ISCTE IUL

University Institute of Lisbon

Department of Information Science and Technology

Energy Consumption Monitoring in a Smart Campus

Catarina Marinho Nogueira dos Santos

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Supervisor
Prof. Doutor João Carlos Amaro Ferreira
Co-supervisor
Prof. Doutor Vasco Nunes da Ponte Moreira Rato
Oral Presentation Committee
Doutor Porfírio Pena Filipe, Prof. Adjunto do ISEL
Doutor Fernando Brito e Abreu, Prof. Associado do ISCTE-IUL
Doutor João Carlos Amaro Ferreira, Prof. Auxiliar do ISCTE-IUL

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"Achievement is impossible without dedication."

Unknown

Resumo

O aumento do consumo de eletricidade em países desenvolvidos, causado por um grande número de dispositivos mais potentes e diversificados, cria picos de consumo, que criam uma necessidade de integração de novas formas de produzir, distribuir e consumir energia com mais eficiência. Considerando, também, o aumento constante nos preços dos combustíveis, as ameaças de aquecimento global, as implicações da emissão de carbono, entre outras emissões de combustíveis tradicionais, surgiu um interesse crescente em melhorar a eficiência energética.

Nesta dissertação, apresentamos um protótipo escalável, que é capaz de monitorizar energia, temperatura e luminosidade, demonstrando os dados em tempo real e, posteriormente, com os dados recolhidos, podem ser efetuadas análises mais específicas, permitindo que os *stakeholders* tomem decisões mais informadas, trabalhando para a eficiência energética e sustentabilidade. O protótipo desenvolvido, que inclui tanto hardware como software, é baseado em dispositivos IoT de baixo custo e na implementação da rede LoRa, para criar um sistema apropriado e adaptável a qualquer sala da universidade.

São demonstrados os dispositivos escolhidos e toda a implementação feita, e, demonstra-se, também, a análise feita com os dados recolhidos durante o período de observação, para atingir medidas de eficiência energética.

Esta abordagem para construir serviços de eficiência energética, onde informações contextual de sensores localmente instalados podem ser manipuladas, para identificar padrões de consumo e, posteriormente, implementar ações de modo a poupar energia no edifício. O uso de informações externas, como mapas locais, materiais de construção, condições externas climáticas e ocupação da sala, pode ser usado para melhorar as ações de poupança.

Palavras-chave: Internet of Things, Sensores, Sustentabilidade, Eficiência energética.

Abstract

The increase electricity consumption in developed countries, caused by a larger number of more powerful and diversified power-connected devices, creates consumption peaks, which lead to the need of integrating new ways to produce, distribute and consume energy with more efficiency. Also considering the constant increase in fuel prices, the threats of global warming, implications of carbon, among other emissions from traditional fuels, a growing interest in improving energy efficiency arose.

In this dissertation we present a scalable prototype which can monitor energy, temperature and luminosity, showing real-time data and afterwards with the gather data, do more specific analysis, allowing for stakeholders to make better informed decisions, to work towards energy efficiency and sustainability. The developed prototype, which includes both hardware and software, is based on low cost IoT devices and LoRa network implementation, to create an appropriate and easily adapted system to any room in the university.

We demonstrate the chosen devices and all the implementation done, and, also demonstrate the analysis done with the data gathered during the period of observation, in order to get energy efficiency measures.

This approach towards building energy efficiency services, where context information from locally installed sensors, can be manipulated to identify consumption patterns and, later, implement actions in a service basis to save energy in a building. Usage of external information, like local maps, building materials, external weather conditions and room occupancy can be used to improve further saving actions.

Keywords: Internet of Things, Sensors, Sustainability, Energy Efficiency.

