

Energy Performance Visualization of Buildings

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Abstract—Electricity consumption of a building can be broken down into three different categories based on their end use. These categories are plug load, lighting load and mechanical load. This break down of electricity consumption is enabled by a Building Management System (BMS) which is powered by a collection of sensors in the building and a software. However, in the building management industry it is common to overlook the meaningful patterns and trends in the collected data due to a lack of proper visualization idiom. The Center for Interactive Research on Sustainability (CIRS) on the University of British Columbia (UBC) campus is no exception to it. The aim of this project was to design a visualization idiom that would give the managers of CIRS an insight into the energy performance of the building and also provide them with a better understanding of its consumption regimes. The managers identified four high level goals in the interviews conducted by me. The data collected from the building was visualized by the means of an interactive line chart, a pie chart and a day/hour heatmap. The interactive line chart and pie chart were designed to discover the overall trends along with knowing the contribution of different parts. The heatmap enabled the managers to look at what an average week would look like in the building. Lastly, the idiom was designed using JavaScript libraries, namely D3.js and highcharts, to grant the managers their last request to have it easily published on the web.

Index Terms— D3.js, Highcharts, CIRS, Heatmap, Interactive line chart, Pie chart

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INTRODUCTION

Availability of more energy performance data for buildings than ever before has raised the standards of care in term of managing them. Nowadays it is common to see the total energy consumption of a building broken down into three main categories, namely mechanical load, plug load, and lighting load. However, the values for these categories are commonly reported as cumulative annual numbers which do not represent the trends and patterns in the data at a finer scale. This design study with a real client and a real problem had the objective to showcase the power of proper visualization in deriving useful information from large datasets created by energy monitoring sensors of a building. A building on the University of British Columbia (UBC) campus was identified as the source of data for this project. This building, called the Centre for Interactive Research on Sustainability (CIRS), has a powerful system in place which records minute-by-minute data from the electricity panels installed in the building.

The data from these panels is broken down into three main categories, namely plug load, lighting load, and mechanical load. As this building is renowned for being a sustainability living lab there was an interest from the building managers to be able to better understand and optimize its energy performance. A rich dataset along with a lack of a proper visualization seemed the perfect match for a visualization course project.

After conducting interviews with both the Green Building manager and the operations manager of the building, four high level goals were identified to be addressed by the visualization. The goals were:

- Discovering overall trends in consumption in specific areas of the building
- Knowing the proportion of each space
- Understanding what an average week looks like in specific areas
- A web-enabled tool

To accomplish these goals, I designed an idiom which consists of an interactive line chart, a pie chart, and a heatmap. JavaScript libraries such as D3.js, Highcharts, and Bootstrap were used to implement the design ideas. It is worth noting that the data for only plug load and lighting load was used and mechanical load consumption was left out due to the complexity surrounding the mechanical system running in the building. The available data for this project was from January 2016 to October 2016.

1 RELATED WORK

In order to be able to extract useful information from large datasets created by energy monitoring systems installed in buildings, two different aspects have to be considered: (I) Break down of the data with respect to its end use and (II) a proper visualization that addresses the concerns of the manager.

1.1 Break-down of the data

As an attempt to gain a better understanding of how the Centre for Interactive Research on Sustainability (CIRS) is performing, the total energy consumption of the building was broken down into plug load, lighting load and mechanical load[1]. An extensive work was done to break down the electricity consumption into its end use and put it into three categories of mechanical load, plug load, and lighting load. However, a poor choice of visualization has made it difficult to extract useful information from the cluttered graphs.

