Predicting the Energy Performance of a New Low Carbon Office Building

“Thermal modelling software tools such as DesignBuilder EnergyPlus can provide close virtual representations of a building in use and have been proven to generate the levels of accuracy that are acceptable not only to designers but also to vendors and occupants.”

By Edward Murphy (Technical Director, Mott MacDonald during the study).

New Office Building, Sheffield UK

Introduction

This case study demonstrates how DesignBuilder EnergyPlus was used to good effect to predict the energy performance of a new office building, both at the concept and post-occupancy stages of the project. The building is the second of three office buildings that form a new modern city centre commercial office district in Sheffield in the north of the UK.

Background

There has been much publicity in recent years about the ‘performance gap’ between the predicted and actual energy performance of buildings. The case study compares in-use metered energy monitoring results from a completed office building with that of its virtual design-stage thermal models. The study also examines the how regulatory compliance processes compare to dynamic simulation models and actual in use energy. Verification of the live energy use of the building came following extensive two-year post-occupancy energy monitoring of the building and its systems.

The test case building is a 10,483 m^2 stand-alone eight-storey comfort cooled speculative office. Construction of the building shell was completed in February 2009. The UK Government purchased the building from a speculative developer and then contracted a team of professionals led by Drivers Jonas to undertake a major fit-out to install all partitions, fixtures, and fittings. The building fit-out was completed in June 2010.

Following handover of the building in June 2010, a research team led by Edward Murphy (then working with Mott MacDonald), Holly Castleton of the University of Sheffield, and a client representative collected two years' worth of half-hourly metered data from 53 meters. This collected data was compared with the original concept design simulation data. The simulation data was mapped to metered sub-systems regulated (use determined by building plant systems controls) and unregulated (use by determined by occupant's use of office equipment and lifts) for direct comparison.

Case Study Building

Reception Area

Rooftop PV Panel Array

The architectural style is typical of a modern speculative office building in the UK. There are six floors of offices sitting on top of a double height reception and separately demised retail units, with a car parking space at basement level and a smaller floor plate staff café/restaurant and library at roof level.

Design Simulation

Over the timeline of the project from inception in March 2009 to the end of the Post Occupancy Evaluation (POE) in September 2013, three major thermal simulation models were developed. These were identified as Models A, B and C. Model B was an SBEM compliance model using a different software vendor to DesignBuilder so is not discussed in any detail in this case study.

Model A: Concept Stage Model

Model A was constructed at concept stage in March 2009. The modelling and simulation were undertaken using DesignBuilder EnergyPlus and established the likely in-use energy consumption patterns of the building. The model formed a benchmark comparator for the testing of several energy efficiency options during the early concept design and options appraisal process. The dynamic simulation model was a functional representation of the office floors only, and as such excluded the retail areas and the basement containing the separable data centre, car park, plant spaces, and subterranean storage spaces. The appraised options were as follows:

- Option 1: Effect on energy consumption of applying external shading to the floor to floor windows.
- Option 2: Effect on energy consumption of applying an environmental veil over the south and west facades of the building.
- Option 3: Effects on energy consumption of some plant modifications, which included insertion of a thermal wheel heat recovery device into the main fresh air handling plant, by replacing existing runaround coils.
- Option 4: Life cycle costs and available area to place photovoltaic panels on the roof of the building.

The resultant early stage thermal simulation analysis concluded that options 1 and 2 were not economic. Neither was effective enough in lowering cooling energy sufficiently to offset the capital cost of the external shading devices retrofitted to the building façade. It transpired that shading from other surrounding buildings was already effective in this regard. A planned (but not yet constructed) new 14-story building next door to the case study building was included in the model analysis (eventually completed in 2015). Local planners were resistant to any proposal to change the aesthetic of the case study building. However, Options 3 and 4 to include the thermal wheel and the photovoltaic panels were included in the final proposals that went on to be implemented in full.

Post Occupancy Evaluation and Modelling

The post-occupancy evaluation (POE) study was undertaken over a two-year period. The primary purpose of the study was to understand where energy was being principally consumed, at what time of day and how much was being used outside normal working hours. The study also looked at the effects of interventions by the FM team on annual energy, as user behaviour in response to maintained design comfort levels. The study was based upon data downloads of half-hourly energy data from 53 building meters and using CIBSE Technical Manual 22 as a universal tool to categorise the recorded data. Energy and heat meters and sub-meters complied with CIBSE Technical Manual 39 requirements. Additional portable meters were installed to separate fan coil and lighting energy which were supplied from the same electrical sub-distribution boards.

All meters were connected to an energy management system (EMS). Half-hourly data from each meter was downloaded in CSV format from the EMS system for analysis yielding a fully authenticated dataset with full systematic breakdowns of regulated and unregulated energy use.