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Contents

List of Figures

List of Tables

Abbreviations

ABP - **A**ctivation **B**y **P**ersonalization

AC - **A**lternating **C**urrent

AI - **A**rtificial **I**ntelligence

API - **A**pplication **P**rogramming **I**nterface

App - **App**lication

BLE - **B**luetooth **L**ow **E**nergy

Cap - Capita

CO_2 - **C**arbon Dioxide

CT - **C**urrent **T**ransformer

DB - **D**ata**b**ase

DC - **D**irect **C**urrent

DevOps - **Dev**elopment and **Op**erations

EdP - **E**nergias **d**e **P**ortugal

EUI - **E**xtended **U**nique **I**dentifier

GDP - **G**ross **D**omestic **P**roduct

HDMI - **H**igh-**D**efinition **M**ultimedia **I**nterface

HTML - **H**yper**T**ext **M**arkup **L**anguage

HTTP - **H**ypertext **T**ransfer **P**rotocol

HVAC - **H**eating, **V**entilation and **A**ir **C**onditioning

ICT - **I**nformation and **C**ommunications **T**echnology

ID - **Id**entification

IEMS - **I**ntelligent **E**nergy **M**anagement **S**ystem

IoT - **I**nternet **o**f **T**hings

IP - **I**nternet **P**rotocol

ISAmI - **I**nternational **S**ymposium on **Am**bient **I**ntelligence

ISCTE-IUL - **I**nstituto **S**uperior de **C**iências do **T**rabalho e da **E**mpresa - **I**nstituto **U**niversitário de **L**isboa

ISO - **I**nternational **O**rganization for **S**tandardization

IST - **I**nstituto **S**uperior **T**écnico

IT - **I**nformation **T**echnology

JSON - **J**avaScript **O**bject **N**otation

LAB - **Lab**oratory

LAN - **L**ocal **A**rea **N**etwork

LTE - **L**ong **T**erm **E**volution

LED - **L**ight **E**mitting **D**iode

LoRa - **Lo**ng **Ra**nge

M2H - **M**achine **to** **H**uman

M2M - **M**achine **to** **M**achine

MAC - **M**edia **A**ccess **C**ontrol

MicroSD - **Micro** **S**ecure **D**igital Card

MQTT - **M**essage **Q**ueuing **T**elemetry **T**ransport

Mtoe - **M**illion **T**onnes of **O**il **E**quivalent

OTAA - **O**ver-**T**he-**A**ir **A**ctivation

PaaS - **P**latform **as a** **S**ervice

PAN - **P**ersonal **A**rea **N**etwork

PoE - **P**ower **o**ver **E**thernet

SI - **I**nternational **S**ystem of Units

SMS - **S**hort **M**essage **S**ervice

TTN - **T**he **T**hings **N**etwork

URL - **U**niform **R**esource **L**ocator

USB - **U**niversal **S**erial **B**us

VNC - **V**irtual **N**etwork **C**omputing

WAN - **W**ide **A**rea **N**etwork

Chapter 1

Introduction

The convergence of several technologies like wireless technology, real-time computer decision making, computer learning, small sophisticated sensors, cheap high resolution cameras and embedded computers, in everyday appliances, promoted an evolution of the vision of the internet. Computers, in so many areas, are enabling the interconnection of devices and appliances into a collection of what is known as the Internet of Things.

The Internet of Things (IoT) is a new, but at the same time old term. The main difference is the fact that nowadays, the average person has 4 to 5 digital devices, soon 5 billion people will be connected to the Internet, and the number of devices already exceeds the human population [1], so there is nothing fundamentally new on the Internet of Things.

So, today, IoT has the ability to transform a simple physical device into a smart one, using embedded technology and computational power [2]. Some problems, which a few years ago seemed to be only possible to fix through science fiction, are now possible to be solved by the reality of IoT. An example of this is energy waste and energy efficiency in buildings. A phenomenon called global warming is happening, being that the world's energy consumption is increasing, as is the CO_2 emission. As such, experts in this area are emphasizing the need to conserve energy in the industry, transportation and building sectors. The later should consider separately service and residential buildings because the energy consumption patterns are considerably different. This is particularly true in University campuses where students do not have any direct insight or feedback on their energy consumption [3].

1.1 Objectives

The main goal of this dissertation is to provide a prototype which reads real-time data such as energy consumption and temperature through a sensors network. This data is analyzed through an IoT cloud platform, allowing for consumption patterns to be identified, correlate consumption with room usage and with internal and external temperatures in a room.

In specific, this prototype is done towards building energy efficiency in an university campus, namely, in the ISCTE-IUL university campus. The university has currently a sustainability program with a particular focus in studying the energy efficiency having in mind the reality of IoT.

The objectives of this dissertation are set as follows:

- IoT prototype for measuring energy consumption and temperature;
- Study energy efficiency with the implementation of a network of sensors (measuring temperature and energy) and correlating them with external conditions as exterior weather and room occupation;
- Build a prototype that can be scalable to the whole campus.

1.2 Structure of the Dissertation

In Chapter 2, we review a range of concepts important for this dissertation, as well as related work in the area of smart campus and energy monitoring.

In Chapter 3, we present our developed prototype and describe its detailed implementation.

In Chapter 4, we analyze the data collected by the prototype in a real case study.

Finally, in Chapter 5, we discuss the results obtained through this dissertation and the improvements that can be implemented for future work.

