Programme Area: Buildings

Project: Building Supply Chain for Mass Refurbishment of Houses

Title: testing of the ETI thermal efficiency core model

Abstract:

Please note this report was produced in 2011/2012 and its contents may be out of date. This deliverable is number 4 of 6 in Work Package 1. It provides details of the testing procedures that have been carried out on the Beta version of the computer model developed across Work Packages 1 and 2. The aim of the model is to be able to characterise the thermal efficiency of residential properties at two levels, 1) the individual building level, and 2) the UK housing stock level. The ultimate aim of this is to be able to identify the optimum thermal efficiency interventions which can be made at a building and stock level, and to quantify the impact on energy efficiency which these interventions will make. The testing described within this document describes the testing of the 'single dwelling' core of the computer model which has been carried out at a number of different levels of granularity.

Context:

This project looked at designing a supply chain solution to improve the energy efficiency of the vast majority of the 26 million UK homes which will still be in use by 2050.It looked to identify ways in which the refurbishment and retrofitting of existing residential properties can be accelerated by industrialising the processes of design, supply and implementation, while stimulating demand from householders by exploiting additional opportunities that come with extensive building refurbishment.The project developed a top-to-bottom process, using a method of analysing the most cost-effective package of measures suitable for a particular property, through to how these will be installed with the minimum disruption to the householder. This includes identifying the skills required of the people on the ground as well as the optimum material distribution networks to supply them with exactly what is required and when.

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The **ENERGY ZONE CONSORTIUM**:

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eDF

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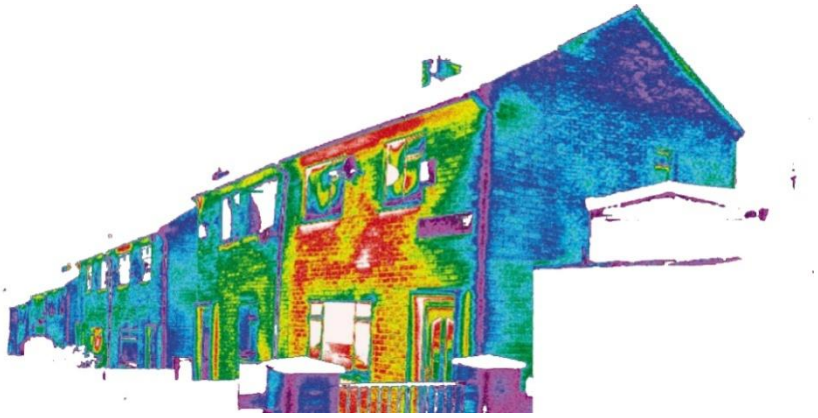
wates



Optimising Thermal Efficiency of Existing Housing

Testing of the ETI-Thermal Efficiency core model (WP1.4)

FINAL REPORT

Submitted by BRE on behalf of the
ENERGY ZONE CONSORTIUM

June 30, 2011

TABLE OF CONTENTS:

Executive summary

This note sets out the testing procedures that have been carried out on the core of the computer model for of housing refurbishment which being developed for the ETI Thermal Efficiency project.

The computer model is being developed in several stages. The first two stages produced an assessment of the most suitable methodology to be used as the model's core energy engine. This assessment recommended a BREDEM 2009 aligned methodology, substituting and supplementing with additional algorithms and methods where applicable. The next stage in the model development was the production of a formal functional specification for the model. The functional specification outlines how the user is to interact with the model, what outputs would be produced and acts a technical template to begin coding of the model.

The software itself is released in three separate versions: alpha, beta and gamma. Each version of the model is developed on from the previous version based on comments and feedback from users and the changing needs of the project in an 'evolutionary development cycle'. The alpha-model is the initial version of the software, containing the core model code, and initial functionality for improvements. This version of the model was released in March 2011. The alpha-model is superseded by the beta-model which has been informed by tests on the alpha-model and feedback from users. The beta-model was released on 30th June 2011 (the same date as this note). The final version of the model is the gamma-version of the model, which is due to be completed in September 2011 and will incorporate any changes which result from additional tests and comparisons to other models and data, and further user feedback.

