Assessing the Operational Energy Profiles of UK educational buildings: findings from detailed surveys and modelling compared to measured consumption

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ABSTRACT

This paper presents the preliminary findings from the first stage of a physical survey and modelling Case Study conducted to obtain Modelled and Actual Energy Consumption Profiles for a UK multi-storey mixed use educational building. The purpose of the study is to provide an insight into how accurately current models and software can predict the actual energy consumption in such a building, with a view to informing the development of Operational and Asset Ratings for Buildings in the EU as part of the EPBD Article 7 requirements. The study also briefly discusses the potential problems inherent in the use of modelling techniques for assessing the energy performance of buildings.

The data obtained through this study allowed predicted energy usage profiles to be compiled from the level of individual items of equipment through to the whole building. These data were subsequently analysed using standard spreadsheet and building energy simulation software. The results of the analysis enabled predicted energy consumption profiles for both heating/cooling and electrical energy use to be obtained, as well as a UK iSBEM asset-type compliance rating.

The predicted profiles and compliance rating were then compared to the monitored actual energy consumption profiles obtained over the same period. The main conclusions were that, despite the time needed to undertake the physical survey, the level of detail of this study and survey were insufficient to predict the energy consumptions of the building with confidence. It was seen that the various approaches gave a reasonable estimate of the gas consumption using ECOTECT, and a reasonable estimate of the electrical consumption using iSBEM. However, overall it was felt that the models were too inaccurate to be used with any confidence.

This results of this Case Study also support the view that for prediction of electrical consumption then statistical measures, such as benchmarks, are likely to enable more confident predictions of energy use by generic activity type.

1 INTRODUCTION

The aim of the study, from which this paper is drawn, is to examine some current building energy use prediction models and techniques to assess how accurate they currently are, and to provide information which will help inform the development of building energy use prediction tools through identifying the types and forms of data needed to make these as accurate as possible.

This study takes place against a backdrop of the imminent practical implementation of the EU Energy Performance of Buildings Directive (EPBD).

The primary aim of the EPBD is to assist Member States towards achieving buildings which consume less energy. As the uncertainty over energy prices and availability also increase, then this call is being echoed by clients as well. These two powerful market drivers mean that the design and procurement of low energy buildings is becoming a mainstream requirement for building designers and operators. They are therefore looking for tools and advice to help them achieve this aim.

However, despite many decades of advances in tools in this area we are still in the relative infancy of being able to accurately predict the energy performance of real buildings occupied by real people undertaking real activities. The current state of the art is struggling to consistently predict the performance of simple buildings with simple occupancy.

The lack of progress in this area has not stopped many countries introducing legislation which requires the prediction of the energy performance of buildings as part of their design requirements. They also provide tools, generally based on the CEN umbrella document PG-N37[i], to help show compliance. These tools generally use the heat balance method of gains and losses within zones in a building.

The potential problem with these tools is that they will be used to design new buildings, or alterations to existing buildings, to try and achieve the best rating they can. The questions therefore have to be 'how much can we rely on these tools?' when using them to assess the actual performance in use of a building, and "does accuracy matter in this situation?"

If the long-term purpose of the EPBD legislation is to assist in reducing energy consumption then perhaps accuracy is not so important, but if the aim is to eventually produce buildings which consume a known amount of energy in a 'resource poor' future then clearly the accuracy of this prediction is important.

This paper presents a research study to explore how accurately a building survey and two current building energy prediction tools were able to predict the actual consumption in a UK mixed use educational building, representing a building of reasonable complexity in size, shape and occupancy. The paper also presents the findings of an occupant questionnaire in the same building.

The two software tools used to assess the building's heating and cooling needs were the software tool ECOTECT[ii], and the iSBEM[iii] (interface to the Simplified Building Energy Methodology) version of the UK's National Calculation Methodology.

The differences between the tools are not discussed here other than to note that the timesteps over which they calculate their results vary from 1 hour (ECOTECT) to monthly for iSBEM (hence the Simplified term).

