Bridging the gap between predicted and actual energy performance in schools

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Abstract

There is currently a significant gap between design stage estimates and actual energy performance of buildings, mainly due to a lack of understanding of the factors affecting energy use. The current work focuses on investigating which factors have the greatest influence on energy performance in schools and how the performance of the building in use differs from design assumptions.

Sensitivity analysis was performed to rank the importance of various factors affecting energy use. In addition, visits to 15 schools across the UK were carried out. The aim of these visits was to collect data on a number of factors relating to building energy use, as well as to determine the likely variability of these factors.

Preliminary results show that operational issues and occupant behaviour have a major influence on energy performance of schools, and therefore play a significant role in the discrepancy between design estimates and actual energy use. Hence an effective handover and user-education are essential to optimise energy performance.

Keywords: energy performance, schools, sensitivity analysis, post-occupancy

1. Introduction

The discrepancy between predicted and actual energy performance of schools is becoming more evident. At the same time, designers are increasingly being requested to provide accurate estimates for energy use in schools, and to provide guidance on how these energy targets can be achieved.

This paper forms part of a Knowledge Transfer Partnership (KTP) project between University College London and consulting engineers Max Fordham LLP, which is investigating which factors have the greatest influence on energy performance in schools and how the actual building in use differs from design assumptions. The approach includes the use of sensitivity analysis and the collection of data from a number of schools.

The aim of this work is to investigate various factors which may differ from design expectation, to find out why they vary and by how much, and to explore how this variation from predicted values is likely to affect the energy use estimates. This will help the design team provide a range of likely energy use, instead of a single “predicted” energy consumption figure, together with a list of influential factors which need to be managed and addressed in order for the building to achieve its energy targets. It will enable both the design team and building management and occupants to understand how they can influence their school's energy performance.

Background: Factors contributing to the discrepancy in energy consumption

Discrepancies of over 100 per cent in the energy performance of buildings have been reported [1], with factors related both to the simulation process as well as to the physical buildings identified as possible sources for this discrepancy. The various factors which affect the accuracy of predictions are discussed in the following sections, in the order in which they manifest themselves from design stage through construction and use.

Model simplifications

The process of transferring a real building to a computer model introduces uncertainties into the modelling results due to the necessary simplifications which are made. Although potentially robust, simplistic models are usually used, building operation and the underlying physical processes are, in reality, very complex. Thus it is impossible for the model to be an exact imitation of the actual building, with the level of detail in the model affecting the level of uncertainty in the final result [2], [3].

Changes between making predictions and the final building

At the design stage of a project, when early energy predictions are being made, designers are required to make considerable assumptions and approximations due to a lack of data about various aspects of the building. The designer may rely on experience, rules of thumb or guidelines taken from design standards [4]. However, studies have found that values in guidelines tend to differ from actual values [5].

During design development, construction and commissioning, the building fabric, services and controls may be altered from what was originally specified. This may be due to changing requests from clients or value engineering exercises [1], as well as due to poor workmanship. The HVAC services installed, as well as operating schedules are significant in determining the energy consumption of the building [5]. However, plant operating hours may differ substantially from those assumed in initial predictions [6].

The lighting energy consumption of buildings is frequently higher than predicted due to much of the day-lighting resource being neglected [5]. Electricity consumption may also be higher than predicted due to additional small power loads, as well as running equipment and appliances for longer hours than anticipated.

Occupants

Occupants have a major influence on the energy performance of buildings as they control internal temperature, ventilation, lighting, equipment and hot water, thus assumptions about occupancy patterns and behaviour, which are unpredictable in their nature, have high uncertainties associated with them, inevitably lead to significant uncertainties in energy predictions [4], [2]. Several studies have shown that energy use was higher than predicted due to occupants' control over building systems. Occupants sometimes find it difficult to understand and operate control systems [1], [7].

Commissioning, controls, management and maintenance

Good controls can lead to a reduction in energy consumption while increasing thermal comfort in buildings [7]. Unfortunately, the control strategy is frequently responsible for the energy consumption of buildings exceeding the predicted value, either due to controls not working as intended or due to a lack of fine-tuning of the strategy during the first few years of building use [5], [8].

Insufficient understanding of the building by the occupants and management, as well as poor maintenance, also contributes towards energy use exceeding expectations. An effective energy policy may mitigate this [7]. However, this may be largely unknown and unpredictable at the design stage. Studies have shown that successful buildings are those where occupants are well-informed, either intuitively or by their management [9]. Researchers have also highlighted the role of experienced facilities managers who are well-prepared to deal with operational issues, as well as better data management in achieving energy targets [8].

