Household Energy Management Application

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ABSTRACT

Our household has been getting filled with more and more electrical energy using devices. When electrical appliances appeared, they were very expensive and not widely available, but then, as mass production enabled them to be more widespread, people began to acquire electrical equipments to do all sorts of tasks. This led to a great increase in energy consumption and, nowadays, we have our home’s utility completely dependent of electrical energy. This energy is most of the times consumed arbitrarily and without taking into consideration any kind of good practice. In this work, this issue is addressed and both passive and active management of energy consumption is promoted. This is done through past consumption data visualization, which displays the past usage of energy by the equipments, and through equipment usage scheduling, to better optimize the energy consumption on each household. This will enable the end user to get a better understanding of what is happening in its household when it comes to electrical energy consumption (and production, if available) and provide the tools to make better use of the energy contracted to the energy distribution company.

Keywords
Energy management; Scheduling; Household; Power generation; Power consumption.

1. INTRODUCTION

Due to the fast-paced evolution of technology we have been witnessing in the last decades, and the consequent creation of machines to do almost all of the tasks we usually do at home, our households have been filling with more and more devices to do the things we would otherwise have to do by hand or with the help of some mechanical and labour intensive tools.

This increment in electricity powered devices requires the energy generation and distribution infrastructure to keep up with the demand and the companies running it have been adapting to the growing requirements of the population. These companies have been creating some incentives to manage the energy usage in the household such as promoting the usage of high energy consuming devices during low overall usage time frames.

1.1. Problem definition

These kind of initiatives being promoted by the energy distribution companies are good for both the consumer, who gets some kind of discount in the price of the electricity used in those special time frames, and the energy distribution companies, who get their overall energy consuming balanced between usual high usage periods and usual low usage periods, thus enabling a more constant and balanced flow of energy from the production and storage facilities to the final consumer.

While these initiatives are good for the consumer, they present some challenges such as the difficulty for the consumers in the household to manage their energy expense between the usual high usage periods and the low usage periods. The reason for the “low usage periods” to happen is a direct result of this difficulty to manage and balance the energy consuming times in the household.

Some electrical devices are not exactly suitable for this kind of management, as they need to be used “in real time” such as lamps, the television or the kitchen oven. These devices can only be managed by the end user, with action such as avoiding leaving the lights on when there is no one in the division.

There are some electrical devices which can be managed to turn on only when the electricity price is lower. These devices include the clothes washing machine, the dishwasher and every other device that doesn’t need human interaction in real time to perform its function.

Additionally, we can find energy producing devices in the household, such as solar panels and wind turbines generators.
This multitude of device types and behaviors makes the energy management of the household a very complicated task to perform and optimize, in order to lower the energy costs.

1.2. Solution objectives

The objective for this work is to develop an application that will help people managing the energy expense and optimize it, accounting for the cost saving initiatives of the energy distribution companies and the potential energy production in the household.

This will be done through a web application, suitable for both desktop and mobile usage, that gets data from the household electrical devices and uses it to predict and schedule future usage in order to optimize the overall expense.

1.3. Document structure

In chapter 2 I will begin by showcasing some of the currently available energy plans and energy management equipments for the household, both made by the energy distribution companies and by different manufacturers. I will also present the features, benefits and defects of the technologies selected to implement the project.

Afterwards, in chapter 3, I will focus on a single energy management solution, listing its features and defects so that we can have a baseline comparison for the project.

Then, in chapter 4, I will describe the implementation of the project. From the data model with all its classes containing the values to be used on the application, to the backend where the calculations and data generation occurs to the frontend where there are graphs and organized data for the user to manage its household energy expenses.

Chapter 5 contains a display of results from the implemented solution, showing if and how it fulfils its objectives of providing a good way to manage the energy in a household.

The conclusion of this work happens on chapter 6, where I present some possible future work as well as an overview of what has been achieved.

2. RELATED WORK

In this chapter, we will explore some of the concepts directly related to the project work. From the energy distribution companies, which provide the mains source of energy to be used in the household, to the current available options of household energy management applications and finishing with the technologies to be used in the project itself.

