of comfort in some rooms. The net effect of this may be to encourage occupants to raise overall house temperatures to compensate for loss of comfort and to combat condensation. This will in turn increase energy consumption.

3.4.4. Results of tenant surveys

Results of the survey of tenants in both groups before and after improvement can be summarised as follows (full results are set out in appendix 5):

- Tenant perception of warmth has changed with most tenants in both groups feeling that house temperatures after improvements are "just right". This compares with a general perception of houses being either "too cold" or "much too cold" before works. The fact that there is little difference between the groups in their perception of temperatures seems to bear out the findings of the temperature monitoring which shows only a very small overall difference in average temperatures. Spot measurements of internal and external temperatures were made during the interviews but are very difficult to interpret because outside temperatures during the interviews in March 1993 were between 2°C and 5°C higher than in November 1991. Hence the higher internal temperatures in both groups during the "after" interviews are likely to be a function of the relatively high external temperatures at the time (15.7°C - experimental group and 17.3°C - control group) rather than the affect of improvements (see appendix 5).

- In line with the perceived improvement in temperatures is an increased satisfaction with heating. Most tenants in both groups express satisfaction after works compared with a general level of dissatisfaction prior to improvements.

- The most common way in which tenants used their heating was to use the central heating and gas fire in combination, although slightly more tenants in the control group used central heating only (6 as against 3 in he experimental group). The way in which the two heat sources are used in combination may have an important impact on energy efficiency since in the case of the experimental group there is a large difference in efficiency (almost 50% in some cases). This point is discussed further in section 3. 8. Control of the heating system is split evenly between manual switching and automatic timing.

- Although condensation is still a feature of the houses after improvement, the number of tenants reporting problems has reduced in the experimental group (from 23 to 14) but has shown no change in the control group (9 in both surveys). The ventilation improvements coupled with the insulation improvement in the experimental group are likely to have been an important factor in this change.

- The level of concern about heating costs has fallen in the experimental group but the control group remain as concerned as before.

3.5. Discussion

Large variations in energy consumption between houses of the same level of energy efficiency are commonly observed in housing field trials (for a review of some of the literature on this issues see Bell et.al 1996). This is largely due to differences in the way in which occupants use their homes. To investigate the differences in this case would require detailed interviews with occupants and careful energy modelling in order to duplicate occupant behaviour. Such an investigation was outside the scope of the monitoring undertaken.

3.5.1. Variations in construction

Variations in construction resulting from maintenance and repair activity during improvements to the control group could have affected results. Checks reveal that this is the case in only one property in the control group. In the case of control house number 4. improvement works included substantial window replacement on repair grounds. Some 80% of windows were replaced and incorporated double glazed units. The energy consumption of this house is one of the lowest in the control group and has clearly been affected by the window replacement. Variations in the quality of cavity filling could also have acted to confound the results since checking the extent of cavity filling is extremely difficult. However endoscope surveys of a sample of properties do not indicate significant under-filling of cavities.

3.5.2. Use factors

In an attempt to assess the likely use issues, an interview was carried out with the occupants of one of the experimental houses. The house exhibited an energy consumption some 40% above the predictions of the NHER program despite internal temperatures similar to those which were predicted by the model. Part of the discrepancy would appear to relate to the use of the gas fire. The fire chosen by the tenant was an enclosed gas flame fire with an efficiency which varies between 59% at high output and 47% at minimum output. The use pattern which emerged during the interview indicated that the gas fire was operating on its low setting from about 2.00 in the afternoon to 11.00 in the evening and was also on for about an hour in the morning. The gas fire was used even during the timed heating periods. Since the lounge radiator has a thermostatic radiator valve the heat from the gas fire would turn the radiator off for long periods especially during mild weather. This means that most of the lounge heat would be provided by the fire running at about 47% efficiency compared with the condensing boiler at about 90% efficiency. A crude assessment of this effect would suggest that this factor could account for just under half the difference between measured and predicted levels of consumption. A broader analysis of the gas fire choices in the experimental and control houses indicates choices of fire which are similar to that in the above example.