The alpha-version of the model was released at the end of March 2011. Prior to, and following, this date the core model has undergone multiple stages of testing by BRE, UCL, EDF R&D and other users of the model. These tests have acted to test the core model code (principally the implementation of the BREDEM 2009 methodology and the mechanism of applying improvements). Many of these tests have been repeated on the beta-version of the model prior to its release on June 30th 2011 to check that any changes between the alpha- and beta-models have not inadvertently affected the integrity of the core model code. These results of these tests were positive and we can be confident that the beta-version of the model is operating as designed and specified in the functional specification. Therefore, it is now possible to undertake additional tests comparing the model results to French models and to data on actual consumption. The results of these tests will be used to inform the gamma-version of the model as appropriate.

The first stage of testing of the core model was the internal checking of code as it was produced (checking both the ability of the model to compile and operate, as well as the visual interrogation of the code itself). This was accompanied by a process of alignment of outputs from the ETI model with those directly from the BREDEM 2009 specification, which was achieved for all outputs. This ensures that the ETI-TE model is satisfactorily

representing this methodology. These tasks were carried out by the main model development team at BRE.

A parallel stage of testing was the independent interrogation of the model code by third-party developers and the running of sensitivity tests to identify and resolve further problems. This task was undertaken by a team of analysts at UCL. The results were passed back to BRE developers for further investigation and resolution.

Additional testing was undertaken by all members of the Energy Zone Consortium itself. The development of the model is explicitly an ‘enabling tool’ for other workpackages in the project to allow the investigation of the potential for thermal efficiency projects. All users of the model were asked for user feedback on alpha-model functionality and their requirements to ensure that the needs of each workpackage in the project were being met. This resulted in several requests for additional functionality to be included in the beta (and gamma) versions of the tool.

Having completed tests on the core model code, and having achieved alignment with the BREDEM 2009 specification, it is now possible to compare the results from the model to French models operated by EDF R&D. This will allow the comparison of BREDEM results with those from an independently produced (non-BREDEM) tool. Additionally, the results of the model will be compared to any available data from EDF Energy (UK) on actual consumption of their customers. This work will be undertaken in summer 2011. We are also investigating the feasibility of further comparisons to additional data on actual energy consumption as available.

The results of these additional tests, together with feedback from all project partners on the outputs and functionality of the code, will be used to update the model as appropriate in the production of the final gamma-version of the model which is scheduled to be completed in September 2011.

Testing of the ETI-TE core model

INTRODUCTION

This document outlines the tests which have been carried out on the core code (referred to as the core model) which is used in the alpha-version (and initial beta-version) of the ETI-Thermal Efficiency computer model. Presented are the mechanisms and results produced by BRE and UCL and a description of further testing that is being carried out by EDF R&D on the model, including the comparison of data against information held by EDF Energy (UK) on customer consumption.

EVOLUTIONARY DEVELOPMENT OF THE ETI-TE MODEL

The development of the ETI-TE model is being undertaken through an 'evolutionary development cycle'. This process is initiated through consultation with users of the software, and a resultant specification of requirements to meet their needs. Following this, an initial version of the software is produced (the alpha-version) and released to users for comments and feedback. Further versions (the beta- and gamma-versions) are produced based on this feedback as the needs of the project as it develops. This process of evolutionary development helps to ensure that the needs of users are met. This process is particularly appropriate for this project as it allows for some flexibility to adapt to evolving questions and queries.

TESTING THROUGHOUT THE DEVELOPMENT CYCLE

Testing of the model occurs at all stages of the development cycle. Indeed, the cycle itself (through the feedback) acts to test the functionality of the model from the perspective of the user.

The initial tests were carried out internally by the primary model developers (BRE) as each development version model was built. Algorithms were tested and the functionality was examined to ensure that the requirements of the formal model functional specification (item WP1.3a) were met. The functional specification outlines the technical requirements for the model, and includes a requirement to align the model with the BREDEM 2009 specification.

Following the release of the model to all partners, feedback was sought on functionality and outputs. Two partners, UCL and EDF R&D, are also assigned additional responsibilities to provide in depth testing of the model throughout its development (using their specific technical knowledge and expertise). UCL were charged with third-party developer testing, primarily using the alpha-model. EDF R&D have been asked to provide some comparisons of results with independently produced French models to identify differences, and to compare results to data on actual consumption held by EDF Energy (UK). This will be undertaken using the beta-model. These roles are expanded upon below.