2.1. Energy Distribution Companies

There are 4 main energy distribution companies currently operating in Portugal, all of them regulated by ERSE (Entidade Reguladora dos Serviços Energéticos) [1]:

- EDP (Energias de Portugal) [2]
  - The company with the biggest client share (76.8% [3]) in Portugal;
  - Portuguese company;
- Galp [4]
  - Has a 5.6% [3] client share;
  - Portuguese company;
- Endesa [5]
  - Has a 5.7% [3] client share;
  - Spanish company;
- Iberdrola [6]
  - Has a 5.7% [3] client share;
  - Spanish company;

All of these energy distribution companies have multiple taxing plans, some quite simple while others have different taxation based on the day of the week and time of the day.

In EDP’s bi-horary plan there are two options of usage type. The first one is weekly based, changing according to the semester of the year, and depending on the day of the week there will be a different scheduling of high/low cost of energy. The second option is a global daily plan, disregarding the time of the year and even the day of the week, this plan has the same scheduling for every day of the year.
In the low usage times of the selected scheduling the user will have the electricity sold to him at a discounted price, whereas in the high usage the price of the electricity will be higher. This helps the energy distribution companies manage the overall energy usage by their clients, giving the said clients an incentive to use their equipments in a time where most of the population will not be using theirs. Even if everyone used this kind of energy usage scheduling, there would always be high and low usage times, such as the daily usage from the workplaces and the “prime-time” nightly usage time.

Those energy usages can not be rescheduled but some others can, much like what is done in this project in a smaller household scale.

This project is independent of the energy distribution companies and enables the user to adapt its functionality as needed depending on the contract celebrated with the respective company.

2.2. Household Energy Management

The energy distribution companies from section 2.1 have multiple ways of managing the energy consumption, from different energy plans that promote energy usage in globally low usage hours to simulators that find the best plan for your household to even energy management solutions.

The problem with those is that since they were made by a specific company, they only include options of that same company and, in the case of the energy management solutions, force you to buy equipments that will be rendered useless if you change to another company.

There are some energy distribution company independent services and products such as the following:

- Energy plan simulator [7] by ERSE (Entidade Reguladora dos Serviços Energéticos) [1]:
  - A simulator that tries to find the best energy plan for your household;
  - Made by an independent entity;
  - Includes all major energy distribution companies;

- Eve app [8]:
  - An application that lets you control your household energy;
  - Requires the use of Eve own brand equipment to be manageable in the app;
  - Closed system;

- Sense energy monitor [9]:
  - An energy monitor installed in the home’s electrical panel that provides monitoring;
  - Only monitors, does not let the user control the appliances;
  - Closed system.

As we can see, these kinds of options, while useful in their own way, don’t give the user the ability for the user to manage its household energy usage in a cheap and modular way.

The most complete solutions, although possessing the capabilities of displaying usage dashboards and providing remote control of the household equipments, require the user to keep buying their solution’s ecosystem approved management equipments, such as outlet sensors or full on electrical appliances.

None of them provides a management interface that can interact with all kinds of equipments without regards for the model and specially, the brand.

This open to all brands and models solution is what this project aims to achieve.

2.3. Tools and Frameworks

The selected tools and frameworks were selected due to their widespread availability and community and also because of their good performance.

2.3.1. ASP.NET Core MVC

The ASP.NET Core MVC [10] is a framework created to help developers in building web applications using the Model-View-Controller design pattern. This design pattern aims to separate the responsibilities between these three areas. The model represents the state of the application and all the business logic and operations. The view is the part responsible for creating an user interface for the user to see. The controller part guides the workflow of the application, so that it knows which view to show the user. Being based on .Net Core enables the application to be served from devices with various operative systems (Windows, mac OS and Linux [11]) and therefore making it widely available.