The impact of gas fire usage in the two groups is likely to have a more marked effect in the experimental group compared with the control group as the efficiency discrepancy is greater in the experimental group. If for example a gas fire was providing 20% of the heating the increase in consumption would be 14% in the experimental group but only 4% in the control group.

The issue of gas fire choice and use has been discussed in some detail in order to illustrate the potential impact of use on consumption and also to highlight the need for some consideration of this issue so that guidance can be provided to tenants on both the choice of fire (if any) and its use, particularly in houses fitted with condensing boilers. This need for advice is further reinforced by the findings of the social survey which showed that a very high proportion of tenants (80%) used some combination of gas fire and central heating. One particular fire choice (the "Valor Dream" - an open chimney type) should be reviewed not only because it is only 42% efficient at all settings but also because the open chimney increases ventilation losses even when the fire is not in use. Other aspects of use in the case investigated related to the opening of windows in bed rooms hot water consumption and thermostat settings, most of which would tend to increase consumption in this particular case.

3.5.3. Design, buildability and cost issues

The effect on costs of the variation of wall constructions indicates the importance of effective modelling and assessment of measures on a house type by house type basis. In addition, if some of the measures applied in this project became a regular part of the improvement scheme, a reduction in costs would be expected as contractors became familiar with the work and materials were ordered in larger quantities. Since the work on this project was carried out, cavity wall insulation costs in York have been reduced from £150 per house to a unit cost of around £100 in larger contracts.

Capital costs are also influenced by the design and sizing of the heating systems used. In the early part of the project there was a tendency to over size the heating systems. Although with condensing boilers this does not have a large effect on efficiency, it can increase the capital cost significantly. The design of energy efficiency measures requires the integration of both insulation and heating to produce a balanced and cost effective scheme. The use of energy modelling is an important tool in this process and detailed design and contracting arrangements should allow for its effective use. In addition, many improvements in insulation can be made at marginal cost if combined with works of repair. One example would be the mansard roof section of house type C, where the cost effectiveness of improved insulation would be greatest if done at the same time as reroofing or the renewal of internal plaster work.

With the exception of cavity wall insulation the measures adopted in the 30 house scheme were carried out using the existing tenant's choice contracting systems. Little difficulty was experienced in adopting this approach and with more control of the design of heating systems and the detailed specification of insulation works there is no reason why such an approach should not continue. During interviews with one tenant problems relating to the maintenance of the condensing boiler emerged. In the case discussed, there seemed to be a lack of experience on the part of the servicing and repair engineer with this type of boiler. This is likely to be a transient problem as domestic condensing boilers are still relatively rare and repair experience takes time to build up. However maintenance programmes should be developed which ensure that training is provided for maintenance personnel.

4 The Bell Farm scheme

4.1 Introduction

The Bell Farm scheme was established to give York City Council the opportunity to apply the lessons from the York Energy Demonstration Project as widely as possible. In all some 200 houses were eventually improved under this scheme, to a standard close to that of the 4 house scheme.

Monitoring of the Bell Farm houses was undertaken with two objectives. The first was to confirm the measurements made in the 4 house scheme. The second was to investigate the impact of providing detailed one-to-one energy advice to these tenants.

One of the features of the Bell Farm scheme compared with the 4 house scheme, was the lower degree of control exerted by Leeds Metropolitan University over the details of energy related works. Thus, a number of the houses in the Bell Farm scheme were fitted with non-condensing boilers. In those houses that were monitored, this was where the tenants wanted the option of a living room fire with a back boiler. The boilers in these houses were fitted with optimisers. All of the gas heated houses in the Bell Farm monitoring scheme were fitted with focal point flame effect fires, the thermal efficiencies of which vary from bad to awful. One of the houses in the Bell Farm monitoring scheme was all-electric and was heated by storage heaters and a 2 kW focal point electric fire.

