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TESTING BREDEM 8 AGAINST MEASURED CONSUMPTION DATA AND AGAINST SIMULATION MODELS

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SYNOPSIS

BREDEM 8 has been tested against measured consumption data and against simulation models. The testing has addressed both the annual and monthly energy use predictions and the predictions relating to important design issues.

Testing against measured consumption data of the highest quality has confirmed that the model produces overall predictions which are reliable. Testing against simulation models also demonstrates that BREDEM 8 produces overall predictions which are very comparable to those of the simulation models.

The tests against simulation models also allow the performance of BREDEM 8 to be assessed for a number of important design issues. The results show that, except in one very extreme case, BREDEM 8 exhibits the same trends as the simulation models. Furthermore, the resolutions of the models when BREDEM 8 is included are almost as good as those for the simulation models alone, and in some cases they are as good. The resolutions observed are quantified.

INTRODUCTION

BREDEM 8 is a version of the Building Research Establishment Domestic Energy Model which calculates the energy use of a dwelling on a month-by-month basis. This improvement over the annual versions allows BREDEM 8 to address a wider range of dwellings and design issues. In particular, BREDEM 8 is better able to consider low-energy and passive solar dwellings. A previous paper (1) described the extensive testing of BREDEM 8 against measured consumption data. That work indicated that the space heating calculation within BREDEM 8 worked very well, although some modifications to other aspects of the model were suggested. The indications were that BREDEM 8 had the potential to be an extremely useful simplified design tool. That view is supported by the further testing results presented in this paper which provide considerable confidence in the capabilities of BREDEM 8.

The paper presents the results of two types of test. Firstly, it presents the results of further comparisons between BREDEM 8 predictions and measured consumption data. The aim of this testing is to explore how well the model works when measured consumption data of the highest quality (Milton Keynes Energy Park) are used. This work was undertaken by the Building Research Establishment.

The second type of comparison is against simulation models. This type of testing allows specific aspects of the model's performance to be checked and thereby addresses concerns about the possibility of cancelling errors. The testing considers both the overall predictions and some important design issues. This work was undertaken by De Montfort University working under contract to the Building Research Establishment.

The analysis of the results where simulation models have been used relies on the concept of resolution, which was first introduced in the Applicability Study 1 project (2). The resolution of a particular predicted value is a measure of the maximum expected variation that would occur in that prediction if a different program was used to conduct the same analysis. The resolution indicates the scale of the prediction uncertainties. By calculating the resolution for the simulation models alone and then recalculating the resolution including BREDEM 8 it is possible to obtain a quantitative assessment of how well BREDEM 8 has performed.

THE DATASETS USED IN THE COMPARISONS

The Milton Keynes measurements have been described before and the reader is referred to that description for details (1). Only dwellings with conventional gas central heating systems have been included in order to maintain comparability with the tests against simulation models where a responsive heating system was assumed. Total gas consumptions were known very accurately. Space and water heating consumptions were determined from these totals using heat meter readings to determine the appropriate allocation. This process also involved estimating the gas cooker consumptions. Consequently, the space heating consumptions were known less accurately, although the estimates should normally be within 10% of the true values. In total, 19 dwellings were considered, each with data covering a period of two years.

The Linford house, and variations of it, had been previously simulated by three models (ESP, HTB2 and SERI-RES) for Applicability Study 1 (2). A reference house, which was essentially the same but had different orientation and glazing distribution, was also modelled. In total, this produced 36 benchmarks against which to compare BREDEM 8 predictions.

The typical UK semi-detached house (3) was simulated using the three models ESP, HTB2 and SERI-RES. Altogether, these simulations produced 24 benchmarks against which to compare BREDEM 8 predictions.

A single zone within a dwelling had also been previously simulated (2) using the three models ESP, HTB2 and SERI-RES. Since BREDEM 8 is specified as a two zone model, some modifications were needed to model this particular case. The changes made were logical extensions of the original BREDEM 8 specification. Altogether, there were 14 benchmarks against which to compare BREDEM 8 predictions.

