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Benchmarking the heating energy efficiency of primary schools in Hampshire, U.K.

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Abstract

This study investigated the heat energy consumption of primary schools in Hampshire, United Kingdom. Half hourly gas consumption data was analysed for 101 suitable schools to calculate a benchmark. Data envelopment analysis (DEA) was used to compare the normalised annual heat energy intensity values of each school to the best practice 'efficiency frontier'. The schools were then allocated with an efficiency rating between A and E, based on the DEA analysis. A selection of schools were investigated in more detail to contextualise the results. Heat energy use load profile analysis of schools from different efficiency rating bands provided an insight into the reasons for varying efficiency ratings. The patterns of energy use throughout the day suggested considerable differences in heating management techniques. Overall a strong link between heating management strategy and energy efficiency was found, highlighting the importance of effective heating control and management.

Keywords: heating, schools, efficiency, benchmarking, rating.

1 Introduction

This paper presents the research findings from the author's dissertation project: Benchmarking the heating energy efficiency of primary schools in Hampshire, U.K. (Emery 2012). The dissertation investigated the heating energy efficiency of primary schools in Hampshire. The following sections provide a synthesis of the methods and results of the research, discussed within the context of building energy efficiency.

As energy prices are rising and the need to minimise carbon emissions is growing, the importance of reducing the energy consumption of buildings across the public sector is high. English schools generate 18% of public sector greenhouse gas emissions (CAMCO 2011). Energy usage represents the greatest contributor of greenhouse gas emissions, with space heating using fossil fuels (predominantly natural gas) accounting for almost 60% of energy consumption (Carbon Trust 2010).

Reducing energy consumption is especially important in schools due to its link to the thermal comfort and air quality of classrooms. It also provides an additional benefit of raising pupil awareness of environmental issues if children are involved in efforts to reduce energy use (Dimoudi and Kostarela 2009). An important part of the process to reduce the energy use of schools is to collect energy usage data and to analyse this information to identify areas in which improvements are possible. Schools are generally unaware of the amount of energy they consume, but the use of automatic meter readers (AMRs) helps to increase awareness of energy wastage (Energy Saving Trust 2009).

1.1. Study Area

The study schools are located within the unitary regions of Hampshire County Council (HCC), in Hampshire, Southern England. The study attempted to illustrate how the automatic meter readings (AMRs) could be best used to analyse the energy efficiency of the schools. It endeavoured to demonstrate how analysis at the school and county level could provide valuable information to inform decision making and assist energy reduction efforts. Hampshire County Council carbon emission reduction targets are 20% by 2015, 35–40% by 2025 and 100% by 2050 (Hall 2010). To meet such carbon reduction targets, energy use will need to be reduced substantially, with immediate action to improve the energy efficiency of the schools (DCSF 2010).

1.2. Heating methods and controls

Energy reduction efforts often focus on the technical components of energy management. Considering heating management as a socio-technical system takes into account the influence of both technical and social factors influencing energy consumption (Kouloura 2008). This is valuable because the efficiency of the system is not only a function of the building and equipment efficiency but also the heating management efficiency (Chung et al. 2006). This research attempts to remove the influence of the buildings and equipment to investigate the influence of heating management upon energy performance. While improving the energy efficiency of building and equipment can be very expensive, improving heating management can be as simple as adjusting the controls of a programmer or the general strategy.

Of particular interest to this research is the influence of the heating load patterns of schools. A good heating strategy can be identified by low heat energy intensity totals, a high amount of seasonal consumption variation, and a daily heat consumption profile which suggests good heating management. Good heating profiles reflect the heating demand with low heat consumption out of school hours (Carbon Trust 2011).

2 Methodology

In total, 101 schools were suitable for study (e.g. with AMR, building and boiler data available and no pool). Analysis of gas consumption totals allowed comparisons of the heating energy efficiency of the schools. In order to remove the influence of school size, the gas consumption totals were divided by the floor area of the schools. The resulting monthly gas consumption intensity values were then converted to heat energy consumption values to normalise for the influence of boiler efficiency upon gas consumption. This provided heat energy intensity values for the schools. The annual total of this metric formed the basis of the main body of the analysis.