INTERNAL DEVELOPER (BRE) TESTING

Throughout the production of the development of the core model code, internal tests on the model were undertaken by BRE. The purpose of these tests, for the development of the core model, was to ensure that the software compiled successfully and that it accurately replicated the BREDEM methodology. Differences between the model results were identified and investigated, and the model adjusted as required.

The internal testing regime for the development of the model at BRE consists of:

i. Testing of code as the model is run
ii. Secondary checking of each others' code by developers
iii. Comparison of outputs with manually calculated results from the BREDEM specification

This was undertaken by a designated testing team. This team will continue to test aspects of the model as it develops to the gamma-model stage. The model testing team at BRE consists of:

- One systems analyst who oversees the development of the model as a whole.

- Two model developers who:
    - Undertake testing of algorithms throughout the coding process
    - Act to check each others' code to look for coding errors and bugs
    - Investigate and fix problems passed on by testing coordinator.

- A designated testing coordinator who:
    - Defines tests to be carried out by the testing team
    - Provides the results of tests to developers (and suggests solutions) as required

- A team of six testers who:
    - Undertake the tests outlined by the testing co-ordinator.
    - Propose possible causes and solutions of problems
    - Pass results of the tests back to the testing coordinator.

In the process of building the model, procedures and functions were checked to ensure that they compiled (and operated) successfully throughout development. Secondary checking of code was undertaken by each of the BRE developers by inspecting the code of the other developer as it was produced to identify potential problems. This process acted as a first check on the model code ahead of the production of outputs, and gave confidence that the software ran and appeared to be performing calculations successfully.

To check the accuracy of the outputs the model results were compared to results produced using the BREDEM specification. A total of twenty different types of dwelling were compared to identical dwellings calculated directly using manual calculations. All results were then compared. The process required the following steps:

a) Full BREDEM inputs were produced for twenty dwelling stereotypes.
b) Outputs for each dwelling for the base (unimproved) position were calculated using manual calculations from the BREDEM specification directly

c) Identical dwellings were input into the ETI-TE model
d) Outputs for the base (unimproved) positions were produced using the ETI-TE model
e) Outputs from both models were compared and results / recommendations passed to the testing coordinator
f) The testing coordinator made recommendations to the developers
g) Tests were rerun as required
h) All tests were run until convergence was achieved between the BREDEM specification outputs and the ETI-TE model outputs.

After repeated iterations of this testing procedure, convergence was achieved successfully. This is shown for total annual energy consumption in figure 1 below. The x=y relationship shows that the ETI model match the BREDEM specification results for all twenty types.