A single zone building had been previously simulated using five models (ESP, HTB2, SERI-RES, BLAST and DOE) in an IEA Task VIII (4) study. In restrospect, this dataset was not well suited to BREDEM 8 testing. BREDEM 8 had to be adjusted to cope with a whole building being treated as a single zone and the internal algorithms for solar gains had to be overridden to allow correct inputs for the Denver and Copenhagen climates. Also, many of the benchmarks could not be used because they involved cooling which BREDEM 8 does not model. Consequently, only five benchmarks for each of the two locations were usable. In addition, the monthly consumption predictions of the simulation models could not be retrieved so that even these few benchmarks were not fully comparable with those from the other datasets. In view of these difficulties, and the fact that BREDEM 8 is only intended to be used for modelling conventional dwellings under UK climatic conditions, less importance has been attached to the results for the IEA Task VIII benchmarks.

METHODOLOGY

For the comparisons against measurements the first stage was to select only those dwellings for which the measurements showed no obvious problems. Then the space heating consumptions were determined from the measurements as outlined earlier. The inputs to the BREDEM 8 model were then determined and the model was run. The inputs included the dwelling specific heat loss rate (determined from element areas, U-values etc.), heating patterns (deduced from the internal temperature measurements and the social survey responses), heating efficiency (fixed within the BREDEM 8 model according to the type of heating system), external temperatures and solar radiation (measured), and number of occupants (from the social survey). Once the inputs had been determined and verified the corresponding model outputs were "frozen" - no attempt was made to adjust inputs to obtain better agreement.

For the comparisons against simulation models the methodology used was the same as for Applicability Study 1 (2). Having verified the inputs to each of the models, including BREDEM 8, the outputs were "frozen" before being compared. In the case of the simulation models most of these "frozen" outputs already existed from previous work (2,4).

Great care was taken to ensure that the inputs to BREDEM 8 were equivalent to those for the simulation models. Since BREDEM 8 is a time-averaged model, this involved determining appropriate averages of several of the simulation model inputs. For example, the internal gains were calculated by averaging the hourly internal gains used by the simulation models over a 24 hour period. Likewise, the monthly mean weather data were derived from the hourly mean external temperatures and hourly mean solar radiation on the horizontal. Material properties, air change rates, areas and volumes were taken directly from the simulation model input datasets. The window U-value was time-averaged over the daytime (blinds open) and night-time (blinds closed) values and the ground floor U-value was calculated in accordance with section A3 of the CIBSE Guide (5).

The most difficult aspect of determining equivalent inputs related to window solar transmission factors since BREDEM 8 requires a single value for any given type of glazing. The values used were derived from Page and Lebens (6) by averaging the monthly mean transmission factors over the whole year and over all orientations. The data used for normal solar transmission in Page and Lebens (6) agreed with the values which had been used by the simulation models.

PREDICTION OF ANNUAL AND OVERALL MONTHLY CONSUMPTIONS

Figure 1 shows the results of the testing for all months taken together and for the whole year. The graphs on the left show the individual predictions plotted against the corresponding measurements. The diagonal is the line representing perfect agreement. The dashed line is the regression line (with a forced zero). It can be seen that there is excellent agreement between the predictions and measurements, and this is reflected in the very high correlation coefficients (both in excess of 0.95) and the gradients which are close to unity (0.94 for the monthly results and 0.96 for the annual results).

Figure 1 also shows, on the right, the results obtained from testing BREDEM 8 against simulation models. Again, there is a graph for all monthly results taken together and for the annual results. The graph giving the annual results excludes the IEA Task VIII benchmarks in order to be fully consistent with the monthly results. Details of the IEA Task VIII results can be found in Table 1. The upper graph plots the monthly BREDEM 8 predictions against the mean of the simulation model predictions. The regression line has a gradient of 0.99 with a correlation coefficient of 0.99.