Various studies have underlined the importance of post-occupancy monitoring, as this leads to continuous improvements in energy performance, thus targets can be met in a shorter period [8]. A better handover, improved management and continuous monitoring therefore contribute significantly towards reducing the discrepancy between predicted and actual energy consumption.

2. Methodology

Simulation work

During the first stage of the project, dynamic thermal simulation (DTS) was used to investigate the sensitivity of various factors affecting energy use. A detailed building model of a school in North London was constructed using EnergyPlus v.4.0.0.024 with Design Builder v.2.1.0.025 as an interface. The school, completed in 2008, is a two-storey building with a floor area of 3900m^2. It has a rectangular plan, oriented with the longer sides facing north-south. The construction is in accordance with UK Building Regulations [10]. The building is heated using a combination of underfloor heating and fin-tube convectors. Spaces along the perimeter are naturally ventilated, with mechanical ventilation in the building core.

Differential sensitivity analysis (DSA) involves the variation of one input in each simulation, with other inputs remaining at their base case values. This allows the modeller to measure the direct impact that changes in the input parameter have on the output value [11]. DSA was used to investigate which factors had the greatest influence on energy consumption. This involved selecting a ‘base case’ value for each factor, based on design assumptions, and lower and upper limits for each variable, based on literature from similar studies, or observations from experience and the school visits. The simulation was initially run with all variables set to base case values; this provided the 'base case' results to which all other results were later compared. The first variable was then set to its lower value, with all other variables remaining at base case value, and the model was re-run. This process was repeated for each variable individually set to lower and upper values respectively, while all other variables were kept at their base case value. Figure 1 summarizes the variables and input values, with base case values shown in red. The change in annual gas and electricity consumption, as well as the change in CO_2 emissions, were analysed for each simulation.

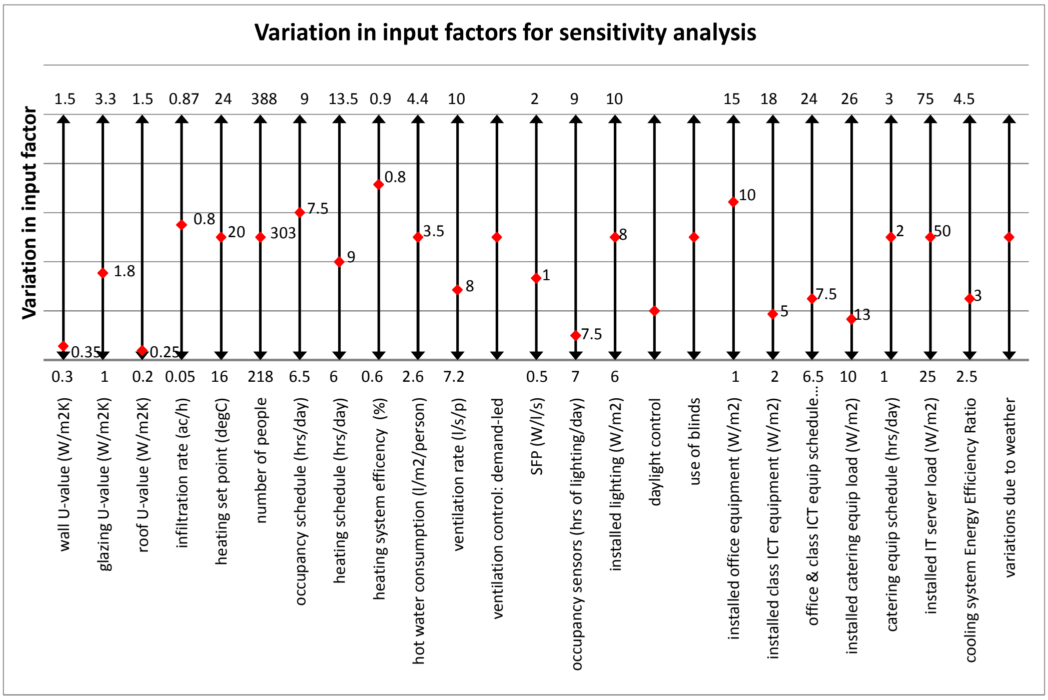

Fig.1. Variation in input factors for sensitivity analysis.

Site visits

The second stage of the project involved visits to 15 schools across the UK, during which the site manager was interviewed about how the school is used. All schools had been constructed or refurbished since 2002. The aim of these visits was to collect data on a number of factors relating to building energy use, as well as to determine the likely variability of these factors. The selection of variables was informed by the sensitivity analysis described above, which helped focus the interviews on the factors which had the greatest influence on energy use.