Regression analysis was adopted to quantify the influence of building construction type upon the heat energy intensity values of each school. The regression model coefficients for each construction type were multiplied by the amount of associated floor area for each building type before being added together to create a predicted annual heat consumption value for individual schools. Data Envelopment Analysis (DEA) was carried out to compare the efficiencies of the schools. DEA forms an efficiency frontier, passing through the highest performing schools, while regression analysis models the average efficiency (Chauhan et al. 2006). The DEA output produced values for total, technical and scale efficiency. The efficiency of the schools was compared to the best practice (efficiency frontier) schools to provide efficiency values which were classified into rating groups (A to E, with A representing highest efficiency). Assigning the schools a rating dependent upon their overall efficiency made it possible to compare their energy performance.

Seven case study schools were analysed further. Each case study included analysis of the efficiency rating, monthly consumption values, load profile and building characteristics. One randomly chosen case study school was considered from each overall efficiency band, along with the highest and lowest performing schools.

3 Results

The monthly gas consumption intensity values resulting from normalisation are shown in Fig. 1. The distribution of values suggests that heating energy efficiency is highly variable across the study schools.

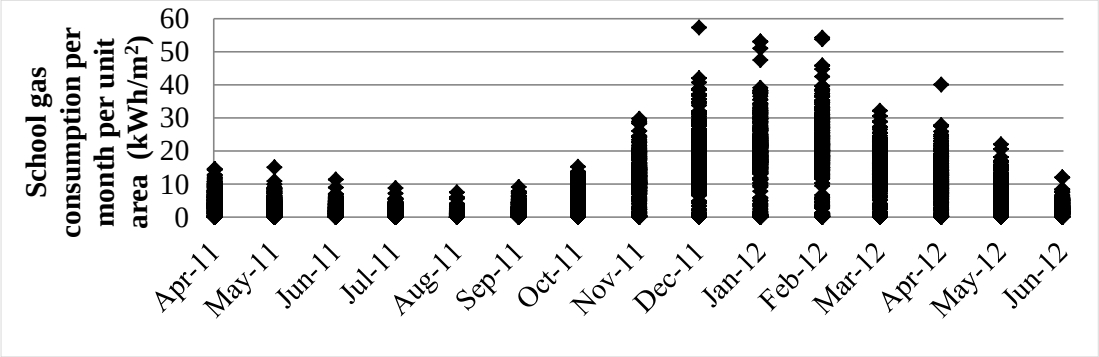

Fig. 1. Corrected monthly gas consumption intensity values for schools. Adapted from Emery (2012).

The heat energy intensity values vary between 50 and 190 kWh/m^{2}year. Building type also influences heat consumption. The building types vary from Victorian brick-built classrooms to post-war system buildings to modern structures built in the last few years. The age range of the school buildings in this study is almost 300 years.

The regression analysis creates a model for the influence of building construction upon heat energy consumption. Modern frame-constructed buildings are suggested to be the most efficient, whilst the old brick built buildings have the worst performance.

The frontier analysis of the DEA is illustrated in Fig. 2. The frontier represents the schools with the highest efficiency, and so is considered the best practice target for other schools.

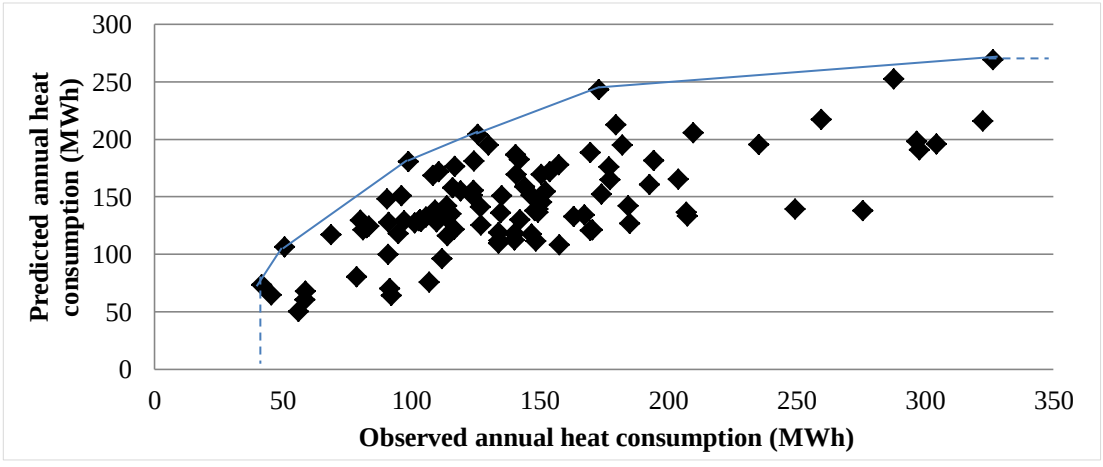

Fig. 2 The frontier (blue line) used for the DEA to calculate the overall, scale and technical efficiency of each school. Adapted from Emery (2012).