The annual graph identifies the individual simulation model predictions. The regression line is that determined using the mean of the simulation model results as the independent variable. It has a gradient of 1.03 and a correlation coefficient of 0.98. There are systematic differences between the predictions of the simulation models for the higher energy use cases (these correspond to the semi-detached house with traditional construction). For these cases, BREDEM 8 is in good agreement with SERI-RES.

Figure 1 shows that, overall, BREDEM 8 predicts both monthly and annual consumptions which agree well with measurements and with simulation models.

Table 1a shows the annual consumption resolutions for each of the individual datasets for the simulation models alone and for the simulation models plus BREDEM 8. Excluding the IEA Task VIII dataset the resolutions including BREDEM 8 are very similar to those for the simulation models alone.

PREDICTION OF CONSUMPTIONS FOR INDIVIDUAL MONTHS

Lack of space precludes the inclusion of equivalent graphs to those in Figure 1 for individual months. However, Figure 2 presents a typical example of one particular winter month showing that the agreement is good. In fact, the agreement is good across all the winter months. In the summer months, as would be expected, the consumptions are more difficult to predict.

A typical comparison with the monthly predictions of the simulation models is also shown in Figure 2. The predictions for individual months are shown to be similar to those of the simulation models. Thus, although BREDEM 8 is primarily intended to produce reliable estimates of annual energy consumptions, its monthly predictions are close to both measured consumptions and to simulation model predictions.

PREDICTIONS RELATING TO DESIGN ISSUES

The comparisons between BREDEM 8 and the other models produced a lot of information on the ability of BREDEM 8 to predict the energy implications of certain design changes. An overview discussion of these results follows. The reader should refer to Table 1b and Figure 3 for the details. Table 1b quantifies the performance of BREDEM 8 in terms of resolutions for each design issue. Figure 3 shows illustrative examples for some of the design issues. These are all for the Linford house except that at the bottom right of Figure 3 which is for the typical UK semi-detached house.

The effect of orientation on energy use was considered in all datasets. The trends in energy use with orientation were always consistent with the simulation models. For the two single zone datasets the resolution including BREDEM 8 was as good as that of the simulation models alone. The resolutions for the other datasets were worse with BREDEM 8 than for the simulation models alone.

The glazing type was varied in the case of the Linford house and the typical UK semi-detached dwelling. The resolution including BREDEM 8 was found to be as good as that of the simulation models alone.

The area of the south facing glazing was varied for three of the datasets. The resolution including BREDEM 8 was slightly worse than that of the simulation models alone for the Linford and Applicability Study single zone cases. It was considerably worse than the simulation models alone for the IEA Task VIII dataset when the results for Denver were included. However, it was as good as the simulation models alone if only the Copenhagen results were considered.

The trend in energy use as the south facing glazing area was varied was similar for all models up to 100% relative glazing area (this corresponds to a passive solar design with south facing window areas equal to about 30% of the floor area of the rooms containing the glazing). Above 100%, the trends predicted by all the models diverged so it was hard to draw any conclusions. However, there was evidence from the Applicability Study single zone dataset that for huge glazing areas (above 140%) BREDEM 8 showed a trend which was different from that of the simulation models.

For the case of the Linford dataset a reference design was also modelled. This was essentially the same as the Linford house except that the orientation and glazing distribution were altered so that the dwelling was no longer passive solar. The change in energy use between the two designs was assessed for several different circumstances. The resolution for all four models was only slightly worse than the resolution for the simulation models alone.

For the typical UK semi-detached dwelling the influence of construction type was studied. Two construction types were considered - traditional and modern heavyweight. The energy savings obtained by changing from traditional heavyweight to modern heavyweight predicted by BREDEM 8 were always higher than those predicted by the simulation models. The resolution including BREDEM 8 was some five percentage points worse than the resolution of the simulation models alone.

