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BREHOMES  
A PHYSICALLY BASED MODEL OF THE ENERGY USE  
OF THE UNITED KINGDOM HOUSING STOCK

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ABSTRACT

Models used for forecasting of future energy demand are often econometrically based and do not attempt to look in detail at end uses of energy. It has become clear in recent years that this approach to energy forecasting can produce more realistic estimates of future demand in the building sector if it is used in conjunction with models which cover important physical and social parameters and the constraints which these impose (Grubb 1990; Grubb 1991). Such complementary models provide insights which would otherwise be missed. The BREHOMES model meets the requirements of such a complementary model for one particular part of the building sector - it is a physically based model of energy use in the United Kingdom housing stock which also takes account of social aspects.

This paper explains how BREHOMES works, describes the data which it uses and presents examples of how the model is being used in practice.

INTRODUCTION

Traditionally, the forecasting of future energy demand has been by means of econometric methods. Experience has shown, however, that such forecasts can be wildly inaccurate (Grubb 1990; Grubb 1991). The reasons behind this are, with hindsight, not difficult to see. Everyone now knows that energy use and economic growth are not rigidly tied together. Physical and social parameters also come into play - and these impose constraints which a purely econometric approach does not take into account.

To give a simple example, people do not heat their homes to ever higher temperatures just because they can afford to do so - there comes a point at which the occupants are comfortable and beyond which they will not go. There are many other such saturation effects which operate. Clearly, these effects must be taken into account if energy forecasts are to be as realistic as possible. At the very least, there is a need for a physical approach to forecasting (taking account of social factors), to complement the econometric approach. Each approach will provide insights that the other might miss.

This paper describes a physically based model which can be used for forecasting purposes. The model is called BREHOMES (Building Research Establishment Housing Model for Energy Studies) and it is concerned with the energy use of the United Kingdom housing stock (which represents about 30%

of total UK energy consumption). The model was conceived as a policy advice tool and is routinely in use for this and other purposes. Some examples of how the model is used in practice are presented in this paper.

THE BREHOMES MODEL - GENERAL DESCRIPTION

There are about 22.5 million households in the United Kingdom. Each household uses energy for a number of purposes which can be broadly classified as space heating, water heating, cooking and lights & appliances (space cooling is virtually unheard of in UK dwellings). The number of possible ways in which households use energy is probably as large as the number of households. Clearly it is impractical, even if one had all the data, to do 22.5 million calculations of energy requirements in order to produce an estimate of the total housing stock demand. On the other hand, it is quite possible to use survey data to capture this variability within a reduced level of disaggregation. There are some obvious factors which must be included in any disaggregation - the dwelling type (built form) and age, for example.

The BREHOMES model disaggregates the housing stock into over 400 categories, defined by 4 age groups, 17 built forms, 3 tenures and by the ownership of central heating. For each of these categories the model does 10 calculations of annual energy demand. The reason for doing 10 calculations per category is that heating patterns vary across a broad range - and about 10 representative patterns are needed to adequately encompass this range. These 10 representative patterns are pre-defined but the proportion of homes having a particular heating pattern vary from category to category. The distribution of heating patterns varies from one category to another both for physical and social reasons. The type of dwelling, its insulation standard and the type of heating system together determine the likely running costs for different heating patterns. These costs, in turn, influence the choice of heating pattern. Home owners are more likely to heat to higher standards than those who rent because, in general, they can afford to spend more on heating their homes.

Thus, the model does over 4000 annual calculations in total within each "calculation loop". In total, 3 calculation loops are required before the model produces a satisfactory match to the known annual energy consumption of the housing stock. In broad terms, therefore, the model performs around 12,000 individual annual calculations on each run.