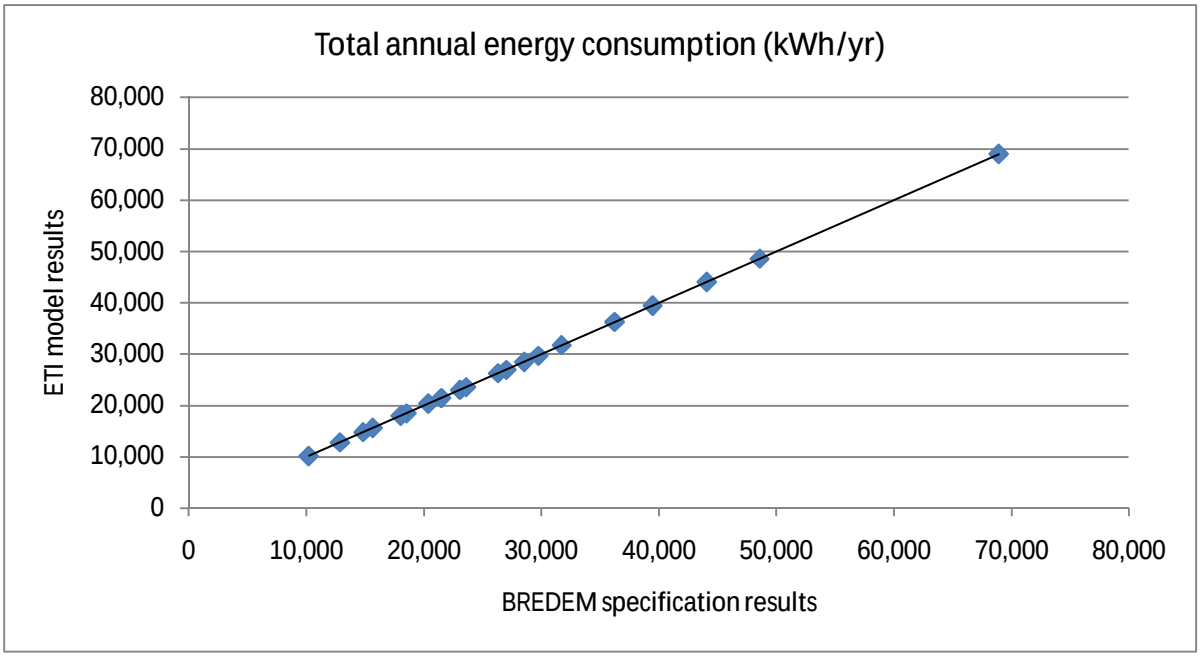


FIGURE 1: COMPARISON OF ENERGY CONSUMPTION FROM ETI MODEL WITH INDEPENDENT BREDEM SPECIFICATION CALCULATIONS FOR TWENTY DIFFERENT DWELLINGS. THE CHART SHOWS CONVERGENCE OF THE TWO SETS OF RESULTS.

To allow testing of the improvements engine in the ETI-TE model, improvements were also simulated using both the ETI model and the BREDEM specification. The testing and feedback process was identical to that outlined in for the base position (a-f) above.

For each scenario and dwelling type, the following outputs were investigated:

i. Energy for space heating split by fuel
ii. Energy for water heating split by fuel
iii. Energy for cooking split by fuel
iv. Energy for lights and appliances
v. Total energy requirement
vi. CO_2 from space heating split by fuel
vii. CO_2 from water heating split by fuel
viii. CO_2 from cooking split by fuel

ix. CO_2 from lights and appliances
x. Total CO_2
xi. Other outputs as required by testing

THIRD PARTY DEVELOPER TESTING (UCL)

Following the successful internal testing of the model, the software and source code was passed to UCL for third-party developer testing.

This phase of the testing process involved inspection of the code by UCL developers, queries to BRE relating to the code or the BREDEM specification, and suggestions for improvements. Much of this work was undertaken as part of the micro-DE ETI project which required the running of the model to investigate scenarios, a process which highlighted a number of bugs and improvements (principally in the improvement functionality) which could be made to the model. The vast majority of these queries related to the details of micro-DE technologies. UCL particularly focussed on examining the sensitivity of the model to varying data items, particularly the testing of the improvements functionality.

The testing program at UCL was implemented by a team of 7 researchers led by Professor Tadj Oreszczyn and involved two main components.

Sensitivity Analysis: A sensitivity analysis (primarily of the micro-DE technologies). The sensitivity analysis was followed by the subsequent debugging of the various versions of the model submitted throughout the development period.

Scenario Testing: Nine uptake scenarios with varying assumptions on technical, physical and financial constraints were tested to demonstrate the functionality of the model. This testing phase incorporated a modelling exercise that aimed to assess the impact of energy efficiency upgrades on the desired thermal comfort temperature.

The results of UCL's tests were communicated to the BRE development team via an online 'bugtracker' which can be viewed at the following address (password required): http://eti.model.webfactional.com/questions

This system allows the third-party developers to identify problems and pose queries, which the development team at BRE could then investigate and resolve. It is also a useful mechanism for the third-party developers to suggest potential solutions to be incorporated in the next version of the model. An example of the bugtracking system is shown in the screenshot in figure 2 below:

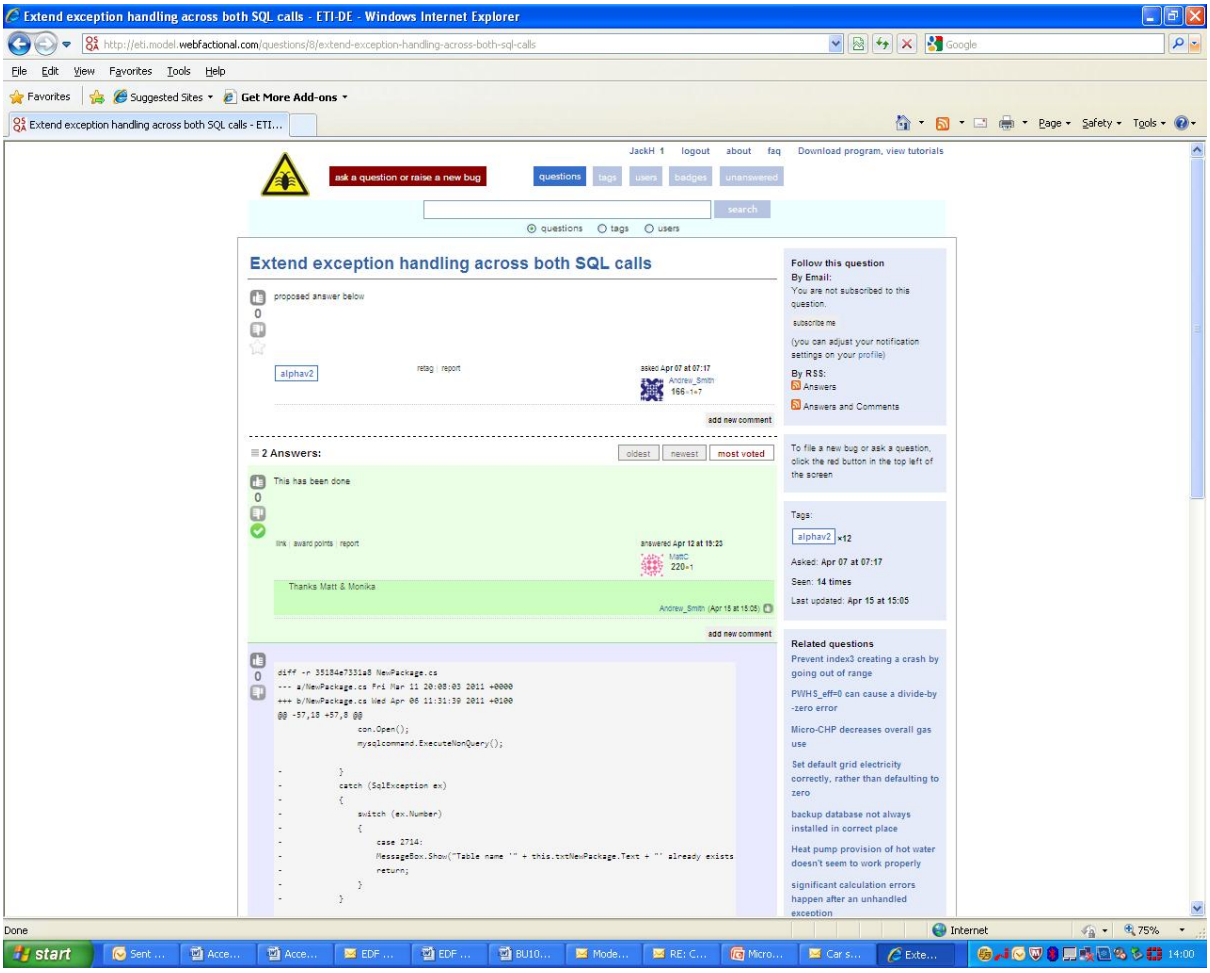


FIGURE 2: THE 'BUG-TRACKING' SYSTEM USED TO PASS ON QUERIES BY THE THIRD-PARTY DEVELOPER TESTERS.

For the beta model, the third party developers at UCL have themselves added some additional and alternative algorithms which will be tested by BRE (i.e. UCL and BRE's testing roles will be reversed for these specific developments) and which will be included in the final version of the model.

THIRD PARTY MODEL COMPARISONS AND COMPARISONS TO DATA ON ACTUAL CONSUMPTION (EDF R&D)

Alongside the third party developer testing being undertaken by ETI, EDF R&D have also been asked to produce some comparisons of the output of the model with their own French suite of models and, using data provided by EDF Energy (UK) to the consumption of energy from real homes. A comparison with French models was considered particularly appropriate because the French models are likely to have a different evolutionary basis to BREDEM. As such, the differences between the two models will help identify where any systematic biases may exist within the BREDEM methodology. We are also seeking a mechanism whereby

EDF R&D are able to access to EDF Energy (UK)'s consumption data to allow comparison of modelled results from the beta model with real data.

To allow any systematic biases or errors of this type to be identified, and for a comparison against real data of this sort to be useful, it is important for this type of testing to take place using an internally validated version of the model (otherwise the results may simply reflect an error in the translation of the BREDEM specification, rather than a systematic bias in BREDEM itself etc). Therefore, for this testing to be achieved successfully, we have asked that these tests are conducted using the initial version of the beta model (rather than the alpha-model). The findings of this work should become available in the summer of 2011 to allow incorporating into the gamma-version of the model as appropriate.

