# Identifying energy saving opportunities in buildings by the analysis of time series data

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## Abstract

This paper describes how the analysis of time series energy data can be used to identify energy saving opportunities in buildings. Using readily available historic records of energy consumption, particularly quarter-hourly and half-hourly electricity time-series data, and with basic knowledge of the building, potential energy saving opportunities can be highlighted.

A review of energy monitoring and targeting (M&T) procedures and techniques of analysing time series data have been carried out. The analysis of electricity time series data has been reviewed in the UK. This has involved analysing demand for power in 8 office buildings. Three different analytical approaches have been applied, simple visualisation and interpretation of energy use patterns, contour mapping and recurrent cumulative sum deviation (CUSUM).

This paper concludes that such approaches to analyse electrical power demand could increase the cost-effectiveness and reliability of energy audits and surveys.

## Background

The building sector accounts for 40% of EU final energy use and is the sector with the greatest potential for reducing energy demand and carbon dioxide emissions through improved energy efficiency. The European Commission action plan (EC 2000b), indicates that energy efficiency has the economic potential for reducing European Union (EU) energy demand by 18% by 2010. The Commission (EC 2000a) also states that 20% of current energy demand in buildings could be eliminated through no or low cost energy efficiency measures. Since buildings may well last over than one hundred years, it is important to reduce energy demand in the existing building stock. Identifying cost effective ways of achieving this is crucial in order to meet national targets for reducing greenhouse gas emissions and reduce EU dependence on imported energy sources.

### ENERGY AUDITS

Energy audits or surveys are generally the first step in assessing energy performance and identifying energy saving opportunities in buildings. However there is no agreed definition of an energy audit or survey. Furthermore, the definition and understanding of what energy audits involve varies between countries. Terms, such as energy survey, energy assessment or energy labelling, are often interchanged on translation. For example, what in mainland Europe is generally referred to as an energy audit, is understood in the UK as an energy survey. In the UK the term "energy audit" is used when referring to a simple study that just determines the quantity and cost of each energy input to the building, (CIBSE 1991). Other authors in the UK refer to the energy audit process as involving the assessment of the energy management structure within an organisation in relation to an energy matrix tool, (Harris 1992).

There is some energy auditing activity in most of EU countries. This began following the oil crisis in the 70's and 80's, reduced during the period of low oil prices in the 90's and is now enjoying a resurgence with action to reduce energy related carbon dioxide emissions. However, despite all this activity, little attention has been given to monitoring energy auditing activity and assuring that they are performed at a minimum cost and maximum quality.

In an attempt to establish a common terminology to avoid misunderstandings, a study of energy auditing practices in Europe (Motiva et al. 2000) suggests the dissemination and use of the term energy audit. The study offers a general definition of energy audit, as follows:

"Systematic procedure that:

- Obtains an adequate knowledge of the existing energy consumption profile of the site.
- Identifies the factors that have an effect on the energy consumption.
- Identifies and scales the cost-effective energy saving opportunities."

However, a definition of the technique that can assess the energy performance and identify energy saving opportunities in buildings/industry is of relative unimportance. It is far more meaningful to analyse other issues inherent to energy auditing activity, such as:

- **Cost-effectiveness of energy audits:** The ratio between the cost of the audit plus the total cost of implementing all recommendations and annual estimated savings. The cost of the audit is usually the energy consultant's fees, which can reach up to 500 Euro/day. Therefore, one can argue that the cost of an audit carried out by a consultant can be excessive for SME's and new buildings, i.e. the energy cost savings identified may be small when compared with audit and investment costs. However, this may not be the case for large companies, in which an energy audit can be very cost-effective.
- **The quality of the energy audit:** This is assessed by its outcome – the audit report. This report presents the energy performance appraisal and the identification and quantification of energy saving opportunities in the building or industry under analysis. Therefore the audit quality is related to the validity and reliability of the analysis techniques and tools used to assess energy performance, identify energy conservation opportunities and estimate potential cost savings.

Cost effectiveness and quality of energy audit issues have not been widely reviewed, however, there are example approaches that have been conducted. (Motiva et al. 2000), reviews energy auditing programmes, the situation of energy auditing and audit models in 16 European Countries (EU member states and Norway). Also, Heckle (Heckle et al. 1990), presents the results of a detailed comparison of energy audits carried out by 4 different consultants from 3 European countries (France, Italy and Switzerland) on the same set of buildings. The objective was to compare commercial energy auditing methods from the point of view of accuracy and cost-effectiveness. Audits were compared not only to each other but also to a more detailed benchmark survey conducted by the researchers. Audits ranged from detailed and costly studies involving the use of infrared study of building envelope and dynamic thermal simulation to non-instrumented, walkthrough audit. Large differences were found between the results of all the audits. However, no audit was consistently very much worse or better than the others. Furthermore, the benchmark study identified a considerable number of potentially cost-effective energy-saving measures, which were completely overlooked by commercial audits. Consultants based their recommendations on a relatively small number of common energy saving opportunities, which may indicate strong reliance on general checklists. (Heckle et al. 1990) found no correlation between the level of detail and cost of the audit and its overall cost-effectiveness. Interestingly, both (Motiva et al. 2000) and (Heckle et al. 1990) refer the need to establish auditing practices by interchanging information on energy auditing models, tools and techniques used in different countries.

