Analysis of Building Electricity Usage through Clustering

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1. Introduction

For small to medium businesses (SMBs), profit margins are razor thin and they actively look out for ways to cut costs. One way this can be done is by reducing electricity bills and operating efficiently. In order to obtain insights on energy consumption behavior, characterization of daily temporal patterns in energy consumption is performed. This analysis aims to answer questions such as:

- How much electricity is consumed on a typical operational day for the business?
- What patterns in consumption are observed and where can energy efficiency measure be implemented?

2. Dataset

The dataset that was used for this analysis contains aggregate electricity consumption (in kWh) for a single small business in 15 minute intervals over the course of a year.

A summary of the electricity consumption is shown in Table 1. From the table, it is clear that there is significant variation over the consumption in a 15 minute window. Hence, some part of the analysis was performed by normalizing the consumption over each day. This ensures that variation in consumption over days does not affect the analysis.

Table.1: Summary of electricity consumption for the SMB

Factor	Mean	Median	Q1	Q3
Electricity consumption	0.2031	0.09	0.04	0.21

3. Analysis

3.1 Explored patterns in daily consumption behavior

As a first step in understanding the patterns in consumption behavior, investigative sequence plots of the consumption over arbitrarily chosen days revealed that the SMB has times of peak consumption during 9 am – 7 pm (Fig.1). Which suggests that if the load could be shifted to off-peak hours, the business could benefit from TOU electricity prices. However, this process of understanding how the consumption looks like for a representative (typical) day for the SMB can be done systematically through clustering methods. This will be explored in the next section

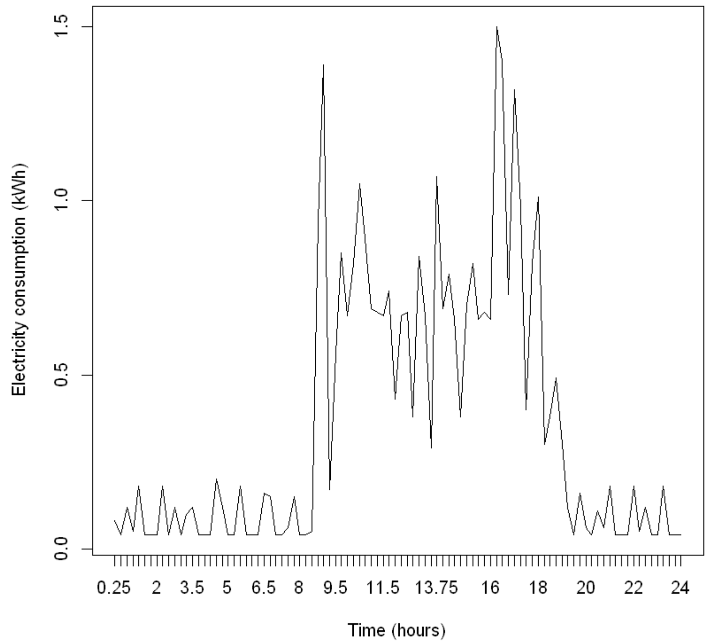

Fig.1 Plot showing electricity consumption of an arbitrary day for the SMB.

3.2 Clustering of normalized daily consumption

To be able to quantitatively understand what typical days of the week look like for the SMB, k-means clustering was used to cluster the 365 daily-consumption profiles into 7 clusters. Note however, this clustering was not performed on the raw data, but rather on the normalized daily consumption profiles (as mentioned in the section on the Dataset). This clustering, combined with the analysis of the histogram of these clusters for each day gave an insight into the type of clusters that best represent each day of the week. As shown in Fig.2, Cluster Type I, which is representative of weekends (Sat & Sun) and ~50% of Mondays; represents that largest proportion of days for the SMB. This figure shows a clear difference between how the business splits its electricity consumption on weekends and weekdays.

However, since the clustering was performed on the *normalized* daily consumption, only inferences regarding the most accurate representation of typical days can be made. To obtain insights regarding the difference in *quantity* of electricity consumed, clustering was performed on the raw data, which is detailed in the next section.

