Energy savings from insulation improvements in electrically heated dwellings in the UK

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Abstract

When the UK electricity industry was privatised over a decade ago, obligations were placed upon suppliers to improve energy efficiency. The resulting Energy Efficiency Standards of Performance (EESoP) have been in force since 1994, overseen by the industry regulatory body and funded through a special revenue allowance. This paper describes the results of monitoring to observe savings actually achieved as a result of the provision of insulation measures in electrically heated properties under the first two programmes, EESoP 1 and EESoP 2, covering the period up to March 2000.

Two different approaches were used. In EESoP1, an analysis of a sample of meter readings from 5% of dwellings[1] before and after installation of measures was undertaken. In EESoP2, temperature and consumption monitoring of a smaller sample of dwellings was undertaken, including customer questionnaires to identify any external factors that may have influenced electricity consumption.

Analysis of meter readings from almost 8 000 dwellings in EESoP1 revealed a 12% saving in electricity consumption, corresponding to a reduction of 163 kg C per property in yearly CO_2 emissions. Although large enough to be considered cost-effective, the savings were lower than expected. This has previously been attributed to a 'comfort factor', which assumed that savings were realised as higher indoor temperatures. The analysis described in this paper finds that the main reason for lower savings is that the homes monitored appear to be heated to a lower standard than assumed in the calculation of the savings, although a small rise in average indoor temperatures was observed after insulation.

Introduction

After it was taken into public ownership in 1947, the UK electricity supply industry developed as a highly integrated system, covering generation, transmission, distribution, and billing. It was organised on a regional basis for distribution under Area Electricity Boards, and centrally for generation and transmission under the Central Electricity Generation Board in England and Wales. In Scotland, the two Area Electricity Boards were responsible for generation and transmission as well as distribution; Northern Ireland Electricity had a similar level of vertical integration. All parts of the industry were publicly owned and required to act in the public interest.

Privatisation in the early 1990s caused profound and continuing changes to the structure of the electricity supply industry. (Surrey 1996) In the context of this paper, one of the most significant changes was the establishment of the Office of Electricity Regulation (OFFER), an agency of the state with wide-ranging powers relating to the public supply of

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[1] The term *dwelling* is used throughout this paper to describe a physical housing unit – a house, bungalow, or flat. The term *household* is used to describe the group of people that occupy a dwelling and is defined by social and economic rather than physical attributes.

electricity and the licensing of suppliers, the promotion of competition and a statutory responsibility to promote energy efficiency. The role of OFFER was extended in 2000 and assumed by a new regulatory body, the Office of Gas and Electricity Markets (Ofgem).

The obligation to promote efficiency in the use of energy by households has been met principally through the Energy Efficiency Standards of Performance (EESoP), which were first introduced in 1994 in England and Wales and a year later in Scotland. EESoP1, which ran until 1998, obliged the Public Electricity Suppliers (PES)[2] to achieve a defined level of energy savings funded through a special revenue allowance equivalent to £1 per customer per year. EESoP2 extended similar obligations for a further two years up to March 2000, and EESoP3 until March 2002. The key features of EESoP programmes are being continued under the Energy Efficiency Commitment, a 3-year programme with a target of 62 TWh savings.

The work described is this paper was aimed at assessing the savings actually achieved by the EESoP1 and EESoP2 programmes. Two different approaches to assessment were taken.

- For EESoP1 (1994-98), meter readings before and after installation of measures were obtained from suppliers for a representative sample of 5% of the participating households. These were normalised and corrected for weather variations, both between the two periods and for different geographical locations. Statistical analysis was then undertaken to observe relationships between actual and expected savings and dependence on factors such as built form and level of energy consumption.
- For EESoP2 (1998-2000), indoor temperatures and consumption were monitored in a smaller sample of properties, supported by customer questionnaires aimed at identifying any other factors that may have influenced electricity consumption before and after installation of measures. One of the key aims of the monitoring was to establish the extent to which the benefits of the measures were taken in higher indoor temperatures, rather than reduced consumption.

Results from EESoP1 monitoring

Analysis of meter readings from almost 8 000 dwellings in EESoP1 indicated average annual savings of 1 383 kWh/year/household. The standard deviation in the observed savings was 3 667 kWh, and the standard error of the mean 41 kWh. The savings amounted to a 12% reduction in electricity consumption and an average reduction in yearly emissions of 163 kg C. Taking account of the proportion of units saved at off-peak and peak tariffs, the savings are worth around £50 per year per household. Based on the sample of dwellings monitored, the aggregate savings from EESoP1 is estimated at around 220 GWh. However, the measured savings were just over half of the savings that were expected.

The expected savings were calculated using BREDEM, a method consistent with the European Standard EN 832 and widely used in the UK (Anderson et al, 2002). The initial calculations assumed adequate levels of heating (21°C in living areas; 18°C elsewhere) both before and after insulation, and also that there were no changes to other factors affecting energy usage, such as ventilation rates. Savings for particular measures were calculated from a standard case typical of each house type rather than from audits of individual dwellings, which would have added considerably to cost.