## ENERGY MONITORING AND TARGETING

Energy monitoring and targeting (M&T) is an energy management activity that deals with the analysis and interpretation of energy use in the form of time series data. This is normally used on a monthly basis (i.e. based upon the utility billing cycle). Energy M&T differs from energy auditing, as the latter largely depends upon a site visit. However it has been argued that energy M&T can often provide useful information prior to an energy audit, (DETR 1996, 1998b).

The purpose of energy M&T is to continuously assess energy consumption so as to avoid unnecessary use. This is achieved by detecting deviations from expected patterns of energy consumption. It can be applied to manage energy in buildings as well as industrial processes. Energy M&T has much in common with quality management and in fact both activities rely upon similar data analysis techniques.

Energy M&T requires time-series data that could be obtained on monthly, weekly, daily or sub-daily (hourly, half-hourly and less) time scales. Routinely collected accurate (i.e. not estimated) time-series energy data is the key to energy M&T. Time-series energy data can be acquired from electricity and other fuel bills, and/or meter and sub-meter readings. However data on variables that affect energy use may also be required. For instance, in manufacturing businesses, time series production data would also be relevant to the analysis. Similarly for M&T energy consumption in heated or air-conditioned buildings, ambient temperature time-series data can be used to analyse alongside energy consumption data. This data is usually modelled with the use of degree-days. Degree-days are a measure of the extent and duration that ambient temperature was above or below a given base temperature. Typically the base temperature is considered to be the building inside control temperature, less the incidental gains from appliance and people. This data can then used to examine the energy demand in buildings as a function of weather, (DOE 1993) and (Harris 1999), and provide an indication of the efficiency of the heating and cooling strategies in buildings.

Energy accounting and M&T software identifies excessive consumption of energy or changes in demand patterns. The data is typically presented on time scales of months and data is often normalised for production or weather using linear regression, DETR (1998c).

It should therefore be possible to make the energy audit or energy survey more cost-effective, by rapidly inspecting

**Table 1. Comparing physical survey and time series energy analysis** (adapted from (DETR 1996)).

| Physical Survey | Time series data energy analysis |
|---|---|
| ADVANTAGES<br>Focus on tangible facts<br>Identification of visible faults<br>DISADVANTAGES<br>May require an external consultant | ADVANTAGES<br>Can be initially based on existing data<br>Can identify intermittent faults<br>Can be less expensive (no visit)<br>Can be used to quantify the extent of the problem<br>DISADVANTAGES<br>Limited to the bills and metered information |

**Table 2. Short time series data energy analysis techniques** (adapted from (DETR 1993a, 1998c).

| Analysis Techniques | Description |
|---|---|
| Profiles | Display of weekly or daily consumption repeatable patterns. |
| Contour mapping | Multi-coloured chart for displaying half-hourly data over a month. |
| CUSUM | Identify changes in demand, using cumulative sum of the difference from predicted consumption. |

the existing readily available data on a building, prior to the visit, using M&T energy analysis techniques. The paper describes the analysis of time series electrical energy data for 8 office buildings as an initial phase in the energy audit process.

## Analysis of short time-series energy data – first resort approach

Support for the application of energy M&T analysis techniques to assess building energy performance was described in the UK Chartered Institute of Building Services Engineers (CIBSE 1998). This states that the analysis of time-series data using M&T analysis techniques is a way to increase the detail of energy audits and surveys, although the publication provides very little detail on how to do this.

An overview of how M&T energy analysis techniques could be used as first approach to energy management in buildings is presented in Energy Savings in Buildings: methods for quickly identifying savings, by the UK Energy Efficiency Best Practice Programme, (DETR 1996). It is suggests that individually both approaches have advantages and shortcomings, and that the best result comes from the association of the physical energy audit and the time series data energy analysis approach, Table 1.

Although M&T energy analysis techniques are often considered to be fully developed and extensively applied to energy management activities, there is little information published on the analysis of short time series (i.e. less than hourly) data. Short time series data is becoming easier and cheaper to obtain, and it is now available from a large number of buildings and industrial sites. For instance, in the UK, since 1994, it is mandatory that all the sites above 100 kVA electricity peak demand have half-hourly metering installed. These sites are billed according to a half-hourly electricity tariffs. Similarly, in Portugal all sites wanting to buy electricity outside the public electricity system need to install quarter-hourly remote metering equipment. Advances in metering technology has decreased the cost of automatic metering in recent years, and it is expected that sub hourly metering will be available for more buildings and become more common place for gas and water metering in the near future.

#### ANALYSIS TECHNIQUES FOR SHORT TIME-SERIES ENERGY DATA

Table 2 introduces the three short time series energy analysis techniques used in the study here presented. The first two are visualisation techniques, while the last is commonly used in energy M&T.

A further analytical technique, Correlation Regression Analysis, is often used to relate energy consumption with the weather, energy consumption with production or energy consumption with both weather and production. However, for the 8 office buildings considered here, electricity consumption was not weather dependant nor was there any energy related production. This approach has therefore not been used in any of the 8 office buildings. However, weather related half hourly time series data could be used with half hourly electricity data to establish the cooling related electricity consumption of air conditioned office buildings.

#### Electricity demand profiles

Energy use, particularly electricity consumption in buildings, is usually of repeatable nature. Three cycles can usually be identified: daily, weekly and seasonal. If historical short time series electricity consumption data is available it will be possible to identify the daily cycle, i.e. the variation of electricity consumption throughout the day. However the daily cycle may not be the same for all days of the week. Figure 1 presents weekly electricity demand profiles, based on half hourly electricity consumption data for 8 office buildings. The profiles are for each of the 48 half-hour periods for each day of the week. There are several energy M&T commercial software packages that provide some analysis of half-hourly data to generate demand profiles of buildings (DETR 1998c). These profiles enable comparisons of energy consumption to be evaluated throughout any period.