The application also makes use of dependency injection [12] which is a software design pattern that enables (among other things) the project’s classes to depend from interfaces instead of actual implementations, making the process of changing dependencies really easy and without the need to change the dependent class.
2.3.2. Bootstrap

This framework, namely in its 4th version [13] enables the application to be easily responsive and to have a coherent style throughout. It includes styling and functionality in a single, simple to use and well documented [14] package. It is also free to use, with a huge community to help in case of any doubts.

The overall style of the application is based on bootstrap components [15]. It also makes use of some JavaScript functionalities included in it to make the application behavior more dynamic [16].

2.3.3. Chart.js

The Chart.js framework [17] makes it simple to create informative and functional graphical presentation of data. With the data being sent from the backend to the frontend, this framework enables the application to render a nice and easy to read chart for the user to visually gather information from.

The used chart was the stacked line chart [18], containing multiple equipment usage points over time.

3. SOLUTION DESCRIPTION

To demonstrate the proposed functionalities, I developed a web application with three main components.

The first one is the data model, a standardization of all the input data from the multitude of devices from all over the household, which can be of different brands and/or models.

The second one is the server side, or backend, which aggregates the available data in order to process and generate new data to be used by the client side of the application.

Lastly, the client side, or frontend, displays information through numerical and graphical visualizations, so the end user can access the information in a useful and simple to analyze way, in order to optimize the energy management at home.

The overall architecture is displayed in the following image:

![Architecture Diagram]

3.1. Data Model

The data model contains all the necessary information for the system to work. This is a simplification of all the formats of data sent by the multitude of energy management devices available for purchase and use on a household. The information sent by those devices varies between brand and even between the type and model of the devices, and therefore, this abstraction had to be done for the application to properly use the information it is fed by the devices.
3.1.1. House

The House is the class that includes all the information regarding the household being managed. This includes things such as the energy plan contracted to the energy distribution company to the maximum power available to be used in the whole house.

Having a class with the house information and identification also enables the application to have multiple houses, so that a single user can manage multiple households with a single login in the application.

3.1.2. Division

The Division is the class that allows the separation of the household equipments for each division of the actual house.

3.1.3. Equipment

The Equipment class has been created to standardize all different kinds of devices into a common one, to be used by the application after proper data conversion. This is needed since depending on the brand and/or model of the equipment, there can be very different data formats.

This conversion is done through the mapping functionality available in .Net Core, which reads the field values from the input data (using a specific class for each brand and/or model) and then proceeds to create a new instance of the common Equipment class with the previously read values set in this common class, thus making them available to be used throughout the application.

To add a new kind of device input format to the application, and since it is done using .Net Core it is quite easy to perform such increment in functionality, a new class must be created containing the fields to be read from the input data with their respective field names. There is no need to include all the fields, since the mapping functionality is able to read only the ones present in the class. Then, the “conversion” class must be updated with a method that receives this newly created class with the input fields and inserts them in the common Equipment class. During this process, if needed, it is possible to convert the values of the input data to the needed correct units for the common Equipment class.

3.1.4. Usage

This provides the application with the necessary data to create graphical and numerical visualizations of the equipment usage throughout the household. The historical values of the equipment usages are also used to calculate future usage predictions and from those predictions, generate a schedule of usage to be used in the future.

3.1.5. Time Slot Usage

The Time Slot Usage class represents the usage of the household equipments in a fixed interval of 30 minutes. This block is calculated from the data in the Usage class and is required due to the fact that for the data visualization and scheduling generation, the time is divided in blocks of half an hour.

3.1.6. Chart Equipment

The Chart Equipment class represents the usage of each equipment for a chart being rendered.

3.2. Backend

In this project, the backend side is “where the magic happens”. That is, the part of the code where the input data from the various devices available in the household is gathered, parsed and analyzed in order to provide useful visualizations (later to be rendered by the frontend part of the project) and equipment usage scheduling. As previously stated, this part of the project is done using the C# language over the .Net Core Framework (version 2.1), which allow for a modular and fast environment capable of being executed in a multitude of devices (Windows, Linux or Mac OS).

3.2.1. Data Input

The data values to be used in this project are simulated through a class that generates dummy test data when the application is started. This enables the project to be tested while using only a single computer and doesn’t require a whole set of equipments running and sending data in real time for a period long enough (a week at least) to enable the generation of a prediction of usage data set and for the latter generation of a schedule of usage data set.

