USING UK GREEN DEAL ASSESSMENT DATA OF A STOCK OF DWELLINGS TO RUN A BATCH OF BUILDING ENERGY MODELS

ABSTRACT

This paper introduces prototype software, FE+, which runs batch-simulations to predict the energy demand of UK houses.

At each simulation run, FE+ creates an input file from data collected by surveyors conducting assessments for the UK government's Green Deal initiative. This feeds the simulation-engine EnergyPlus7.2. Post-processing code then manages the results. The energy-demand prediction was conducted for 15 houses. For two houses, the predictions of the FE+ software are compared to the results obtained using standard dynamic-modelling of the houses. A 15% difference in predictions is observed, and the reasons for this are discussed. Planned refinements to the software are presented.

INTRODUCTION

Dynamic thermal modelling (DTM) is a powerful tool that enables the evaluation of building thermal performance subject to: design, building materials, systems and controls. The extensive input data requirements, and run times, mean, however, that DTM is usually impractical for predicting the energy performance of stocks of buildings. Therefore, simpler models are often used, for example, in the UK, the Standard Assessment Procedure is used to assess house energy demand. By automating the simulation process, and using simplified input data sets it may, however, be possible to harness the power of DTMs to make reasonable predictions of the time-varying energy demands of housing stocks.

As part of the research project 'Digital Energy Feedback And Control Technology Optimization' (DEFACTO), hundreds of UK houses will be undergoing measurements of energy consumption and indoor conditions both before and after refurbishment. The homes are expected to have new heating systems and heating controls installed, as well as fabric upgrades. To evaluate the energy-savings brought about by these measures, a reliable modelling method is needed that can predict what the energy demand would have been had the new energy system and other measures not been implemented. A DTM operating within an automated processing environment is one obvious solution.

EnergyPlus, developed by the US Department of Energy, is a widely used and trusted DTM that predicts the dynamic energy performance of buildings. It is best described as a simulation engine that features simple inut/output file structures. Several tools have been developed to run EnergyPlus simulations using a Graphical User Interface such as DesignBuilder and Simergy software. Other tools have been developed to assist running batch-simulations, for parametric analysis and for simulation-based optimization, e.g. Genopt (Wetter M 2000), JEPlus (Zhang Y 2009) and, most recently, ROBESim (Chuah JW et al. 2013).

The efforts needed to get these tools working efficiently for a specific task, can sometimes be as difficult as developing one's own tool. Therefore, for the DEFACTO project, a new tool, FE+, was developed, with two versions to run: batch-simulations based on house assessment data, and parametric analysis for all possible combinations of parameters.

METHODS

Green Deal Assessment Data

In the DEFACTO project, house refurbishments will be carried out in line with the UK government's Green Deal (GD) scheme. The scheme was launched in 2013 to fund energy-efficient measures in buildings and reduce carbon emissions. The GD-assessment is an initial mandatory step before owners/tenants can join the scheme. This is carried out by an approved GD-assessor.

The GD assessment generates building information that feeds into the National UK method for existing buildings, the 'Reduced Data Standard Assessment Procedure' (RDSAP). This building information for the GD-assessment is set under two datasets about the property and occupancy assessment, respectively. These datasets follow the so-called central register schema format with the Extensible Mark-up Language (XML). The assessors need to feed in the necessary input according to the specified format. That makes a standard useful database of UK

buildings. For this work, eleven example files were obtained from anonymized data. The files included the property datasets of 11 houses. That has two main portions of input that can be beneficial for DTM, called: *Property Summary*, and *SAP-Data*. They mainly include house type, construction and fenestration information, floor dimensions, and information about the heating systems. The same file format was used to create additional files for four test-houses that belong to Loughborough University (LU). That makes a sample of 15 houses for the work of this paper.

Standard-Modelling Tool

DesignBuilder3.2 was used to model two of the 15 houses, based on own survey to be compared against the new batch-simulation tool (FE+) based the authors′ on the GD- assessment data. These two houses were selected from the LU test-houses. The houses were fully modelled using DesignBuilder3.2 and exported as IDF-files. The simulation was then carried out with EnergyPlus7.2, the same program that is used with the FE+. DesignBuilder3.2 was also used for creating the initial IDF-templates for the batch simulations.