It was recognised that the calculations were likely to overestimate savings obtained in practice, because some households would take the savings in the form of improved comfort (higher indoor temperatures) rather than reduced consumption. When targets were originally set, it was assumed that low income households would take 50% of potential savings from insulation measures in improved comfort, while other households would take 20%. Low income households accounted for two thirds of installations, giving a weighted average of 40%. The overall average savings expected were therefore 60% of those calculated initially, amounting to 2 614 kWh/year/household. (Calculated savings were 4 356 kWh/year/household)

The 40% of savings not expected to be observed as reduced consumption were described as a ‘comfort factor’, by implication attributing all of the difference between calculated and observed savings to rises in indoor temperature. This differs from the terminology used in North America, where it is usual to refer to the ‘take-back effect’[3]. Although ostensibly a more inclusive term, take-back could equally well be used in this context. In practice, there are other reasons why theoretical savings may differ from those actually observed, including measures that perform less well than expected, the use of window opening to control temperature, and systematic errors in either calculation or measurement of the savings.

Even the most cursory analysis of meter reading data shows that low prior consumption is a significant factor in the shortfall in savings. The expected level of energy savings cannot be achieved because, on average, the monitored households use much less energy than assumed in the calculation of the savings. Put simply, the households in question could not be expected to save electricity that they were not using in the first place. To illustrate this point, 9% of the households had electricity consumptions before improvement that were actually less than the expected savings, even allowing for the comfort factor. Much of the analysis reported below explores the relationship between savings and consumption.

DIFFERENCES BETWEEN CALCULATED AND REALISED SAVINGS

Before looking in detail at the relationship between savings and consumption, it is appropriate to consider how differences might arise between actual savings and those calculated in advance. Possible outcomes for the calculated savings

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[2] The privatised successors to the former Area Electricity Boards.

[3] ‘Take-back occurs when people with more efficient homes use more energy than expected because they are less cautious about maintaining thermostat setbacks and other basic efficiency measures.’ (Extracted from a paper by Jeff Ross Stein in Home Energy Magazine, Sept/Oct 1997) The terms ‘snapback’ and ‘rebound’ are also used in the same context.

are summarised below, including both some that are readily observable and some that are not observable directly.

- Some of the calculated savings may simply be unavailable in practice. Consumption prior to improvements may have been overestimated; the calculations may overestimate the effect of improvements; or the measures applied may not perform as specified.
- Savings may be observable as expected reductions in electricity consumption, in increased indoor temperatures, or in reductions in the use of other fuels.
- Savings may be discarded (consciously or inadvertently) by opening windows more frequently to control indoor temperature. This would increase ventilation heat loss and would partially or wholly counteract the effect of insulation in reducing heat loss. It could result in some benefit in air quality but would not be measurable as a temperature increase.
- Errors in measurement may arise, e.g., savings may be partially obscured by growth in the use of electricity for purposes other than heating.

In practice, it is frequently impossible to distinguish between several of those outcomes as it would require very detailed monitoring to do so. In the case of the monitoring from EESoP1, the only information is the meter data for periods of about a year before and after measures were installed and it was only possible to observe directly actual reductions in consumption. For the EESoP programmes (and indeed for most energy efficiency programmes in the UK), standard practice has been to calculate savings in advance of applying measures and to attribute any shortfall in savings actually realised to a 'comfort factor'. In the context of EESoP, the comfort factor is defined by the expression:

$$F_c = \{1 - \frac{S_{act}}{S_{cal}}\}.100\% \quad (1)$$

where S_{act} and S_{cal} are actual and calculated savings respectively.

By definition, any observed shortfall from the calculated savings was accounted for by such a 'comfort factor'. This terminology might appear to imply that all of the shortfall could be attributed to increased indoor temperatures, but it is clear that any of the effects listed above could have contributed to it. Indeed according to this definition, a poorly heated house could have a very high comfort factor, even if the insulation improvements were as expected and heating standards were similar before and after improvement.

Despite its limitations, this definition of comfort factor is used below in describing the analysis of EESoP1 savings. As noted above, an average comfort factor of 40% was estimated in advance for EESoP1. The analysis that follows shows the comfort factor observed from actual savings.

THE RELATIONSHIP BETWEEN COMFORT FACTOR AND LEVEL OF CONSUMPTION

While the information from EESoP1 monitoring is limited to before and after meter readings, the number of cases is high (almost 8 000) and statistical analysis may be undertaken both for the whole data set and for selected groups within it. Linear regression was used to look for relationships between the savings realised and other variables, such as built form and type of measure applied. However, the strongest and most interesting relationship revealed by the data is that between savings and the level of energy consumption.

The complete data set contains different dwelling types, ranging from 1-bedroom flats to detached houses, with widely different heating requirements and expected levels of savings. This must be taken into account when observing the relationship between comfort factor and consumption. Two dwelling types were selected for analysis based on the fact that they were well represented in the data and on the expectation that each is expected to be relatively homogeneous in terms of floor area and heat loss. The types chosen were semi-detached houses (1 947 cases) and 1-bedroom flats (343 cases).