Most of the houses in this scheme were fitted with Glidevale vents in living rooms. Six of the monitored houses were fitted with passive stack ventilation systems, supplied by Willan, extracting from the bathroom and kitchen. At least one had an air-brick as well as a Glidevale vent in the living room. Little effort was made in these houses to improve airtightness. Existing loft hatches were retained and suspended floors were not skinned with hardboard.

4.2 Monitoring

Monitoring in the Bell Farm houses was a combination of manually read utility meters and three internal temperatures. The latter were measured using 2 kΩ thermistors and were logged by a Grant Memory logger. The logger recorded hourly averages of the three internal temperatures, and was intended to be downloaded approximately monthly. In practice, this approach was unsatisfactory. Hourly recording generates a large quantity of data, with a much greater level of detail than can be used to good effect in such a large project. This hourly data had to be boiled down by hand, to daily, monthly and heating season means, at which level of detail it has considerable explanatory power. Data handling and analysis would have been much more convenient if most of the temperature data had been recorded at daily intervals, but the software supplied by Grant was unable to do this.

The battery life of the Memory Loggers was approximately 6 weeks. Because of the difficulty of gaining access to peoples' homes on a regular basis, there were many occasions when much longer periods than this elapsed between readings, and as a result batteries failed, or memory was filled and logging ceased.

Finally, electrical contacts both to the battery and to sensors proved unreliable. This resulted either in the complete failure of loggers, or in the loss of data from 1 or more channels over substantial periods. The manpower available to the monitoring exercise meant that it was impossible to chase up and correct such failures, and substantial amounts of data were lost.

4.3 Energy use and temperatures in the bell farm houses

Despite the problems outlined above, enough temperature and energy data were collected to enable us to make a convincing assessment of the energy performance of 10 of these houses. The mean delivered energy use in the gas heated houses was just under 18,600 kWh/a. Heating season internal temperatures could be estimated in 5 of these, and the median of these was 18.8°C. One of the houses for which internal temperature data was available appeared to have an internal temperature of about 23°C over a heating season, and this house also had the highest delivered energy use at 23,800 kWh/a. Figure 4.1 compares mean energy use in the gas heated houses at Bell Farm with energy use in the other groups of houses monitored at York over the period from 1992 and figure 4.2 shows a comparison of mean internal temperatures over the same period. The all-electric house has been excluded from this comparison to avoid an additional source of uncertainty, but the picture does not change qualitatively even if it is included.