1.2 Proper Visualization

A close look at the needs and requirements of the building operators and managers is taken and even a prototypical visualization is introduced to address those requirements [2]. In short, two of the requirements of a proper visualization that help the building operators and managers are as follows:

- High-level overview with drill-down capabilities, including visualization of end-use energy information including lighting, plug loads, and HVAC components
- Support for normalization

1.3 Matches and Mismatches

In an attempt to address the need for a scalable and effective visualization tool to analyze the energy performance of large building portfolios, a number of visual encoding choices were introduced in collaboration with the domain workers in terms of matches and mismatches[3]. Use of a calendar matrix of energy intensity was proposed as a potential match to address the need for a high-level overview. Faceted bar charts were introduced to facilitate drilling down to more details. Interactivity played a vital role in facilitating different views. Also, it is worth noting the domain conventions among the energy workers which dictated

design choices such as line graphs for raw energy demand or their unfamiliarity with the term heatmap.

2 DATA ABSTRACTION

There are 27 electricity panels installed in the building. Each panel is responsible for distributing electricity to a different part of the building. The name of each panel encodes both the location and the end use of the distributed electricity. There are three different categories of electricity consumption, namely plug load, lighting load, and mechanical load. For the purpose of this project 12 panels responsible for only plug load and lighting load consumptions were taken into consideration. The data from these panels were given to me in form of Excel workbooks. In total, there were 10 workbooks each approximately 160 MB. A screenshot of one of the workbooks is given in Figure [1].

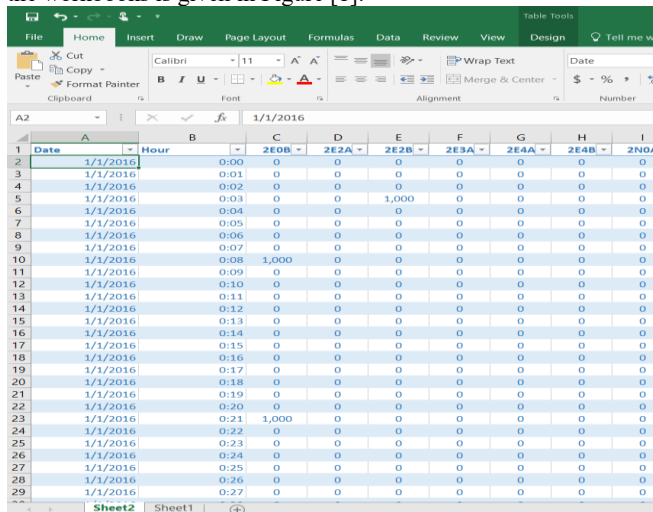


Fig. 1. A typical workbook with the data.

The first row of each workbook is the date, hour, and the panel names. The following rows with the date and hour headings are time in minute-by-minute increments starting from 12 am January 1st 2016 until 12 am October 31st 2016. Starting from the 3rd column, where the panel names start, one can read the relevant consumption of each minute in the day for a particular panel in kilowatt hour (kWh) units. It is worth noting I put a lot of effort and time into making this workbook look like what it does in Fig [1]. The previous version of this workbook showed some cumulative numbers for each minute and in order to calculate the minute-by-minute consumption of each panel I had to subtract the value in each row from its following row. Moreover, there was a column next to each panel name which showed the quality of the data recorded at the time it was read. A “BAD” quality meant that the data could not be used for calculations. Therefore, I had to check all of the panels in all of the workbooks and cross out the data with a “BAD” quality tag. Then I had to replace the crossed-out data with its neighboring values.

The panels of interest were the ones responsible for the office spaces in the building, the café, and appliances such as fridge and dishwasher in the building.

To put it in context, the dataset type is a table with static availability filled with time-series data. Attribute types are categorical for the panels names and quantitative for the time and values of each panel. The values of each panel come in sequential ordering and the hour time in cyclic ordering.

2.1 Type of Input Data

Two file formats were chosen as inputs to the tool and the initial data which was in the form of excel workbooks was changed to match the two formats. One CSV which is used for the line chart and 6 separate TSVs which are used as inputs to the heatmap. The CSV files were made after cleansing and aggregating it as mentioned in the previous section. The TSV files were generated after calculations using Microsoft Visual Basics were done by me on the cleansed data. The calculations were aggregating the data based on hour of the day. For instance, the values for all Mondays at 11 am were aggregated together. Then I took an average of this value among all Mondays in the dataset. Special holidays were not counted in this calculation so that the numbers would be more representative of an average week in the building.

