New Approaches to the Analysis and Interpretation of Half Hourly Energy Metering Data from Buildings.

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Abstract

Historically, energy surveys have been carried out to identify efficiency improvements and understand annual or monthly energy use. However, meter readings are increasingly collected half-hourly, generating large volumes of data. (For the CaRB - Carbon Reduction in Buildings project, the data set is 2.5 million samples and growing). This paper outlines some key aspects of the work: Firstly, the management of building information which is used to interpret the metering data but which may also be used for building energy modelling and labelling. An overall top-level system for data management is described which is future proof, but which can also use building data collected from previous surveys. Secondly, new approaches available for handling this data are described. Thirdly, changes in survey techniques are outlined which can help to maximise the usefulness of half-hourly data, in terms of intelligent interpretation. Finally, two case studies showing analysis of half-hourly metering data are presented.

Introduction

The Leicester Energy Agency, run by Leicester City Council, have half hourly metering systems installed in over 200 buildings, mostly in Leicester, and mostly owned by Leicester City Council. These include typical local government buildings such as schools, offices, libraries, but also commercial buildings such as industrial units, and shops. Metering data available is usually electricity (kWh) and gas consumption (m^3), and frequently also water (L). Sometimes electricity consumption KVA values are also available. As part of the Carbon Reduction in Buildings (CaRB) Project [1], A database is being populated with metering data, and building survey data, with a view to producing improved understanding and models of energy use in the UK building stock.
The metering data is used as the starting point for population of our database. Energy surveys are carried out, initially at buildings of topical interest to the Energy Agency, such as sites of corrected major faults, refurbishments, with a rollout programme to include surveying of the whole metered stock. The surveying project is called the ‘Leicester 200’, with two main aims.

1. To see where the established energy audit (i.e. in common use before advanced metering was widely available [2]), may be augmented with half-hourly metering, whilst determining which survey data is useful for interpretation of half-hourly data.

2. To determine which types of data from both half-hourly metering and survey data are most useful for the production of a building model.

Building Information Management

A database server running MySQL [3], on a RedHat Linux [4] operating system, is used to store around 20 million data points for meter readings from 2002 onwards. This database is interrogated using Matlab [5] software, from remote Windows machines. The Matlab software is able to issue SQL commands over the local network to the database server. Post-processing is then carried out in Matlab. This system combines the speed and reliability of a dedicated database engine with the flexibility of a high level scripted programming language. The provision and processing of the data stored within this database, are described in the next section.

Qualifying the Data

Key to the construction of the building database is the open-source database server system described in section 1. In years to come, a building modeller may want to know if data was inferred, measured directly, measured from drawings, etc. a 'data metric' is proposed along the lines of the following.

7 – Known absolute (e.g. heating type, number of floors), no potential for error
6 – Accurately measured (e.g. sonic distance probe, metering data)
5 – Approximately measured
4 – 'Paced out', measured from photographs
3 – Inferred from other parts of building or national stock
2 – Word of mouth / Anecdotal
1 – Inferred from building age
0 – Not known

The system is flexible, and other data performance metrics can be added, possibly even a metric for whether data quality is known or not. A sample dataset, with example data metrics is shown schematically in Figure 1