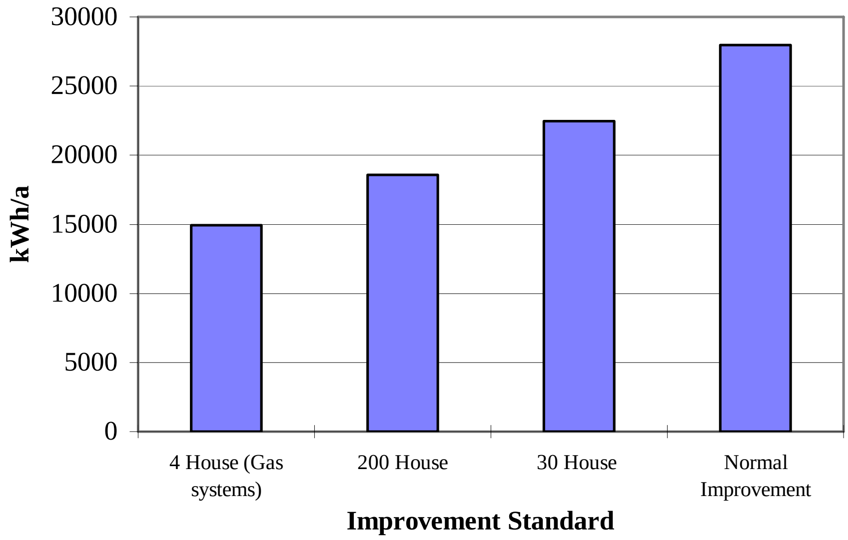

Figure 4.1 Comparison of total energy consumption

Figure 4.1 shows Bell Farm at a point midway between the 30 house scheme and the 4 house scheme in terms of total delivered energy use. This result is unsurprising given the measures that were undertaken in the three groups of houses. Energy use in the all-electric house at Bell Farm was just under 12,000 kWh/a, a figure which is very close to the consumption measured in the two electric houses in the 4 house scheme. This house was occupied by an elderly single lady, who tended to keep her living room warm and her bedrooms rather cool, and who possessed an electric blanket.

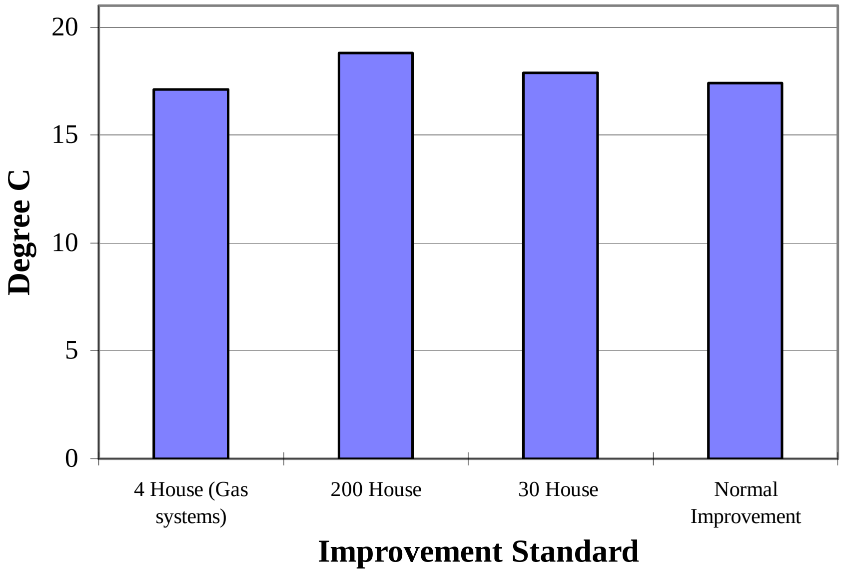

Figure 4.2 Comparison of mean internal temperatures

4.4 Energy advice

A proposal was made to test the effectiveness of providing detailed energy advice on a one-to-one basis, at Bell Farm. In this proposal, the advice was to have been given in the middle of the heating season (it was thought that it would have more effect then, than at any other time in the year) and energy use and internal temperatures were to have been measured for 6 months before and after. It was hoped that comparisons of internal temperatures, and of energy use as a function of external temperature, would enable the effect of the advice to be detected, without the need to monitor energy use for a whole heating season before and after advice was given.

In the event problems with data collection meant that meaningful comparisons could not be made. A total of 8 households were visited and extended advice sessions were held with 5 of these. An advice sheet (Appendix 6) was left in all cases. The advice sessions that were undertaken did throw up a number of interesting pieces of qualitative anecdotal information, which are summarised below.

- At least one occupant did not understand her heating system programmer. She relied on her son, who lived next door, to make adjustments for her. This household was balanced by another household where the programmer was well understood.

- Households appeared to vary in the amount of use made of the gas fire. Some used it regularly, either in the morning or in the evening, while others reported that they made little use of it.

- Room thermostat settings were very high in two houses - 25 and 30°C. Occupants of these houses were advised to experiment with the room thermostat, to find the temperature that best suited them.

- All of the water cylinder thermostats that were examined were found to be set at 60°C. Several occupants observed that this was, if anything, too hot. The energy adviser showed the occupants of all houses visited how to adjust the cylinder thermostat, and turned the thermostat down to 50°C in all cases.