FE+ Simulation tool

The FE+ tool was developed using the G programming language on the LabVIEW platform. The main routine consists of three sub-routines that: 1) parse the XML-files of houses data and create IDF-files; 2) run EnergyPlus; 3) carry out post-processing of results (Figure 1).
The interface of FE+ allows users to assign the location of houses' XML-files, number of houses, location of IDF-templates, location to save the produced IDF-files, and output report. The users need to save weather files for different geographical sites under the 'Weather Data' folder in the EnergyPlus7.2 main folder. The users also need to create IDF- templates of different types of houses (e.g. Deached, semi-detached, mid-traced, etc.) and mark/provide unique search tags or numbers. Further details are explained in the following section. The user interface shows the houses′ data, the progress of the EnergyPlus simulation and a chart/indicator of the chosen post-processed results at each simulation. The latter was featured to reveal any simulation errors at an early stage. The simulations can be stopped at any time, if necessary, using the LabVIEW run/stop controls. The FE+ tool can run on any computer, not necessarily with a LabVIEW licence, using the free download of the runtime engine. Another version of the FE+ tool was adjusted to run parametric analysis based on a matrix of parameters.
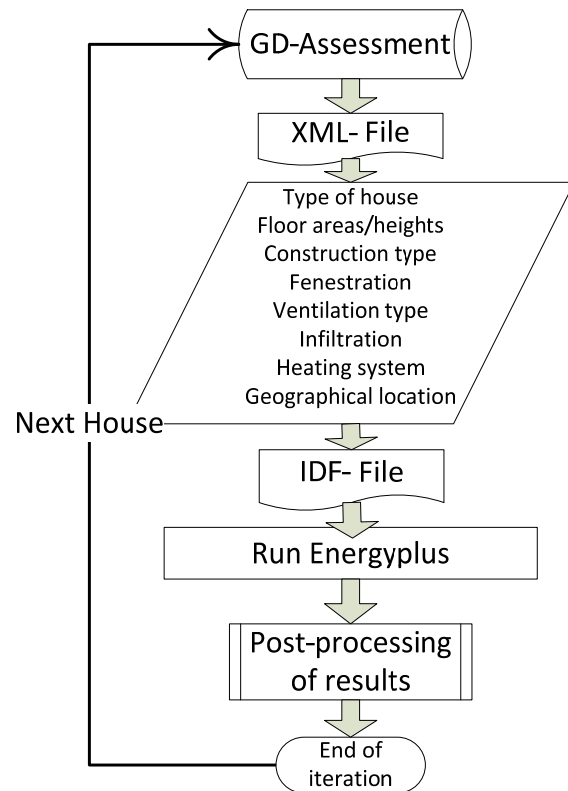

Figure 1 A flowchart of FE+ application

Use of GD-Data and Modelling Approach

This section describes the modelling approach and implementations, based on GD data. Table 1 lists the main implementations used to construct a house model. The following discusses in details the modelling approach.

1. IDF-template

For the simulations with FE+, four IDF-templates were created: a semi-detached house; a semi-detached house with an extension; a detached house; and a detached house with an extension. This was based on the observed types in the sample of 15 houses. The templates were created initially using Designbuilder3.2 to model simple rectangular geometry, and input the construction data, schedules, internal gains as well as the system data. The templates were then modified with the EnergyPlus7.2 IDF-editor to: add the simple fenestrations; revise the numeric values of detailed surfaces vertices; and to include all the materials and constructions. Further types of houses may be added in future developments. Different central heating control strategies may also represent a variant of a house template. The extension zones and interaction with the main dwelling can be further investigated to reduce the number of templates.

Table 1
Modelling approach and main implementations

INPUT	IMPLEMENTATION
IDF-template	House type from GD data
Weather	Post code initials from GD data
Geometry	GD data: Floor area and height
Construction	GD data: walls, floor and roof
Window type	GD data: Type& Multiple-glazing-proportion
Infiltration	Leakage surface reference is estimated based on GD data
Ventilation	No window operation applied at this stage
Internal gains	Lumped, 10W/m²
Heating Season	January-April& October-December
Heating schedule	WD: 6:30-9:00& 16:00-22:30 WE: 7:00-23:00
Heating system	Gas boiler and water radiators

2. Weather

In the FE+ code, a matrix with the post codes′ initials was created. That was then linked to corresponding weather files of the geographical location. As the GD-Data provides that post code initials, then the FE+ accordingly assigns the hourly weather file for each house simulation. The current test reference year (TRY) weather files were used in these simulations. Those files were downloaded from PROMETHEUS project website (EPSRC-GR/M88075/01).