Clearly, to do 12,000 calculations routinely one needs to use an energy model which is sufficiently simple that it will quickly produce a result. There is no point in trying to use a sophisticated simulation model because the data entry and running times would be excessive. It is also highly questionable whether the end result would be any better by using a simulation model - bearing in mind the uncertainties in some of the data on which the calculations have to be based. Within BREHOMES, therefore, it is necessary to use a simplified energy model for the individual calculations. The model used by BREHOMES is a version of BREDEM (Building Research Establishment Domestic Energy Model). BREDEM (Anderson et al. 1985) is a model which is based on practical experience of what actually happens in dwellings. It is theoretically based but it also contains some empirical procedures. The BREDEM model benefits from measurements made in many houses accumulated over several years. It has been extensively tested against measurements in occupied dwellings and is known to produce realistic results (Henderson and Shorrocks 1986; Shorrocks et al. 1991). Even so, the model is constantly being reviewed and it is updated whenever sufficient relevant new data becomes available.

There are a number of versions of the BREDEM model, tailored towards particular applications, but they all share certain things in common. One of the most important aspects, common to all of the versions of BREDEM, is the recognition of the influence of social factors and the resulting emphasis on occupant requirements. Such behavioural matters are carefully taken into account. Thus, the model does not simply assume fixed "conventional" internal temperatures. Instead, as discussed above, it uses information on the times of heating and the heating extent to determine mean internal temperatures. This is particularly important because partial and intermittent heating of dwellings is quite common in the United Kingdom. In other respects, BREDEM is broadly similar to other simplified energy models. The monthly version of BREDEM, for example, bears strong similarities to the model described in ISO 9164 (International Standards Organisation 1989).

So far, BREHOMES has been described in general terms without specific reference to the data which it uses. In fact, the data and the model are really inseparable. For example, the categories into which the model disaggregates are, to a large extent, dictated by the form in which the data is collected. In this respect, BREHOMES is not simply a model - it is also a database. The statistical sources used by BREHOMES are numerous. The most important sources are an annual survey of insulation ownership by Audits of Great Britain, the Digest of United Kingdom Energy Statistics (Department of Energy, published annually), the English House Condition Survey (Department of the Environment, published every 5 years), the General Household Survey (Office of Population Censuses and Surveys, published annually) and the Family Expenditure Survey (Department of Employment, published annually). There are several other sources which also provide useful information and which are used as necessary. In addition, of course, the research work which led to the development of BREDEM is a further indirect source of data used by BREHOMES.

None of the above mentioned sources of data is sufficient on its own to form a coherent picture of the energy use of the United Kingdom housing stock. Taken together, however, they represent a considerable amount of relevant information. The BREHOMES model provides the means to bring this information together in a form which is suitable for making predictions of energy demand or of savings due to particular energy efficiency measures.

BREHOMES, therefore, is designed to take whatever information is available and make the best possible use of it. This approach may be less satisfactory than the alternative of a single survey specifically dedicated to BREHOMES. Such a survey, however, would be extremely costly. Avoiding this unnecessary cost by using the information which is already collected is, therefore, a more sensible approach. The operation of the model ensures that any inadequacies in the data are minimised in the results produced by the model.

#### THE BREHOMES MODEL - HOW IT WORKS

The operation of the BREHOMES model is best explained by reference to Figure 1. This figure presents a much simplified illustration of how BREHOMES works. In particular, only a few of the many inputs to the BREDEM model are shown and only 1 output (rather than 10) is indicated for each category. Similarly, the data sources listed on the left are only a representative selection rather than an exhaustive list. Nevertheless, Figure 1 does provide an accurate picture of the essential features of the operation of the BREHOMES model.

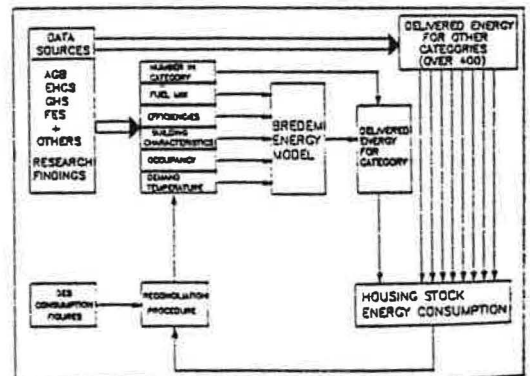


Figure 1. The BREHOMES model of the energy use of the United Kingdom housing stock.

