A METHOD TO EVALUATE THE SAVINGS FROM DOMESTIC SOLAR WATER HEATING SYSTEMS

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ABSTRACT

A review of the solar water heating equations in the BRE Domestic Energy Model was carried out using data from a recent monitoring project. The savings predicted by the model did not match the test data well, so improved equations were devised. Predictions from the new method were then tested against the measured savings from monitored systems and found to match the test data much better.

KEYWORDS

Solar water heating, utilisation factor, BREDEM, SAP.

INTRODUCTION

In the UK, BREDEM[1,2] (BRE Domestic Energy Model) is the most widely used method for estimating household energy use. It forms the basis of the UK government's SAP[3] (Standard Assessment Procedure) rating for dwellings, which is one method of demonstrating compliance with the energy conservation section of the building regulations. Over the years, various aspects of the model have been updated and modified to reflect the best of current knowledge and as part of the latest updates, a review of the energy saved by the presence of solar water heating systems was deemed necessary. This paper describes the review and the new method devised. Although it is designed for use in a specific energy model, it is likely to be of interest in other situations where an estimated saving for a solar system is required.

It is worth introducing a few key concepts before embarking on a description of the work. Firstly, the solar system being modelled: the method assumes a solar collector with water pumped through it, which passes through the heat exchanger of a hot water tank to heat the water in it. A supplementary heating system such as a boiler or immersion heater is also present. The system is connected to a temperature sensing circuit such that the pump will only run if the water in the solar collector is hotter than the water in the tank. This stops the solar system effectively working in reverse and cooling the water in the tank, perhaps while it is heated by the supplementary system. For this reason, the system will not be able to utilise available solar energy whilst the water in the tank is hotter than that in the collector loop. Another utilisation issue may occur on very sunny days where the water may be heated to a higher temperature than required.

The utilisation factor is a key consideration when estimating savings. The solar energy incident on the panel does not itself answer the question of how much energy is saved by the system. It is also necessary to know what proportion of that energy can be usefully transferred to the hot water tank. Only there is it useful.

The utilisation factor depends on how much energy is collected and how much is required. If more is available than can be used, some of the excess will be wasted, so the utilisation will be lower. If more hot water is used, then a greater fraction of the available energy can be utilised. This gives rise to the need for a variable called the load ratio (LR). This is simply the ratio of the heat required (the demand) to the heat available (the collected solar energy). The variation of the utilisation factor with the LR is important to this study.

METHOD AND FINDINGS

To review the BREDEM algorithms for solar water heating, three tasks were identified:

1. To test the predictions of the old method against the new data[4], to see if they matched well
1. If the predictions were found to differ unacceptably, to improve the calculation method
1. To confirm that the new method was superior by comparison with other monitoring data available.

Testing the old method

Daily data for the amount of useful energy delivered from the solar water heating system to the hot water tank was summed to give monthly figures. These were then compared to the monthly savings predicted by the BREDEM calculation. An example comparative plot is shown in figure 1.

