Energy Consumption In Non-Domestic Buildings: A Review of Schools

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Abstract: The energy consumption associated with non-domestic buildings represents 11% of the UK's total energy consumption, 11% of Europe and 18% of the USA's. A nnual non-domestic building energy consumption is often presented in the form of average benchmarks, such as 450kWh/m²/year for a large air-conditioned building and 200kWh/m²/year for a small naturally ventilated office. Benchmark values give very little insight into how and where a building consumes energy. While some benchmarks provide a breakdown of energy use by energy category (lights, IT, cooling, heating), these data still fails to demonstrate how the energy associated with each category varies throughout the year. To further understand building energy use, a more detailed data breakdown and analysis is required. The electricity demand data for a variety of school buildings (secondary, primary, specialised) in Scotland has been made available for analysis. This consists of half hourly resolution data spanning several years for 50 s chools, allowing key trends and patterns in energy use to be identified. T hese trends can include differences between annual profiles, differences between winter and summer months, and differences in weekday and weekend energy use. Additionally, the effect of other variables such as climate, user behaviour and general building data on the buildings energy consumption can be investigated. A database of half-hourly school energy demand data, with corresponding building details has been set up and a preliminary analysis preformed. Alternative method of pattern recognition in non-domestic energy usage are discussed, and the variables necessary to calibrate this information. This demonstrates the possibility of creating generic energy profiles and hence new benchmarks.

Keywords: *Non-Domestic Energy, Electricity Demand, School Energy*

1. Introduction

Energy consumption is continually increasing throughout the world and a large proportion of this can be associated with non-domestic buildings. In 2007 the UK consumed 157.8 million tons of oil equivalent (Mtoe) or alternatively 1,835TWh of energy [1]. To better understand how energy is used in the UK, it is necessary to breakdown the energy consumption into the different sectors. The total energy distribution of the UK is as follows; domestic consumption: 29.4%, transport consumption: 37.1%, industry consumption: 20.8% and "other" consumptions: 12.7% of total UK energy consumption [2]. The percentage of energy consumption associated with buildings in relation to total energy consumption was 42.3% [2]. The assumption is that the "buildings" mentioned in, [2], consists of both domestic and non-domestic properties.

Non-domestic buildings in 2003 w ere reported to account for 11% of total energy consumption in the UK, 11% in the EU and 18% in the USA [3]. The similarity between UK and EU consumption is probably due to their similar work habits, daylight hours and climate, while the USA's higher proportion may be due to the higher presence of air conditioning, or due to a different proportion of offices to other types of buildings.

Only by collecting and analysing building energy consumption data can an idea into how and when a building uses energy be gained. Introducing other factors such as seasonal demand profiles, both for weekdays and weekends, average daily consumption for each month, and determining any trends in standby/peak power over one year for each school, can ideally identify trends in energy use. With the help of this information, 'generic' profiles can be constructed allowing quick power reference and the creation of newer benchmarks for non-domestic energy use in this particular environment.

2. Current Benchmarks

A key area in the non-domestic sector is education. There have been numerous studies ([1], [4 -11]) into the energy consumption of schools and school energy performance benchmarks, and benchmark data us readily available for schools in the UK (as well as other counties) for the last few decades. Primary schools in the UK typically consume 119kWh/m²/year of energy [4], with the UK one of the few countries that have set energy benchmarks for schools. A target of 110kWh/m²/year is considered as an ideal or "good practice" target [5]. Other school benchmarks are detailed in the "Good Practice Guide 343, or more commonly known as GPG343 [6]. For a primary school, the 'typical' annual consumption target is 191kWh/m²/year where as the 'good practice' value is 135kWh/m²/year. For a secondary school without a pool, the 'typical' benchmark is 196kWh/m²/year and for a secondary school with a swimming pool, the benchmark is 223kWh/m²/year. This guide also divides the benchmarks into either electricity or fossil fuels, and provides a generalised breakdown of energy use in schools represented in a pie-chart.