Potentially enough information for both tools to be run could be gathered from a paper exercise – and this is what is likely to happen in practice, but this Case Study has used a physical survey to obtain more precise details of the small power and equipment loads in the building, along with an occupant questionnaire to assess when this equipment was likely to have been used, and when the occupants were present. The information collected by the survey did not provide information on the usage profiles of equipment in those rooms which were for common use, or the more complex laboratory and media laboratories. One of the questions for the work was how much difference this might potentially make if we were to assume that these rooms could be described by the occupied room usage profiles.

The predictions of energy use gained from the tools and survey are compared against 'reality' in the form of the half hourly electricity data metered for the building over a year, and the monthly gas consumption data for a year.

2 BRIEF FINDINGS FROM THE PHYSICAL SURVEY

The physical survey of the Case Study building took place over a period of 4 weeks and examined over 300 separate spaces in the building. The survey specifically aimed to establish the location and average power consumption of energy consuming equipment in the building, along with obtaining information on the layout and fabric of the building suitable for modelling purposes. The building was predominantly naturally ventilated.

Some brief findings from the survey are:

- The average floor area per occupant was 16 m^2.
- The average small power load in the building was 18.6 W/m^2.
- The average installed lighting load in the building was 16.2 W/m^2.

- The installed building services electrical load in the building was 1.2 W/m^2 excluding mechanical ventilation and A/C.
- The estimated average installed electrical load in the building was 35.9 W/m^2.
- The total installed capacity for gas was 1,380 kW and that identified for electricity was 399 kW
- The installed boiler capacity was 124 W/m^2

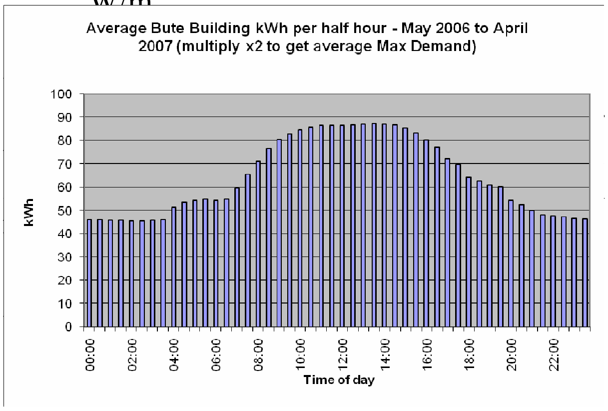


Figure 1 shows the metered average half hourly electricity consumption for the whole building over the year ending April 30th 2007. This figure shows that the average 'out-of-hours' electricity use of the building is substantial, indicating probable poor control of the electricity consuming equipment in the building.

The Maximum Demand identified over this period in any one half hour was 259.4 kW at 15:30 on the 12th December. This figure is nearly 65% of the identified installed electrical load. We also note that the total annual consumption is equivalent to having ALL the identified electrical power consuming equipment on for 32% of the year.

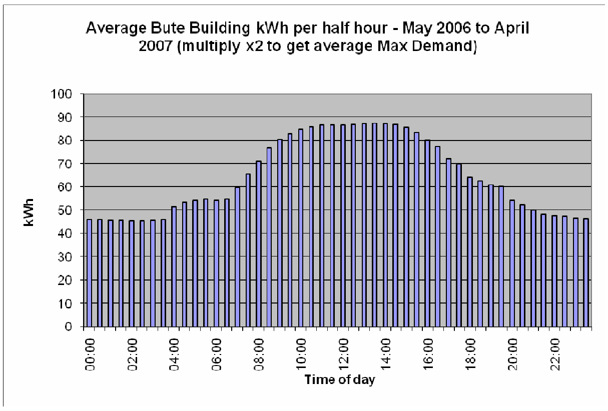


Figure 1. Average half-hourly electricity consumption for the whole year

Figure 2 shows the same data but as monthly consumption in kWh for the same period. From this figure we can see that there is not a large variation in electricity use between the winter and summer in the building, indicating that the electricity consumption is not very influenced by seasonal factors.