In DEFACTO project, the plan is to use actual weather data files for the simulations of the large cohort of houses.

3. Geometry and Building Surfaces

The GD data based on RDSAP only provides floor areas and heights. Thus, a constant aspect ratio was assumed for the width and length of the building. This was taken (at this stage) as 1.36 based on available data of a medium size semi-detached house. In a house model, the detailed building surfaces require determination of surface vertices. The lower left-lower-corner is set to the origin point (0,0,0) as per an IDF-template. Additionally, unique numbers with 3 decimals are used for the width X, length Y and height Z. Similarly, more unique numbers are used for the full height, pitched roof related dimensions, and building extension. The FE+ code searches for these unique numbers and replaces them with the correct house dimensions. The zones′ floor areas and volumes are also overridden to eliminate any truncation errors in their calculation. In this approach, each floor is modelled as a single thermal zone. Thus, a house model consists of two occupied zones and a roof zone plus an extension zone (if applicable).

The window and door surfaces are modelled as simple windows and doors. Thus, they require only a reference X and Z values. At this stage, the surface area of windows is assumed to be 20% and 50% of the exposed building envelope for the main dwelling and extension, respectively. The building is also assumed to have 2 external doors plus one extra door for the building extension. The extensions are dealt with, in this work, as a single extension that has the same width as the building and faces the assumed backyard direction. The length of the extension is then determined based on the floor area. The GD data do not provide the building orientation. The RDSAP orientation assumption of E-W is used in these simulations.
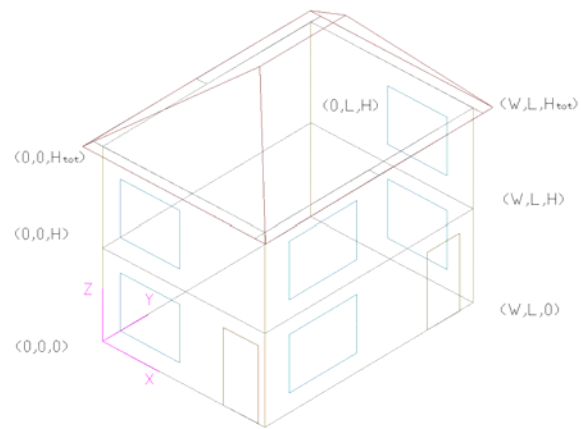

Figure 2 House model geometry

4. Construction types

The construction types of walls, floor, and roof are taken from the GD data. The IDF-templates contain the properties of the required materials; and constructions that are named according to the standard names in GD assessment (e.g. 'Solid brick, as built, no insulation (assumed)'). The FE+ code then parses the XML-file and replaces the special tags marked in the IDF templates by those construction types. In addition, the wall and insulation thickness are also replaced under the 'Materials' class in the IDF-template.

The type of windows in the GD data is referred to as 'Full or Partial-double-glazing'. Additionally, the glazing type is also associated with a quantity called multi-glazing-proportion that apparently gives the percentage of double-glazing. The FE+ code assigns the type of the various windows based on that quantity using a range from 10-100%. Then, if that multiple-glazing-proportion equals 60%, 4 windows out of 6 will be double-glazed and 2 will be single-glazed. Pitched and flat roof constructions are represented by one of only two fixed constructions.

The variations are mainly in their insulation thickness based on GD data.

5. Infiltration and Ventilation

The EnergyPlus airflow network calculations are used with these simulations. That is desired to give an estimation of the infiltration and ventilation loads based on calculations rather than assumptions. However, the reference condition parameters of air mass flow coefficient and exponent need to be set for surface cracks and windows/doors. In these simulations, an infiltration indicator was estimated based on the GD data. This indicator was calculated using the same procedure as in RDSAP, giving a value for the particular construction type and the percentage of draught-proofed windows and doors. For instance, a higher infiltration indicator is given for a masonry house type with a suspended timber floor. The parameters were obtained from the default crack templates given in DesignBuilder. At this stage of seeking simplifications, the windows were assumed to be closed in these simulations. In future work, further comparisons will be carried out with calculated natural ventilation.