Review
The final stage of the project, which is currently ongoing, involved reviewing the variable limits used in the model to reflect the variations observed in the schools which were visited. The results from these updated simulations are presented in the following section.

3.1 Results

Simulations
The sensitivity analysis was carried out on the model for a particular school, therefore the simulation results presented are for that specific school. The school used for the study has two main functions. Teaching spaces for children with special educational needs (SEN) account for around 30 per cent of the total floor area (compared to an average of 55 per cent teaching area in the schools visited during the post-occupancy stage of the project). Another 30 per cent of the floor area in the modelled school is used for administrative purpose, which is considerably more than one would expect to find in a 'typical' school. Furthermore, there are a number of therapy rooms which contribute towards the building's energy consumption pattern. While the school may be atypical, it was selected as the management agreed to continuous monitoring of the building, which enabled the model to be constructed more accurately and verified through comparison with actual energy data. Nevertheless, the results give a good idea of the significant factors that would be expected in a more typical school.

The sensitivity analysis results are presented relative to a 'base case' building. As described previously, this is the building model with input parameters set to the values as predicted at the Scheme Design and Planning stage (RIBA Stage D), which is the stage at which a planning application is submitted. Figure 2 below shows the variation in predicted annual CO_2 emissions as a result of changes in various input variables. The variables which resulted in a change of less than 0.2 $kgCO_2/m^2/yr$ are not shown. The key variables shown account for around 80 per cent of the overall variation in CO_2 emissions.

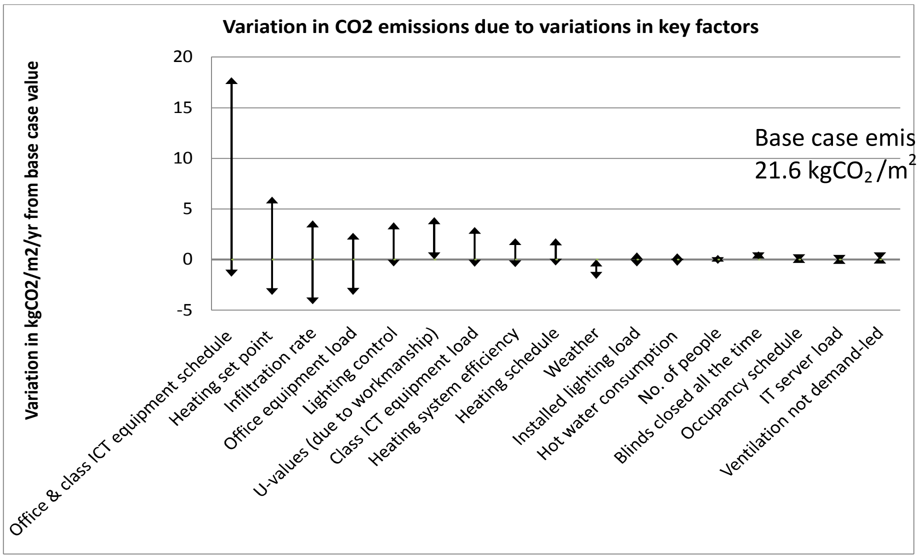

Fig.2. Variation in CO_2 emissions due to variations in key factors

The analysis shows that variables controlled mainly by occupants, including the office and class ICT equipment load and hours of use, heating schedule and temperature set point are among the factors which have the greatest influence on energy use. Variables associated with construction also have a significant effect on CO_2 emissions, with infiltration and U-values being most influential. This underlines the importance of build quality and good workmanship in achieving energy performance targets. The most important design-related factors are lighting control and heating system efficiency, highlighting the importance of proper commissioning.

Site visits
The second stage of the project, as described previously, involved visiting 15 schools across the UK to assess the likely variability in input factors and to investigate how school buildings are used. Figure 3 summarizes the variability in key input factors for the schools visited. The average value for each factor is represented by a red point along the arrow.