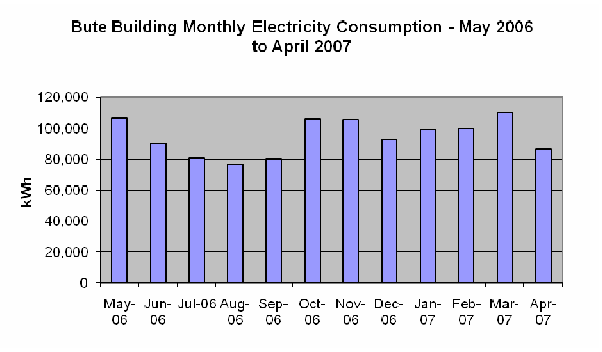


Figure 2. Monthly electricity consumption

Figure 3 shows the actual metered gas consumption for the same period. For the installed capacities noted above this is equivalent to running the boilers at full capacity for 11% of the year. The January consumption figure is misleadingly high due to meter reading dates, so if we assume a peak monthly gas consumption figure of around 220,000 kWh, this provides an average gas power consumption of around 295kW over the November to March peak heating period assuming 24 hour heating. The summer period is purely DHW use and equates to an average load of 1.0 W/m^2 or 8.6 kWh/m2.a

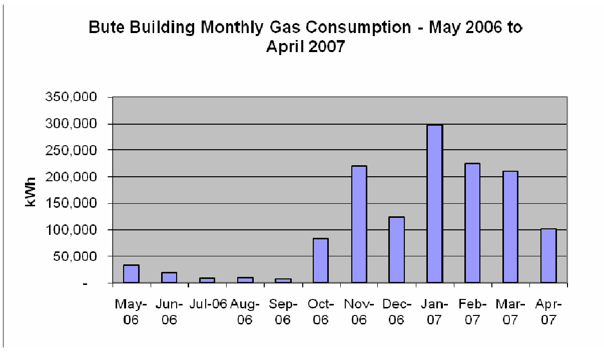
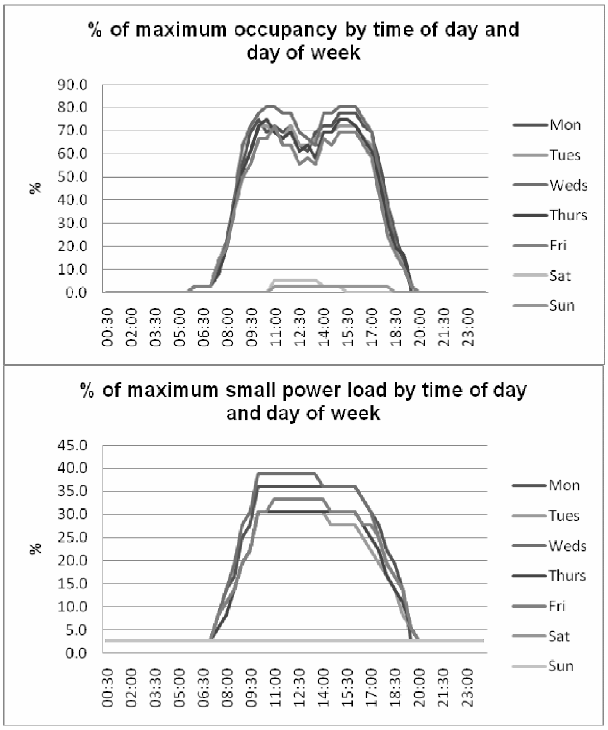


Figure 3. Monthly gas consumption

3 INITIAL FINDINGS FROM THE QUESTIONNAIRE

The aim of the questionnaire was to assess when the occupants were present in the building, and when they used the small power and lighting under their control. The schedules of average use of the building by time of day, and day of week, are derived from the questionnaire and are shown in Figure 4.