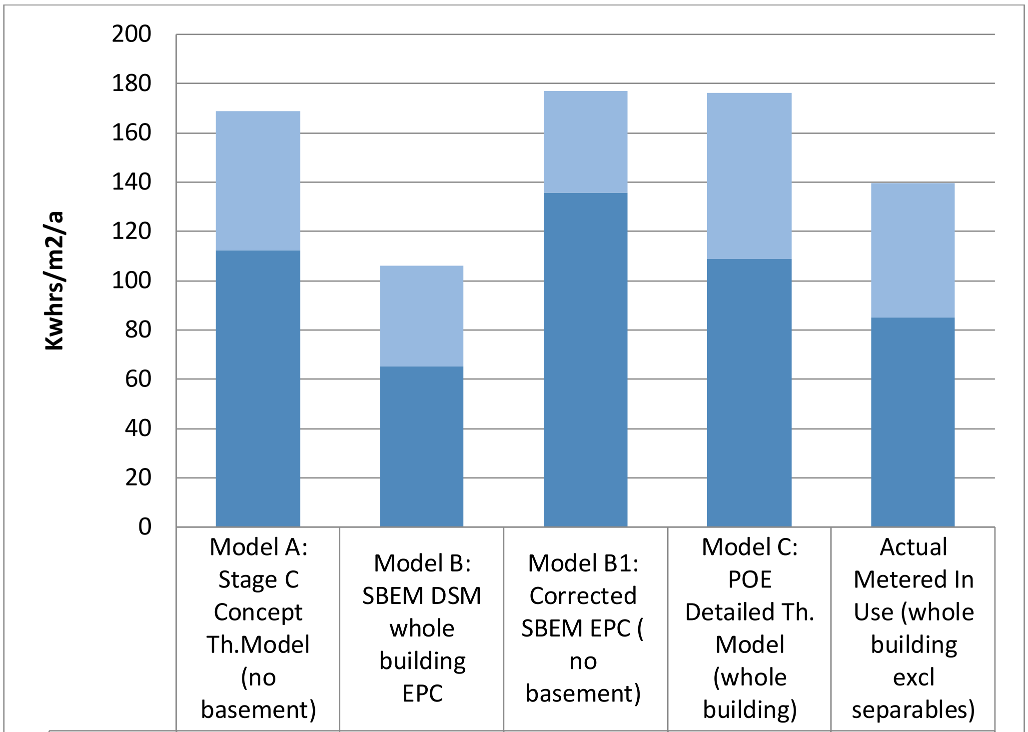
A substantial update of Model A was undertaken using DesignBuilder to produce Model C to better reflect the completed “as-built” building. The updates of Model A to arrive at a more detail Model C included:

- Addition of the basement areas including the data centre, plant rooms, stores, and occupied areas.
- Updates to the third floor to include the large meeting spaces and conference suite zones.
- Addition of kitchen, library spaces, and level 7 ventilation plantroom as distinct control zones.
- Improve the zoning of offices to suit sub-meter zoning, allowing modelled zone energy data to be directly compared with sub-meter data.
- Remove the adjacent 14-story building included in Model A, to reflect the fact that its planned construction had not yet taken place due to the 2007/2008 property recession.
- Update all occupancy profiles to closely reflect actual occupation of the building.

All DesignBuilder results from the EnergyPlus simulations of Models A and C shown below are from one version of the software to achieve a consensus for comparison across both sets of data.

Comparative Results

Comparisons of Models A (the concept, part building), and updated Model C post occupancy (whole building) yield good consensus in total predicted energy. The models are based on the same input datasets and do not give rise to an underestimated energy performance gap as can be seen from the results graph below:

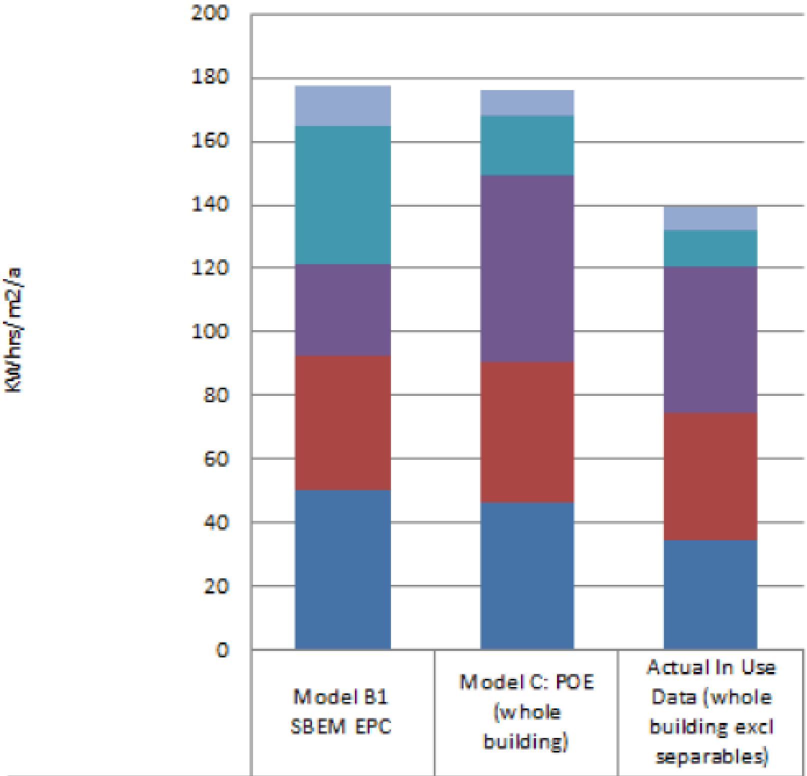


	Model A: Stage C Concept Th.Model (no basement)	Model B: SBEM DSM whole building EPC	Model B1: Corrected SBEM EPC (no basement)	Model C: POE Detailed Th. Model (whole building)	Actual Metered In Use (whole building excl separables)
Thermal	56.6674416	40.84	41.51	67.32113538	54.31
Elec	112.3088671	65.3	135.61	108.9567326	85.17581662