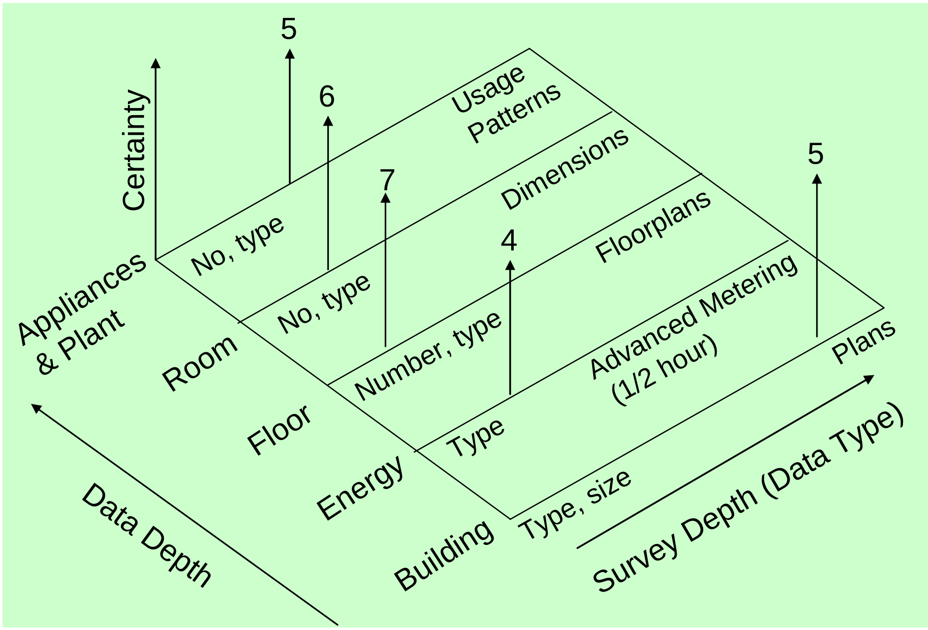

Figure 1 - Survey data structure

Gathering Data

Metering data gathering may be augmented by variables such as temperature and humidity, to provide the building modeller with valuable additional information. In most cases, spare data channels are from meter logging telemetry equipment (such that data logging is provided). In this case, additional instrumentation may be added to a building at minimal cost. Table 1 provides a summary of low-cost instrumentation technologies which could augment energy surveying and monitoring. All electrical and thermal devices listed can be used with existing building with no modifications. Ultrasonic flow meters may also be used in a non-invasive retrofit. Valve mounted meters, require plumbing-in, as would a pulse output gas meter.

Table 1: Measurement technologies.

Measurement Function	Technology	Approx. Cost	Notes
Power consumption	Clamp meter	£150	Suitable for separate electrical phases, large range.
Power consumption	Plug in meter	£40 - 100	Suitable for plugged appliances
Power consumption	SMS pulse retrofits	£40 - 100	Uses SMS messaging to report metering data
Temperature	Thermocouple	£8*	Used for higher temperatures, precise
Temperature	Thermistor	£12*	More suitable for indoor monitoring than Thermocouple
Temperature	RTD	£40*	Wide temperature range
Humidity	Capacitive	£18	Most commonly used
Humidity	Resistive	£2*	Stable output, field interchangeable
Water Flow [6]	valve mounted meter	£70	Attaches to valve body in place of valve stock (requires water system to be shut down)
Water Flow [7]	Ultrasonic meter	£1800	Cost of technology is decreasing rapidly. Non-invasive.
Gas flow	Gas Meter with pulse output	£70-100	Invasive installation, but existing meters with pulse outputs useful for instrumentation.
Luminance	Photocell Luminance meter	£40 - 100	Handheld devices usually featuring digital readout, often with signal.
Distance	Tape Measure	£15	Handheld, no batteries, 3 – 50m.
Distance	Sonic tape	£50	Handheld devices, working effectively to ~20m
Distance	Laser Measurer	£300	Handheld devices, working effectively to ~200m
Air flow	Anemometer	£100-200	Handheld devices usually featuring digital readout, with signal.
Building condition	Camera	£100-200	Useful for all building surveys

*Requires additional signal conditioning circuitry, typically £40 per measurement channel.

Summary of options for Post Processing of half-hourly metering data

The CUSUM [8] method of analysis of time series data is well documented, and is an effective tool for analysis of data. However, additional software and modelling tools would be required to connect CUSUM detected events with real-world data. Also, the method does not readily lend itself to automated fault detection (though some researchers are working to remedy this). The following technologies are mature enough to warrant consideration by researchers and implementers, and could be more applicable to multivariate analysis, as well as providing a fully automatic fault detection system. Their suitability is explored as part of the project.

Novelty detection is the identification of new or unknown data or signal that a machine learning system is not aware of during training. Novelty detection is one of the fundamental requirements of a good classification or identification system since sometimes the test data contains information about objects that were not known at the time of training the model. The technique is suggested as potentially useful for machine tool control in manufacturing engineering [9] , and would clearly also be useful for fault detection in buildings.

The Fourier Transform, is a method of splitting a signal in the time domain, into it's component frequencies, and has found many practical applications for time series data, such as in machine condition monitoring. Fourier Series have been used to predict energy consumption [10], and spectral analysis methods are emerging as suggested tools for energy consumption analysis. The ability of spectral methods to detect periodic events, can provide automatable methods, for example to obtain an acceptance mask for dataset of the same series in which the category and size of a fault can be detected. Thus the detection system can be 'tuned' to detect/ categorise specific faults, with adjustable sensitivities, a technique which fairly standard when using the Fourier Transform in signal processing, but is not inherent to techniques such as CUSUM.

The wavelet transform is of particular interest. This can be used to reveal time domain information as well as frequency domain information, i.e. which periodic events are occurring at which times [11]. This has reached the application stage since the mid 1990's, particularly in manufacturing [12] , but not in building energy monitoring. The output from a wavelet transform is thus usually viewed as a 3D plot, but the process lends itself to automation - wavelet data can be appropriately thresholded to detect building system faults, or unexpected changes in patterns of consumption.