CONCLUSIONS

The results presented in this paper have demonstrated that BREDEM 8 predictions of annual and overall monthly energy use are usually in good agreement with both measurements and with the predictions of simulation models. Results for individual months have also been shown to be close to both measured consumptions and to simulation model predictions.

The results have also demonstrated that BREDEM 8 is able to address many design issues. Comparisons with simulation models have shown that BREDEM 8 will predict changes in energy use which are in the right direction for all the design issues considered. The one exception is the case where south facing glazing areas are increased well beyond what is normal practice even for passive solar design.

In some cases, the predictions of the absolute changes in energy use (ie energy savings) produced by BREDEM 8 have been found to be as good as the predictions of the simulation models. In the remaining cases, the predictions are comparable with those of the simulation models. Table 1b suggests that BREDEM 8 predictions of energy savings can generally be expected to be within five percentage points of simulation model predictions (excluding the IEA Task VIII results for the Denver climate) and will often be much closer.

Finally, it is worth noting that the BREDEM 8 model is very similar to the models contained within the International Standard ISO 9164 (7) and in the draft European Standard PrEN 832 (8). Indeed, the development of BREDEM 8 has been influenced by both these standards. The results presented in this paper suggest that the core procedures of these standards are robust.

ACKNOWLEDGEMENT

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Table 1a: Model resolutions for annual energy consumption

	Linford		Typical semi [2]		AS1 single zone		IEA single zone [1]	
	Simulation models only	Including BREDEM 8	Simulation models only	Including BREDEM 8	Simulation models only	Including BREDEM 8	Simulation models only	Including BREDEM 8
Annual energy consumption	10.0%	11.0%	28.5% (20.0%)	31.5% (20.0%)	16.5%	16.5%	38.5% (6.0%)	78.5% (15.0%)

Table 1b: Model resolutions for annual energy savings

	Linford		Typical semi		AS1 single zone		IEA single zone [1]	
Energy saving due to changing the	Simulation models only	Including BREDEM 8	Simulation models only	Including BREDEM 8	Simulation models only	Including BREDEM 8	Simulation models only	Including BREDEM 8
Orientation of main glazing to south	3.0pp	8.0pp	3.5pp	5.5pp	7.5pp	7.5pp	6.0pp (2.0pp)	6.0pp (2.0pp)
Glazing from single to double double to low-e	5.0pp	5.0pp	2.5pp	2.5pp				
South facing glazing area	3.5pp	5.5pp			3.0pp	5.0pp	5.0pp (3.5pp)	15.0pp (3.5pp)
Traditional to modern construction			7.5pp	12.5pp				
Design to passive solar	12.5pp	15.0pp						

pp: percentage points (all values quoted to nearest half percentage above calculated value)