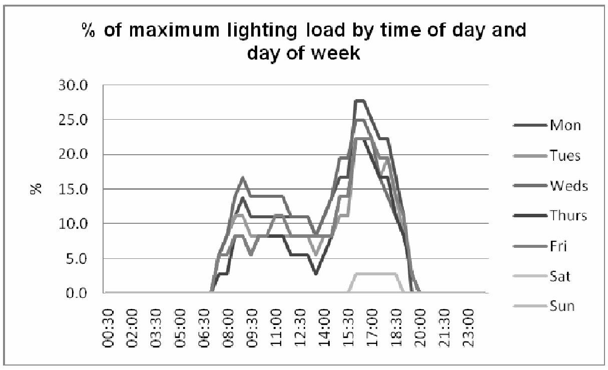
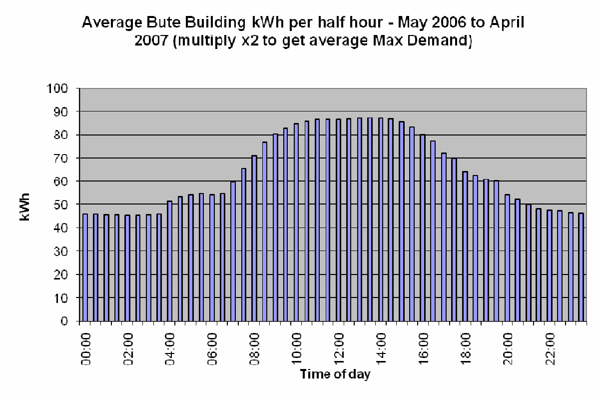


Figure 4. Daily schedules for occupancy, small power and lighting use from questionnaire

These graphs show that the occupants reported different daily schedules for their occupancy, lights and equipment. They also reveal that the reported usage profile of small power and lighting in the building does not correspond with the actual building electricity consumption profile shown in Figure 1. This is believed to be because many rooms, such as computer terminal rooms, did not have dedicated occupants and therefore the usage profiles of the equipment in these rooms is not reported in the survey.



The occupancy profile reported is as expected, with a dip around midday for lunch, whereas the equipment schedule shows that when equipment is turned on it is not turned off at midday.

The lighting schedule also reveals that on average many people turn off their lights in the middle of the day and do not turn on their lighting again until late afternoon.

The questionnaire also provided an insight into the perceived monthly variation of the occupancy and hence lighting and small power use.

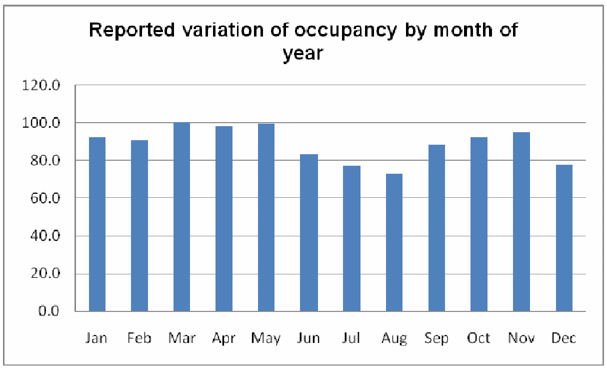


Figure 5. Monthly variation of occupancy and other internal gains expressed as a % of March occupancy.

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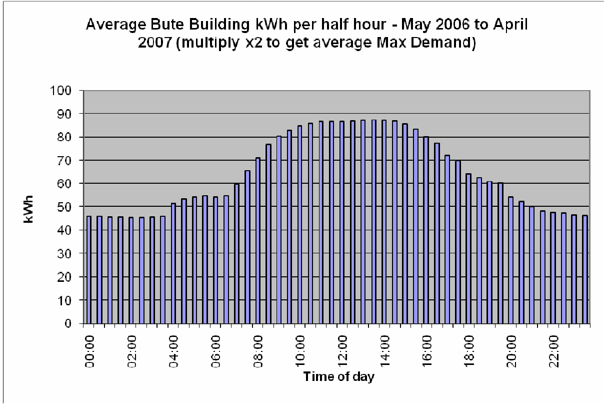