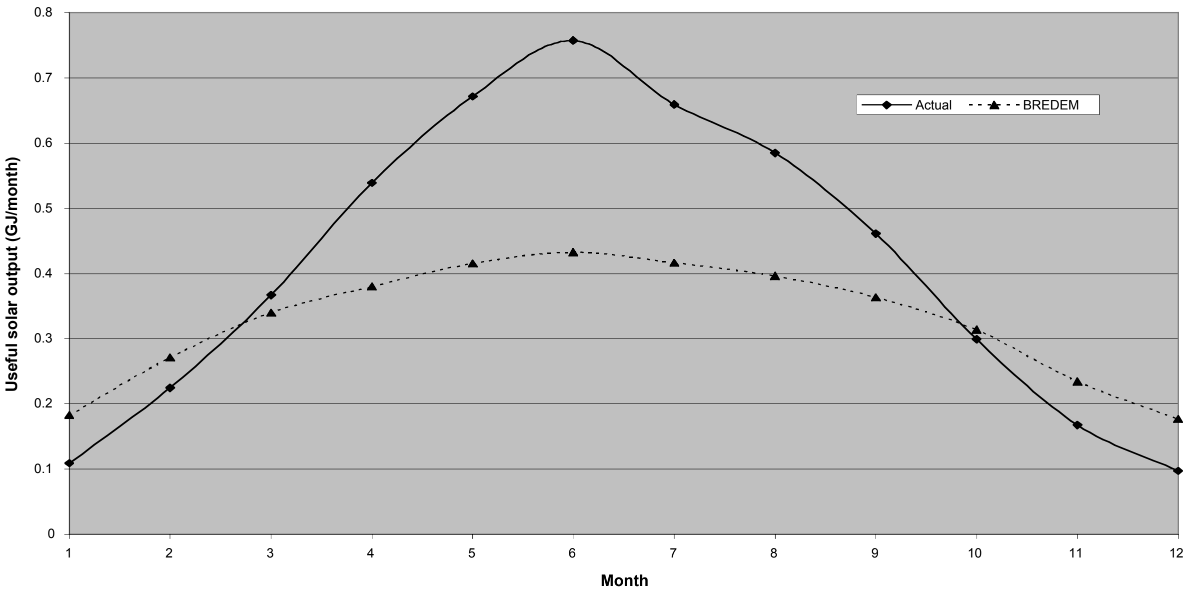

Figure 1: Predicted versus actual monthly savings.

It can be seen that the two data sets do not match well, particularly in mid summer. To understand why, it is necessary to examine the formulae involved in the calculation.

Old BREDEM calculation

The calculation method is based on the ratio of demand to supply, the load ratio, from which an estimate of the utilisation factor is calculated. This utilisation is then multiplied by the total amount of energy available from the solar collector to get an estimate of how much of that energy is *usefully* delivered. Q_s is the energy saved in the month (MJ), f is the collector efficiency, S is the solar flux for that month (MJ/m^2), A is the area of the collector (m^2).

$$Q_s = fSA\left(\frac{1}{1+(1/LR)}\right) \tag{1}$$

Where

$$\frac{1}{LR} = \frac{fSA}{Q_u} \tag{2}$$

Q_u is the hot water energy required. The bracketed term in Eqn. 1 is the utilisation factor (U), such that

$$U = \left(\frac{1}{1+(1/LR)}\right) \tag{3}$$

Eqn. 1 can be rearranged to make the utilisation factor its subject ($U = Q_s / fSA$). In the monitored data, where f, S, A and Q_s are known, U can thus be calculated and compared to that produced in the BREDEM method. This comparison is presented in figure 2.