3.2.2. History charts data generation

The historical usage data is stored though the Usage class, that includes the used equipment, a starting time and an ending time for the period where the equipment was turn on. To use this data to display graphically, the backend
of application must gather and process the historical usage instances in the time period to be displayed and format them so that the frontend of the application just needs to read the values and display them graphically.

To begin the process, the relevant data is requested from the repository. This is abstracted through interfaces on the application, so that while now the data is stored in memory and therefore requested directly from memory, the data could otherwise be requested from a SQL database or some other kind of persistent storage without the application having to change its behavior. For the application side all that matters is the format of the data.

After acquiring the necessary chuck of data, the process continues with a splitting of the whole period of time in smaller blocks of 30 minutes. This way, the graph will be aligned and easier to read when it comes to cumulative values. Using the time blocks of 30 minutes, the historical usages are assigned to each one of them. Note that an equipment usage can be present in multiple time blocks of 30 minutes, depending on the duration of said usage. The equipments are also sorted by type during this process, so that the schedulable equipments are separated from the unschedulable equipments when the graphic is rendered, making a base layer value with the unschedulable equipments representing the amount of energy being consumed that cannot be changed easily and on top of those are the schedulable equipments, visible to the user in a separate color so that he can see clearly which equipments can be managed in a better way. Since not all equipments will be turn on for each and every one of the time blocks of 30 minutes, a base value of 0 will be appended to the data on each equipment when it is not being used, so that the graph can have a value for every point in time.

In the end of this process, the result will be data to be used in the two axis of the graph, X and Y. Those values are:

- X axis – All the time blocks of 30 minutes for the period to be included in the graph;
- Y axis – An array of equipments, each one with an array of the values of the power being consumed for each time block of 30 minutes.

Using these resulting values, the frontend part of the project is able to render a graphical display of the data representing the usage of energy throughout the household.

### 3.2.3. Equipment scheduling generation

The scheduling algorithm works with the historical data previously gathered by the application to generate a scheduling of future usage for each of the selected equipments.

The first step is to ask the user which of the schedulable equipments to create a schedule to, and, for each one of those, how many times will they be used in the time interval of the scheduling. This is done in the frontend and sent to the backend to start processing the scheduling request.

With the list of schedulable equipments to use, the next step is to create an average of usages of the unschedulable equipments for the same period as the schedule to be generated (e.g. a week), only in the past. With this period, we can have an idea of how the household equipments are used and try to find the best time slots for the schedulable ones to be used.

Since the historical data is needed to generate the scheduling, it is not possible to generate a proper schedule in a newly configured household, as there will be no past usages to get the usage trending from. Taking into account the usages from the past and also power generating equipments, the algorithm proceeds to fill the lowest usage time slots with the equipments to be scheduled, from the most power consuming to the least power consuming. This optimizes the power usage and provides a more stable power usage value on the household, enabling the user to even lower the contracted power from the energy distribution company. This last step also needs to find timeslots where, besides having low power usage, the equipment duration can be fit inside. For instance, if we have an equipment to be scheduled that has a working cycle of 2 hours, the time slots of low usage that are less than 2 hours long will not be suitable for it and will be left empty for other equipments with a smaller usage window. Using the number of times for the scheduled equipments to be used throughout the scheduling period, the algorithm makes a division of this scheduling period into subsets, each one for a single usage of the equipment. This is done because even if it was more power optimized, it makes no sense to schedule all 10 usages of the dishwasher to the first few days of a month and leave it off for the rest of the month (considering a monthly schedule). This way the equipment usage will be balanced according to the needs of the user.

After the generation has been completed, the scheduled equipment usages are saved in the data storage and are then sent to the frontend to be displayed to the user.

### 3.3. Frontend

The frontend part of the project is the rendering system that will enable the household final user to actually see what is happening, both in real time and historically. It will also enable the scheduling equipment usages according to the household inhabitants’ parameters.
This part of the project has been done using HTML, JavaScript and CSS. There are also some extra frameworks being used: Bootstrap for the visual style and Chart.js to render the charts throughout the application.