In comparison French primary schools average 197kWh/m²/year, Greek schools consume 57kWh/m² and Irish primary schools consume 119kWh/m²/year [5]. Hermandez, [5], used 'GPG343' to establish that the typical value for UK primary schools is 157kWh/m²/year whereas the best practice value is 110kWh/m²/year. They used EnergyPlus software for the energy consumption calculations and a grading system based on a methodology outlined in "Energy Performance of Buildings"[12]. This method involved using the schools energy consumption (kWh/m²), a stock regulation value, and a stock reference value (based on either a sample mean or the building stock mean). A table of different conditions involving the three values determined the energy rating and benchmark.

A problem with previous studies and results is that they do not provide sufficient information to give a full understanding of how energy is used in a building. Energy performance benchmarks only provide the total annual energy consumption of a generalised school per floor area. Details such as weekly, monthly and seasonal trends are omitted. However, benchmarks can be used as a quick indication of energy efficiency or a simple tool for quick school comparison but are limited due to this additional detail. This paper discusses the analysis of a sample of schools and the key outputs of the analysis, aimed at providing more detail of school energy consumption than the standard benchmarks. In addition, average electricity demand profiles are analysed and their potential use in explaining energy usage are discussed.

3. Methodology

The interpretation of energy usage in schools is completely dependent on the availability of accurate energy data from a wide range of schools. The first stage therefore is identifying a reliable source or organisation that is willing to provide the data. Several local authorities in Scotland were contacted to allow monitoring of schools in their area to take place. Initially it was decided to select various school buildings and install several non-intrusive load monitoring (NILM) equipment in the schools. There are several advantages of using NILM systems, opposed to introducing equipment into the electricity network. A key advantage is that the buildings electricity supply is not interrupted, minimising disruption to the building. Another advantage is that the equipment can be set up without the need of an electrician or power engineer.

There are several disadvantages to using NILM electricity equipment. The first is that NILM equipment (for a 3-phase electricity monitor) is expensive, (about £4000 per unit). The second problem is the equipment is limited in monitoring the meter side of the buildings electricity supply. Further equipment is needed to monitor each distribution board, to fully understand how the building uses energy. To create a large database of different types of schools, several sets of equipment would be needed, increasing the project costs. Lastly, the data collection phase of the project was relatively short. Ideally several years of data would be needed to ensure it is representative.

An economical alternative was available because several of the authorities, who agreed to participate in the energy data collection, had access to electricity consumption data from their power suppliers. This was in half hourly time resolution that represents the meter side of the building. Having access to this data overcame the possible limitations of using expensive NILM equipment and the short assessment/data gathering period.

Table 1 highlights the studied schools and the associated details, such as year of construction, number of pupils, school type, total energy consumption and whether the school has a swimming pool. This table is used as a reference in determining any trends in energy use. The data presented in table 1 was collected by contacting the schools directly and by referencing the school's website.

4. Normalisation of Data

An important part of analysing the data is comparing the schools energy consumption against other schools. A basic idea of energy consumption can be gained by just comparing kW in terms of load profiles, or kWh in terms of total energy consumption. One hypothesis is that a large school will consume more energy than a small school. By normalising by floor area, this size factor is removed. By introducing pupil numbers, further normalisation can occur. Normalising by pupil number, however, is not as straightforward as normalising by floor area as it is influenced by how the building is used. Floor area and number of occupants are not entirely independent from each other. A school is built to accommodate a maximum number of students. Even with varying number of students, the assumption is that the same number of classrooms, sports halls and even IT facilities will be continually used. This results in similar total energy consumption for the school, regardless of pupil numbers. In contrast, normalising energy consumption of office buildings by occupant numbers appears to be more appropriate, due to the differences in how both schools and offices are used. Office workers generally use their own PC, or their own IT equipment, hence the energy usage associated with IT will vary with the number of occupants. This an important factor to consider when normalising by pupil number. For this reason, the presented results and charts are given in kW/m^2 or W/m^2