1.3 Scientific Contribution

The research made during this dissertation originated in an article that was accepted in the international Ambient Intelligence conference (ISAmI 2018), thus, contributing to its dissemination to the scientific community.

- C. Santos, J. Ferreira, V. Rato and R. Resende, "Public Building Energy Efficiency an IoT Approach", The 9th International Conference on Ambient Intelligence (ISAmI 2018), 2018

Chapter 2

State of the Art

While IoT has evolved and developed a number of devices, systems, and processes to measure energy and evaluate energy efficiency, there is still a long way between having the devices, collect data and having information for better decisions. In this chapter, we review from top-to-bottom the approach to use IoT to solve energetic problems. In Section 2.1, we start by describing the existing energetic problems, with a special emphasis in buildings and what are the solutions to this problem. In Section 2.2, we focus on how to monitor energy with an IoT approach. Within Section 2.3, we describe the sustainable development and how it is related to developing a smart campus; finally, in section 2.4, we present the related work developed in the energy monitoring and smart campus fields.

2.1 Energetic Problems

It is known that the energy demanded by our civilization is in significant part supplied by fossil fuels such as mineral coal, oil and natural gas, as seen in Figure 2.1. Although its use contributes and promotes the comfort for the majority of the world's population, it is also creating issues which threaten the stability of the kind of civilization we currently have.

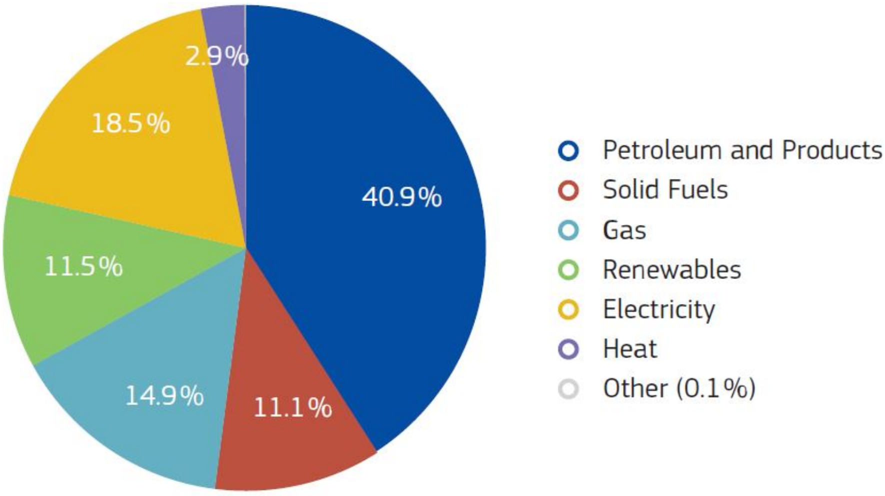

FIGURE 2.1: World Energy Consumption by Fuel in 2015 [4]

The fossil fuels are the major source of pollution all over the world, having severe impacts on health and issuing gases to the atmosphere that are causing the global warming. In Figure 2.2, it is possible to visualize that in countries like Canada, United States, Russia, among others, the CO_2 emissions are higher than 10 tones per person in 2014, which has a serious environmental impact and, although the use of renewable energy is increasing, the CO_2 emissions are not decreasing as expected [5].

FIGURE 2.2: CO_2 emissions per capita in 2014 [6]

Fossil fuels are also the origin to several problems that compromise the safety of energetic supply, seeing that many countries do not have oil and gas reservoirs and are dependent on the political pressure of suppliers such as countries from the Middle East and Russia [7].

2.1.1 Energy in Buildings

The growth in energy consumption is linked to the development of cities. Nowadays, half of the world's population lives in cities and within 35 years it will increase to 2 out of every 3 humans calling a city home [8]. As such, there is a duty to recognize, especially in cities, the important weight buildings have in energy consumption - this is visible in Figure 2.3, where sectors *services* and *residential* refer to buildings [9].