Figure 1 shows the comfort factor plotted against annual consumption prior to measures being applied for the two dwelling types. As there is considerable scatter when individual points are plotted, the points were first sorted by annual energy consumption and divided into 10 groups. For example, the first group for the 1-bedroom flats contains the 10% of the total with the lowest consumption, the second group the next 10% in order of consumption, and so on. Each point plotted represents the average consumption and average comfort factor for a group consisting of 10% of the total sample. As there were a total of 332 1-bedroom flats, each point represents the average of 33 cases except for the highest consumption group, which contains 35 cases. The corresponding numbers for semi-detached houses are a total of 1 947, and 195 cases in each group except the highest, which contains 192. When the cases are grouped in this way, comfort factor shows a very strong relationship with consumption for both dwelling types.

Figure 1 shows the two dwelling types following distinctly different lines. This is to be expected because the level of consumption required to provide the standard of heating assumed for the calculation of savings is dependent on specific heat loss, which is much greater for the houses than for the flats. It is instructive, therefore, to relate the level of consumption to the level that was expected. Although it was not included in the data set for individual cases, it was possible to return to the source of the original savings calculation to obtain the assumed level of consumption before improvements were made. For the 1-bedroom flats, this was 9 700 kWh/year and for the semi-detached houses 21 000 kWh/year. Figure 2 shows the same data as Figure 1 except that the consumption (x-axis) is expressed as a percentage of the expected consumption.

When plotted against consumption normalised as described in the previous paragraph, the data for the two dwelling types show very similar characteristics. When prior consumption is as assumed when the expected savings were calculated, the comfort factor is around 35%, which means that 65% of the calculated savings are realised. However, when prior consumption is only 35% of that expected, the comfort factor rises to around 100%, which means that no savings are observed. In broad terms, this is not at all surprising, as households using just 35% of expected electricity

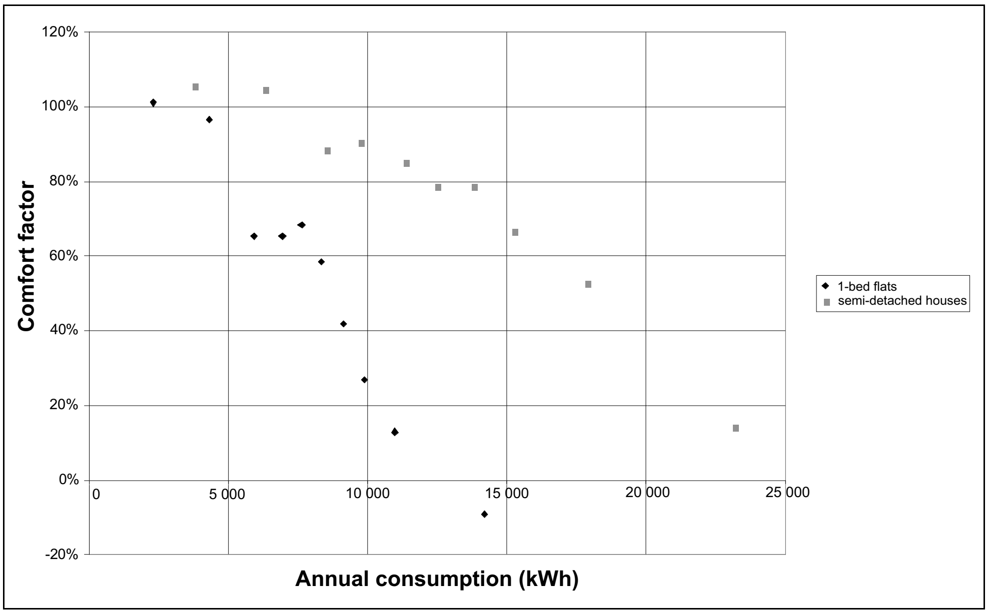

Figure 1: *Observed comfort factor for semi-detached houses and flats against prior energy consumption.*

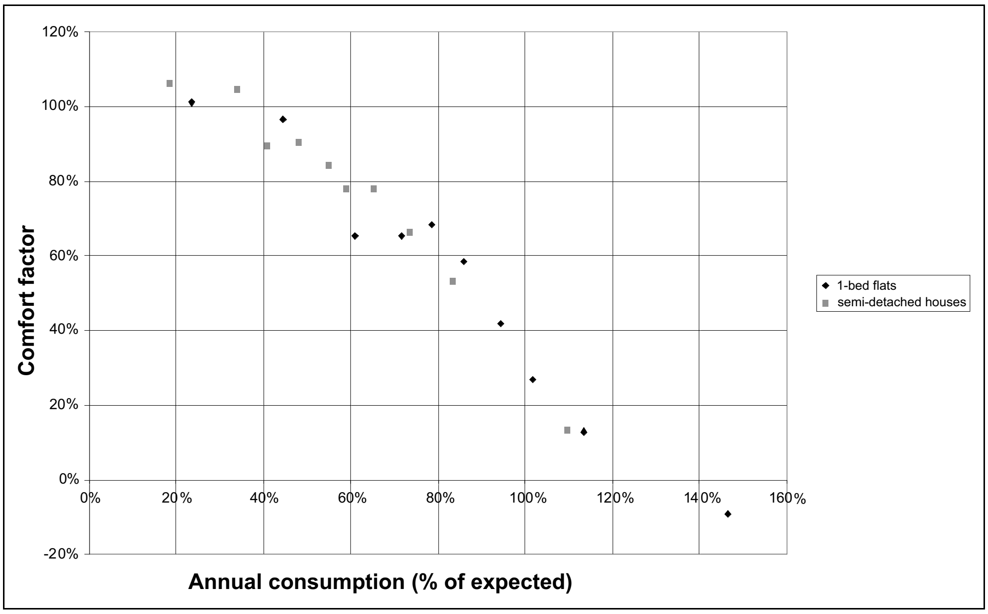

Figure 2: *Comfort factor against percentage of expected consumption.*

consumption could not have been using much electricity for space heating and therefore insulating the building fabric could produce little or no saving. Linear regression may be used to derive the relationship between comfort factor and consumption. A good approximation for comfort factor for both dwelling types is given by the expression

$$F_c = 134 - 0.99C\ (\%) \qquad (2)$$

where C is the ratio of actual to expected consumption expressed as a percentage.