5. Categorisation

Table 1- Key School details

School	Year	Floor Area (m^2)	Total Energy use(kWh)	School	Year	Floor Area (m^2)	Total Energy (kWh)
A	1983	8042	667,233	**L**	1960	9561	888,443
B	1960	2535	195,221	**M**	1930*	14909	687,511
C	1980	9835	342,507	**N**	1940*	13559	607,708
D	1989	11430	512,819	**O**	1940*	11052	730,518
E	1991	12349	863,421	**P**	1950	14265	602,720
F	1954	13145	441,056	**Q**	1960	11852	605,890
G	1960	15368	695,154	**R**	1979	10156	492,587
H	1970	11535	643,994	**S**	1975	11927	945,627
I	1893*	11742	565,302	**T**	1960	1225	235,543
J	1978	11436	1,433,075	**U**	1980	7871	354,727
K	1965	11918	584,281	-	-	-	-

*School built at this date, but renovated post 2000

The complete database consists of 48 schools, including 32 Secondary schools, 11 primary schools and 5 specialised schools. Within the secondary school category, 21 schools were built before 2000, and 11 were built after 2000.

To analyse energy usage in schools, it is important to compare schools with similar properties. A large modern secondary school and a old small primary school will have different building characteristics, and differing electricity demands. In order to determine key trends in energy usage, the schools were initially categorised into two key groups: Primary and Secondary schools.

Secondary schools, or High schools, can be defined as premises that educate children from the ages of 11 to 17. High schools have a total floor area from 1,225m² to 15,368m² and total electricity usage between 1,433,075kWh to 195,221 (Table 1). It should be noted that the smallest school (by floor area), school 'T', does not have the smallest energy use (instead school 'B' has) emphasises the importance in normalising the data if comparisons are to be made. This result highlights the need for normalisation of energy use. Within the High/Secondary school category, two additional sub categories can be defined. The new categories are based on age of construction of the school; pre-2000 and post-2000.

The primary schools are defined as the first stages of education, catering for children aged from 5-11. Primary schools tend to be considerably smaller than secondary schools, as well as having smaller pupil numbers and represents 23% of the schools within the database.

Specialised schools are smaller, more focused schools, aimed at helping students with learning difficulties. These schools represent 10% of the studied secondary schools, but because of their small floor area and small pupil number, it is necessary to analyse these buildings separately from the other secondary schools.