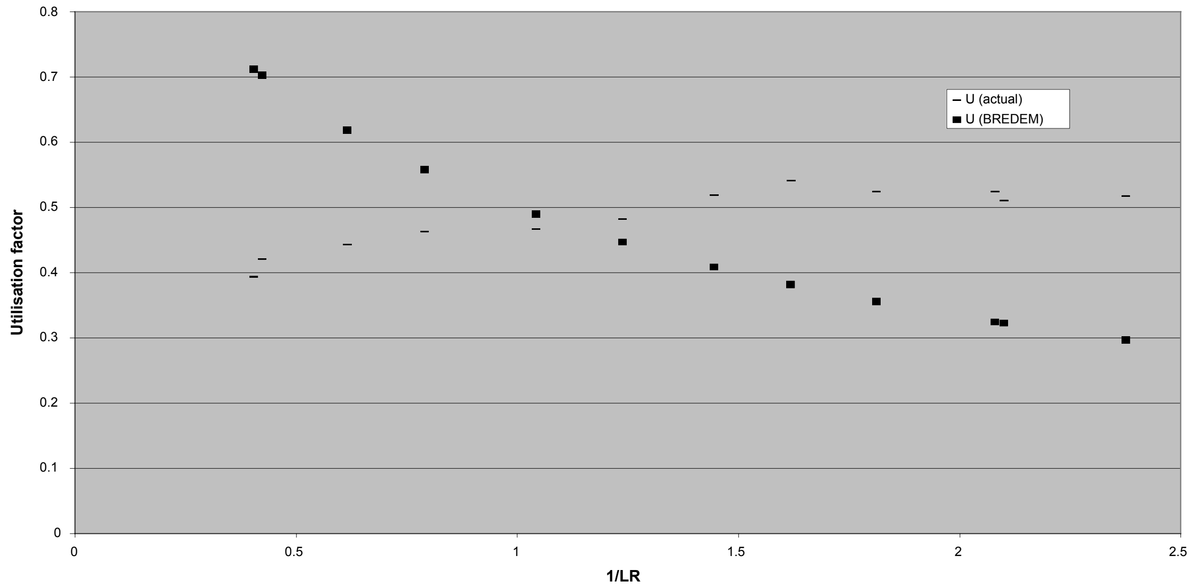

Figure 2: Predicted versus actual utilisation of available energy.

From this, it is immediately apparent that the two curves are very different, implying that there is a problem with this aspect of the BREDEM equation. The effect of this problem is to inflate the predicted saving in the winter months and deflate it at the sunniest times of year, causing the differences seen in figure 1. To sense check what is happening, it is worth thinking about why the utilisation curve looks the way it does. Firstly, consider the old BREDEM method. The argument for it starting at 1 and then slowly tending towards zero at high 1/LR at first seems reasonable. A low value of 1/LR implies that demand heavily outweighs supply, so it makes sense that nearly all the energy available should be useful. But this doesn't take account of the way in which the system operates. Only if the water in the solar collector is at a greater temperature than that already in the tank will the circulation pump be activated (to avoid removing heat from the tank), so on dull days it may hardly come on at all. The small amount of energy getting to the water in the collectors will simply sit there and eventually (if the temperature never gets high enough to turn the pump on) leak away to the external air. A well-insulated hot water tank which has been heated to 60°C in the morning (for example) and has had only a little water drawn from it, may never get below 50°C. To raise the water in the collector to more than 50°C will require a significant amount of solar radiation and if only a small amount is available, it is likely that it will not be utilised. As the amount of radiation increases, the water in the collector is more likely to reach a sufficient temperature to turn the pump on and therefore be usefully delivered to the tank. This reaches a maximum however and by the time the supply of heat outstrips the demand, energy will begin to be wasted in overheating the tank and in increased losses to the external air, since the water flowing round the collector loop will be doing so at a higher temperature. Tank losses will also increase if the temperature of the stored water exceeds its required temperature, so excess energy becomes less useful the more it exceeds demand and the utilisation factor falls off towards zero.

Developing a new method

From the analysis above, it is clear that the problem lies with the formula used to calculate the utilisation factor, so the obvious solution is to change it to better reflect the utilisation factor of the test data. First, it is an opportune moment to re-examine the definition of the load ratio. The current method seems to have two shortcomings: it doesn't take account of tank losses in the heat required and assumes that all of the energy can be utilised in the supply term. Of course, exactly how much can be utilised is not known until the LR term itself is known, but a first order approximation can be obtained by looking at the data from the monitored systems. It is quite close to half over the course of the year in each case and so it is proposed that an approximate utilisation factor of 0.5 be applied in this term. As the tank losses are already calculated as part of the overall energy use calculation in BREDEM, adding the tank loss term Q_t, is straightforward. Using these new assumptions then, the equation for the LR becomes:

$$\frac{1}{LR} = \frac{0.5 \times fSA}{Q_u + Q_t} \tag{4}$$

Using this new definition, the utilisation factor from the test data was re-plotted and a formula was derived to match it as closely as possible without being excessively complicated:

If 1/LR < 1 (usually a dull month)

$$U = 0.5 \times (1/LR) + 0.35 \times \left(1 - (1/LR)^2\right) \tag{5}$$

If 1/LR ≥ 1 (usually a sunny month)

$$U = \frac{0.5}{(1/LR)} \tag{6}$$

The predicted value of U is plotted against the value of U taken from the data in figure 3 and can be seen to match it quite closely.