[1] Results for Copenhagen only shown in brackets

[2] Results for modern heavyweight construction only shown in brackets

Figure 1: Annual and overall monthly predictions

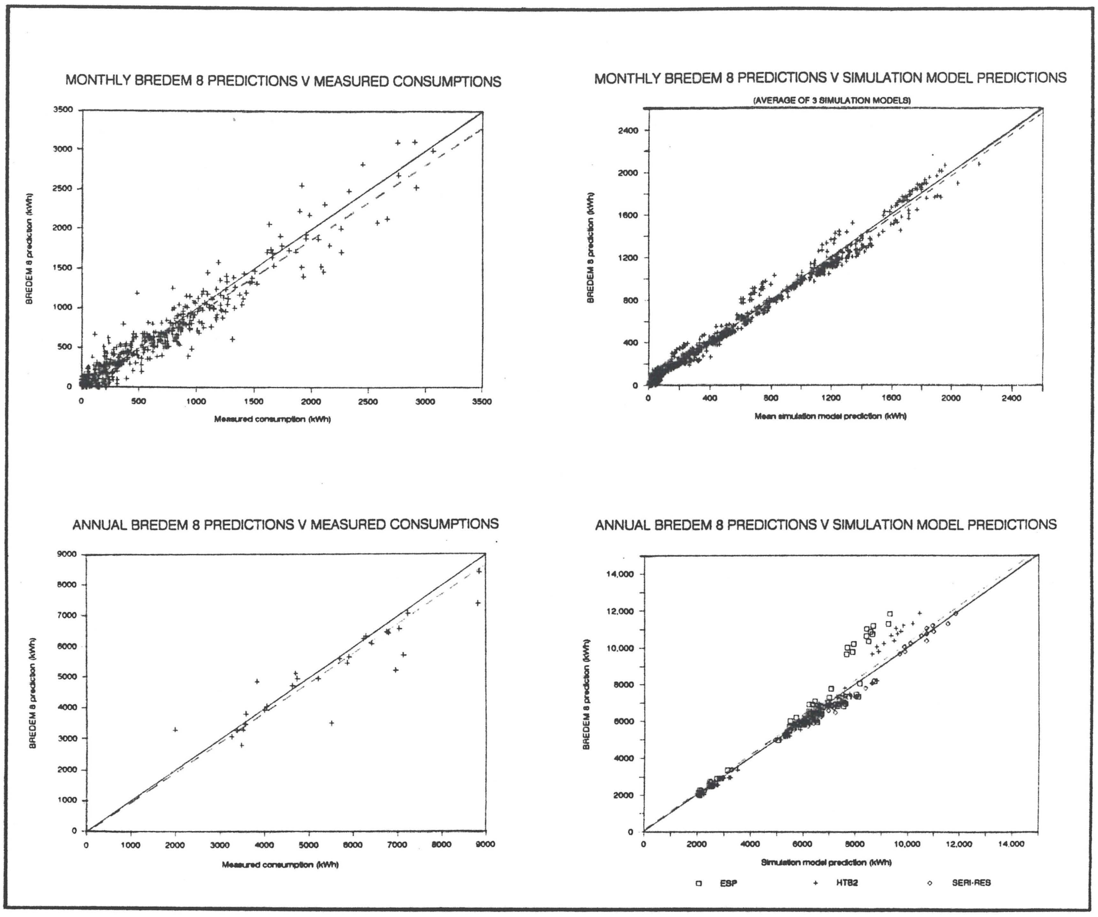

Figure 2: Predictions for individual months

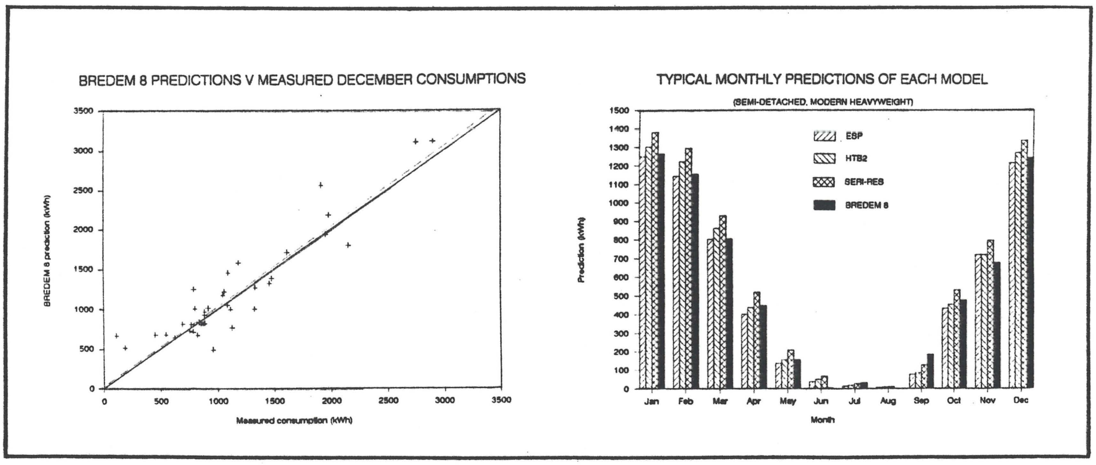

Figure 3: Predictions relating to design issues