In the centre of the figure is the BREDEM energy model. To run the BREDEM model one needs to have information on the physical characteristics of the particular dwelling type under consideration (areas, U values etc), the occupancy, the demand temperatures (ie: the setpoints), fuels used, efficiencies etc. This physical and social information comes, usually after some manipulation, from the data sources listed to the far left of the figure. For example, AGB (Audits of Great Britain) data provides information on the insulation standards of each category of dwelling - from which



typical U-values can be deduced. Floor areas are obtained from the EHCS (English House Condition Survey) and these can be used, together with some geometrical considerations (based on research findings), to estimate the areas of individual elements. When these are combined with the U-value estimates, the overall heat loss in a house is obtained. These figures can then be used by the BREDEM model. There are complications, of course. The categories from the AGB do not exactly match those of the EHCS - and AGB refers to Great Britain whilst EHCS refers to England. The categories used in the surveys also change from time to time. Consequently some "common sense" adjustments have to be made to do the necessary calculations.

In a similar manner, it is possible to use the data sources to build up all the inputs necessary to run the model. As indicated above, in some cases there may be considerable uncertainty surrounding the values which are used whilst other inputs are well characterised. The way in which the BREHOMES model works, however, means that the effect of the uncertainties is minimised, as discussed below.

Multiplying the energy consumptions calculated by BREDEM by the number of dwellings in that category gives an estimate of the delivered energy for that category. By summing the results from all categories one obtains an estimate of the housing stock energy consumption. This can then be compared with the known housing stock consumption taken from the Digest of United Kingdom Energy Statistics (referred to as DES on Figure 1). The small difference between the estimate and the actual consumption is then used to determine by how much it is necessary to alter the demand temperatures in order to obtain a match. The demand temperatures are then altered accordingly and the calculation loop is repeated. This continues until the calculated consumption and the actual consumption are reconciled. Three calculation loops are required to obtain a satisfactory match. The demand temperatures, therefore, are used as parameters to ensure that the model produces the correct overall result. Even so, the final temperatures are quite plausible as real setpoint temperatures ( $-20^{\circ}\text{C}$  in centrally heated dwellings and  $-13^{\circ}\text{C}$  in non-centrally heated dwellings).

Thus, although some of the inputs to the model are uncertain, the overall result is correct. This fact, together with the plausible demand temperatures, indicates that the model can be used with some confidence at more disaggregated levels than the whole stock. Inevitably, however, as one goes to more and more disaggregated levels the less confident one can be in the predictions. Nevertheless, the model does use a logical and consistent approach throughout. When one remembers that the primary use of the model is for policy advice then consistency of approach is particularly important. Furthermore, the estimates that one obtains with the model are probably the best possible within the constraints of the data. They are certainly much better than having only the raw data to rely on.

When the BREHOMES model has been run and reconciled as described above one has assembled a database for the energy performance of the United Kingdom housing stock for that particular year.

The above procedure has actually been carried out for a succession of years. Using the information which this has generated it is possible, therefore, to assemble a complete picture of the changes which have taken place since the early 1970s. Thus, the database also has a time dimension, which is particularly important for assessing the impact of energy efficiency policy in practice and for forecasting what might happen in the future. The historical trends were thought to be so important and interesting that a report on these has been produced (Henderson and Shorrocks 1989). It is planned to regularly update this report as a routine part of the work on BREHOMES. The first update (Shorrocks et al. 1991) should have been published by the time this paper appears.