The school with the best practice energy efficiency has an efficiency of 1.0 while poor performing schools have lower values. The majority of schools fall into the 'D' rating band, with very few highly rated schools (Fig. 3).

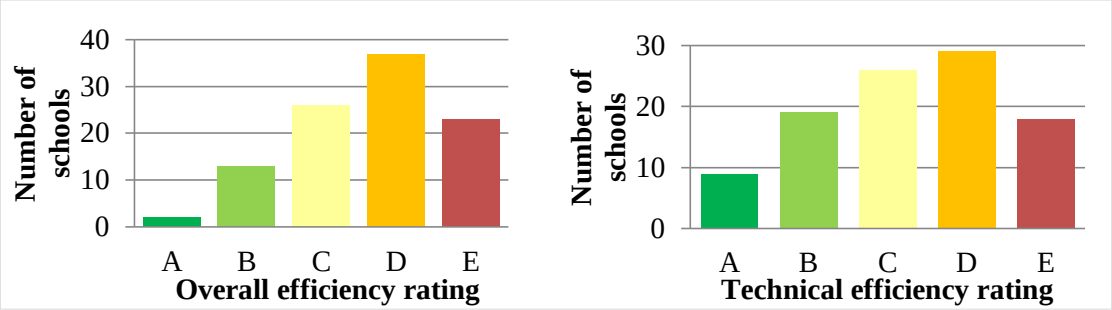

Fig. 3. The number of schools in each efficiency rating band. Adapted from Emery (2012).

The schools were ranked in terms of overall efficiency. The benchmark (median) of the heat consumption values was 99.1 kWh/m^2 per year. The case study schools were randomly selected for further analysis (Table 1).

Table 1. The efficiency ratings of the case study schools.

School	1	2	3	4	5	6	7
Efficiency rating	A (best)	A	B	C	D	E	E (worst)

The seasonal and daily load profiles of the schools are shown in Fig. 4 and Fig. 5.

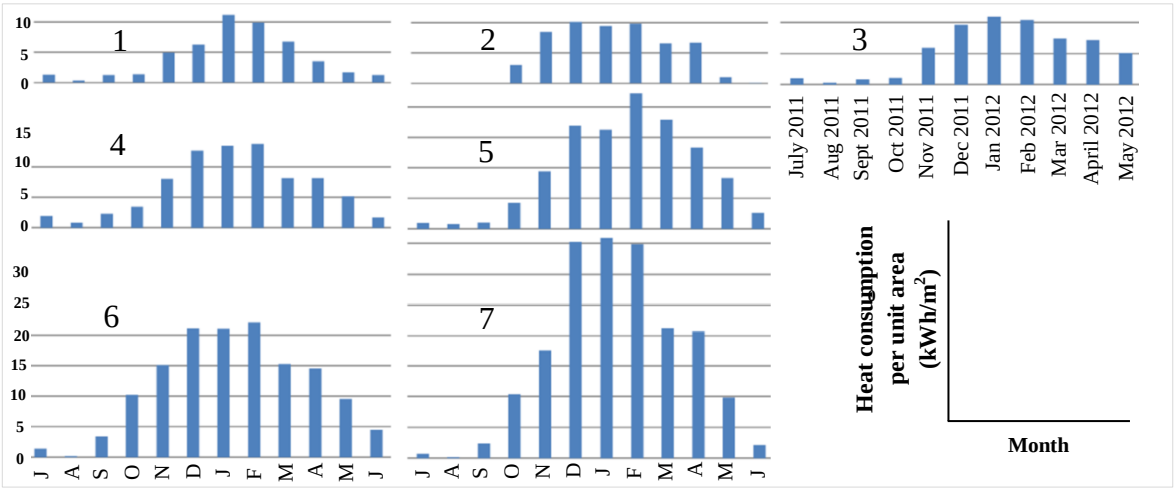

Fig. 4. Monthly heat consumption intensity profiles with equal proportions for each school (numbered). The bottom right graph provides axis labels for the other graphs. Adapted from Emery (2012).