3.3.1. History Charts

The historical charts contain all the information about equipment usage in certain periods in the past.

In the current state of the application these historical charts have only two available usage periods, last week (last 7 days) and last month (last 30 days).

The data is generated as explained in point 4.2.2 of this same document.

In the rendered screen, there are two main sections:

- Resume table – A table with the average values that occurred in the selected time period:
  - Average power consumption – the average sum of power being used by the household equipments;
  - Maximum power consumption – the maximum sum of power being used at a certain time by the household equipments;
  - Average active equipments – the average number of active equipments during the time period;
  - Maximum active equipments – the maximum sum of equipments being used at the same time during at a certain time of the time period;

- Power usage graph – A graph of the stacked line type containing the power usage over time of the following equipments:
  - Unschedulable equipments – The equipments that are not capable of being rescheduled;
    - Shown in the base of the graph as they can not easily be changed on their usage times;
    - Displayed in red tones, dependent of their power consumption levels;
  - Schedulable equipments – The equipments that are capable of being rescheduled;
    - Shown on top of the unschedulable equipments as their usages can possibly be changed to more appropriate time slots;
    - Displayed in green tones, dependent of their power consumption levels;
  - Power generating equipments – The equipments that generate power instead of consuming it;
    - Shown under all of the other equipments since they represent power generation or, in other terms, negative power consumption;
    - Displayed in yellow tones, dependent of their power generation levels.

The power usage graph is rendered using the Chart.js framework. It receives the necessary data from the backend of the application and uses it to configure and generate the graph accordingly.

The power usage graph can be zoomed in, enabling an easier inspection of a specific time period. This zoom in function is usable by selecting a certain area of the graph with the mouse cursor. That selected area will be the area appearing in the new zoomed in graphic.

The power usage graph also contains a tooltip for every time slot, displaying information about all the equipments’ usage in that specific moment as well as the household total power consumption value.

3.3.2. Equipment Scheduling

The equipment scheduling starts with the parameters for that same scheduling being selected by the household user. Those parameters are only available for the equipments that are actually schedulable. Those equipments and their respective parameters are listed in the screen. After selecting the parameters for each one of the schedulable equipments, the user has to click the “Generate” button. This will send the selected parameters to the backend of the application, where the scheduling will be processed as explained in point 4.2.3. When the processing has been done, the backend will return the scheduling data back to the frontend, which will be displayed in the screen.

The schedulings are also available in the Scheduling listing screen, so that the user can check what has been scheduled and not yet converted into past usage. The screen is similar to the result of a single scheduling, only containing additional schedulings from other periods.

4. EVALUATION

With the conclusion of this project, I’ve successfully created an application the enables the end user of an household to manage its energy usage in the past, the present and the future. In this chapter I will show the various capabilities available for the user to manage its household energy usage.
4.1. Data Visualization

The user has multiple places where to obtain information about the household power usage. I have divided them in 3 different categories for this document: the past, the present and the future. Those enable the user to know how the energy has been used, how it is now currently being used and what is scheduled for use in the future. In this section we will only take into account the global views, since in section 5.2 there will be an explanation of the data visualization for the single equipments.

4.1.1. Past

The graph on the history pages presents static content that can be consulted for a quick glimpse of the last week usages, the graph allows us to go further in detail and see what the usage for each of the 30 minutes time slots in it was.

4.1.2. Present

The data of the current usage of energy throughout the household is available on the main screen of the application. This current data visualization is divided in two parts:

- Current usage table:
  - Power – The sum of the power currently being used (and/or produced) by the currently active equipments;
  - All Equipments Power – The sum of all the household equipments’ power, either currently active or not (and including energy production);
  - Active Equipments – The ratio of currently active equipments and all equipments in the household;

- Usage graphs:
  - Current Power Usage – Displays, in an easy to see fashion, the power being used, being generated and not being used at all(“Available”);
  - Current Equipments Usage – Displays, in an easy to see fashion, the ratio of equipments currently being used and not currently being used.