#### Contour mapping

Contour mapping is a visualisation technique for converting half-hourly energy data into an easy to read coloured contour map. Figure 2 presents the contour maps for the same 8 buildings. Each row of the grid represents one day, divided

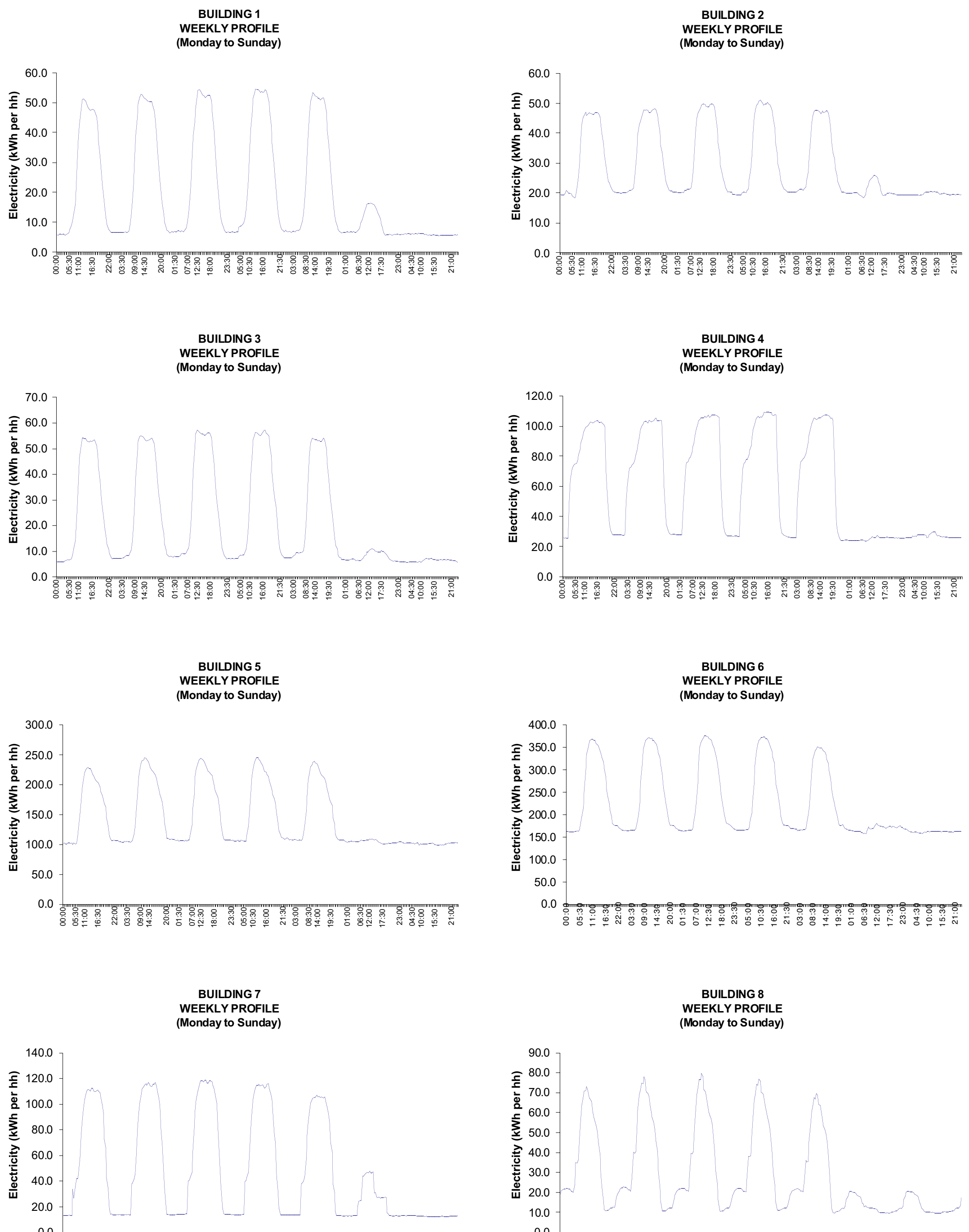


***Figure 1. Average weekly demand profiles*** *(building 1 to 8).*

in 48 blocks. The contour map was generated using the entire set of data available for each building. For a full year this represents 17 520 data points. The contour map provides a visual impression of the seasonal, weekly and daily cycles occurring throughout the year. It is the only technique that allows the display of several months or even years of actual half-hourly data. This simple procedure will tease out electricity demand overnight, during weekends and quiet periods of building use such as holidays, periods of demand, which are uncharacteristically high and occasions when systems may have failed. However it is difficult to quantify accurately the amount of unnecessary electricity that had been used just by looking at the contour map alone.

### CUSUM plots

Cumulative Sum Deviation (CUSUM) is a technique for measuring and quantifying bias in time series data. CUSUM is extensively used in energy M&T, usually employed to monitor monthly energy consumption data, (Harris 1989,

1992) and DETR (1998a, 1998b). The use of short time series can increase the resolution of the CUSUM technique.