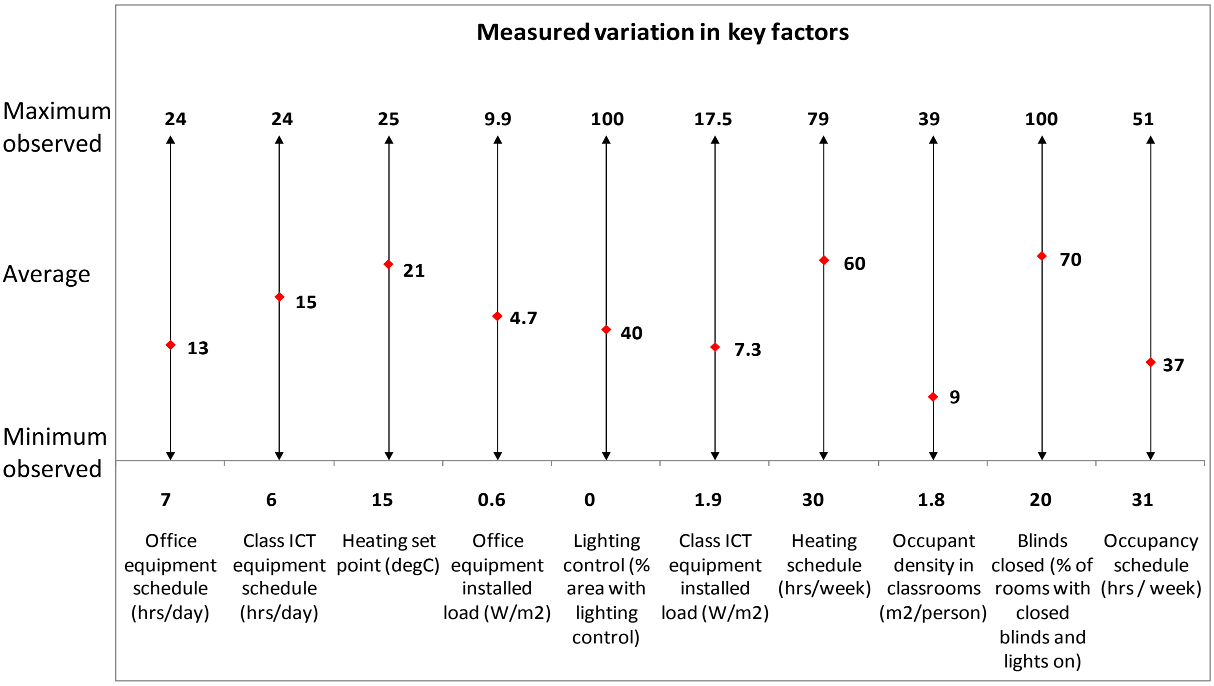

Fig.3 Measured variation in key factors.

The chart shows that there is a large variability in factors controlled by occupants, including office and class ICT equipment hours of use and installed load. The temperature set point in classrooms in different schools also varied significantly, and was generally above the 18°C set point suggested in compliance method for schools BB87 [12]. This may have a considerable effect on energy use for heating.

The days of use per year, as well as the occupancy schedule, varied widely across schools, reflecting the increased out-of-hours use of school buildings as community centres. Further data was collected including utility rates, occupant density and heating schedules, as well as some qualitative data on the handover process, occupant training and maintenance details.

3.2 Discussion

The analysis clearly shows that there are a number of key issues which contribute towards the discrepancy between the predicted and actual energy use of schools. At the design stage, clearer assumptions need to be made which are based on previous experience or the client brief, rather than potentially non-representative benchmarks. Furthermore, early stage energy predictions need to be updated as the project nears the construction phase, so that energy models reflect the actual building more closely. During construction, build quality should be given increased attention as poor infiltration rates and U-values contribute significantly towards the energy performance of buildings. Post completion, proper commissioning needs to be carried out to ensure that systems operate at their optimum efficiency and that controls are operating as intended. Throughout the life of the building, systems should be maintained well as this also affects their efficiency and performance.

One of the main findings of this research was the substantial influence that the occupants have on the energy performance of schools. The most significant factors highlighted in the sensitivity analysis were related to occupant use; these factors also showed the greatest variation across the schools visited. It is evident that management and occupants need to understand their building and the systems installed so as to ensure that the building is used as intended. This also highlights the importance of a better handover and post-occupancy analysis and education, which help to ensure that occupants are aware of various design features, thus enabling them to operate their building more efficiently.

4. Conclusion

The findings bring to light one of the main difficulties in making energy predictions: occupant behaviour is highly variable and unpredictable, yet variables controlled by occupants are among the most influential factors in determining energy consumption. This leads to the conclusion that it is not meaningful to make specific energy predictions. It is more practical, and feasible, to estimate the range in which energy consumption is likely to fall, and highlight the key factors affecting where a building's energy use will fall within that range. This will allow designers and occupants to focus on the factors, throughout procurement and operation, which influence their building's energy performance most significantly.

One of the main limitations of the work carried out so far is that the results are specific to the building modelled, which as discussed earlier is not a typical school. The analysis is therefore to be extended to a more generic school building. Furthermore, the sensitivity analysis technique will be improved so that a greater spread of input values is used. The improved technique will also allow the investigation of links between input variables.

The research will lead to an enhanced understanding of energy use in schools and will enable designers, architects and clients better understand the impact of design decisions and building operations on energy performance.

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