In order to make predictions using the BREHOMES database it is necessary to have programs which can directly interrogate the database. These afford the possibility of using the data without having to use the BREHOMES model itself. The advantage of this is clearly apparent when one recalls that each run of the model involves some 12,000 annual calculations! The programs, however, are still regarded as part of BREHOMES since the database would be of limited use without them. At present, there are three main programs. The programs are constantly being developed to improve their "user friendliness" and their power as analysis tools. All the programs make use of the BREDEM model - the same simplified energy model that is used by the BREHOMES model itself.

#### THE BREHOMES PROGRAMS

When using the BREHOMES database there are, broadly, three types of question which are most often asked. This is the reason why there are three main programs - each program is designed to handle a particular type of question.

The programs themselves are called IHCALC, BREHOMES and DYNAMIC. They are described in outline below. The name BREHOMES was given to the first of the programs developed. With hindsight, this was not a good idea because it can cause some confusion when statements such as "BREHOMES predicts that..." are used. In practice, however, the BREHOMES model/database and the various programs are used directly by only a few individuals (the authors of this paper) who are well aware of the distinction between the BREHOMES model/database and the BREHOMES program.

The reason why the model/database and programs are used by only a few people is easy to appreciate when it is remembered that their primary use is in policy advice. This type of information and the associated analysis tools could easily be misused by people who are not entirely familiar with them. Nevertheless, one of the overall aims of the work is to increase the availability of the information (hence, Henderson and Shorrocks 1989) and to make the programs more readily usable by others. The program IHCALC could probably be safely used by anyone who is reasonably familiar with basic building heat loss / energy calculations. DYNAMIC, on the other hand, involves much more than basic heat loss / energy calculations (it requires a thorough knowledge of recent trends, for example) and it is important to appreciate the complex links between the many factors in order to use it effectively. It is unlikely, therefore, that

DYNAMIC will ever be used by more than a few people - although it is undoubtedly the most powerful of the various programs. The BREHOMES program is intermediate between IHCALC and DYNAMIC in its ease of use - it would require someone who was aware of many of the same things that are required to run DYNAMIC but it does not have quite the same potential for serious misuse (because it does not have an explicit time dimension built into it).

#### IHCALC

Sometimes questions arise concerning a "typical" dwelling. For example, the questions might be asked: "What is the annual space heating consumption of a typical pre 1919 semi-detached house, and how much could this be improved upon using simple energy efficiency measures? Would it be feasible to improve it to match the standard of a modern semi-detached house?" To answer questions such as this one needs the relevant physical and social data (contained in the BREHOMES database) for the particular categories of dwelling and an energy model which can do calculations on individual dwellings. IHCALC is designed to answer these types of question. It can be used to answer a lot else besides, but it is always concerned with individual or representative dwellings. IHCALC is, in fact, simply a straightforward implementation of the BREDEM model - with the advantage that it can call up information directly from the BREHOMES database.

Because IHCALC is just an implementation of BREDEM this presents the opportunity for it to be made a little more sophisticated. For example, one could consider introducing a more detailed treatment of solar gains. Detailed information on dwelling orientations within the United Kingdom housing stock is not available. Even a casual observation, however, would strongly suggest that it is actually randomly oriented (there are exceptions, of course). Consequently the programs, and the BREHOMES model, assume average solar gain factors in all cases. When one is considering an individual dwelling, however, it may be of interest to explore the effect of orientation. For this and other reasons, a version of IHCALC has been developed which uses the monthly BREDEM model. The monthly model has a much improved treatment of solar gains and its handling of certain types of heating system is thought to be more reliable than the annual models - so there are situations when it is preferable to use this model with the BREHOMES database. There are plans to make the monthly IHCALC commercially available.

#### BREHOMES

Often questions are asked which relate to entire categories of dwellings, or to the entire stock. For example, the question might be asked: "What would be the effect on national energy consumption if all lofts were to be insulated to the standard currently applied to new dwellings?" There are, of course, many possible answers to this question because it depends on what else might change while the lofts are being insulated (more homes will probably acquire central heating, so typical demand temperatures may change - but, at the same time, the overall space heating efficiency will probably improve). The BREHOMES program allows this and many other questions to be answered. It also allows some of the possible concurrent changes to be explored.