The method used for calculating CUSUM involves the following steps:

1. Identify the baseline – the expected value ($\hat{y}$) for the variables that affect energy consumption.
2. Subtract the predicted variable from the actual (energy consumption) to obtain the differences for each time series period. Actual energy consumption ($y$) minus the expected ($\hat{y}$).
3. Add up the differences from the first period to the last in order to calculate the cumulative sum of the differences, according to Equation 1.
4. Plot a graph of CUSUM against time, Figure 3.

$$\sum_{i=1}^{n}(y_i - \hat{y}_i)$$

***Equation 1.*** *Mathematical expression for CUSUM*

CUSUM is not a technique exclusively for energy management, Harris (1989). Different forms of CUSUM plots have been developed for particular applications. There are essentially three types of CUSUM forms: invariant, parametric or recurrent forms. CUSUM forms differ mainly in the identification of the baseline. The parametric form is the most common in energy management. In this type of CUSUM the baseline ($\hat{y}$), is determined by the relationship between energy consumption and degree-days. However electricity may not correlate well with heating and cooling degree-days or any other known variable. This is even though electricity consumption may show a regular daily or weekly variation pattern, which can be seasonal, weekly or daily. In this case it will be necessary to use the recurrent form of CUSUM, in which the baseline consumption is usually based on the average daily electricity use for each day of the week. Figure 3 presents the recurrent CUSUM plots based on daily electricity demand, obtained from half-hour time series data, for the same 8 office buildings. Figure 4 reproduces the same sections as weekly profiles. For example, in the CUSUM plot of building 4 it is possible to identify six events that changed the consumption patterns, and consequently seven sections, representing different patterns of electricity demand. The CUSUM technique also offers the possibility to quantify how much energy was used above or below the baseline, which is considered to be the building energy demand under normal conditions, for each of the seven sections/patterns. From this you can work out the change in consumption and hence the change in cost from "the normal" pattern.

## Results and discussion

Each of the three analytical techniques investigated in this study have been applied to the 8 office buildings. The main objective of this study was to assess the usefulness of analysing half-hourly electricity consumption records to identifying and quantifying potential energy saving opportunities remotely. That is, before someone visits the site. To rapidly provide an analysis of data that someone carrying out and energy survey could use to make the energy survey more cost effective.

### AVERAGE DEMAND PROFILES

Figure 1 presents the weekly average electricity profile for the 8 buildings under analysis. Calculating an average for every half-hourly period and plotting the weekly chart should take less than 5 minutes. Analysis of these profiles reveals arrange of facts about electricity use in the building.

**Occupancy periods**, such as:

- *Working days of the week*, typically for office buildings are Monday to Friday, though in six buildings, it was possible to detect some level of activity on Saturdays. In buildings 8 there was also some energy consumption on Sundays.
- *Working hours* that were measured on the daily profile curves. Building 6 has quite a slim profile (5h30 to 19h30), similar to buildings 1 and 3. Conversely, building 4 has a wide daily profile (2h00 to 20h00), which may in fact not be completely linked to the occupancy period of the building, but instead to some other activity.

**Maximum electricity demand**. Average maximum demand ranges from around 94 kW in building 2 to over 700 kW in building 6.

**Base load consumption** represented by the average night time demand. Base load represents the electricity consumption that is required all the time, even if the building is unoccupied. Comparing average night time demand with average maximum demand, it is possible to identify buildings in which base load can be considered:

- *High* (above 40% of average maximum demand), in buildings 2, 5 and 6.
- *Low* (under 20% of average maximum demand), in buildings 1, 3 and 7.

**Other characteristics of the demand profile**, from which important information can be derived:

- *Morning shoulders* - increasing electricity demand very early in the day. This characteristic exists in the demand pattern from buildings 4, 7 and 8. In building 4 the shoulder is the result of electricity demand starting very early in the morning (2h00) rapidly increasing until 4h00 and then more slowly until 6h00.
- *Small dips in demand over lunchtime* can also be identified in some of the weekly demand profiles, notably in buildings 1, 2 and 3. In office buildings activity during lunchtime is usually reduced, so one would expect electricity demand to be reduced. However this is not the case for all the buildings, which could be indicative of unnecessary energy consumption over lunchtime.