3 TASK ABSTRACTION

I conducted several interviews with both the Green Building manager and the operations manager of the building to clearly identify what they wanted to see in the final visualization that they were unable to do so at that time. Four high level goals were identified as a result of these interviews. These goals are:

- Discovering overall trends in consumption in specific areas of the building
- Knowing the proportion of each space
- Understanding what an average week looks like in specific areas
- A web-enabled tool

To put the identified goals in context of actions, I abstracted the tasks as discovering, exploring, identifying, and summarizing. The targets of these actions are trends and features in the data.

4 SOLUTION

After abstracting the tasks and data, I started sketching my ideas and getting as much feedback as possible from my client. After a number of iterations, I finalized the design. It is a dashboard with three different sections which you can see in Figure [2].



Fig. 2. Overview of the idiom.

The upper section is an interactive line chart along with a pie chart which are the most expressive and effective means to show the overall trends and proportionality, respectively. As the main goal of the line chart is to show trends, it was preferred to other alternatives such as bar charts.

One can easily switch between viewing plug load or lighting load by clicking on the relevant icons on the upper left corner of the screen. Upon clicking plug load, for instance, both the line chart and the pie chart is updated to show the data for plug load consumption. The vertical axis for the line chart shows consumption in kWh unit and the horizontal axis stretches from January 2016 to October 2016. The pie shows proportions of different categories compared to the total in percentage coded by both size and color.

Clicking on the legend of the line chart will show the item that was clicked on or remove it from the graph. In both cases, the axes of the graph are adjusted to the values of the present items. The line chart is both coded by shape and color for different categories. Both hues and shades were used for color coding. The reason for coding the data both by shape and color is that the person using the tool would be able to easily identify the same categories across both the line and pie chart without the need to read the notations on the pie chart. Also, when one hovers over the line chart or the pie chart a tooltip pops up which shows the information of the relevant section of the chart.

The lower section of the screen is dedicated to the heatmap. This sections shows what an average week looks like in the building. There are 6 tabs provided below the map which enables the user to switch between different spaces in the building. The managers of the building specified these spaces to be of high importance to them in term of their average weekly usage. The vertical axis is dedicated to the days of a week from Monday to Sunday. The horizontal axis shows different hours of the week from 1 am to 12 pm. The value of each square is the average value of that hour of that day for the time period of available data. For instance, a value of 100 for Monday 11 am means that on average Mondays at 11 am 100 kWh of electricity was being used in that space. There is a tooltip that pops up when you hover over the map showing the relevant value of that square in kWh. I designed three bins for the heatmap with sequential color coding. The values of the bins differ when switching between tabs. The first value is the minimum value, the second one is 25% of the difference between the maximum and minimum value, and the third one is 75% of that range. These values were specifically required by the managers and the reason to go with a sequential color coding approach is that there was no interest to know the difference in value in those buckets. The managers were mainly concerned about only in which bucket the value falls into.

To summarize, the data was encoded by means of aligning and expressing. Color coded with hues and shades. Also shape and size were used as other means to encode the data. In terms of manipulation, the options of selection and hover is given to the user. The facet of the tool is a juxtaposed view which used filtering and aggregating to reduce the data.

5 IMPLEMENTATION

To implement the proposed solution, I chose programming and coding over using existing softwares such as Tableau for two main reasons. First being my goal to learn coding for visualization and second being the fact of the flexibility of coding with regards to heatmaps.

I used JavaScript libraries to implement the design ideas. The libraries are as follow:

- D3.js
- Highcharts
- Bootstrap
- jQuery

D3.js was used to make the heatmap while Highcharts was used for the line chart and the pie chart. Bootstrap was used to manage the juxtaposed the views along with jQuery to enable the interaction such as switching between plug load and lighting load.