6. Internal gains

In these simulations, the internal gains were lumped for people, lighting, and equipment. The gain was assumed as 10 W/m² for all occupied zones. Default domestic profiles from DesignBuilder were used for these gains. The simplification here was aimed at enhancing the relevance of the comparison between the multi-zone and detailed standard-modelling, and the batch-simulation approach. In future, for DEFACTO houses, the measured energy consumption will be used to help set the internal gains specifically for each house case.

7. Heating systems

All IDF-templates contained a gas boiler system with a central heating (CH) loop and zonal water radiators. This was used, as it is the system of interest for the DEFACTO project. The system parameters, at this stage, were mainly set to 'auto-size'. In addition, no domestic hot water (DHW) production was associated with the system. The GD data provides information about the main heating system and the use of secondary heating. The differences in systems and the breakdown of produced energy between the main and secondary system will be considered as a post-processing of the energy performance results. That is, by assigning the proper efficiency for each energy production method. As the houses in the comparison have no secondary system, this post-processing for the system efficiency was not implemented in this version of the FE+ code.

The heating schedule was based on two heating periods for a normal weekday with a total of 9 hours operation (i.e. 6:30-9:00& 16:00-22:30), while it was one period for the weekend from 7:00 to 23:00. The heating season was set as January to April and October to December.

In the DEFACTO project, the choice of system description will be investigated further together with the control strategy to enhance modelling accuracy.

RESULTS AND DISCUSSION

Standard and Equivalent House Model

The main aim of this paper is to provide a first evaluation of the developed batch-simulation (BS) tool (FE+) in comparison with standard-modelling (SM). It should be noted that, the FE+ tool constructs an equivalent house model, simplified to some extent and based on: the available standard GD data; and the above-mentioned modelling approach. In this paper, that is compared with SM work of two houses (i.e. House 12 and 13) from a sample of 15 houses. The main variations between the constructed models by the two methods are listed in Table 2. Figure 3 shows a 3D-sketch diagram (created from the simulation output dxf-files) of the SM geometry and house model created for the BS. The correct orientation is not followed in Figure 3 to better illustrate the geometrical differences of the models. As can be seen from Table 2, the rule for fixing the glazing ratio at 20% of exposed envelope is not adequate. While it overestimated the glazing area by nearly 6m² for the House 12 case, it underestimated that by 5m² for House 13. The RDSAP correlations for the calculation of window area, based on age band and total floor area, also showed discrepancies of similar magnitude in the estimated glass area.

The assumed orientation has also varied by -90° and +90° for the 2 houses, respectively. This could result in a difference in energy demand prediction, especially with the semi-detached house regarding its party-wall direction. Additionally, the buildings′ outer geometry and multi-zoning details may also contribute to these differences.

Table 2
Models main differences from the two methods

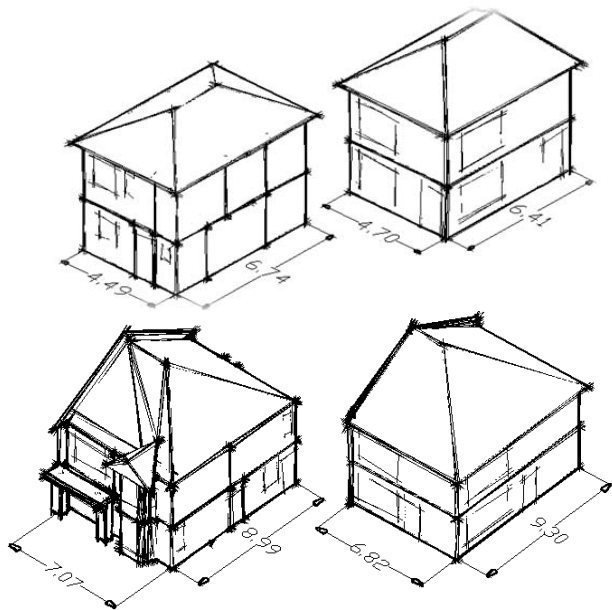| HOUSE 12	SM	BS
Glazing area	10.76 m²	16.6 m²
Orientation	180°	90°
Aspect ratio	1.44	1.36
HOUSE 13	SM	BS
Glazing area	29.88 m²	24.6 m²
Orientation	0°	90°
Aspect ratio	1.25	1.36

Figure 3 Standard-modelling (SM) and equivalent batch-simulation (BS) house models

A parametric analysis is needed to understand the impact due to each item and in combinations.