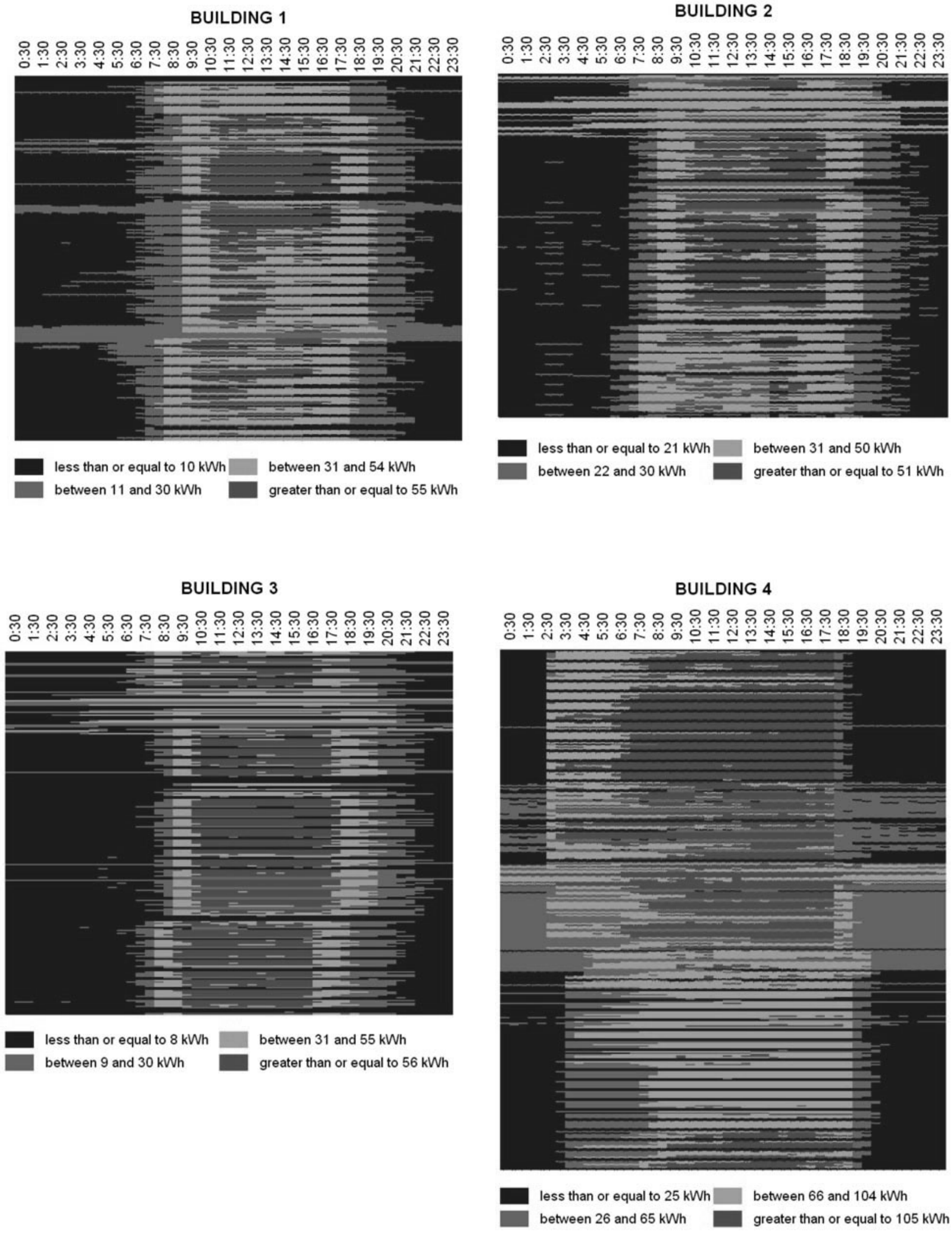


***Figure 2.*** *Contour maps (Building 1 to 4).*

- *Symmetry morning/afternoon*, i.e. comparing the rate of increasing demand in the morning with the rate of decreasing demand in the afternoon. Buildings 1, 2 and 3 can be said to have symmetrical demand profiles. Interestingly, in buildings 5 and 6 demand increases very rapidly in the morning and then decreases slowly in the afternoon, resulting in a profile that resembles a shark's fin.

#### CONTOUR MAPPING

Contour maps display pictorially the distribution pattern of energy consumption across the time span of the assessment. If the average demand profile has already been plotted and the scale of the map is set accordingly, again it should take less than 5 minutes to prepare the analysis. Figure 2 present the contour maps for the 8 office buildings. The colour code chosen is simply designed to show up as much detail as possible.