Our initial investigation of the effects of energy advice has been inconclusive. The present authors have covered the existing literature on energy advice in more detail (Bell et al 1994). It is worth noting that a much larger study of the effects of energy advice is presently being undertaken by the BRE, funded by the Joseph Rowntree Foundation.

4.5 Conclusions from the bell farm scheme

The Bell Farm scheme broadly confirms the energy consumption reported from the 4 house scheme. The difference between these two schemes is likely to be due to a complex mix of causes which include:

- installation in the Bell Farm houses of gas fires with low efficiency and no thermostatic control;

- the fact that the Bell Farm houses are likely to be less airtight than the 4 houses, due to the need to provide fixed vents for gas fires in living rooms, and the omission from the Bell Farm scheme of measures to make timber suspended floors more airtight;

- the presence in some of the Bell Farm houses of solid, uninsulated walls in passageways between houses.

There is a limit to how much more can be read into the difference between the 4 house scheme and the Bell Farm scheme, because of the small numbers of houses involved.

5 Conclusions

The York Energy Demonstration Project has demonstrated that significant environmental and financial benefits can be realised by the application of well established energy efficiency measures to existing housing. Achieving the level of energy savings demonstrated in this project is no longer a matter for research but of the systematic integration of energy efficiency measures into every housing modernisation and maintenance scheme which is carried out. The conclusions from the York Energy Demonstration Project are set out below.

5.1. Energy and CO_2

- Energy use in existing housing can be reduced to below that in housing constructed to 1990 building regulations, and that overall savings of the order of 50% can be made if existing housing is modernised to a standard similar to that achieved in the 4 house scheme.

- In houses where space heating and hot water is fuelled by gas, CO_2 emissions can be reduced by around 2.4 tonnes per annum per house if existing modernisation programmes are enhanced to the level of the 4 house scheme at York.

- Absolute reductions in emissions of 4.5 tonnes per annum per house may be possible if housing which has not been modernised since the 1950's is modernised to the level of the 4 house scheme. Part of this saving results from the displacement of electric space and water heating by gas.

5.2. Cost effectiveness

- The pay-back periods for the packages of measures implemented at York, in the most straightforward of the houses treated, were of the order of 5 years based on measured data.

- The capital cost of many of the house at York was significantly raised by the presence of complex wall and roof constructions, which could not be insulated simply or cheaply. The effect of omitting the insulation from these details would result in large capital savings, and reductions in pay-back time from of the order of 17 to 8 years, based on measured data.

- The most cost effective measures were, in order, cavity wall insulation, condensing boiler, loft insulation top-up to 200mm.

- Predictions of energy use based on BREDEM show that double glazing has a pay-back time of around 8 years if installed when window frames are replaced.

- Experience at York shows clearly that the cost effectiveness of individual energy efficiency measures can vary greatly depending on the extent to which they are incorporated within maintenance and modernisation works.

- An opportunistic approach to energy efficiency is likely to provide the best chance of improving the cost effectiveness of measures. This applies particularly to window replacements, but opportunities may arise in all maintenance and modernisation programmes. Budget managers need to be encouraged to recognise energy conservation opportunities and to be able to call upon funds when they arise.

5.3. Detail Design

- The detailed design of heating systems should more closely reflect the insulation improvement in each house type. If condensing boilers are used, their efficiency is unlikely to be affected by over-sizing, but the impact on capital cost can be important. Savings may also be possible on components such as radiators which may be smaller in well insulated houses.

- As we observe in Chapter 3, the choice and use of independent gas fires in many of the houses monitored may have had a significant impact on the efficiency of the heating system as a whole. Appendix 4 sets out information on fire efficiencies. The list of options available to tenants should be reviewed with a view to avoiding the least efficient appliances. The requirement for permanent ventilation to open flued gas appliances increases the ventilation losses where such appliances are chosen by tenants. As far as possible the use of back boiler type central heating systems should be avoided in favour of room sealed condensing boilers.