6. Results

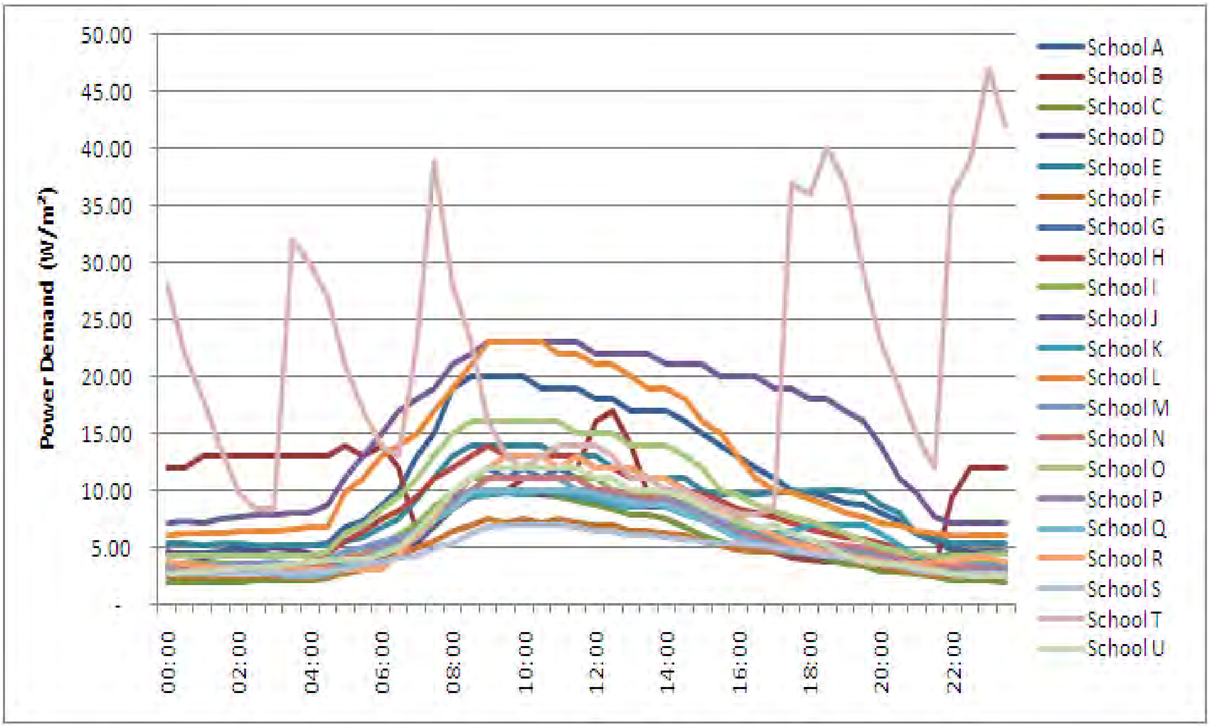

Figure 1- Average Power Demand Profiles

The collected school data was processed automatically by a FORTRAN based analysis program and several output files and profiles were produced. The designed analysis program outputs both a yearly average profile and four seasonal average profiles for each of the studied schools. For this paper, only Secondary schools built before 2000 will be discussed. Figure 1 demonstrates the average daily demand profiles for 21 secondary schools in Scotland, built before 2000. The daily power demand profiles represent the average working day power requirement over the entire year. This eliminates any possible seasonal variation.

School L's power demand profile can be used as an example to describe how a school consumes energy. School 'L' has a standby demand of 6.1W/m² and remains at baseload until 05:00 where it begins to rise. The rise continues until 0600, where the gradient reduces, then increases again. This step in energy use is most likely the result of heating systems (though heating pumps) being turned on. From 06:00 onwards the power demand increases until 09:00 where it reaches a plateau of 23W/m². This second rise is the lighting and IT equipment being switched on, as students and staff start interacting with the school. After 12:00 the power demand starts descending gradually, and at 14:00, the power demand falls from 19W/m² to 10W/m² by 17:00. From 17:00, the power demand steadily falls back to the baseload value by 22:00.

Figure 1 also demonstrates several profiles that have very atypical shapes. Schools 'B','J' and 'T' have power demand profiles that do not appear to resemble other schools. School 'J' has a fixed baseload of 12W/m², and rises slightly to 13W/m² until 07:00. At this point, it then reduces to 6W/m² and proceeds to rise and peak at 12:30 with a peak value of 17W/m². The power demand then falls to 3.1W/m² and sharply rises back to the original value of 12W/m². Although during the time period of 09:00 to 17:30 this profile demonstrates similar characteristics to the other schools in this study (excluding schools 'B','J' and 'T'), the large and constant power demand in the morning and in the evening are atypical. Further investigation has not yet determined why this school has such a profile. Establishing if the demand profile varied from season to season could indicate if the morning/evening demand is heating or lighting related.

The second atypical profile belonged to School 'B'. The profile initially follows the other schools, in that it rises to a plateau at 08:30. The main difference in profile shape occurs after this plateau. While other schools tend to drop in demand, and return close to the standby value between 1600 and 1800. The profile for school 'B' slowly dropped from 22W/m² to 16W/m² from 12:00 to 19:30. After 19:30, the profile returned to the base load value of 7.7W/m² at 21:30hrs. The initial assumption was that this extended power demand outside the normal school hours is due to the school being used for evening classes or for sports activities. However when the profile was compared to other schools that are opened in the evening, School 'B' appeared to have a very high power demand that fell only slowly, and did not present the same 'hill' of power demand seen between 17:00 and 21:00 (as shown in school 'L' for example). On further investigation it was found that the school is part of a larger complex, which includes a large public pool, library and gym. These additional components of the school are open until 22:00 and are used by the local community.