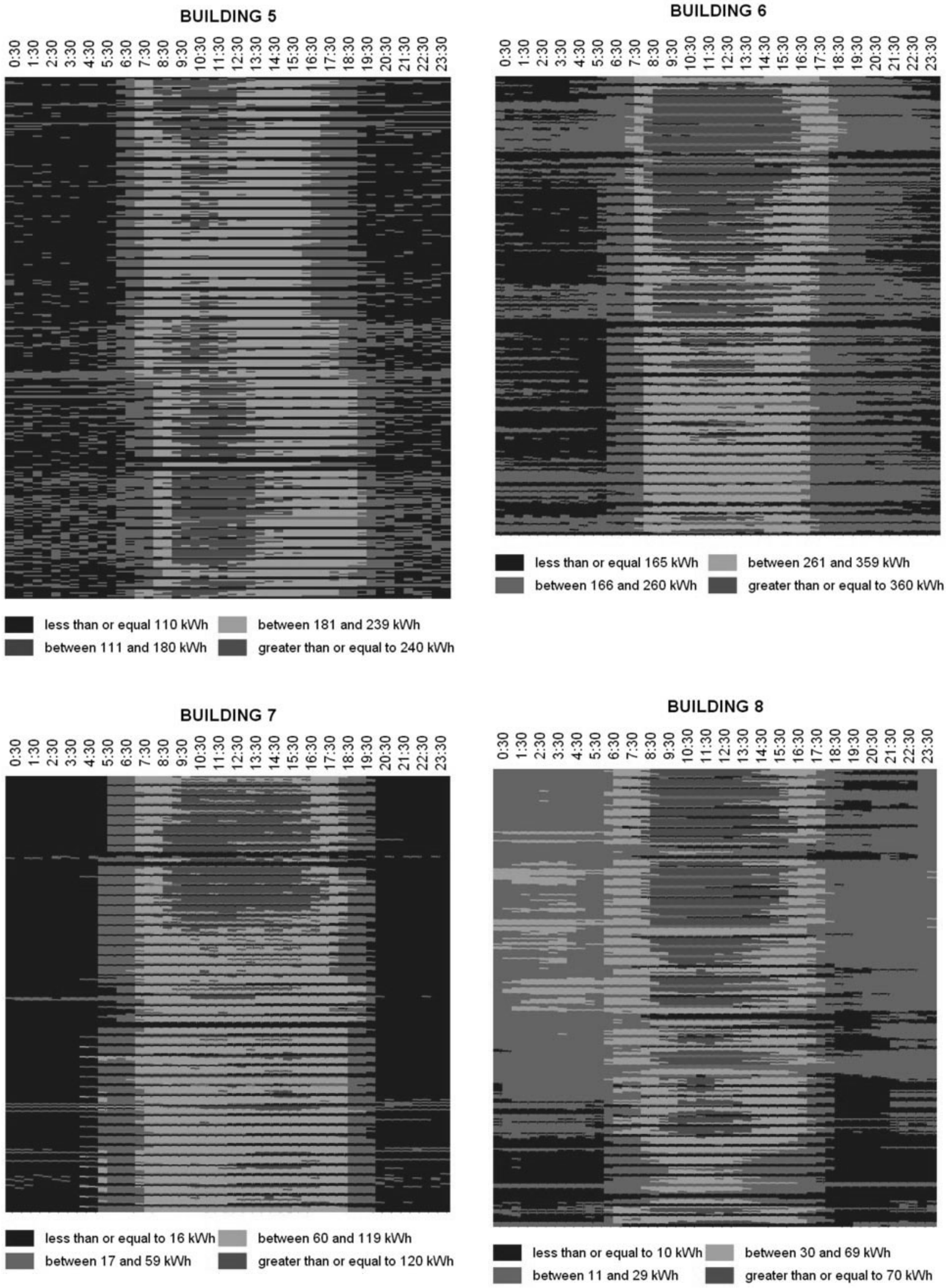


***Figure 2.*** *Contour maps (Continued) (Building 5 to 8).*

Interpretation of the contour maps could identify:

**Building occupancy periods**, assuming that the occupancy starts when the demand is above the base load, which is represented by blue. It is possible to identify:

- *Working hours* in green, orange and red colour.
- *Working days*, horizontal lines in which colours change throughout the half-hourly periods of the day. It is possible to identify non-working days such as weekends and holidays, because the corresponding lines have the same colour, which under normal conditions would be the blue.