The aggregate comfort factor for the whole sample of semi-detached houses is 77%, while for flats it is 53%. While there is a considerable difference between the two cases, they are consistent when considered in the light of the relationship shown in Figure 2. For the houses, C = 58% and for the flats, C = 82%. Those results correspond closely with equation (2), which is to be expected as they were derived from the same data. For the entire EESoP1 data set, the es-

Table 1: Savings and comfort factors observed for different dwelling types.

Dwelling type *(number of cases)*	Average prior energy use		Average savings *(standard error)*		Comfort factor
	kWh	% expected	kWh	% prior use	%
Bungalow (1 216)	12 575	71%	1 139*(195)*	9.1%	75%
Detached (287)	16 236	55%	1 798*(183)*	11.1%	73%
Flat (1 712)	8 907	82%	842*(51)*	9.5%	65%
Semi-detached (1 981)	12 149	58%	1 166*(65)*	11.0%	77%
Terraced (1 080)	10 382	74%	1 146*(84)*	9.8%	68%
All types* (7 923)	11 696	67%	1 383*(41)*	11.8%	68%

**Dwelling type was not identified in all cases so the 'all types' category shown in the final line includes more cases than the sum of the categories above it.*

timated value of C is around 67% and the observed comfort factor is 68%, which is consistent with the expression given in Figure 2. This implies a significant degree of under-heating. However, there is strong anecdotal evidence that many of dwellings in EESoP1 did not rely entirely on electricity for heating, including many houses with fireplaces suitable for burning wood and coal. This could explain part of the shortfall in expected savings.

THE SAVINGS OBSERVED IN DIFFERENT DWELLING TYPES

Table 1 shows savings and comfort factors observed for different dwelling types, together with the average consumption prior to measures being installed. The data available for analysis did not include expected consumption for individual cases and some of the dwelling types shown are known to include a considerable range of built forms and floor areas; estimates of expected consumption are therefore approximate.

The energy use observed before measures were installed varied significantly by house type, as should be expected. However, it also varied considerably as a percentage of the expected energy use, from only 55% in detached houses to 82% in flats. It seems likely that these differences are real and they may be related to the availability of alternative means of heating. Most houses built before 1970 have chimneys and fireplaces, which may be used to provide an alternative means of heating in cold weather. By contrast, many flats have no alternative to electric heating other than portable LPG heaters. It is likely therefore that part of the difference is accounted for by the greater reliance of houses on other fuels, such as coal and wood. It is also possible that there is a greater likelihood of rooms being left unheated in larger dwellings, especially if they are occupied by only one or two people; this could also be a reason for lower than expected energy use in the larger dwelling types, especially detached houses.

The observed comfort factor also varied, tending to fall as the percentage energy use prior to measures being installed rises. This takes the same direction as the relationship observed for semi-detached houses and 1-bedroom flats, although there is too much scatter to confirm quantitative agreement with that relationship.

Greatest consistency between dwelling types is shown for the energy savings expressed as a percentage of prior energy use, which lies between 9% and 12% for all cases. It may appear strange that detached houses have both a high comfort factor (implying savings well below expectation) and relatively high percentage savings; this is possible because the expected savings were high, explained by the large area of external walls available for insulation. A further curious feature of the data is that the average saving for all cases was higher than for any individual type. This arises because the minority of dwellings not identified by type had markedly higher average savings than those that were.

Table 2: Savings and comfort factors observed for different PES.

PES programme *(number of cases)*	Average prior energy use	Average savings		Comfort factor
	kWh	kWh	% prior use	%
A *(465)*	9 905	170	1.7%	97%
B *(1 153)*	11 811	760	6.4%	83%
C *(642)*	11 760	1 036	8.8%	75%
D *(619)*	9 256	853	9.2%	81%
E *(130)*	10 704	1 045	9.8%	82%
J *(873)*	11 178	1 362	12.2%	49%
I *(123)*	12 799	1 584	12.4%	42%
G *(354)*	12 916	1 612	12.5%	73%
F *(461)*	10 720	1 347	12.6%	58%
H *(920)*	11 734	1 523	13.0%	63%
K *(487)*	13 000	1 899	14.6%	58%
L *(861)*	10 933	1 718	15.7%	53%
M *(835)*	14 895	2 750	18.5%	54%

THE SAVINGS OBSERVED FOR DIFFERENT PUBLIC ELECTRICITY SUPPLIERS

All of the Public Electricity Suppliers were subject to the same obligations and relied on similar types of energy saving measures. It might be expected, therefore, that very similar results would be obtained from different PES programmes. However, this was not so in practice, as shown in Table 2. There are very substantial differences in the savings obtained by different programmes, with clear statistical significance. Furthermore, the differences in savings are not explained by differences in energy use observed in Figures 1 and 2, although that may be a contributing factor. Neither does there appear to be any correlation with the types of

Table 3: Energy savings arising from particular measures.