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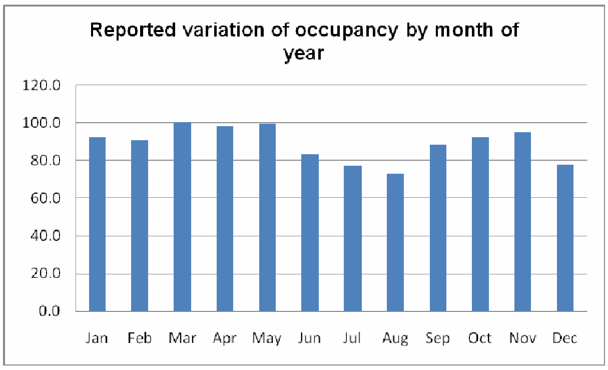

Figure 5 shows the average reported variation by month of occupancy over the year from the questionnaire, expressed as a % of the occupancy during March.

Combining the questionnaire profiles and survey findings together allows us to produce Figure 6, which shows the predicted monthly consumptions for electricity along with the actual monthly consumption figures from Figure 2. The total predicted annual load is around 490,000 kWh – which is only about 43% of the electrical consumption actually recorded.

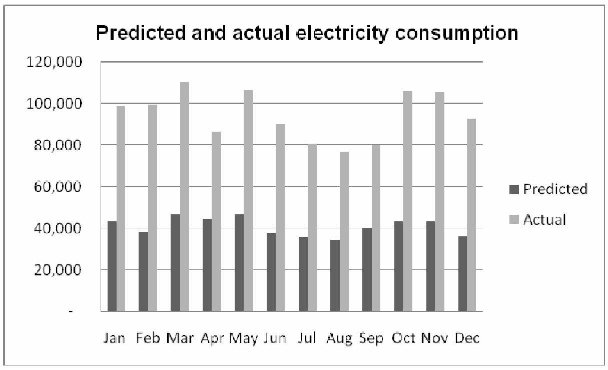

Figure 6. Predicted and actual monthly electricity consumptions

The 'missing' 57% of the electricity consumption is thought to be from the rooms and spaces which had no single person accountable for them, such as computer terminal rooms, as well as from the common building services, including lighting in corridors, etc. This is possible as it is more likely that the equipment in these rooms will be left running continually. If we take Figure 1 and Figure 4 together we observe that 97% of the reported usage of equipment occurs between 06:30 and 18:00, and 61% of the recorded consumption occurs between these periods as well. The unreported consumption periods therefore account for nearly 40% of the total energy use in the building.

One of the key preliminary findings from the survey and questionnaire is therefore that, at the level of detail undertaken to date, they substantially underestimated the overall electricity consumption of the building.

4 FINDINGS FROM THE BUILDING MODELLING

The building was modelled in the ECOTECT tool and then the heating and cooling demands were assessed using the internal calculation engine in ECOTECT.

The ECOTECT building model was then exported for further calculation in the iSBEM tool. Figure 7 shows the ECOTECT model of the building.

In total there are 339 separate activity zones in this model.

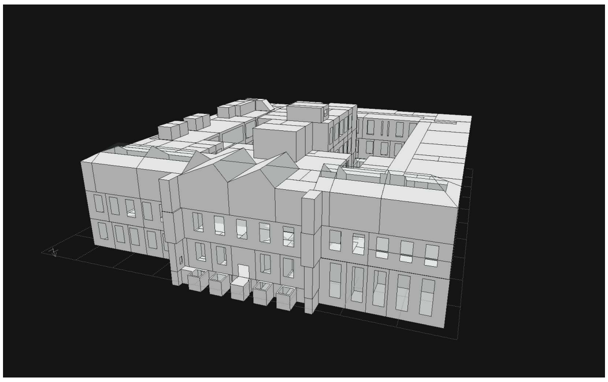

Figure 7. The Bute Building in ECOTECT

The ECOTECT predicted monthly heating and cooling loads for this building, assuming 22°C and 24°C setpoints and under the weather conditions experienced between May 2006 and April 2007, are shown in Figure 8. This figure assumes no heating from June to October, and there is no allowance for DHW use.