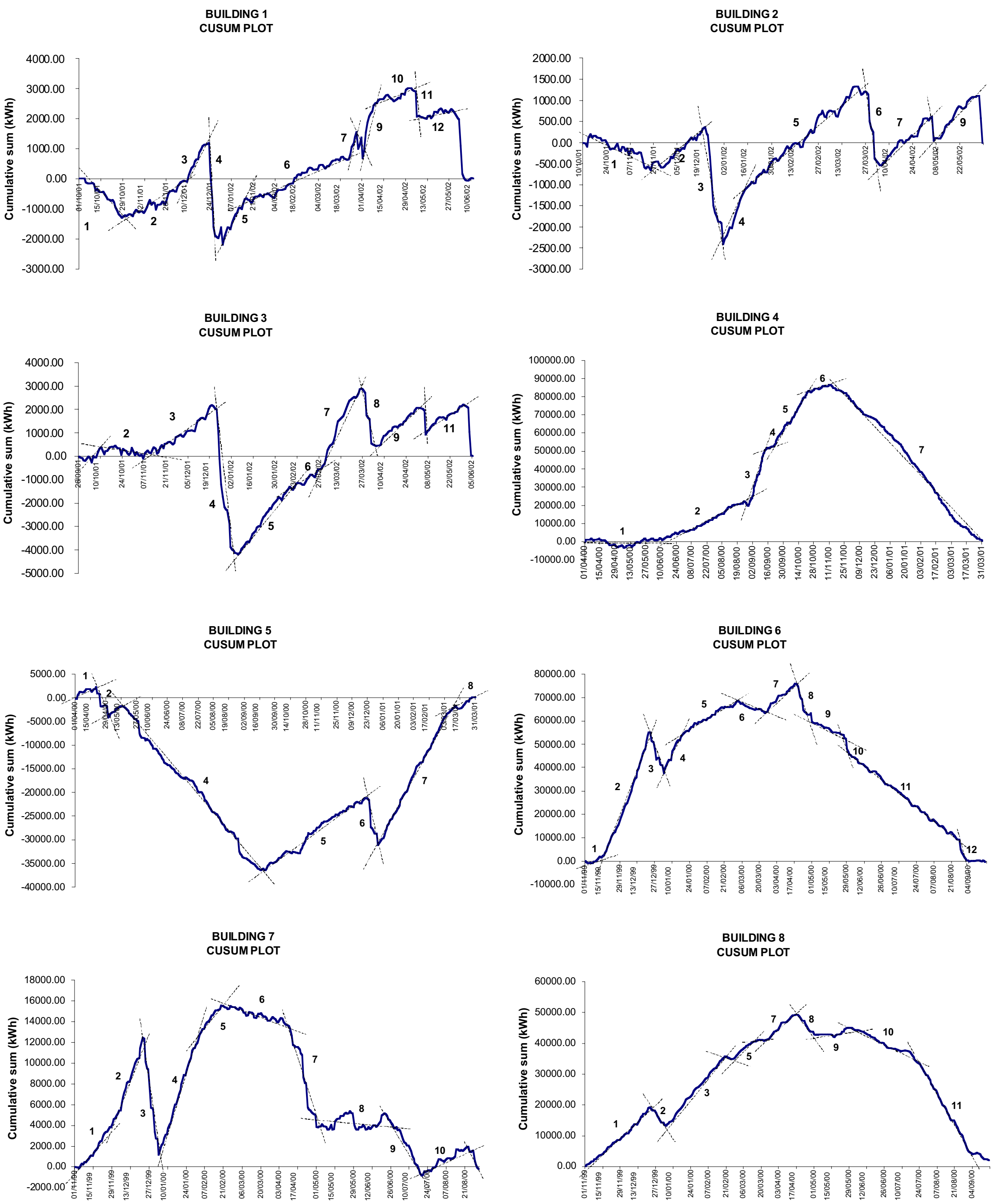


***Figure 3.*** *Recurrent CUSUM plot (Building 1 to 8).*

**Detection of changes expected the typical demand pattern** (weekly profile). For example:

- *Electricity consumption above a typical maximum demand* (in red), which is considered to be the peak value in the average demand profile graph.
- *Periods when the base load level was exceeded during the night or over weekends* (in blue). These are presented as horizontal lines crossing the map side by side. The clearer example of this type is shown in building 2 and 4 contour maps.
- Shifts in the day time pattern of energy consumptions demonstrated in building 6, where the afternoon peak differs between the two halves of the total period studied.

### CUSUM ANALYSIS

The CUSUM analysis consisted of comparing one period with another. Therefore the baseline for CUSUM had to be the average consumption for each day of the week – that is a recurrent baseline. The type of information that can be derived from CUSUM plots, consists on:

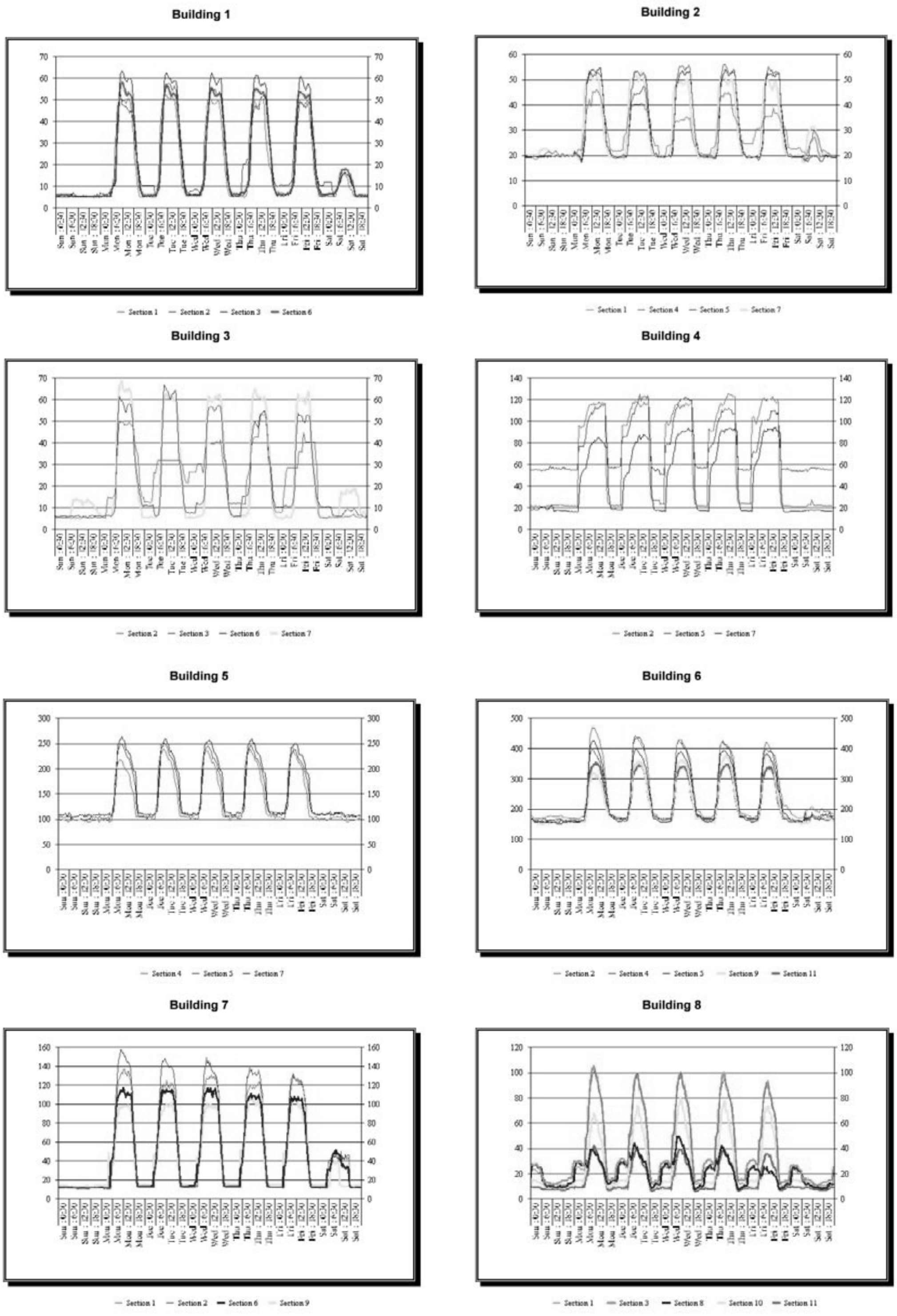


***Figure 4.*** *Comparison of weekly profiles from different CUSUM sections.*

**Accurate identification of different consumption patterns** on daily electricity demand throughout the entire set of data:

- Periods of untypical high and low consumption, between kinks of the CUSUM plot. For instance in Figure 3 plot it is possible to identify 6 events and correspondingly 7 periods, i.e. sections in the plot, which have different consumption patterns – Table 3 that refers to building 4 in Figure 4.
- The converse to teasing out differences in electricity demand is to identify those periods where consumption is similar. This can be done through examination of the slope associated with each plot. Where slopes are at a similar angle, then the weekly electricity consumption is of the same pattern. This can be found for sections 5, 7 and 9 in building 2 CUSUM plot.