- Where small houses are insulated to the 4 house standard, the installation of a conventional central heating system may not be necessary. This could provide important cost savings (about £800 in the case of the gas unit heater house in the 4 house scheme). Experience with the gas unit heater scheme suggests however that care is required in design to ensure an even temperature distribution.

- Measurements of air leakage rates in the electric houses (4 house scheme) suggest that the use of polyurethane foam as a cavity insulation material has assisted in achieving a high level of airtightness in these properties. Polyurethane is a very expensive material when compared with blown fibre, but may perform a structural as well as an energy efficiency role by replacing failed wall ties. Its application in such situations requires the opportunistic approach to energy efficiency work outlined above.

5.4. Use Issues

- The evenness of temperatures across all standards of energy efficiency indicates a desire, on the part of occupants, to achieve comfort levels even in houses which are less well insulated. This suggests that, in many cases where houses are modernised, efficiency improvements which are built into the modernisation scheme are likely to result in real cash savings rather than additional warmth.

- Although the data available in the Bell Farm scheme did not permit the effects of energy advice to be determined, the anecdotal evidence from this and the other schemes points to energy advice as an important consideration both in relation to modernisation schemes and in the long term management of housing. This need has been recognised in other schemes and an extensive study of energy advice is currently being carried out by the BRE with funding from the Joseph Rowntree Foundation in York.

5.5. An Agenda for the Future

Figure 5.1 shows how the best of the houses at York compare with energy use in the average British dwelling, and in three other low energy housing projects. The Pennyland houses (Lowe et al. 1985) represent the best of the UK low energy projects of the 1970's and 1980's, the Longwood House (Bell et al. 1996) represents one of the most energy efficient UK schemes of the 1990's, and Kranichstein in Germany represents the best of the low energy housing projects currently being undertaken in Europe (Feist 1994). Pennyland and Longwood address the concerns of the 1970's, which were the exhaustion of fossil fuels, and security of supply. Kranichstein addresses the much more demanding agenda of the 1990's, which is the stabilisation of atmospheric CO_2 concentration. As can be seen, the houses at York outperform the UK average by over 30%, and approach the level of the Pennyland scheme. They do, however, fall some way short of the levels set by Longwood and Kranichstein.