Measure applied	Number of cases	Comfort factor	Observed savings	
			Average (kWh)	Standard error (kWh)
Cavity wall insulation only (CWI)	2 430	59%	1 293	48
Loft insulation only	714	46%	1 315	107
Heating controls only	28	81%	1 079	388
Cylinder insulation only	45	20%	689	333
Draught proofing only	31	-22%	845	356
CFL only (average 1.75/dwelling)	47	-211%	860	395
CWI + loft insulation only	678	77%	1 541	112
ALL	7 923	68%	1 383	41

measures installed or any other attribute identified in the data. It must be assumed, therefore, that they arose from differences in how programmes were administered, perhaps related to how participating households were recruited.

THE SAVINGS OBSERVED FOR DIFFERENT ENERGY EFFICIENCY MEASURES

Most dwellings received a combination of measures so the data available are not well suited to identifying the performance of individual measures. The greatest opportunity for examining the performance of an individual measures arises where that measure has a large impact in an individual case and there is a large number of cases in which it was the only measure applied. In practice, good estimates can only be obtained for cavity wall insulation and loft insulation.

Table 3 shows the estimated saving based on cases where particular measures were applied in isolation. The large number of cases in which cavity wall insulation was the only measure applied should lead to a good estimate. If it can be assumed that the sample were randomly drawn for the whole population of dwellings, to which the measure could be applied, then the result may be interpreted as indicating that there is a 95% probability that the average saving lies within two standard errors of the average (i.e. between 1 197 and 1 398 kWh). Similarly, the estimate for loft insulation should lie between 1 101 and 1 529 kWh. Physical considerations suggest that the savings from the two insulation measures should add; from statistical considerations we may expect the standard error for the sum to be equal to the square root of the sum of the squares of the individual standard errors. Thus we expect the savings from the two measures together to have a mean value of 2 608 and a standard error of 117 (i.e. to lie between 2 374 and 2 842 kWh). However, the average saving for the 678 cases in which both cavity wall and loft insulation is only 1 541 kWh, with a standard error of 112 kWh, implying that there is only around 2.5% probability that the average is greater than 1 765 kWh. This suggests that the respective samples were not randomly drawn from the same population of dwellings and may well be related to the finding that there appears to be systematic differences between the programmes administered by the various Public Electricity Supply companies, as described above.

The savings obtained for heating controls, hot water storage cylinder insulation, draught proofing and compact fluorescent lamps are all subject to large standard errors due to the small number of cases observed. However, the existence of at least some savings is statistically significant at a 95% confidence level for all measures.

THE SAVINGS OBSERVED FOR DIFFERENT HOUSEHOLD GROUPS

Households occupying dwellings in the EESoP1 data set were identified according to a number of attributes:

- ‘fuel poor’ – where household income is low in relation to the expenditure calculated to be necessary for an adequate standard of heating,
- ‘elderly’ – where the head of the household is retired and in receipt of the state retirement pension,
- ‘disabled’ – where the head of household is in receipt of state disability benefit,
- ‘rural’ – where the property is located outside an urban or sub-urban area ; arguably not a household attribute but nevertheless included in the data set.

Table 4 shows savings for the groups described above. The large group identified as fuel poor shows no significant difference from the whole sample, either in savings realised or comfort factor. This contrasts sharply with the assumptions used in calculating the expected savings, which were that the comfort factor for the fuel poor group would be 50% but only 20% for the others. It might also have been expected that the fuel poor group would show lower average consumption prior to measures being installed but again there was no significant difference. The elderly and rural groups both showed higher savings than the sample as a whole. However, the comfort factor was not significantly different in either case. The disabled group showed the largest savings and the lowest comfort factor; although the differences are statistically significant the number of cases was low and the result should be treated with caution.

Discussion of results obtained from EESoP1

The large data set provides a very solid basis for estimating the overall savings that accrued from the programmes applied under EESoP1. The number of cases is large enough also to allow the sample to be disaggregated to look for differences between groups of participating households, dwell-

Table 4: Energy savings by household category.

Household category	Number of cases	Comfort factor	Observed savings		Average prior energy use (kWh)
			Average (kWh)	Standard error (kWh)	
Fuel poor	3 136	68.5%	1 307	85	11 341
Elderly	1 267	65.0%	1 723	66	12 686
Disabled	165	48.9%	2 093	179	12 961
Rural	1 759	65.4%	1 820	66	13 722
ALL	7 923	68.2%	1 383	41	11 702

ing types and the programmes administered by different suppliers. The most salient results may be summarised as follows:

1. the savings observed were about half of those expected;
2. there is a very clear relationship between savings and energy use prior to measures being installed;
3. there is no significant difference in savings or consumption between households flagged as fuel poor and those who are not;
4. there are significant differences between programmes administered by different suppliers, despite nominally similar measures being applied.