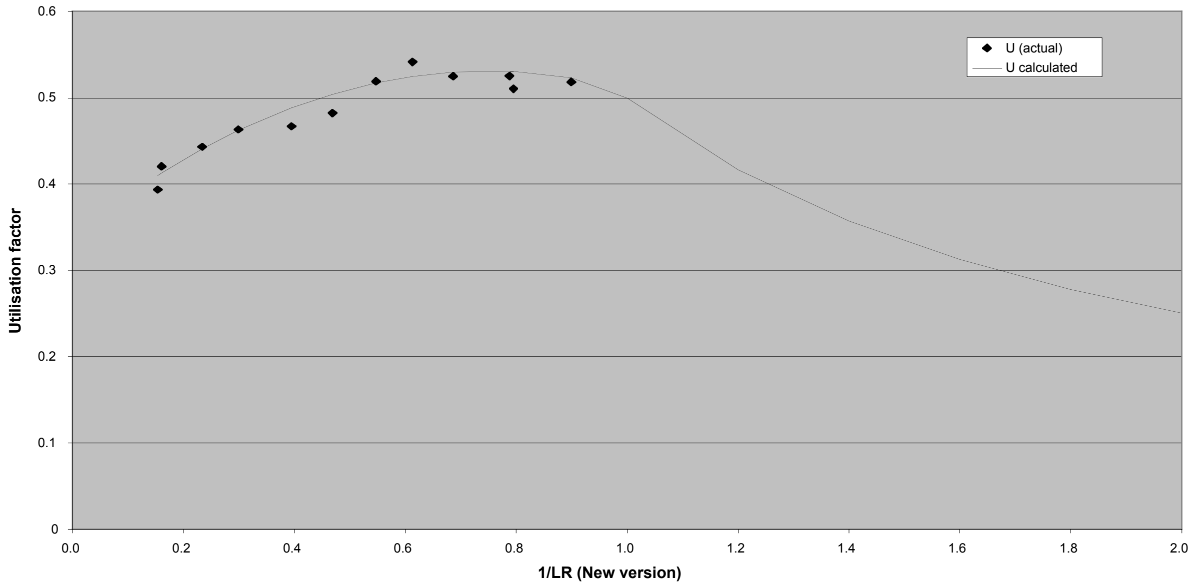

Figure 3: Predicted utilisation of energy available using new method.

Since the actual data only covers a small range of values of LR, less averaged data was used to confirm the behaviour at higher values of 1/LR.

Figure 4 shows the predicted energy savings from the solar system as taken from the data, plotted on the same axis as the predictions of the new and old BREDEM methods. The new method is clearly a much closer match.