Thermal/Electricity Regulated Energy

Scrutiny of the energy splits between thermal heating and electricity illustrates why it is not good practice to use SBEM algorithms as predictors of actual building energy. In this case, the B1 SBEM model significantly underestimated thermal energy and overestimated electricity consumption, most likely due to how it interprets the shading of adjacent buildings.

In contrast, Model C, the detailed POE DesignBuilder EnergyPlus dynamic simulation model is of equal proportion (61% electricity, 39% heating) in its energy splits between thermal and electricity loads to the ratio of actual in-use energy. This would appear to indicate the increased robustness of Model C: POE as a predictor of the actual building performance. In an attempt to provide further validation of the above finding, further results are presented below of the thermal and electricity splits at a systematic granular level.



	Model B1 SBEM EPC	Model C: POE (whole building)	Actual In Use Data (whole building excl separables)
DHW (Other fuels)	12.59	8.00	7.60
Cooling (Electricity)	43.27	18.64	10.93
Heating (Other fuels)	28.92	59.32	46.71
Auxiliary Energy	41.69	43.88	39.67
Lighting	50.65	46.44	34.58

Comparative Thermal Model Regulated Energy Showing System Sub-totals

The initial concept Model A yielded a good approximation to the actual building, even though Model A was only a simplified partial representation of the complete building. When the model was updated to Model C to include the whole of the building, accuracy was increased, and the proportions of energy use in each of the systematic splits including unregulated loads increased. Actual energy use is lower than predicted by Models A and C. The reason for this is believed to be solely down to how well the building is managed, noting the items below that are not fully represented in the models. The key differences between the model input data and the actual on-site situation are:

- The model was not fully calibrated as no site weather data was available.
- Unregulated loads from desktop PCs, lifts, telephones, video communications etc. is lower than expected. This is believed to be due to rolling out “thin-client” PC terminals, which reduce installed desktop PC loads by 50%. The client has also introduced “multifunction devices” (MFD) to bring together printing, photocopying and scanning functions into one low energy machine rather than having separate devices each consuming their own individual standby power.
- The reduced unregulated loads also have a knock-on impact in lowering cooling energy, and this is reflected in the reduced metered cooling figures.

- An intervention to control fresh air volume on return CO2 levels is not included in the POE model, and this too introduces further significant savings on those predicted.
- A decision to turn off the chillers from October to April yielded a further reduction in energy, albeit at the expense of comfort during some unseasonably warm March and October days.
- The reduction in fan speed together with close control on hours of operation of heating helps to explain the differential between the POE model and the in-use thermal energy.
- Auxiliary energy from the central plant systems is lower due to lower air-moving energy than that included in the model, again partially due to the inclusion of CO2 control.
- Finally, lighting energy in-use is lower than predicted. This is explained by the fact that large parts of the basement, third floor and kitchen are unoccupied for long periods and switched off. This was not anticipated by the thermal model input profiles.

Conclusions

There is a need within the industry to understand the degree of sophistication required to bring more accuracy to the whole process of predicting the final energy use and carbon emissions of the proposed building. The “Simplified Building Energy Model” (SBEM) approach does not include the level of sophistication necessary to meet the challenges presented by even simple prototype buildings.

The case study has demonstrated good alignment between the energy consumption predicted by the early and post-occupancy stage thermal models and that measured in the occupied building.

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Acknowledgement

This case study is a summary of extracts from Paper 067 from the IBPSA England BSO14 conference. The original paper was produced by Edward Murphy, Technical Director of Mott MacDonald now Founder of Ollio The Building Performance Consultancy, and Dr Holly Castleton, then a Researcher at University of Sheffield, currently course leader in Mechanical Engineering at Sheffield Hallam University.

Ollio – The Building Performance Consultancy specialises in providing advice to clients and design teams on all aspects of sustainability and low carbon performance of buildings. Using some of the most advanced analytical techniques available, Ollio can provide more in-depth information much earlier in the design process, as a context for more integrated, intelligent and qualitative onward building design solutions. All of which leads to more efficient construction, operation and realisation of the predicted high levels of performance in use.

Running in parallel with this, Ollio provides advice in health and well-being aspects of building design to create opportunities for more desirable and more productive outcomes for occupants. Also, using their extensive expertise in building performance, the consultancy routinely undertakes independent post-occupancy evaluation of completed building projects.

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