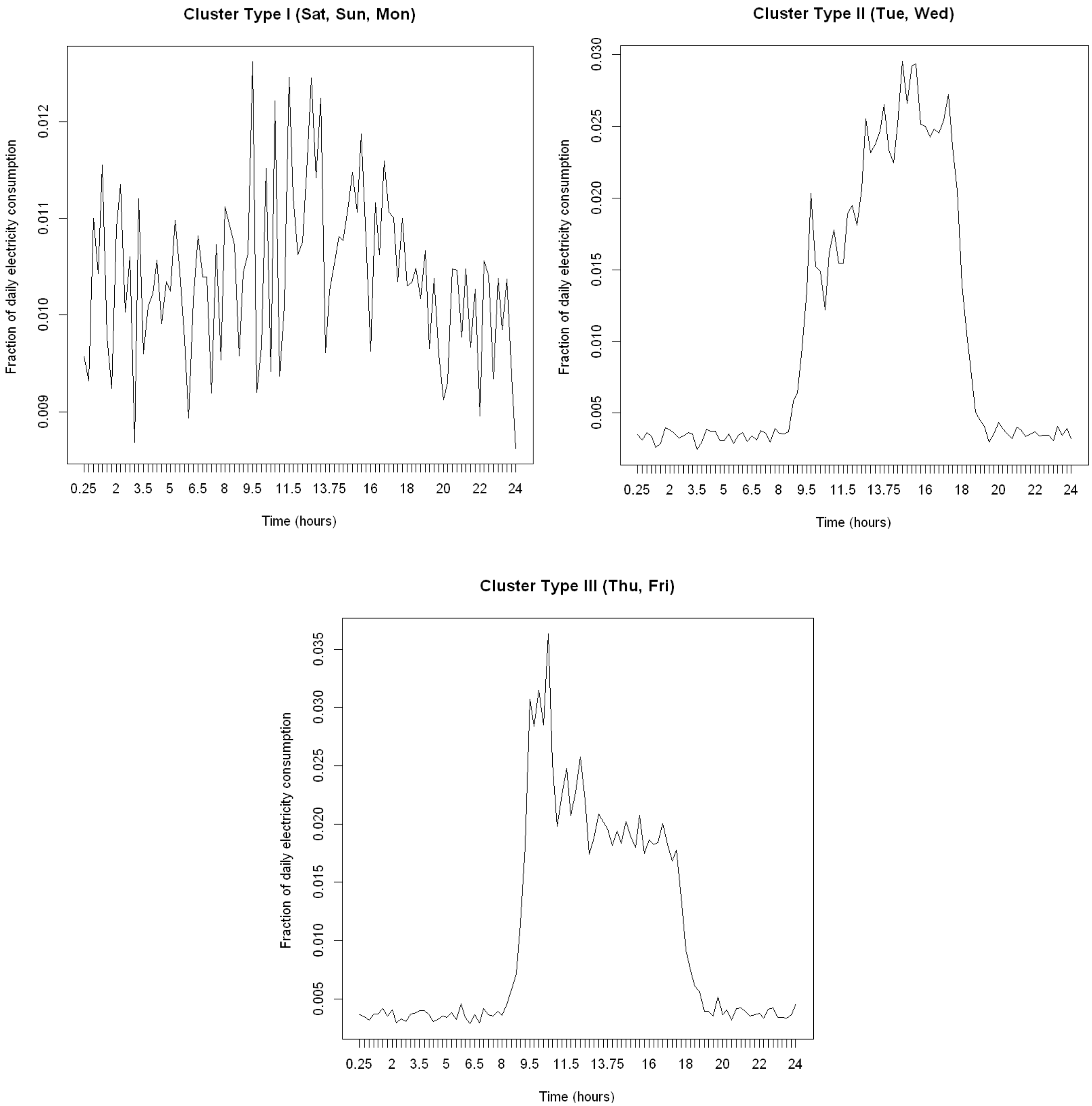

Fig.2 Plot showing the three representative normalized consumption profiles with the days they represent

3.3 Clustering of raw daily consumption data

To understand quantity of electricity the business consumes on weekends and weekdays, a similar clustering analysis was performed on the raw data. Through this analysis, it was inferred that the two specific type of consumption profiles (weekend and weekday), represented ~82% of all days with the weekdays having a higher proportion (~62%) of those days. These results (presented in Fig.3) indicate two main observations:

- The SMB has a non-zero baseload during operational days and weekends that contribute to its consumption, which suggests that the business could benefit from technological upgrades that lower these baseloads and reduce energy costs.