The program, therefore, allows a range of answers to be obtained so that any answer which is finally given may be suitably qualified. In general, however, the answer which would be given is the one which assumes no concurrent changes. In other words, the usual answer refers to the potential energy saving - the saving which would be achieved if the measure were carried out overnight so that all else remained the same. This is often the most useful answer to give because it represents a very well defined, albeit hypothetical, case. Another reason for choosing to use this answer is that the BREHOMES program does not contain an explicit time dimension. Consequently, although some concurrent changes can be specified, there are many longer term changes which can not easily be allowed for. The BREHOMES program is less useful, therefore, for saying what is likely to happen over long time scales. Its main use is for quantifying potential savings - recognising that these savings are not necessarily what would be achieved in practice.

#### DYNAMIC

It will be clear from the above discussion that there is a further kind of question which is sometimes asked - a question which refers to "real time". These types of question are handled using a program called DYNAMIC. Because of the complexity of the calculations involved, such questions can no longer be focused on individual measures, such as loft insulation (indeed, it ceases to make any sense to try to do this because of the complex inter-relationships between the many factors). Similarly, it is no longer really practicable to do calculations on parts of the stock. Although, in the past, separate versions of DYNAMIC were produced for each tenure group, experience showed that they were not as useful as the version considering the stock as a whole.

Consequently, the questions considered relate to forecasts for complete "scenarios" for the entire stock. For example, a key question would be: "What is likely to happen to the energy demand of the United Kingdom housing stock assuming that recent trends continue?" One could then go on to ask: "Relative to the 'business as usual' scenario, what savings could be made by adopting these policies?: a, b, c,.....". Of course, there is an infinite variety of possible policies so it is important to discipline oneself to limit such questions to a few well defined scenarios covering the range of what is thought to be potentially practical.

Questions of the above type can be answered using the DYNAMIC program. This works by allowing the user to define the physical and social parameters necessary to do a BREDEM calculation for the present (already contained in the BREHOMES database) and for set years in the future. Setting the future parameters requires very careful consideration of past trends and their likely continuation and it requires that some estimate be made of the probable ultimate values (ie: the values which will be reached at some far distant time in the future). A lot of effort must go into preparing this information prior to using DYNAMIC. Experience shows that trying to use the program without careful prior preparation inevitably leads to results which are, at best, difficult to interpret and, at worst, meaningless.

The DYNAMIC program calculates energy consumption at the set years given the information supplied by the user for those years. It also interpolates between the set years so that a complete picture can be assembled of how the energy consumption of the housing stock is likely to change assuming a particular scenario. The program allows projections up to the year 2050. Of course the calculated figures for 2050 will not necessarily be realistic because over such a long timescale technologies might emerge which have not even been thought of yet. The figures for 2050 represent the best estimate that can be made assuming that there are no radical new technologies emerging. The real purpose of allowing projections to 2050 is to ensure that the figures for the earlier years are consistent with long term projections of the application of known technologies. In other words, it ensures that the shorter term projections are as realistic as it is possible to make them.

#### USES OF THE BREHOMES MODEL / DATABASE AND THE PROGRAMS

In the previous sections a number of examples of the questions which the programs, together with the BREHOMES database, are used to answer were discussed. Such questions are typical of the type of information which is requested by Government Departments. Two specific examples follow which illustrate how the model has been used in practice.