THE IMPLICATIONS OF SAVINGS BEING LOWER THAN EXPECTED

Measures similar to those installed under EESoP1 are expected to contribute to reductions in CO_2 emissions, as part of the government's climate change programme. If those measures have the same effect as in EESoP1, then their contribution to the climate change programme will be little more than half of what is expected. This is clearly unwelcome but will have limited overall impact as energy savings from electric heating contribute only marginally to the overall savings expected under the climate change programme.

It is important to consider the reasons why the savings were lower than expected. Although the results of monitoring meter readings alone can offer only limited explanation, they did reveal a very strong relationship between low consumption and low savings. It seems clear that this arises principally because low users have little energy to save, whether or not they may choose to raise their indoor temperatures somewhat after the installation of measures. But we are not able to distinguish between low total energy use and low use of electricity due to other fuels being used for heating. Anecdotal evidence for the latter is very strong, especially in the majority of houses with fireplaces suitable for burning coal and wood; in many cases, they pre-date the electric heaters and would earlier have been the principal means of heating in those houses. It is quite likely that improved insulation in many of the dwellings in EESoP1 resulted in some reduction in the use of other fuels, which could offset at least part of the expected reduction in CO_2 emissions. It may also be observed that heating standards are rising and indeed are most likely to rise in dwellings that are poorly heated at present. If that were to happen, then the future effect of the insulation measures would also rise, so the expected savings might well be realised later.

It was noted above that there are many reasons why savings might be lower than expected, some of which offer no offsetting benefit of the kind described above for the case of low prior energy consumption. For example, if the physical performance of the measures was below expectation or the calculations were unrealistic, the savings might simply not accrue in any form. The data available from EESoP1 cannot shed light on particular reasons for shortfalls in savings realised. They do, however, provide a result that gives considerable assurance on the overall efficacy of the measures: when the level of prior consumption is as expected, then the savings are around 65% of those calculated, assuming no change in the temperatures maintained indoors during periods of heating.

THE RELATIONSHIP BETWEEN SAVINGS AND PRIOR CONSUMPTION

While the extent to which consumption was lower than expected may be surprising, the fact that low consumers make low savings should not be. Low consumption compared to what is required for a good standard of heating implies low indoor temperatures, unless other fuels were used in addition to the electricity nominally assumed to provide all of the heating. The relationship between low indoor temperatures and low realised savings in UK housing has been explored previously. Results from a number of field trials and demonstration projects covering an extended period were brought together and summarised in a recent paper (Milne and Boardman, 2000). The paper concluded that for dwellings with a mean indoor temperature of 16.5°C about 30% of the calculated energy saving is realised as increased temperatures and 70% as reduced consumption, while at 14°C, the saving is shared equally between temperature and consumption. Those findings were based on cases within the range of temperatures observed in the field trials reported, which date back as far as around 1980 and contain a proportion of houses with very low levels of heating. The paper also concluded that full calculated savings might be realised at a mean indoor temperature of around 20°C.

The findings reported by Milne and Boardman were for savings calculated on the basis of actual energy consumption before measures were applied. Indoor temperature and energy consumption were measured in both an experimental group of dwellings, to which measures had been installed, and a control group, in which no measures were installed. Heat balance calculations were used to estimate the energy consumption in the control group: (a) had the measures been installed and no temperature change had occurred; and (b) as would be required to maintain the same temperature as in the experimental group without measures. This differs from the situation in EESoP1, where temperatures were not measured and all savings were based on 'ex-ante' calculations, which assume a good standard of heating. The two sets of findings cannot therefore be compared directly, although it is fair to say that there is nothing to suggest that they are mutually contradictory. It may also be observed that the effect on energy savings of 'temperature take-back' (as reported by Milne and Boardman) should not be confused with the effect of low prior consumption when ex-ante savings estimates are used. The use of the term 'comfort factor' to cover both is likely to cause such confusion.

THE LACK OF AN OBSERVED DIFFERENCE FOR THE FUEL POOR CATEGORY

It was assumed that the savings would be smaller and the comfort factor larger for those households identified as fuel poor but no significant difference is apparent from the meter readings. Neither is there a significant difference in their level of energy consumption prior to installation of measures, which might also have been expected to be lower. The sample size is such that there can be no doubt about the statistical significance of this conclusion. However, in many cases the household income status was not reported and it is known that overall around two thirds of participants were considered to have low incomes. This suggests significant under-reporting of 'fuel-poor' status.

Nevertheless, this finding strongly suggests that the assumptions about savings from the fuel-poor category were wrong, overestimating the extent to which they differ from other consumers. Future programme planning should take this into account.

DIFFERENCES BETWEEN SUPPLIERS' PROGRAMMES

There is no doubt about the statistical significance of the differences observed between programmes but no explanation of how those differences could have arisen. They are not explicable in terms of sample composition and other observed differences, such as those relating to prior consumption or dwelling type. The most likely explanation appears to lie in how the various programmes were administered, particularly in how participating households were recruited. If, for example, individual household motivation played a strong part in selection, it might have attracted those with the greatest enthusiasm for saving energy and most likely to make the greatest savings.

The origin of these differences cannot be established from the data available and, if an explanation is to be found, it will require further research into how each scheme was implemented.