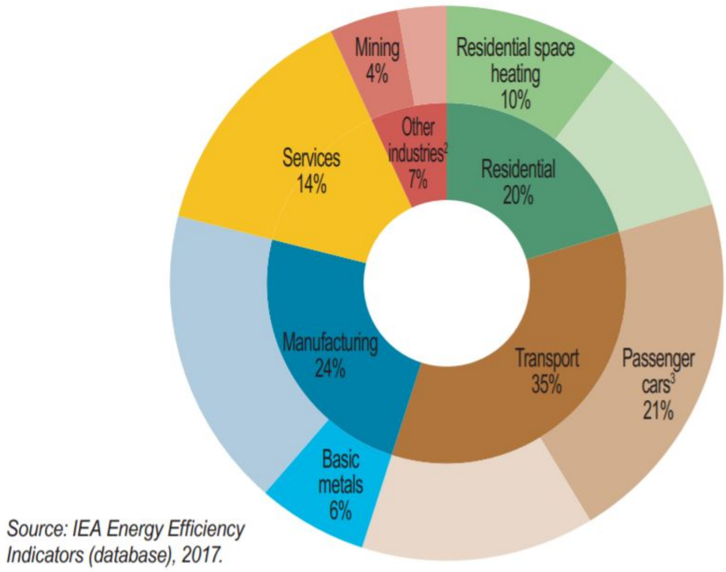

FIGURE 2.3: World's largest end uses of energy by sector - 2014 [10]

Only in the European Union, buildings are accountable for approximately 40% of final energy[1] consumption and 36% of CO_2 emissions [12] [13].

[1]Final energy, the total energy consumed by end users, excluding the energy used by the energy sector itself [11].

It does not exist a straightforward way to balance energy demand when addressing the building needs. Each building is different, and it needs to be adapted regarding two main factors:

1. Climate and local conditions:
   Climate is a driver for space heating and cooling and, also for supplying renewable energy resources.
2. Building type and use:
   The building type will dictate the rest of the energy demand [14].

Of course, there are other factors that may affect the energy performance of a building, such as architectural, environmental or cost issues [14].

Buildings can be classified in two types as shown above, service buildings (offices, educational buildings, restaurants, hotels, retail, and others) or residential buildings (single-family or multi-family) [15]. A simple way to distinguish them is that service buildings have, normally, a higher occupancy rate, more equipment and as a consequence, they have higher internal heat gains.

Energy in buildings is required in two manners:

- Operating energy, or direct, the energy needed to support the services and comforts in buildings such as thermal comfort, refrigeration, illumination, sanitation, communication and entertainment, among others. This energy cost is usually the one in the monthly bill for energy services [8].
- Embodied energy, or indirect, the energy needed for the provision of infrastructures services, the production, and transportation of the materials used in construction or the production of furniture and appliances. This energy depends highly on the design and construction techniques used on the building [8].

2.1.2 Solutions for the energetic problems in buildings

To start solving the energetic problems in buildings, there is a need to improve the energetic efficiency and increase the production/use of renewable energy, creating a synergy, because with more efficiency tasks can be done with a smaller amount of energy, which favours the use of renewable energy [16].

There are three options to try to make the buildings more efficient:

1. By investing in architecture solutions adjusted to energetic efficiency needs, for example, through passive strategies to obtain comfort.
2. By investing in construction solutions appropriate to several factors, such as climate, use of the building (or building type) and vegetation.
3. By investing in more efficient appliances to reduce other energy consumption in the operation of the building, for example, only having green-star rated appliances [14].

From these three options, there are a great deal of energy efficiency technologies and practices to be used, as seen in Table 2.1:

Table 2.1: Energy efficient technologies and practices for buildings [14]

Building's design and construction	Energy-efficient windows, insulation (roof, walls, floor), reduced air filtration
Space conditioning	Air conditioning efficiency measures (e.g., thermal insulation, reduced heat exchanges) Centrifugal compressors, efficient fans and pumps, and variable air volume systems for large commercial buildings
Appliances	Advanced compressors, evacuated panel insulation (refrigerators), washing machines and dryers with higher spin speeds
Lighting	LED lamps[1], advanced lighting control systems (including day-lighting and occupancy sensors), and task lighting
Other	Building energy management systems, passive solar use (building design), solar water heaters

[1]LED lamps consume less 75% energy than incandescent lighting [17].

In 2011, a policy was released to better manage energy systems - ISO 50001:2011 - requiring companies to develop ways for a more efficient use of energy, to define objectives to meet, measure the results after implementing and use this data to understand the use of energy and make better decisions to its use [18].

So, to implement solutions to the referred problems, there is a need to monitor this consumption, to measure it.

2.2 Monitoring Energy

The monitoring presupposes the construction of a set of indicators which will serve as the basis for the evaluation of implemented measures regarding the outlined objectives. The construction of these indicators allows, not only the evaluation of results, but also to see the progress or the verification of the effectiveness of these measures.

Measuring energy, energy efficiency or energy performance, can have different meanings, as there are many ways to measure it. Indicators can be costs, energy or emissions. Some examples of indicators can be seen in Table 2.2.