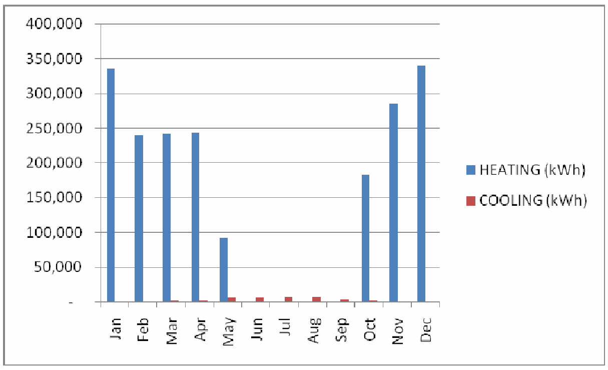

Figure 8. ECOTECT predicted heating and cooling loads

The total annual predicted heating and cooling energy demands are 1,960 MWh and 37 MWh respectively.

Assuming an 89% seasonal efficiency for the heating system and 312.5% SEER for the cooling system (from the iSBEM defaults), then the total predicted use for the building (ECOTECT DHW, heating and cooling loads and Survey/Questionnaire electricity loads) corresponds to 45 kWh/m^2 per annum of electricity and 177 kWh/m^2 per annum of gas.

In contrast the iSBEM model, which is based on the building layout, fabric properties and activity type per space predicts annual electrical consumptions of 98 kWh/m^2 and annual gas consumptions of 2,580 kWh/m^2.

We know the gas figures are not correct, and believe they are due in large part to the use of a generic HVAC VAV system within the calculation which we were unable to amend at this stage. This will be altered in subsequent work, but even when correct this figure will still be substantially higher than the actual consumption recorded.

5 COMPARISON OF MODELS, SURVEY AND REALITY

The findings to date show the ECOTECT and iSBEM models overestimate the actual annual gas consumption of the building. The iSBEM model underestimates the electrical consumption slightly.

However, Figure 9 shows the comparison between the ECOTECT predicted monthly gas consumption and that actually consumed as shown in Figure 3. From this figure it appears that the modelling does predict the gas consumption reasonably closely for some months, and that some of the overconsumption may be due to inaccurate scheduling of the Xmas break within the model.

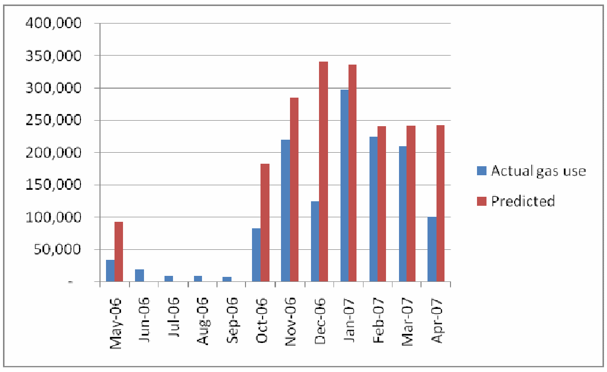

Figure 9. Comparison of ECOTECT predicted and actual monthly gas consumption

Neither model has yet been validated through accepted methods, but ECOTECT is known to give a reasonable estimate of the heating loads in buildings. Therefore, even if we were to export the building to run in, for example, EnergyPlus, we would not expect much greater accuracy. The iSBEM model is designed for compliance testing not accurate building modelling, but it is being used to design and asset rate buildings and therefore its accuracy is important. This Case Study has shown that it is worryingly inaccurate for this building given the data input.

To summarise, the current description of the building and its occupancy appears to provide reasonable figures (about 50% overestimate) for monthly gas consumption for the ECOTECT model, but not the iSBEM model. The iSBEM model also did not provide an estimate of the electrical energy consumption which was close to the actual performance in use of the real building. A new version of iSBEM is due out shortly which is specifically designed to allow asset ratings to be derived for existing buildings, and this will be run in subsequent work.