In terms of the heatmap, I used a prewritten block but had to adjust the buckets values via writing general formulas which would work for all of the tabs. The colors, sizes, and categories had to be changed from two existing blocks in Highcharts. Also, as most of the blocks used data that was written in the codes I had to borrow the concept of reading csv files that I learned while working with D3.js and apply it to Highcharts which enables the tool to adapt to changes to the input files as long as they follow a certain ordering and are in CSV format.

6 RESULTS

Discovering overall trends in consumption was identified as the first goal that this visualization has to achieve. In order to achieve this goal an interactive line chart was developed. First the user has to choose between viewing plug load or lighting load. Upon clicking a line chart and a pie chart will appear on the screen as seen in Figure [3].

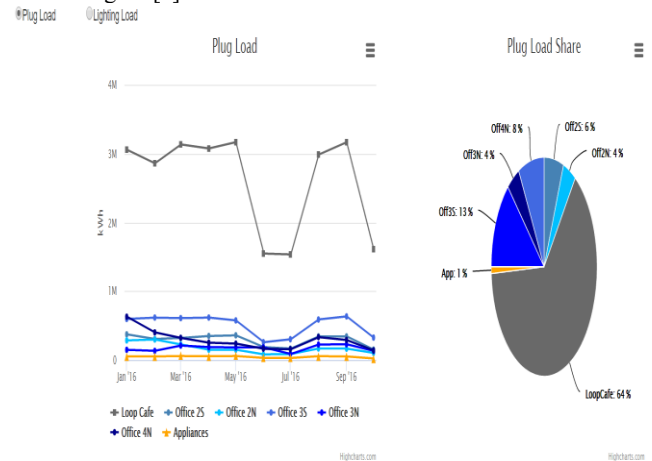


Fig. 3. Interactive line chart alongside a pie chart showing the plug load consumption.

The visual clutter seen in the bottom of the line chart is easily solved by clicking to remove the line with the highest values from the legend. Doing so will result in a view as in Figure [4].

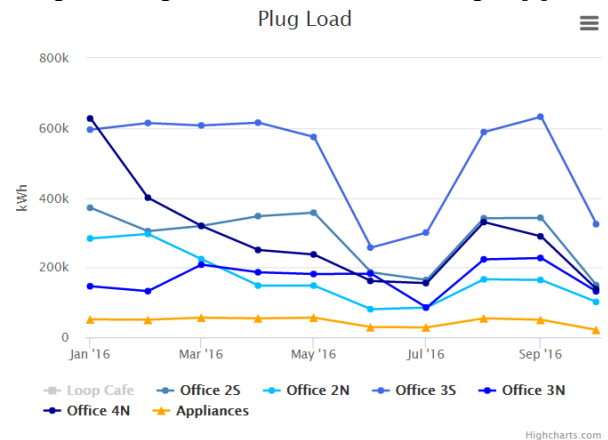


Fig. 4. Interactive line chart showing the plug load consumption with one of the lines removed.

It is worth noting that tooltip functionality is enabled for both the line chart and the pie chart as seen in Figures [5] and [6].

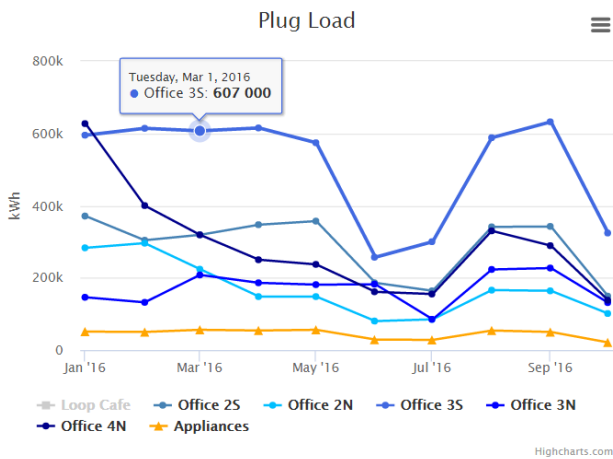


Fig. 5. Interactive line chart showing the plug load consumption with one of the lines removed and tooltip.