EESoP2 monitoring

The EESoP2 programmes were similar to those in EESoP1 in the way they were administered and the energy saving measures that were installed. However, a completely different approach was taken to monitoring the energy savings arising. Instead of the large sample of meter readings used in EESoP1, a smaller number of cases were monitored in greater detail, including measurements of indoor temperature aimed specifically at determining the extent to which temperatures rose after measures were installed.

THE MEASUREMENTS MADE

Data loggers were used to record temperatures in 3 rooms in each dwelling, sampling every 3 minutes over periods of at least 28 days both before and after measures were installed. The electricity used for water heating was also observed by sensing the periods of water heater operation through the temperature of the power cables to the heaters. Overall electricity consumption for each period was recorded through meter readings. Those measurements were backed by a survey to determine the dimensions and construction of each dwelling, which was used to provide the basis for calculating energy savings. Meter reading data was also sought from suppliers records, with a view to comparing results with those obtained from EESoP1, but this was ultimately available for only around half of the dwellings.

The target sample size was 350, covering a representative range of dwelling types, energy efficiency measures, household income and tenure; in practice, data were available for 325 dwellings, taking account of cases in which the measures were not installed when planned. In some cases, the before and after measurements were taken during a continuous period either side of the point at which the measures were installed. In others, where installation was made late in the heating season, the after measurements were made in the early part of the next heating season.

ANALYSIS

In EESoP2 the expected savings were calculated from the dimensions and construction of each dwelling individually, in contrast to EESoP1, where they were taken from a table of savings pre-calculated for different measures and dwelling types. A further difference in EESoP2 was that the calculations were based on the actual temperatures observed in the dwellings before measures were installed, while the tabulated values in EESoP1 had of necessity to assume a given standard of heating. It is not possible therefore to compare the comfort factors observed in EESoP2 directly with those from EESoP1, because the latter have been shown to have been significantly affected by the low consumption prior to the installation of measures.

Two key variables were examined in the EESoP2 analysis.

- The overall comfort factor, which is defined as in equation (1), but based on actual consumption and temperature before the installation of measures.
- The thermal comfort factor, which is the part of the shortfall in expected savings that may be attributed to a rise in temperature associated with the installation of measures. This is defined as

$$F_{ct} = \{\frac{T_{am} - T_{ac}}{\Delta T_{100\%}}\}.100\%$$

(3)

where:

T_{am} is the measured mean temperature after the installation of measures;

T_{ac} is the calculated mean temperature after the installation of measures, assuming set-point temperatures and heating periods are the same before and after;

$\Delta T_{100\%}$ is the calculated temperature rise after the installation of measures, assuming no reduction in energy use after improvement.

If the energy saving measures reduce heat losses as expected, then we should expect F_{ct} to be equal to F_c, relying on the simple physical principle that the energy required for space heating is proportional to the difference between indoor and external temperature. A difference between the two could be accounted for by additional window opening after improvement or by the measures failing to achieve the full extent of the expected reduction in heat loss.

RESULTS

Work on the analysis of results from EESoP2 is continuing, and some aspects are still under investigation. Accordingly, for this paper, it is appropriate to deal only with those aspects that can shed light on questions raised by the results obtained from EESoP1. In particular, the observations of temperature should be able to show the extent to which increases in indoor temperature contribute to the overall comfort factor.

For the two dwelling types analysed in detail, the relationship between comfort factor and prior energy use observed for EESoP1 showed that around 65% of the calculated savings were achieved when the prior energy use was as assumed in the calculation of savings. This relationship may reasonably be expected to hold for other dwelling types also. The shortfall of 35% in savings was attributed to a comfort factor. However, given the absence of more information on temperatures or measurements of specific heat loss coefficients, the shortfall could have been due any one of a number of reasons listed under the heading 'Differences between calculated and realised savings' above. The average temperature rise measured in EESoP2 was around 0.4K, which corresponds to energy savings of less than 5% of prior consumption. Had a similar temperature rise occurred in EESoP1, it would have explained around half the 35% comfort factor. As the great majority of the heating systems were storage radiators with manual charge control, it is highly likely that temperatures were controlled to some extent by increased window opening, so it is not surprising that temperature could not account completely for the observed comfort factor.

In EESoP2, the effect of low prior energy use should have been eliminated because the expected savings are based on actual use rather than a theoretical good standard of heating. It would be reasonable, therefore, to expect that the overall comfort factor observed for EESoP2 would be around 35%, as observed in EESoP1 at the level of prior energy use assumed in the calculation. However, it is much larger at around 60%, which means that over half of the expected savings were not realised even taking account of prior consumption. Moreover, the observed thermal comfort factor is only around 18%, which means that less than a third of the total shortfall in expected savings may be attributed to temperature rise. There is a clear implication that the shortfall must arise from other causes, such as temperature control by window opening or poor performance of the measures installed.

Nearly 17% of the dwellings in EESoP2 were observed to have sources of heating other than electricity, although no information was obtained on how much heat was obtained from them. As electricity is expensive, especially if consumed at peak rate, it is likely that those sources would be used in many cases. If there was a similar proportion in EESoP1 dwellings, it would offer a partial explanation for some of the very low levels of consumption observed.