One question which has been asked a number of times, and in various forms, over the years is: "How much energy has been saved by the application of energy efficiency measures in housing?". A simple, but highly misleading, response to this question would be to look at how the energy consumption of the housing stock has changed (since 1970 it has actually increased at about the same rate as the growth in the stock - so that the average dwelling consumes much the same now as it did then) and proclaim: "The application of energy efficiency measures in housing has not saved any energy". The problem, of course, is that the question being asked is the wrong one! To respond sensibly to this question, it is necessary to turn it around and ask: "What would have happened to the energy consumption of the housing stock if we had not improved its energy efficiency?".

The BREHOMES database contains the information which allows this question to be answered. Of course, there are many possible answers, depending on what is assumed about how other factors would have changed if energy efficiency had not improved. The answer which is obviously most useful and understandable, however, is that which relates to all factors, except energy efficiency, changing in the manner in which they actually have done. Figure 2 illustrates the result of pursuing this line of reasoning (Shorrocks et al. 1991). It is possible, with this figure, to answer the original question in a meaningful way: "It is estimated that, if the energy efficiency of the housing stock had not improved since 1970, then the energy consumption necessary to maintain current levels of service within the housing stock would be about 5% higher than it actually is".

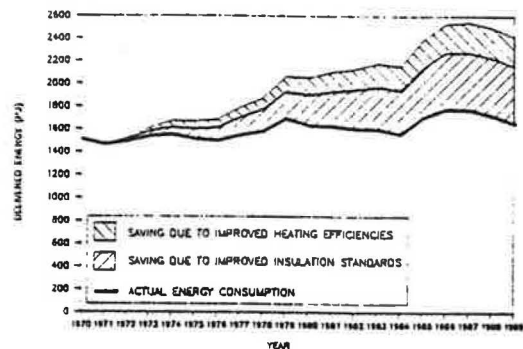


Figure 2. The effect of energy efficiency improvements on the energy use of the United Kingdom housing stock

Another example of how BREHOMES has been used is in the study of the links between energy use and global warming. Burning of fossil fuels to extract energy contributes to the release of gases, particularly carbon dioxide, which are believed to be responsible for this warming. Many countries have made commitments to reduce their carbon dioxide emissions - including the United Kingdom. Clearly, energy efficiency is an attractive means of doing so. It is important to know beforehand, however, which uses of energy contribute most and where the largest savings can be made because this will help in determining the areas which need to be targeted.

The BREHOMES database has been used to assess the contribution which the United Kingdom housing stock makes to carbon dioxide emissions and to estimate the potential savings (Shorrocks and Henderson 1990). Figure 3 illustrates the end uses of energy in the housing stock. The immediate impression is that space heating is by far the most important energy use.

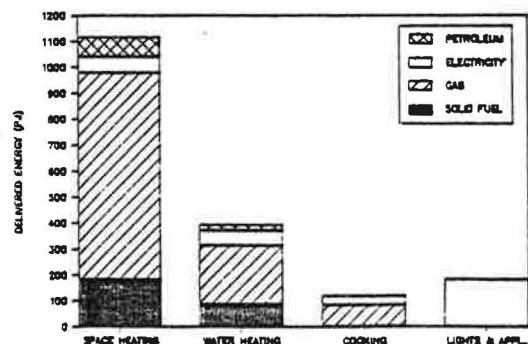


Figure 3. End uses of energy in the United Kingdom housing stock (1987)

Figure 4, however, shows the same information transformed into carbon dioxide emissions. It is clear from this that the relatively small amount of energy used for lights and appliances (~ 10% of the total housing stock energy use) must not be forgotten. The general conclusion of the study from which these figures are taken was that the emission associated with the energy use of the housing stock (about 170 million tonnes of carbon dioxide per year) could potentially be reduced by 25% to 35%. These potential reductions are based, respectively, on internal assessments of those energy efficiency improvements which can be considered cost effective and those which are technically possible. This work is continuing with the development of a number of scenarios (using DYNAMIC) to investigate how emissions might actually develop from year to year. It is expected that the results of this work will be published in due course.