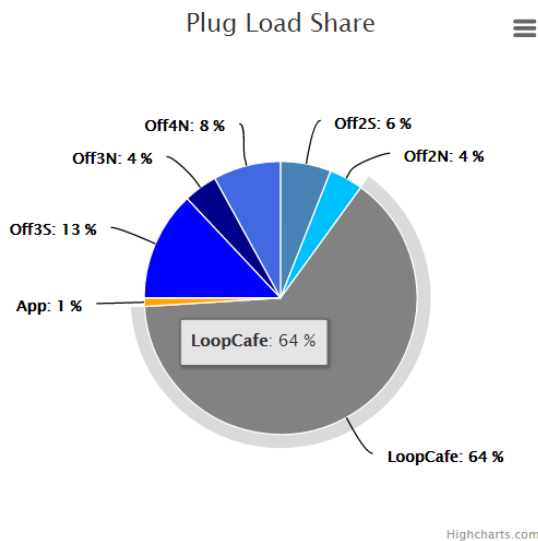


Fig. 6. Pie chart showing the plug load consumption and tooltip.

As it can be seen in Figure [6], the second identified goal of the tool which was showing proportionality is achieved by the use of a pie chart.

If the user wants to investigate consumption regimes for an average week in the building, they need to look at the heatmap provided on the bottom of the screen. As it can be seen in Figure [7], 6 tabs are designed which shows the data for 6 different places of the building. The café and office spaces on different floors.

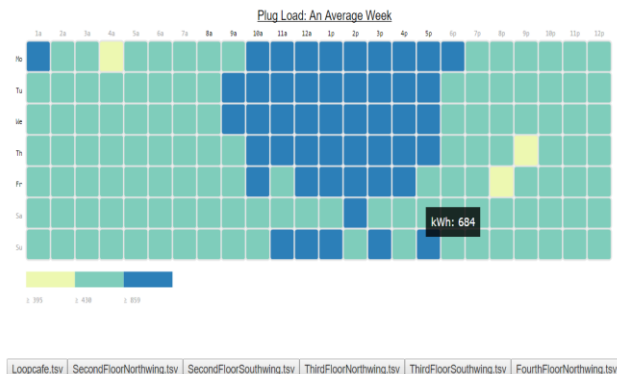


Fig. 7. Heatmap with tooltip.

The same tooltip functionality is enabled for the heatmap.

7 DISCUSSION AND FUTURE WORK

One of the main strengths of this tool is interactivity which has accommodated two different categories of consumption such as plug load and lighting load on a single screen and also helped solve the previously inevitable visual clutter. However, absence of linked highlighting which is an important aspect of juxtaposed facets is clear. It was initially in my designs but due to lack of time and coding knowledge I had to abandon the idea. I tried to link the two upper charts by means shared color coding. Moreover, a cross filter option such as a slider on the line chart that would update the heatmap in return was initially thought of but further left out of the project due to time. Also, the idea of having a schematic representation of the building was brought up is one of the peer project reviews but I never got the chance to implement it.

This project was a great learning experience for me. First, I came to know that data cleansing can consume much more time than I anticipated and much more tedious than I thought. Second, learning D3.js and some jQuery was one of my goals of this course which I did accomplish and hope to continue learning in the future. If I had more time I would have added the linked highlighting feature between the views and the slider. Also, I would have added a floor plan of the building with annual values projected on different parts of it.

8 CONCLUSION

I started this course with the goal to improve the business as usual in the visualization of electricity consumption in buildings and took my workplace building as the source of data. I had the opportunity to interview two managers of the building for several times and viewed them as my client. I designed a tool that achieved the goals specified by them and learned to use JavaScript libraries as well. Despite the shortcomings of the tool it is a great step forward for my client towards a better understanding of the regimes of the building electricity consumption and a stepping stone for me to venture into the visualization field.

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