Discussion of findings from both EESoP1 and EESoP2

As the results from EESoP1 were based on a large sample of dwellings and should be statistically robust, the observations of average savings and comfort factor derived from them must be assumed to be representative of what has been achieved in the overall programme. By far the strongest relationship observable in the data was that between savings and prior energy use, which has a simple logical explanation. Using that relationship, it is possible to say that the savings achieved were broadly as expected when prior consumption is as assumed in the calculations of expected savings. This is an encouraging result in two ways: firstly it gives confidence in the method used to estimate savings and the physical performance of the measures; and secondly, it suggests that higher savings will ensue as heating standards improve.

Nevertheless, the savings actually achieved were much lower than expected and the average overall comfort factor much higher than assumed and expectations for short term savings arising from insulation improvements in electrically heated houses should be reduced. However, electricity is identified as the main source of heating in only around 10% of UK dwellings, which limits its overall impact. Also, it is unlikely that a similar result would be obtained for gas and oil heated dwellings, where overall levels of consumption are much closer to those assumed in calculating energy savings.

The term comfort factor clearly has a broad spectrum of meaning and is only partly related to indoor temperature. When it is used to apply to 'ex-ante' calculation of savings as it was in EESoP1, it is clearly strongly dependent on the level of energy consumption prior to measures being installed; and when that level is well below expectations, the comfort factor will inevitably be high even if there is no rise in temperature. The low level of electricity use in houses that are nominally heated by electricity is broadly consistent with the national average expenditure on electricity by such households. For the year 1998/99 (contemporary with the meter readings before measures were installed), this was £9.62/week (DTI, 2000), which is equivalent to around 11 500 kWh per year[4], and very close to the average for EESoP1. The low level of consumption encountered in EESoP1 could therefore have been anticipated but its impact on expected savings was clearly not taken into account;

the work described in this paper provides a clear basis for doing so in future. It also indicates that there is no substantial difference between households identified as 'fuel poor' and others. This may be in part due to inadequate identification of household characteristics but it argues against making a distinction on this basis when estimating savings expected from future programmes.

It was intended that the monitoring carried out for EESoP2 would observe the temperature rises expected when energy saving measures are installed and show the extent to which they account for any shortfall in calculated savings. While the temperatures were measured successfully, the average temperature rise was much smaller than expected and only accounted for around a quarter of the shortfall in calculated savings. This result is both unexpected and difficult to explain, because it implies that other factors were contributing to reduced savings to a much greater extent than in EESoP1. Had the sample used for EESoP2 been representative of the same population as that for EESoP1, it seems highly unlikely this result would have been obtained, given that expected savings were achieved when prior energy use was as expected. This suggests that the EESoP2 sample was significantly different from the much larger sample drawn from EESoP1, which is also apparent in the average energy annual savings achieved: only 7% for EESoP2, compared to 12% for EESoP1 (expressed as a percentage of prior energy use). However, the savings observed fell within the range observed in different suppliers' programmes, as given in Table 2. Although there is no apparent reason for bias in the sample selection, that must be seriously considered. The more reliable result for overall savings and comfort factor must be assumed to come from EESoP1, because of its much larger sample.

Neither set of results points to large temperature rises accompanying the installation of measures. From the work by Milne and Boardman cited above, temperature rises corresponding to around 30% of gross calculated energy savings might have been expected based on the average temperatures measured in EESoP2, which is around twice what was actually observed.

Conclusions

Analysis of meter reading data shows that average electricity savings of around 12% were achieved by households participating in EESoP1, which is around half of what was expected. The savings achieved by individual households is strongly related to their consumption prior to energy efficiency measures being installed. It appears that the principal reason for the savings being lower than expected is low prior consumption rather than increases in temperature after installation of measures. The monitoring undertaken for EESoP2 provided direct evidence that temperature rises were small, averaging around 0.4K.

Further work is clearly required to develop a better understanding of the results obtained, although much of it will not be possible within the framework of the EESoP2 present monitoring work.

- The composition of the sample selected for monitoring in EESoP2 should be carefully examined for any bias that may have affected the results obtained.
- Future work to monitor indoor temperatures should use periods longer than the 4 weeks used in EESoP2 and should try to establish a relationship with external temperature that can be extrapolated to a typical year.
- New work should be commissioned to measure the in-situ performance of insulation measures, particularly cavity wall insulation, which forms a key part of the UK programme to reduce CO_2 emissions and is important for all types of heating, not just electricity. The necessary measurement technique is well developed and results already reported raise significant questions about U-values achieved in practice. (BRE, 2001)
- The use of window opening to control temperature in dwellings heated with electric storage heaters should be investigated, as it seems highly likely that this plays a part in reducing the savings actually achieved from insulation measures with this type of heating system. This could well be part of a wider project aimed at measuring ventilation rates in UK dwellings. As for the in-situ measurement of U-values, the necessary measurement technique is well developed and could be readily applied.
- Data should be collected on the use of other fuels in electrically heated dwellings, which is likely to be significant in dwellings with very low electricity consumption.

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4. Typical standing charges for day/night rate connections were £40/year and unit prices 3.1p/kWh and 7.6p/kWh for night and day respectively. Assuming an average of 80% of all consumption (including lights and appliances) was at night rate, then the average unit price was 4p/kWh, which equates to a total consumption of around 11 500 kWh/year.