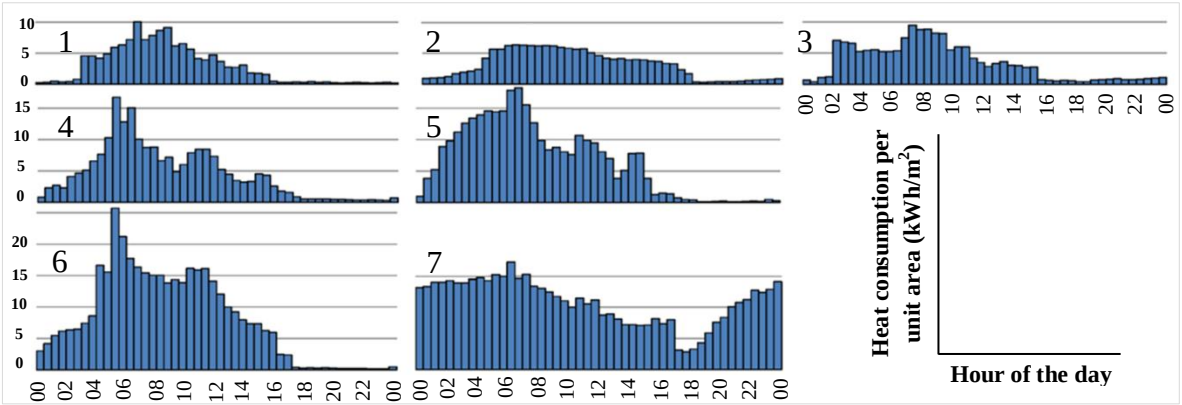

Fig. 5. Daily load profiles with equal proportions for each case study school (numbered). The bottom right graph provides axis labels for the other graphs. Adapted from Emery (2012).

4 Discussion

The normalisation process allows comparison between the study schools. The highly variable heat energy intensity values demonstrate that the efficiency of schools across the county is highly inconsistent. While the regression analysis shows that the type of construction of the school buildings influences the energy consumption of the school, heating management is also a contributing factor.

The benchmark value is not the focus of this study, because DEA allows ranking of efficiency as opposed to just averaging heat consumption totals. The benchmark value is not transferable because it can only be associated with schools of the same region, with data from the same time period to avoid weather compensation error.

Data envelopment analysis allows the quantification of overall, technical and scale efficiency for each school (Lee 2008). The comparison of schools to the best practice efficiency frontier in Fig. 2 shows a high number of schools which have lower than achievable efficiency levels.

The rating of the schools allows comparison between them and prioritisation of the least efficient schools for more detailed investigation. The most common rating is D, and only two schools have the highest rating. This suggests that most schools in Hampshire have the potential to improve their energy efficiency.

The case study analysis suggests a relationship between heating management and energy efficiency. In general, the more efficient schools have lower summer and overnight energy consumption (Fig. 4 and Fig. 5). These schools also have smoother daily heating profiles, linked to the pattern of outdoor temperatures throughout the day. The less efficient schools show higher peaks of consumption suggesting overconsumption at these points. The least efficient school has an unusual daily load profile showing higher overnight heating than during the daytime perhaps suggesting an equipment fault, or high frost setting. Although these inferences are uncertain, they provide an insight into the importance of good heating control (Pedersen 2007).

5 Wider Implications

The methodology of this study can be adopted for future studies at both the county and individual school scale. The ranking process can be replicated to determine the relative efficiency of a number of schools so that the lower performing schools can be targeted for further investigation and investment. On the individual school scale, analysis of load profiles can be carried out to investigate the ways in which a school may reduce energy wastage and improve its heating strategy to better reflect demand.

Uncertainty surrounding the results has the potential to lead to misrepresentation of the efficiency ratings of schools. This misrepresentation could manifest in cases where, for example, schools have an unforeseen cause of high heat consumption, such as regular evening classes, sports halls or an uncharacteristically poor building thermal performance.

6 Conclusion

Overall, the heat consumption values and load profile analysis produce a quantitative efficiency rating for each study school, which demonstrates that the majority of schools in Hampshire have potential to improve their heat energy efficiency. More detailed analysis of a subset of schools adds confidence to the rating bands. While the uncertainty associated with the methodology is relatively high, the overall findings of the report are useful. Although there may be schools with unfair efficiency ratings, the majority are expected to be reasonable.

The overall finding of the study is that the energy consumption of schools is not only influenced by physical variables such as building type, size and conversion efficiency, but also by the ways in which the systems are managed. It suggests that importance should be attached not only to the improvement of the buildings used for schools, but also the training and/or use of equipment to improve heating management. By increasing the awareness of energy efficiency in general, such changes could also prompt schools to save more electricity, along with less direct but equally important influences upon the environmental awareness of the pupils.

7 References

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