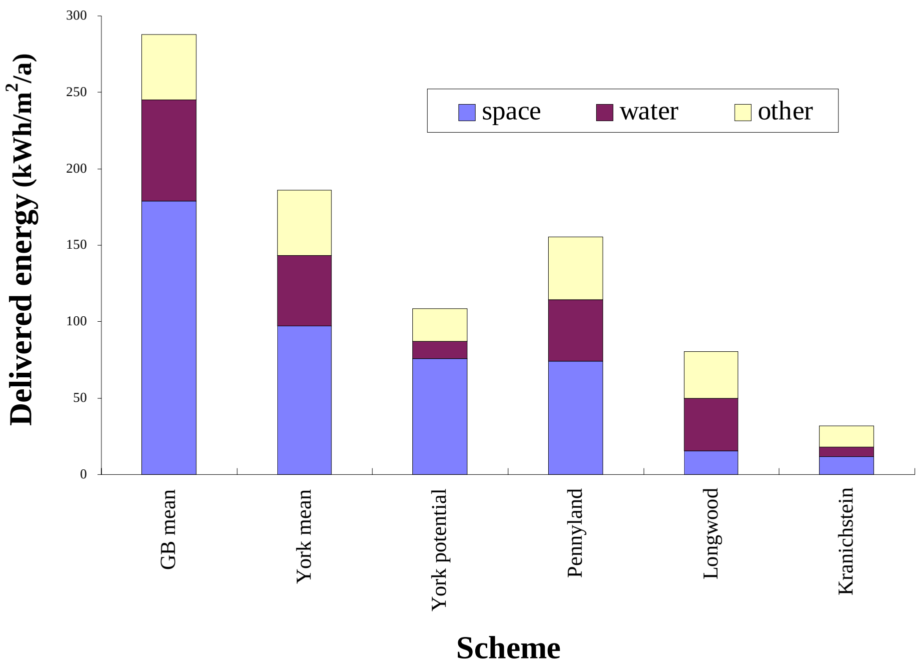

Figure 5.1 Comparison of energy standards

The agenda at York was to implement an energy efficiency programme at modest cost, that could be undertaken by the Local Authority acting alone, within the constraints imposed by existing housing modernisation programmes, concentrating on space heating and to a lesser extent water heating, and using technology of the 1980's. Although significant improvements were made in York, it is possible to identify a number of further improvements in space and water heating which could be made. The likely effect of these further improvements is shown in figure 5.1 (York potential).

The glazing in the 4 House Scheme at York consisted of air-filled, low-emissivity double-glazed sealed units, with aluminium edge spacers. The average unit size was less than 0.5 m², giving an overall U value probably in excess of 2.4 W/m²K. By the use of argon-filled double glazing with insulating edge spacers, and by halving the number of discrete panes, the overall window U value could be reduced to around 1.5 W/m²K. Addition of a third pane of glass could give a U value below 1 W/m²K. The structural simplification of the windows would go a considerable way to pay for the additional pane of glass and argon filling, and would also increase the overall solar heat gain coefficient of the window.

The external doors used at York had a U value in excess of 3 W/m²K and were also leaky. Anecdotal evidence showed that occupants were clearly aware of this poor performance. A U value of less than 1 W/m²K is easily achieved in external doors, and would simultaneously improve airtightness and security. Re-specification of windows and doors in this way would reduce total heat loss by about 20% from the level achieved at York in the 4 House Scheme.

Thermal bridging through party and gable walls, and along eaves in the York houses effectively doubles the U value of the roof, from a nominal 0.2 W/m²K (assuming 200 mm of mineral fibre on loft floors) to a real average of around 0.4 W/m²K. Reducing this thermal bridging would reduce heat loss, and eliminate mould growth and any residual risk of plumbing associated with water storage and header tanks freezing in cold weather. It could be undertaken economically in conjunction with re-roofing. The remaining areas of thermal bridging, around window and door reveals and at the wall-ground floor junction, could not be treated without undertaking major additional works such as external insulation. Such work is unlikely to become viable in the foreseeable future in houses of cavity masonry construction, but may be feasible in houses of solid wall construction, particularly if insulation were applied externally.

Further savings of up to 30% in energy use for domestic hot water are possible through fitting of showers and aerating taps, the application of thermal insulation to hot water delivery and primary pipework[1], and by further increasing the thickness of thermal insulation applied to hot water cylinders.

The areas not addressed at all by the YEDP, which we suggest must form the agenda for any future housing energy field trials, are:

- the systematic reduction in electricity use by all classes of domestic electrical appliances;
- further reductions in energy demand for hot water, for example by the use of active solar water heating.

[1]Although the insulation work suggested here was originally specified for the 4 House Scheme, it appears not to have been completed. The estimate of savings in energy use for hot water is based on the SAP (DOE & Welsh Office, 1994), together with an assumed 20% reduction in hot water use.

Initial calculations suggest that application of all additional measures listed above, would reduce delivered energy use in the 4 House Scheme to about 110 kWh/m²/a. This figure has been improved upon by only a handful of new houses in the UK to date (Olivier & Willoughby 1996), and in existing housing would represent a considerable achievement. Reductions in energy use and environmental impact beyond this would probably require measures on the energy supply side, which might include the use of small scale gas fired combined heat and power systems and photovoltaics. But, as we have tried to show, even without these measures, very considerable reductions in delivered energy use can be made in houses of the types investigated at York.

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