Any discrepancy between the models and reality does not necessarily mean the models are wrong or incapable of calculating an accurate figure, simply that the data input into them did not produce figures that matched what happened.

For this Case Study, the main sources of error in the data input to both the ECOTECT and iSBEM models were felt to be:

- the estimation of the internal gains or activities in each space (as shown by the difference between the predicted and measured electrical loads).
- the estimation of the schedules of occupancy and equipment use in the building (ECOTECT only, iSBEM contains these in its activity descriptions).
- the estimation of the ventilation rates in the building zones.
- the estimation of the annual efficiencies of the heating and cooling equipment.
- the estimation of some of the equipment loads in use (ECOTECT only, iSBEM contains these in its activity descriptions).
- the weather data used for Cardiff was a generic Cardiff file. We have the actual weather data to use in subsequent work and it is hoped this will reduce some of the error for ECOTECT. iSBEM contains its own generic weather files.

6 CONCLUSIONS

A large industry is growing up around the ability to predict the likely Operational Energy Performance of a building in use, therefore allowing the risks of underperformance to be more accurately assessed when designing or refurbishing a building to try and reach an energy or carbon performance target as now required by several EU Member States.

The calculation methodologies as required by Articles 2, 3 and 7 of the EPBD are likely to change over time as experience is derived with the actual performance of buildings in use, and hence feasible targets become clearer.

Part of any building rating methodology is to describe the building to be assessed. The main question to be answered is how detailed should this description be in order to obtain a given level of accuracy in the prediction of energy consumption for asset rating purposes?

This Case Study has shown that, as might be expected, even undertaking a detailed and expensive survey of an existing building over a number of weeks can still fail to provide data of a sufficient accuracy to predict the actual consumption of a building.

This finding appears to support the 'activity benchmark' consumption approach adopted by the UK's iSBEM methodology, derived from the actual electrical consumptions of specific activities in real buildings, to allow a reasonable estimate of the actual internal gains in buildings both in use and at the design stage. For this building the benchmarks used in iSBEM would appear to be quite accurate, but we would need to assess more buildings before greater confidence could be obtained that this was repeatable.

The strong possibility exists that in future we will require more accurate data, or more focussed activity descriptors, or, perhaps most useful, a move from a single number descriptor of consumption to a range which could work through the calculation to give a range of potential performance at the end of the calculation.

The main conclusions from this work are:

- The survey and questionnaire as conducted were not able to predict the magnitude or profile of the electricity consumption of the building
- The modelling, survey and questionnaire seemed able to reasonably accurately predict the heating and cooling demands of the building using ECOTECT, though it is still substantially overestimated. The iSBEM prediction was completely inaccurate.
- The iSBEM estimate of the electrical consumption got far closer than the detailed survey.
- A further positive that came out of this work is that the iSBEM method predicted gas consumptions far higher than those actually achieved, i.e. it erred on the correct side with regards to helping reduce consumption.

Future work will revisit the building with more detailed surveys of those areas not under the control of any one person, to see how much of the installed equipment is left on. The work will also more accurately define the energy consumption ranges of the equipment in the building, as well as sub-monitoring those areas where major electrical energy consumption is considered to be occurring.

The results of this further work will hopefully result in published profiles for individual energy consuming equipment to assist in the 'bottom up' approach to modelling. However, it appears that the 'top-down' approach embodied in methods such as benchmarking are likely to prove more robust under normal circumstances.

As the future studies provide more data for the modelling we aim to produce papers showing in practice what needs to be known to provide a given level of confidence in the modelling results as this information is crucially missing at present.

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[i] PG-N37 Standards Supporting the Energy Performance of Buildings Directive (EPBD)

[ii] www.squ1.com – accessed 20th July 2007

[iii] www.ncm.bre.co.uk – accessed 20th July 2007