- Also, during weekdays, most of the consumption happens during the operational hours (9-7pm) which suggests that, if the business can perform some sort of load shifting to off-peak hours, it can benefit from Demand Response programs. Using large capacity storage systems to perform this load shifting (or even rate arbitrage) can provide significant savings in energy costs for the business.

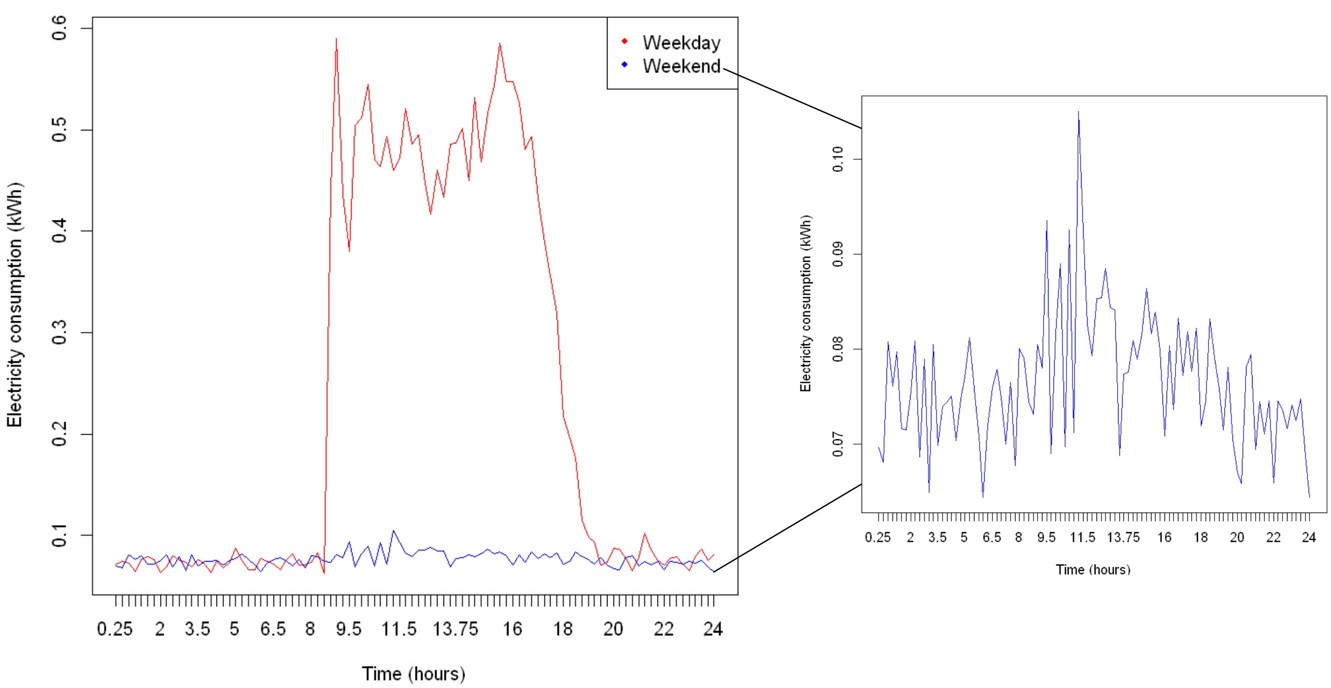

Fig.3 Plot showing difference in energy consumption during weekdays & weekends (left) and the non-zero baseload during non-operational days (right)

4. Conclusions

The analysis provided insights into the electricity consumption characteristics of the SMB over a year and the main conclusions are:

- The nature of energy consumption is different for weekdays and weekends.
    - The peaky nature of electricity usage during weekdays suggest that if load-shifting could be performed to off-peak hours (either organically or through energy storage systems), enrollment in Demand Response programs could offer significant benefits
    - The non-zero baseload consumption during weekends and non-operational times indicate that technological improvements such as efficiency upgrades or structural insulation can prevent inadvertent energy consumption, therefore cutting costs

Analysis of Electricity Usage per End-Use

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1. Introduction

In this section, an analysis of the electricity consumption behavior of commercial buildings is performed with the intent to understand patterns in usage based on end-use. The dataset used in this analysis contains electricity consumption (in kBTU) for over 5000 commercial buildings by different end uses. These factors such as heating, cooling, lighting etc. are analyzed using Principal Component Analysis (PCA) to determine typical combinations of end-use.

2. Analysis

The 9 different types of end-use that were studied are as follows:

Heating	Cooling	Water Heating
Lighting	Cooking	Refrigeration
Office equipment	Computer	Miscellaneous

A PCA was performed to infer the end-uses with maximum variation and the type of combinations of end-uses that could be expected to occur simultaneously. The results of the PCA, indicate that about ~94% of the variation in the dataset is represented by 4 factors: Cooling, Lighting, Computer and Miscellaneous. This means that the largest variations in the energy use come from these categories of end-use. This large variation is represented in Fig.4, where these four factors have significant outliers.

Furthermore, the PCA analysis revealed that only two effective components can be used to represent the variation in this dataset and they have a combination of end use as follows:

- The first component, which represents ~83% of the variation has a combination of Cooling, Lighting, Computer Usage & Misc. factors as end-use. This could represent the typical split-up of energy usage in an office building
- The second component, which represents ~11% of the variation has a combination of Cooling & Lighting as factors of end-use. This could represent a factory/warehouse where the major loads are cooling loads for the machines and overhead lighting. The fact that the Cooling component has a higher weight than Lighting further reinforces the idea of a warehouse

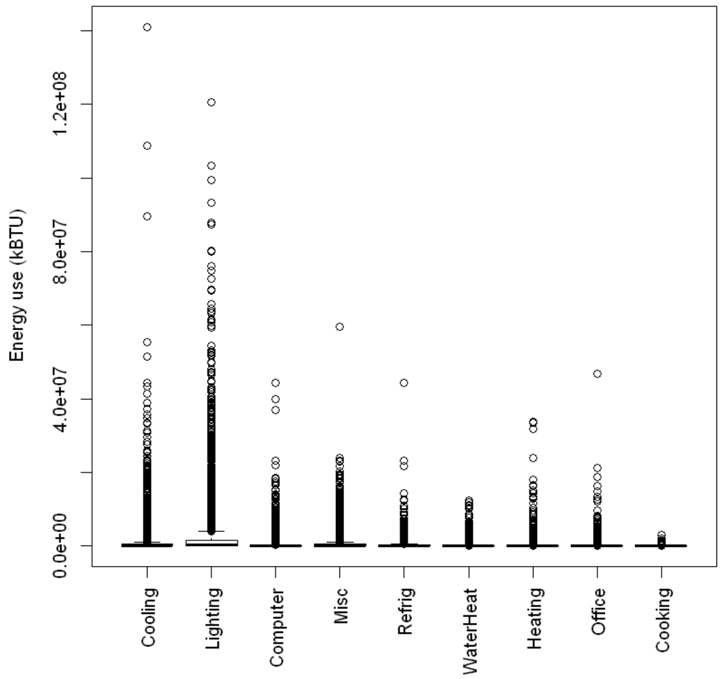

Fig.4. Boxplot showing variation in electricity consumption for each type of end-use

3. Conclusions

The brief analysis presented above indicate that energy usage for commercial buildings usually occurs as a combination of end-uses, with the following types:

- One type representing office spaces – Cooling, Lighting, Computer & Misc
- The other type representing warehouses/factories – Lighting and Cooling