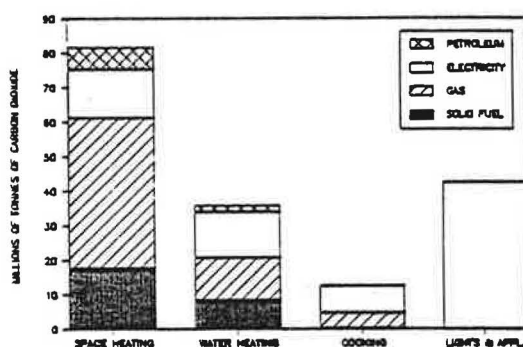


Figure 4. Carbon dioxide emission attributable to the energy use of the United Kingdom housing stock (1987)

Government Departments are not the only customers for the information which can be provided using BREHOMES. Similar calculations to those described above have also been done for other organisations using the BREHOMES database and programs. Some possible scenarios were investigated for the Association for the Conservation of Energy / World Wide Fund for Nature to help with a report which they were preparing for the general public on global warming (Boyle et al. 1989). Work has also been done for the Royal Institute of International Affairs (Grubb 1991).

Work has also been undertaken for customers outside the United Kingdom. The BREHOMES database was used extensively to assist the Statistical Office of the European Communities in a study on household energy consumption within Europe. The database was also used to provide information to the Inter-Governmental Panel on Climate Change on the contribution to greenhouse gas emissions from the United Kingdom housing stock.

The BREHOMES database is regularly used to advise building professionals, energy consultants, the energy industries, local Government, students, journalists and ordinary members of the public of the facts surrounding energy efficiency in UK housing. Such enquiries are most commonly answered

by reference to the publications which have emerged from the BREHOMES work (in particular, Henderson and Shorrocks 1989, and Shorrocks and Henderson 1990) although, occasionally, the question might involve using one of the programs.

The BREHOMES model / database and programs, therefore, are used to advise a wide spectrum of individuals and organisations. The type of advice given covers a similarly large range. At the simplest level it may involve a quick reference to the numbers already contained in the database. At the other extreme, it might involve several months of careful work using the database and programs. The advantage of BREHOMES is that the database and programs are flexible enough to accommodate both extremes and that the answers obtained always have the same consistency of approach underlying them.

#### CONCLUSION

A model, called BREHOMES, which simulates the energy use of the entire United Kingdom housing stock has been described. The model is physically based, takes account of social aspects, and uses a simplified energy model (BREDEM) to do its calculations. Running the BREHOMES model generates a database for that year. The model has been run for several years and so the time variation of the database is known. The database can be interrogated using a number of specially written programs which allow particular types of questions to be answered. Examples of the uses of the model / database and programs have been described. These examples encompass many kinds of advice provided across a wide spectrum of organisations and individuals.

#### ACKNOWLEDGEMENTS

The development of the BREHOMES model / database has been supported by the Department of the Environment. The development of the BREDEM model, which forms an important part of BREHOMES, has been supported by the Energy Efficiency Office (Department of Energy).

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#### BIOGRAPHY

Les Shorrock studied at the University of York where he obtained a first class honours degree in physics in 1977. He continued his studies at the University of Hull and was awarded a PhD in applied physics in 1983. This was for work on experimental laser-plasma physics, aimed at demonstrating the feasibility of x-ray laser action. He continued this work until 1985 when he joined the Building Research Establishment to work on energy efficiency.

Presently, he is a Senior Scientific Officer in the Energy Economics and Statistics Section of the Building Research Establishment. His main areas of work are:

- the development, testing and application of a simplified energy model called BREDEM (discussed in this paper).
- the development and application of a model of the energy use of the United Kingdom housing stock called BREHOMES (the main topic of this paper).
- use of the above models for studying the role of energy efficiency in reducing greenhouse gas emissions (discussed in this paper).

- representing the United Kingdom on CEN TC89 Working Group 4, which is drafting a European Standard for calculating energy use in buildings based on the International Standard ISO 9164 (see references).