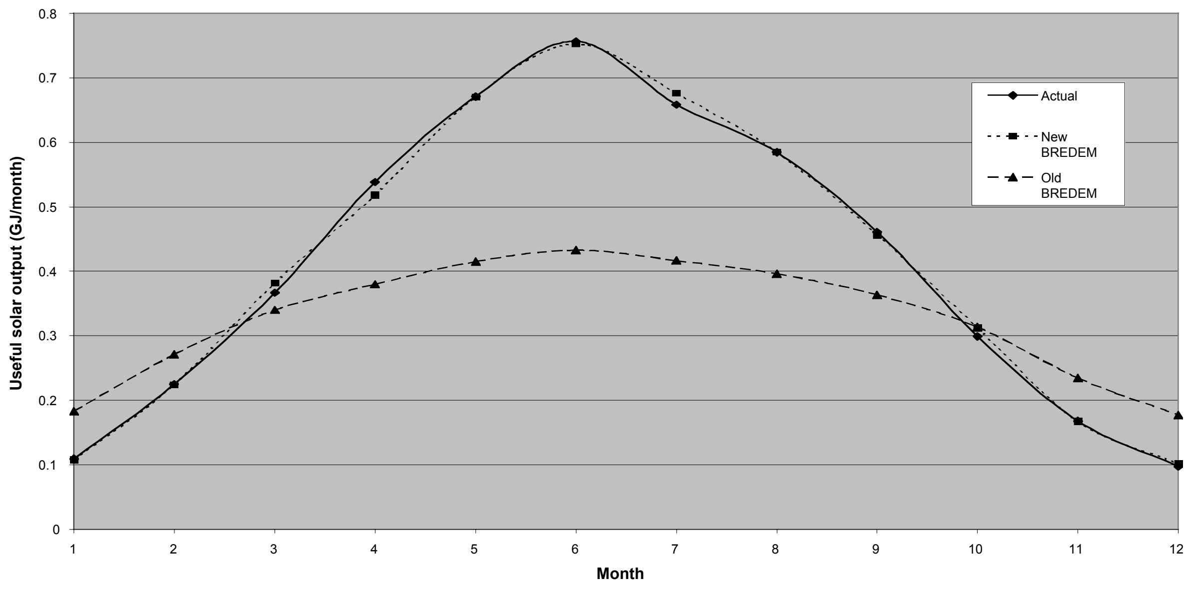

Figure 4: Predicted versus actual monthly energy savings for new and old methods.

Annual method

So far this analysis has only discussed monthly calculations of the solar water heater saving, but a version of BREDEM which bases its energy consumption on a single annual calculation also exists. Therefore an annual version of the calculation was also developed :

If 1/LR < 0.65

$$U = -0.61 \times (1/LR)^2 + 0.63 \times (1/LR) + 0.35 \qquad (7)$$

If 1/LR ≥ 0.65

$$U = \frac{0.65}{(0.67 + 1/LR)} \qquad (8)$$

Further testing

As soon as the results of a monitoring project[5] performed on 8 more systems became available, the predictions could be further tested. Figure 5 shows a typical example plot of the predicted monthly savings and the actual savings from 1 of the 8 monitoring sites. The predicted energy saving from the old method is also shown. In all 8 cases the new method outperforms the old and gives a close match to the test data.

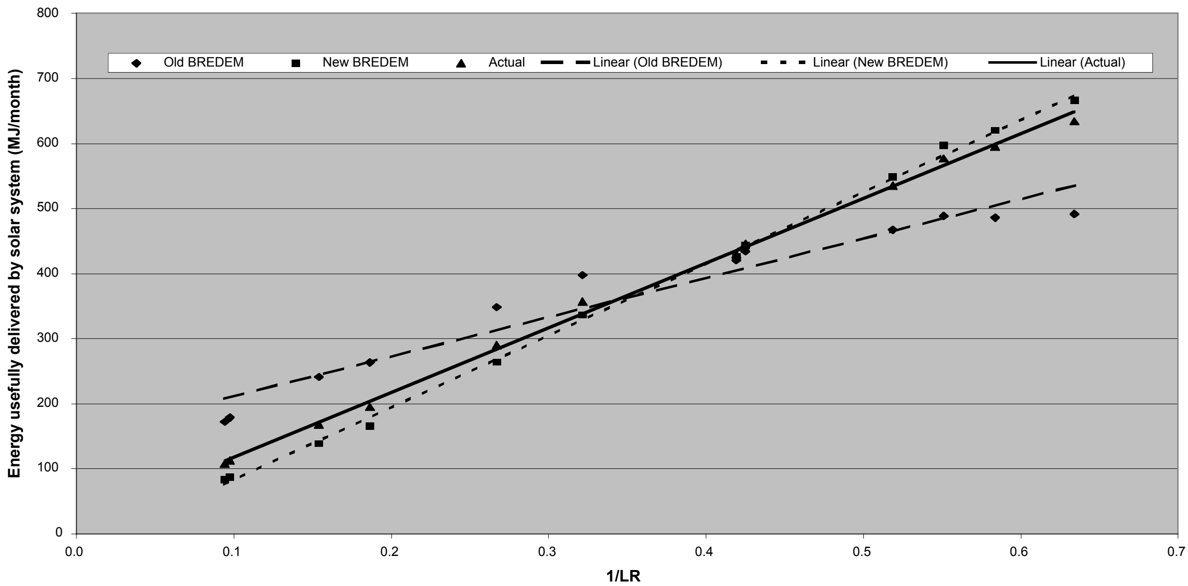

Figure 5: Example plot from one of the 8 test sites, showing the predicted and actual saving.

CONCLUSIONS

Using equations still based on simple properties of solar water heating systems, it has been possible to improve BREDEM's predictions of the amount of usefully delivered solar energy from a number of systems to obtain a good level of agreement with their measured output. The new method has therefore been included in the latest BREDEM specification.

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