This simple home screen enables the user to quickly check what is happening throughout the household without the need to perform any more clicks and navigate through the application.

4.1.3. Future

While it is true we can’t really predict the future, we can still show what is scheduled for the household equipments to do. That means we have a simple way for the user to see when will the equipments be activated. In the Schedulings Listing screen the user is able to see, or ordered by ascending scheduling date (sooner first), when will the multiple schedulable household equipments be running.

4.2. House management

The house management options are available through the “Configurations” menu and “House” sub-menu options. In this screen, the user is able to get an overview of the house divisions and equipments (this house has a fixed division structure and is not configurable, for example purposes). From this overview screen, the user can then click on the “Manage” button for each one of the equipments in order to get more information about it. Clicking on that button will lead to a screen with the equipment information, actions to be performed onto it, schedulings and past usages.

4.3. Usage scheduling

This screen provides the user with all the schedulable equipments in the household, so that he can choose which ones to create schedulings for.

For each one of the schedulable equipments, the user can also select how many times shall the schedule generator create a scheduling in the selected period (for demonstration purposes, this is now fixed as a weekly schedule). This will be the number of divisions that will happen in the selected period, so that the usages are evenly spaced between them and avoid the cramping of usages in a certain moment. After clicking the “Generate” button, the user is shown the recently created schedulings for all the selected equipments.

This simple screen enables the user to optimize the usage of equipments possible of being scheduled (as opposed to instant usage ones, whose usages can’t be easily changed). With this management, the user can generate schedules and since the total power usage will be distributed evenly, the user will eventually be able to lower the amount of contracted total household power contracted to the energy distribution company and, therefore, lower the price to pay monthly.
4.3.1. Single equipment scheduling

This screen enables the user to schedule a single usage for this specific equipment. It can be used when, for instance, the user realizes there is the need to turn off the dishwasher this night as well, besides the already scheduled usages. It gives another option for the user to schedule equipments and also to alter the usage duration.

5. CONCLUSION

With this document and project, I’ve shown an application with simple and modular ways of managing one’s household energy expenses.

Firstly, the application has the historical and current information about the energy usage of the household for the user to consult and analyze. This enables him to get a better understanding of what has been happening throughout the electrical appliances of his house and also to quickly check the current usage of the household energy.

This leads to the usage scheduling, based on the past usages, of future usages so that the overall energy usage of the household is leveraged and kept balanced throughout the scheduled period. The user will then be able to get lower costs on the monthly energy expense from the energy distribution company he has a contract with.

The application also enables the user to easily turn on and off all of its household equipments, wherever he is, with a single click of a button. This prevents the usage of multiple management applications for each of the brands and models of equipments installed in the household.

5.1. Future work

The application, although functional, is limited by its demonstration context. It could therefore be augmented in the following ways:

- **Input data** – As a demonstration prototype, the input data is randomly generated. This avoids the usage of expensive equipment to show the application functionality. There must be created input mappers for the various kinds of devices sending data to it, so that it can be converted to the common data model;
- **Household configuration** – The household configuration is fixed, even though the data model is very modular. There need to be created the functionalities to configure new houses, divisions and equipments;
- **Styling** – While the application is capable of running in all kinds of devices thanks to its responsive design, it is still pretty bland. A design revamp could be used to make it more attractive. This includes the graphs who are a bit cramped before zooming in;
- **Filters** – The listings of usages and schedulings could use additional filters and orderings. This would enable the user to select specific information to consult;
- **Data export** – While the data is fully available in the application, it can be useful to have it exported in multiple formats so that it can be used in other applications;
- **Scheduling options** – The scheduling can have as much options as one can remember of, although making the screen more filled with fields and also the algorithm more complex;
- **Energy distribution companies plans** – The scheduling and data displaying can consider the type of contract celebrated with the energy distribution company, in order to further optimize the data visualization and usage scheduling.

6. REFERENCES

6.1. Bibliographic


6.2. Online