**Immediate quantification** of over consumption for each of the periods/sections/patterns from the baseline. This can be

**Table 3. Identification of changes in energy consumption associated with building 4.**

| | |
|---|---|
| Section 1 | 01/04/2000 to 10/06/2000 |
| Section 2 | 11/06/2000 to 29/08/2000 |
| Section 3 | 30/08/2000 to 16/09/2000 |
| Section 4 | 17/09/2000 to 23/09/2000 |
| Section 5 | 23/09/2000 to 28/10/2000 |
| Section 6 | 29/10/2000 to 12/11/2000 |
| Section 7 | 13/11/2000 to 31/03/2001 |

done directly on the CUSUM plot by calculating the vertical distance between the kinks. For example, during the period represented as section 3 for building 4 (30th August – 16th September, 2002) electricity demand was 30 000 kWh over what could have been expected.

Combining CUSUM and weekly demand profiles give a greater insight into the electricity consumption patterns of the office buildings. For example,

- Identification of specific changes in the daily and weekly demand profiles that may lead to variation in consumption patterns, previously identified by CUSUM plots.

In building 4 one period has much higher base load compared to the standard. During this time the base load rises from approximately 20 kWh per half hour (40 kW), to in excess of 50 kWh per half hour (100 kW). Peak demand during the daytime is however indistinguishable from the variations associated with the other periods.

Buildings 1 – 3, 7 and 8 reveal some activity taking place on Sundays. This is not in evidence in the other buildings. These differences in weeklong profiles may have very reasons underpinning them and demonstrate the usefulness of the analytical approach in defining specific patterns on a building-by-building level.

### DISCUSSION

Three different techniques have been applied to interpreting short time series energy data associated with office buildings. The purpose was to determine the usefulness of a remote analytical approach to data analysis as a first step in the energy auditing process.

Energy consumption profiles are a powerful technique that reveals typical energy use patterns across a weeklong time span. The average profiles during a week can be computed for any extended period of time. Through this process, the electricity consumption associated with base load, shoulders where they exist, peak daytime consumption, and possible weekend activity, can all be assessed. This procedure develops a "profile" of energy use for specific buildings. Similar buildings with similar activities will have similar profile shapes. Actual electricity consumption loads will vary according to other factors, such as total floor area, occupancy and size of the business. However, because of the relatively common shapes of the weekly profiles, it becomes very simple to identify occasions when electricity demand may be uncharacteristic. The benefit in this particular analytical approach is that values of demand are also computed onto the same chart. Thus similar buildings with similar activity and size can be contrasted by overlaying their profiles. Differences in electricity consumption are directly comparable and with specially designed software can be quantified to establish the potential energy savings.

Contour maps are an effective means of viewing all the data associated with any building. These depictions of energy consumption will immediately identify periods of consumption that at first do not appear to fit the norm. This is possible as the approach identifies base load energy consumption attributed to night time demand and quiet periods of building use, such as weekends and holiday. Peak daytime consumption is also highlighted and the day length over which the building is mainly occupied or the main business operation takes place. Where consumption becomes uncharacteristic, a clear indication is revealed. In the case of building 4 from figure 2, the extended night time energy consumption that starts mid way through the period analysed has been determined through further investigation. A faulty electrically powered appliance was left operating night and day. The resultant high consumption in electricity use would be masked during normal working hours, but is clearly in evidence using the contour mapping approach that reveals all data.

CUSUM is a more sophisticated approach to the analysis of time series electricity data. The process adopts a more complicated analytical procedure to determine when exactly energy consumption within buildings alters. This process attaches a date to when these changes have occurred and also indicates how frequently different demand periods have taken place. From these plots it is possible to identify which periods have similar energy demand profiles from those that have different ones. In this way, cyclical periods of consumption are identified which include seasonal variations in demand, as well as special events, such as low-level activity during holiday periods. It is perhaps more difficult to interpret the data from CUSUM plots if the viewer is not trained at the process. For this reason the other visualisation techniques offer better understanding to the untrained eye of when potentially high electricity consumption has taken place. However one significant benefit underpinning CUSUM is that it quantifies the amount of energy that has been used and thus the potential excessive demand.

The three techniques all have their own advantages. When CUSUM is utilised alongside profiling so that profiles of different periods are over layered, particular benefits are immediately seen. Variations in energy consumption in any building are quantifiable for different periods. This will monitor the differences in demand across seasons, between busy and quiet periods of operation, but when used across a number of years will also assess performance during periods where no significant variations in demand are expected.

## Conclusions and recommendations

Applying any of these procedures before undertaking an expensive site visit can provide additional information for an energy auditor. However, to make the energy audit/survey process more cost effective, the analysis should be completed both rapidly and cheaply. Using a combination of weekly demand profiles and CUSUM, it is possible to identify different weekly consumption patterns at specified different times of the year. Armed with this information the energy auditor can enquire the building the manager and the users questions about these specific time period to determine why the weekly profiles should be different. Such an approach can make the energy audit more cost effective by focussing the auditors' time on the changes analysed for at least the previous year. The analysis of the half hour electricity data for the 8 office buildings suggests it could make the approach more cost effective. Further work is needed to analyse the gas and water consumption and to identify the weather and production related consumption in a wide range of different buildings.

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