Lastly the atypical profile of School 'T' consists of five peaks occurring at 00:00, 03:30, 07:30, 18:30 and 23:30, with peak power demands of 28, 32, 39, 40 and 47W/m² respectively. An interesting observation was that between 12:00 and 15:00hrs, the profile matches the same shape as the other schools. Upon further investigation, it was discovered that school 'T' has electric space heating, and not gas heating. The large peaks that occur are the result of the heating being switched on during the morning and evening. The spikes occurring early in the morning and late in the night could be a poorly set-up energy management system or the result of a heating system with a basic thermostat. The full explanation of this profile remains to be established.

7. Discussion and Conclusion

The research discussed in this paper aimed at determining if analysing an energy database can provide information on how buildings use energy, and in turn overcome the current limitations with existing benchmarks. The analysis of the school data to produce average power demand profiles, as shown in Figure 1, helped determine when power is used in a wide range of schools and how much power is required (peaks, and standby loads). The results demonstrate that there is a common shape within the profiles especially within the time period between 07:00 to 16:00. The results also demonstrated that it is possible to group the schools into 'good', 'average' and 'poor' energy/power rating, similar to the system used in the Good Practice Guides [6,13].

Several profiles were identified that did not share a similar shape to schools in the data base. Schools 'B', 'J' and 'T' had atypical profiles that could not be grouped with the other schools. This is an important finding as it highlighted one problem with using 'generic; profiles and the 'reliability' of their widespread application.

This preliminary report of continuing work suggests that it is possible to analyse the different seasonal demand profiles, both for weekdays and weekends, average daily consumption for each month, and determine any trends in standby/peak power over one year for each school. Future analysis will help determine: a) if there are any seasonal trends between the schools, b) how energy consumption varies between each month, c) how the peak values vary throughout the year (highlighting school holidays) and lastly d) if the schools are used during the weekends, and if energy is being wasted. In addition, analysis will be extended on the different categories of schools (primary/secondary). As well as normalising by total floor area and by pupil number (although as already discussed, there may be no additional benefit normalising by pupil number), the data will need to be corrected for local climate. The schools analysed in this study were spread throughout Scotland and variations in local temperature is likely. Analysing local temperature as an independent variable will allow its impact on energy usage profiles to be established. Lastly, user behaviour or interaction will be introduced into the analysis, to help determine when and where energy is being used in the schools. Currently only basic information on pupil numbers for each schools is available. It is unknown how this study will measure, record and normalise pupil behaviour for each studied school.

Generic profiles are of use provided their limitations are recognised. Key information such as peak demands, school type, opening hours, after school use, standby load and construction date can be used to generate generic profiles. A possible approach is to average the school profile data for each school category and produce one profile. A difficulty with this is that atypical profiles, such as for schools B', 'J' and 'T', would be averaged as well, resulting in averaging problems. Additionally, one approach would be taking an average of an average (due to the analysed profiles being constructed using average values). This could lead to errors forming, or incorrect profile shapes. Another possible approach could be creating probability distribution, using every data value in each of the schools. This results in 17,250 data points being analysed, hence 840,960 data points in total for the entire database. The original data analysis program could be altered to include this possible approach. Generic profiles do have several beneficial uses. Energy managers could use a data input screen and enter key building details such as opening times, total area, etc and output a profile that could match their building. Additionally a level of good, average and poor profiles could be outputted as well as new benchmarks. The profiles could be used for determining the impact of renewable energy generation on a buildings daily demand, and could be used by power companies to guide on investment decisions or determining if power upgrades are needed.

The work discussed in this paper is continuing and key outputs, trends and conclusions are being established as the data analysis stage nears completion. This paper has discussed key stages of the methodology, data collection and normalisation. It has also discussed the results of initial analysis of one category of school and one average profile output from a designed analysis program. Lastly this paper introduced the concept of 'generic' profiles, and a possible methodology to gain these profiles. With further research and analysis of the data base, a better understanding of non-domestic energy use can be gained, and new benchmarks created.

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