To begin the comparison of French models to BREDEM, EDF R&D have initially been asked to investigate ten specific scenarios. These are shown in the table below:

	House type	*Measures*
1	Solid wall house gas central heating	LI
2	Solid wall house gas central heating	EWI
3	Cavity wall house gas central heating	CWI
4	Solid wall house gas central heating	HWTI
5	Solid wall house gas central heating	FI
6	Solid wall house gas central heating	DG
7	Solid wall house gas central heating	LI, EWI, HWTI, FI, DG
8	Solid wall house electric storage radiator heating	LI, EWI, HWTI, FI, DG
9	Solid wall house electric storage radiator heating	HWTI
10	Solid wall flat	EWI, HWTI, FI, DG

LI = Loft Insulation, EWI = External Wall Insulation, CWI = Cavity Wall Insulation, HWTI = Hot Water Tank Insulation, FI = Floor Insulation, DG = Double glazing.

Results from these scenarios will be used to inform the final version of the model and to allow successful interpretation of the model results as scenarios are run (item WP2.3 of the project).

The comparison of results to actual consumption data provided by EDF Energy (UK) will also be undertaken by EDF R&D. Additional testing of model results against individual homes may also be possible using other data on actual consumption from a number of sources. The feasibility of this is currently being considered by BRE and UCL, and it is not currently within the scope of the project as currently specified. The result of this feasibility will be presented to ETI shortly.

FUNCTIONALITY TESTING BY USERS (ALL PARTNERS)

The final component of testing, forming a key component in the evolutionary development cycle, is the process of third-party user testing. This process involves testing of the functionality of the model and the by all partners in the consortium to ensure that it adequately meets their needs, and that of the project as a whole. The ETI-TE model, as well as an output in its own right, is explicitly an 'enabling tool' for the other workpackages in the project to allow the investigation of the potential for thermal efficiency measures. To succeed in this objective it is essential that the needs of the project partners are met.

All project partners were presented with a copy of the alpha-version of the model on CD and invited to install the model themselves and provide feedback to BRE. Feedback was particularly sought on the model functionality as it was able to meet the needs of each workpackage. In addition, a specific user requirements workshop was held by BRE in May to ascertain the needs of project partners for the beta- and gamma-versions of the model. Further to this, additional clarification on some specific aspects of the modelling was sought by ETI via the stagegate review in April 2011 and the systems level meeting in June 2011 to be addressed in the final version of the model.

All project partners were invited to submit comments via on online message board on the ETI-TE project website 'Basecamp' which BRE would then attempt to resolve. This allowed BRE to most efficiently convey solutions to known issues and problems to all project partners by acting as a repository for problems and solutions (much like the FAQ section of a website). This can be accessed at the following webpage (password required): https://energyzoneconsortium.basecamphq.com/W3396448.

A screenshot of the message board is shown below in figure 3.