Energy Performance Comparison

The batch simulations carried out for the sample of 15 houses sample took 31 min in total (on a normal laptop PC) for the whole process of parsing XML, creating IDF, running EnergyPlus, post-processing of data and producing an output report. The running time of EnergyPlus simulation varied from 1 to 3min. Figure 4 shows estimated gas consumption associated with the space heating demand for the 15 houses in kWh/m².annum. As expected, the energy demand of the homes with filled cavity wall, double-glazing, loft insulation, etc (e.g. House 7 and 8) was lower than that for the untreated homes (e.g. House 14 and 15).

This paper is mainly focused on the comparison of results for House 12 and 13 using FE+ (BS) with those using standard modelling (SM). Figures 5 and 6 compare the annual gas and electricity consumptions predictions normalized by floor area. Table 3 shows the numeric values for the consumption of these two houses.

The percentage difference in gas consumption (i.e.100*difference/average) between the SM and BS results was -15% for House 12 and +14% for House 13; that is, 541 and 2482 kWh per annum for the two houses, respectively. These results are in line with the direction of difference anticipated given the modelling differences listed in Table 2. It is not in the scope of this paper to identify the contribution of each of these differences in the estimated energy performance.

A total annual difference in the electricity consumption was 1 kWh for House 13 while it was 23 kWh (i.e. 0.3 kWh/m² a) in case of House 12. The difference in electricity consumption for House 12 is apparently an error in setting the internal gains. However, that should not affect the results, as it is minor.
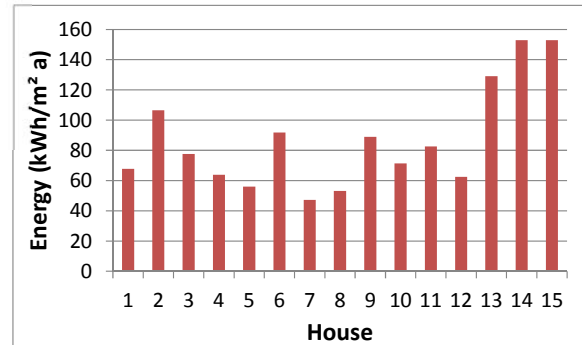

Figure 4 Estimated annual heating gas consumption by standard-modelling and batch-simulation for the 15 houses
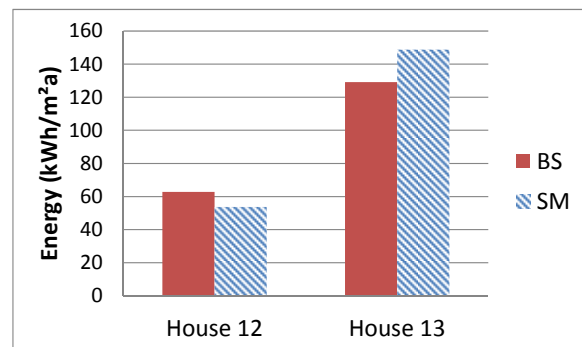

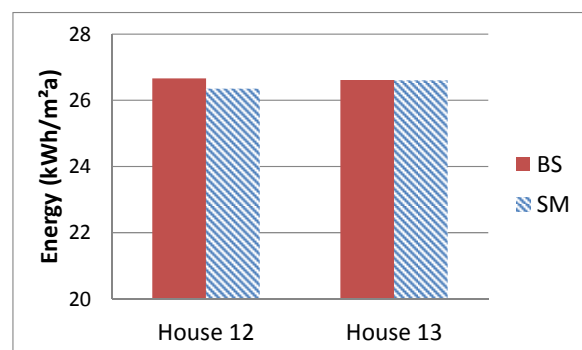*Figure 5 Estimated annual heating gas consumption by standard-modelling and batch-simulation*

Figure 6 Annual electricity consumption based on gains and system from the standard-modelling and batch-simulation

Table 3
Estimated annual heating energies and electricity consumption

HOUSE 12	SM	BS
Gas consumption (kWh)	3237	3778
Electricity consumption (kWh)	1587	1610
HOUSE 13	**SM**	**BS**
Gas consumption (kWh)	18891	16409
Electricity consumption (kWh)	3380	3380

Figure 7 and 8 show the estimated monthly gas consumption by the two methods for the two houses, while Figure 9 shows the corresponding percentage difference. As can be seen, the monthly percentage difference was in a range 5 to18% in case of House 12, while for House 13, it was -9 to -17%. Clearly, the difference increased at the months with higher heating demand.