Fractals and Chaos are relatively new branches of mathematics, since they cannot be explored without powerful computers developed relatively recently. The use of fractal geometry, which has powerful potential to unravel seemingly random and complex data, is currently an emerging field and shall be watched with a view to utilisation [13].

Examples – Data Analysis

Example 1 – Library Data

The following section shows some typical results from analysis of half-hourly metering data, as outlined in section 2.2. Beginning with the Fourier transform, this may be used to identify key cyclic events from metering data. Considering the electricity consumption data given in Figure 2, the data can be seen to be heavily periodic.

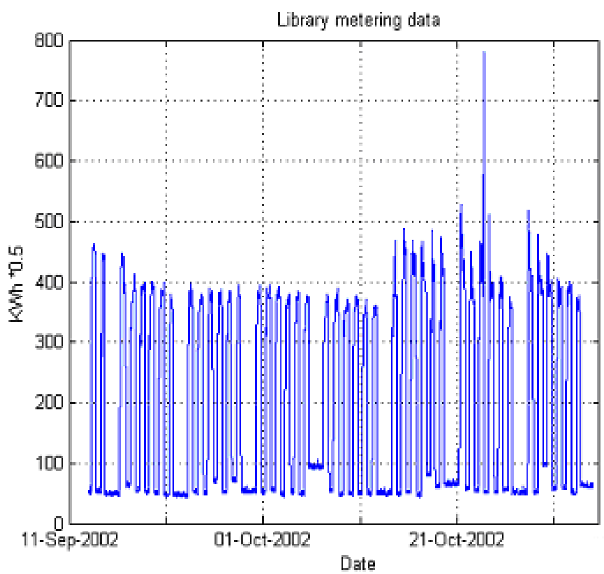

Figure 2 - Library metering data

Figure 3 shows a Fourier transform based spectral analysis of a 4 week period of electricity metering data. The ‘spectral signature’ can be compared to whichever time slice of metering data is under consideration, in order to check for irregularities or possible increases in energy consumption based on faults. The clearest event visible is the 7 weekly ‘spike’ which represents daily consumption. The high frequency spike shown around 21 Oct 2002, is a single event, which does not show up clearly in the Frequency domain, indeed, the Fourier Transform in this instance is used purely for detection of periodic events (although the Wavelet transform may indicate such discontinuities) . Spectral methods such as this are especially useful in condition monitoring of the metering apparatus itself, as data gaps can occur in automatic metering systems and go undetected for long periods. Non-detection of periodic events would therefore indicate a fault in the metering system, whereas purely searching for unchanging meter readings may not be as effective for certain isolated cases, such as buildings with zero baseload.

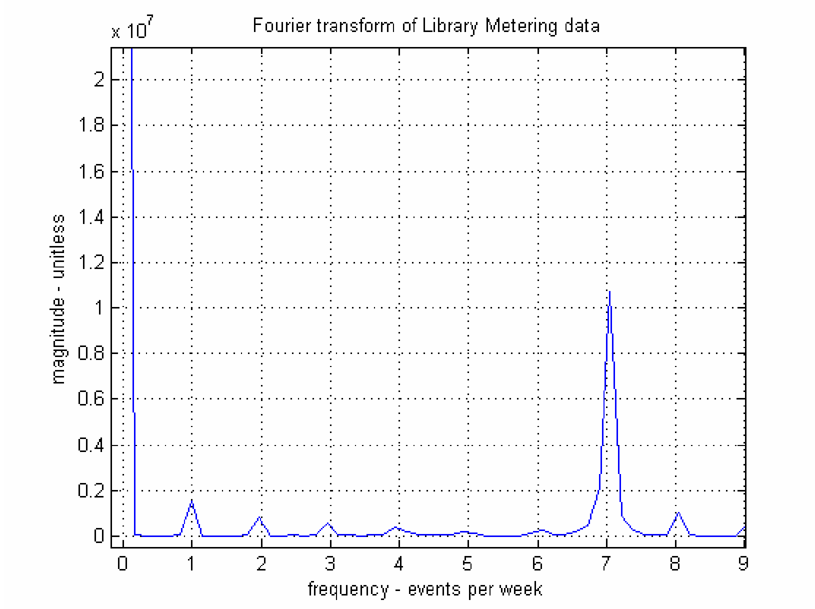

Figure 3 - Fourier Transform of library metering data

Example 2 – Metering Data

Figure 4 represents electricity consumption for a small office – clearly to the right of the plot, can be seen a change in the consumption pattern. Of interest in future research, is whether an automatic system, such as a wavelet transform, can produce a clearly identifiable 'event' which is also present in a CUSUM plot.