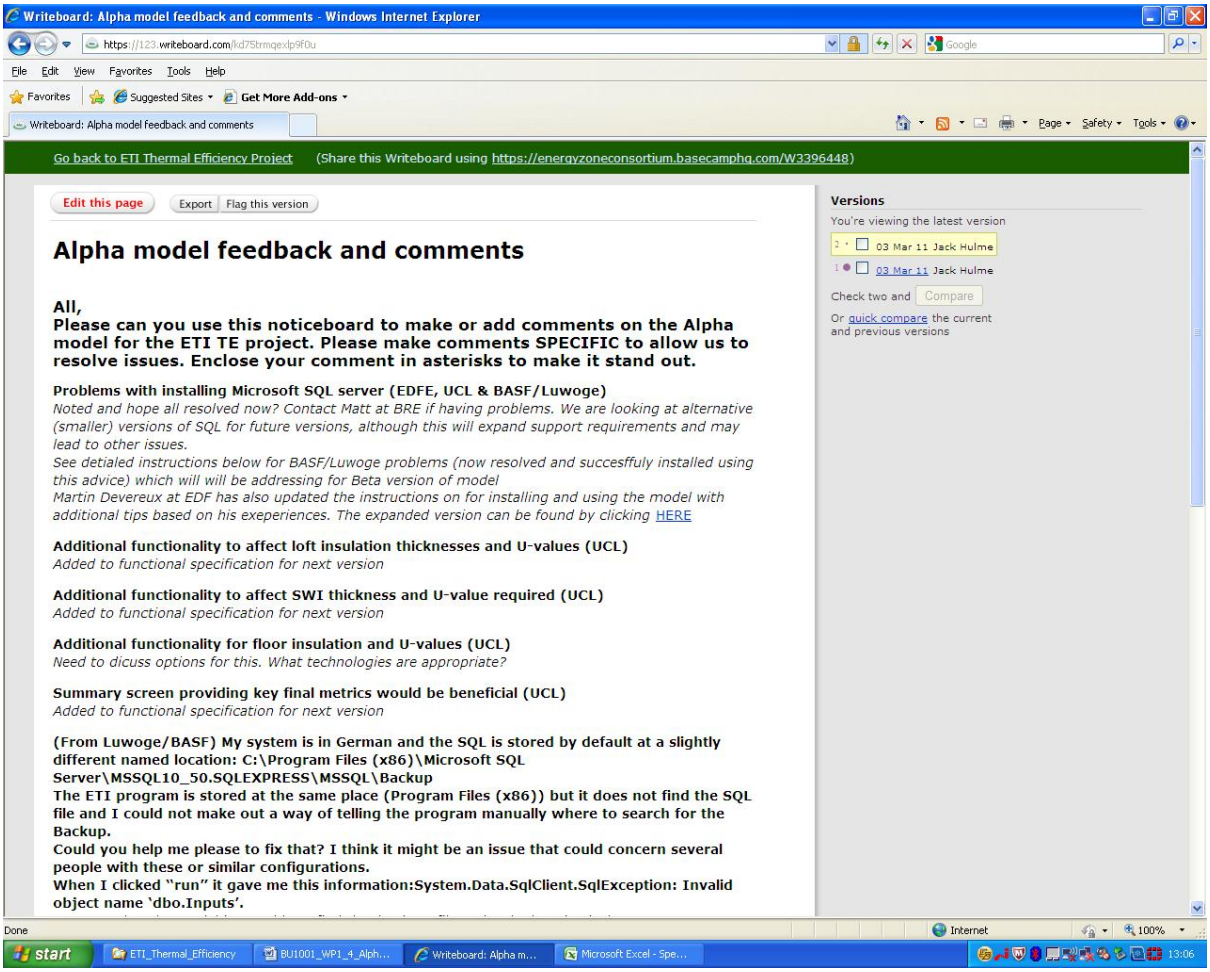


FIGURE 3: SCREENSHOT OF THE MESSAGEBOARD USED TO PROVIDE FEEDBACK AND COMMENTS TO THE DEVELOPMENT TEAM

Partners were also invited to submit problems and issues via telephone or e-mail to members of the BRE team.

A number of requests were made to enhance the functionality of the model, to be included in future versions. In particular:

- Project partners had problems successfully installing 'SQL server'. This is the database engine which is required ahead of installing the ETI model itself. Partners requested that this process is made simpler.
- Project partners would like a tool which is more suited to using in the 'virtual retrofit' component of the project in autumn 2011.
- There needs to be sufficient flexibility within the definition of the costs input into the model to allow the user to specify and change different components of the costs of intervention.
- Users requested the ability to adjust key characteristics of the single dwelling much more easily.
- Users requested the ability to select from default improvements, but also to specify details (e.g. u-values) to investigate scenarios.

RECOMMENDATIONS FOR THE MODEL DEVELOPMENT:

As briefly outlined above, and through WP items 1.1 and 1.2, we have identified BREDEM is the most suitable methodology for meeting the diverse needs of the project, and for use in both an individual and stock model. Following the successful completion of the internal core model testing by BRE, and the third-party developer testing by UCL, we can be confident that the ETI-TE model as it currently stands is a good representation of the BREDEM 2009 methodology.

There remains, however, the potential for systematic bias with the BREDEM methodology itself. To investigate this, EDF R&D will compare the outputs of the (now validated) ETI-TE model to their own tools which are not based on this methodology, and investigate the reasons behind any differences. If appropriate, and feasible we will update the ETI model (for the gamma-version) to account for these differences.

Finally, the model results will be compared to data from real homes, as made available by EDF Energy (UK), and adjusted as appropriate. Additional information may also be obtained from other data sources if required, pending the outcome of a feasibility study into use of this information.