Figure 10 shows the hourly gas consumption for 2 weeks in January. The hourly data resolution indicates the dynamic behaviour of the two models and differences in energy, shown as the difference in the area under the curve.
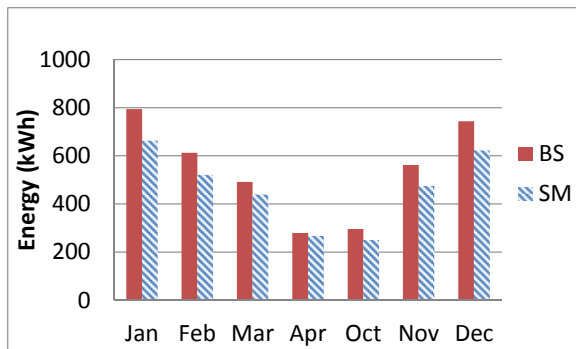

Figure 7 Estimated monthly heating gas consumption by standard-modelling and batch-simulation 'House 12'
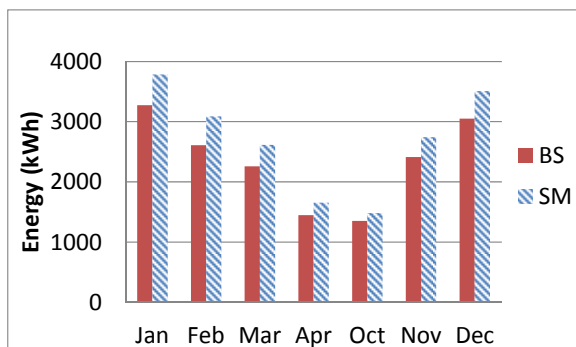

Figure 8 Estimated monthly heating gas consumption by standard-modelling and batch-simulation 'House 13'
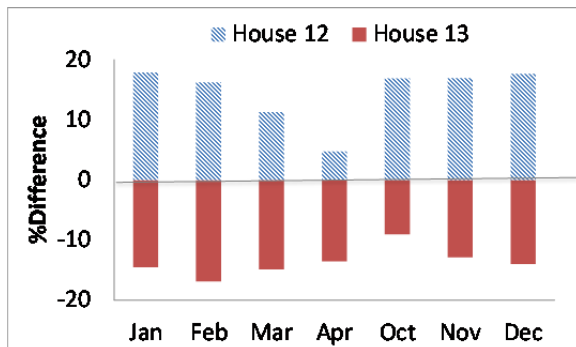

Figure 9 Estimated percentage difference between standard-modelling and batch simulations for the two houses

FE+ and Future Development

This work provided the first testing of the batch-simulation tool FE+. The comparison with standard modelling, based on only two houses, showed an absolute difference up to 15% in the estimated annual heating energy. The FE+ tool needs further testing and development of its modelling approach. In addition, the impact of variations in modelling parameters, due to simplifications, need to be investigated with parametric analysis.

The following bullet-points lists the developments and investigations planned for the forthcoming work of DEFACTO project:

- Developing the modelling of building's extensions geometry, and interaction with main dwelling zones.
- Investigating a possible detailed multi-zoning based on typical layouts of UK houses.
- Applying the RDSAP given correlations for the glass area and testing further its accuracy.
- Investigating GD data files based on a larger sample of houses and modify the FE+ code as necessary.
- Developing CH system parameters based on given system information and implementing the efficiency for main and secondary systems.
- Developing window opening schedules to investigate the natural ventilation impact on comparison results.
- Developing appropriate models of the CH control strategies.
- Investigating possible add-ons to the GD data to enhance the models input.
- Developing the internal gains and DHW based on measured data of typical household size and number of habitants.
- Running parametric analysis to investigate the impact due to simplifications in the modelling approach.
- Investigating the FE+ results with measured data from the DEFACTO pilot study houses (planned for this year).
- Developing the houses′ IDF-templates concept based on house type, and central heating control strategies; and include all possible materials, and constructions.
- Investigating the differences in estimated energy performance with the national UK method SAP 2009; and potential for employing DTM as part of energy assessment procedure for UK housing.
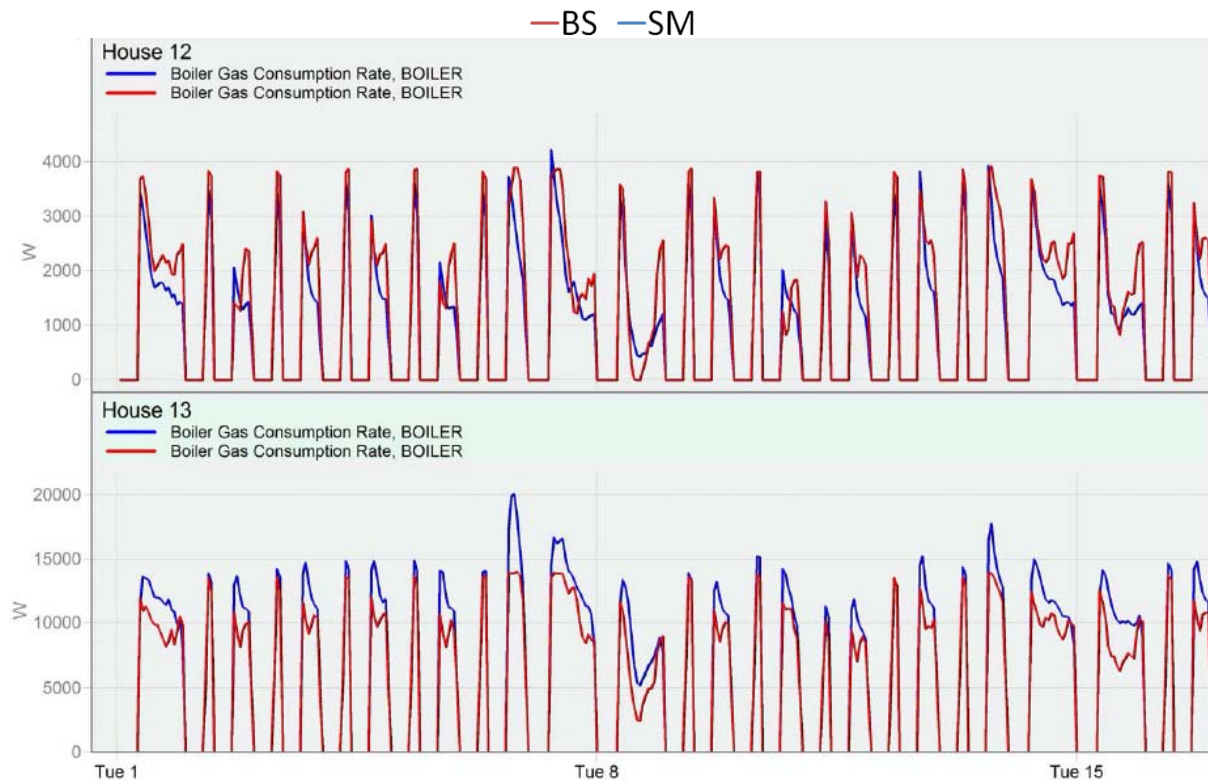
Figure 10 Estimation of gas consumption of the two houses by Standard-modelling and Batch-simulation with hourly resolution over the month of January

CONCLUSIONS

This paper has introduced a new method (FE+) to run batch of building energy models based on pre-refurbishment assessment data. The method uses EnergyPlus7.2 as the simulation engine and has a user interface that shows simulation progress. An initial comparison with standard modelling of two houses showed that the absolute difference in annual heating energy was around 15%, while the monthly values varied from 5 to 18% and in proportion to the space heating demand. The differences are related to the simplifications used in the development of the FE+ software. These are mainly concerned with the glazing area, orientation, zoning and outer geometry simplifications. A parametric analysis will be undertaken to investigate the impact of these simplifications and its combinations. Future work will include adding more details to enhance the models, tweaking the input parameters, and investigating the modelling accuracy against measured data.

ACKNOWLEDGEMENT

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