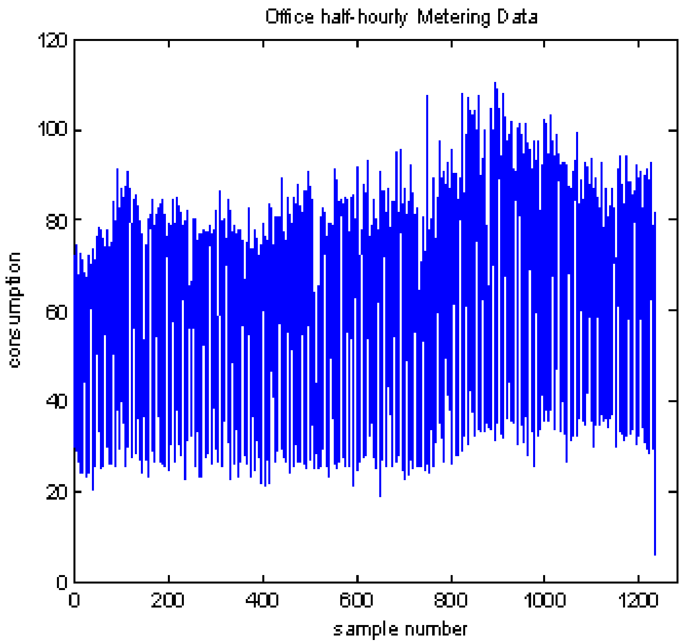

Figure 4 - Office metering data

Figure 5 shows the CUSUM plot produced from this data of particular interest is the event which occurred around sample 870-880 in the previous plot. The 'kink', caused by a disruption in consumption patterns in the curve is clearly identifiable by a human inspector, but could be unreliable for software to automatically detect directly from the data. The large shift in consumption (the underlying 'V' shaped trend), was due to a drastic change in building occupancy, and is relatively straightforward to detect using software.

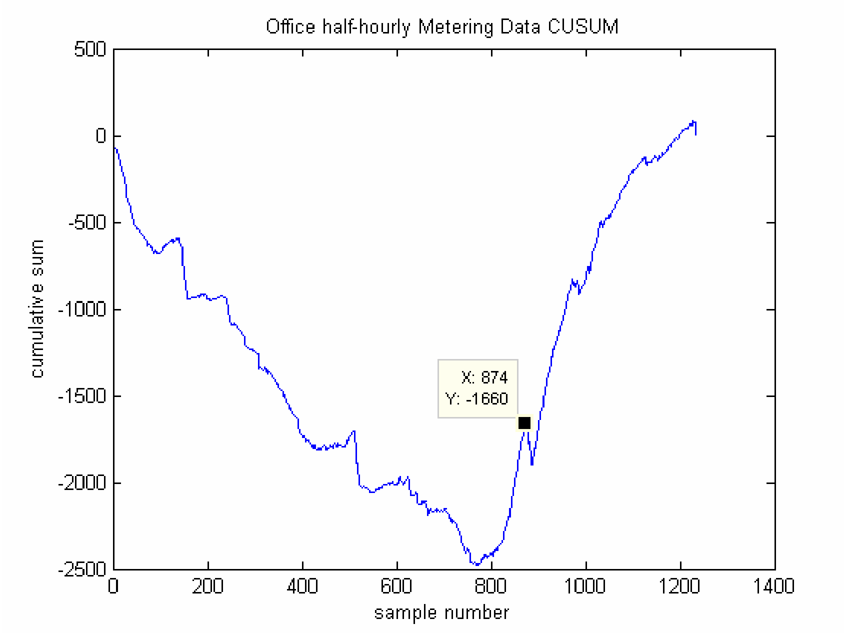

Figure 5 - Office metering data CUSUM

Conclusions

The key aspects of a system of data storage which can be used for retrieval of building survey information, and metering analysis, have been outlined. Emergent technologies for the gathering and analysis of building data have been described. It is clear that the rate at which options for low-cost monitoring and metering are becoming more numerous year on year. Also, the amount of raw data which is becoming available from half hourly metering will necessitate careful post processing in order to automatically extract useful information for building design, energy management, and fault detection, since before long, the data rates involved may make sensible direct human monitoring unfeasible.

It is clear also that with the large amount of data which is becoming available from half-hourly metering, and building monitoring, careful management of the data, and provision for it's future use in terms of data design and storage is important.

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