Energy monitoring is an energy efficiency technique based on the standard management axiom stating that 'you cannot improve what you cannot measure'. It implies the necessity of measurements and data organization [20].

Energy use predictions, to calculate the energetic balance, require two separate aspects of energy flows:

1. Building operational energy.
2. Energy generated on the building [21].

Nowadays, the monitoring systems for buildings are rather basic, and the amounts of data available are small and incomplete [14]. But a significant control is needed

[1] Non-energy consumption includes fuels used as raw materials and not consumed as fuel or transformed into another fuel.

TABLE 2.2: Examples of key energy performance indicators [19] [?]

Designation	Description	Unit
Energetic intensity	Measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of Gross Domestic Product (GDP).	kWh/euro
Energy Source Share	Used to compare the consumption of energy by source. It is calculated as consumption of energy by the source per the total energy consumption.	%
Primary energy consumption	Primary energy corresponds to the Gross Inland consumption minus final non-energy consumption [2].	Mtoe
Final energy consumption	Total energy consumed by end users.	Mtoe
Greenhouse gas emissions per capita	The ratio of the greenhouse gas emissions to population.	$tCO_2\backslash cap$
Energy industrial prices	These are the electricity prices and gas prices for the consumers.	Euro

to manage well the relation between demand and supply of energy [21]. It is impossible to manage the energy demand and supply without information. We need data on what is currently happening to the energy, what will happen (predictive models), add external data and, this way, better management of the energy system is possible.

2.2.1 Using IoT to monitor energy

To have such information and control over energy is only possible with sensorization, in other words, add sensors to collect all the data needed. Hence, the value of IoT, designation for Internet of Things, that is complex concept, depending even on who is defining it. But the basis, in general, is connecting devices together to enable these "things" to communicate between one another and granting people the ability to communicate with them. But IoT is more expansive than just a simple push of a button on the phon, and the temperature in the house appears or unlocks the door. The devices need to be intelligent and interact with their environment and people [22].

The simple creation of information does not allow its productive use, but by capturing all the phases between an action occurring and being improved [23]. Information goes through five stages creating value, this is a way to implement IoT.

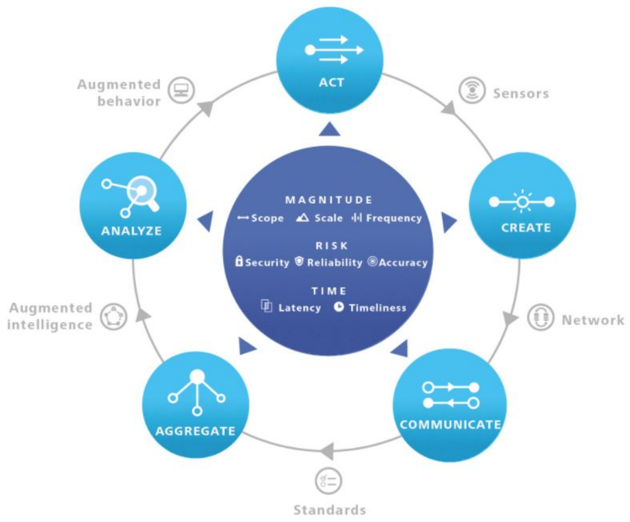

FIGURE 2.4: Implementation of IoT through the Information Value Loop [23]

So there are five important components connected to the five stages of the Information Value Loop, as seen in Figure 2.4.

1. Sensors - in its essence it is a device that produces data derived from an action. Different sensors have the capability to capture different types of information. The choice for a specific sensor is primarily due to the function of the signal being measured [24] and, when choosing the sensors to be used specific factors should be taken into account, such as what does it measure, how accurate and reliable can the data capture be.

2. Network - after the information is produced, the sensor needs to transmit it through a network, e.g., a mechanism for communicating a signal. To start transferring data from one machine to another via a network, it is necessary to have a unique identifier for each machine, which are done through network protocols. The choice of which network technology will depend on the geographical range that needs to be covered [24]. If data is to be transferred over short distances (e.g., a room), a wireless personal area network (PAN) can be used such as Bluetooth or USB. For data transmitted on a

more significant area (e.g., a building), devices can use local area networks (LAN) technologies such as Wi-Fi or Ethernet. For data that has to be transferred over a wider area, more significant than buildings and cities, an inter-network wide area network (WAN) can be setup by connecting a number of local area networks through routers. So to choose the network in itself, the factors taken into consideration should be the number of devices communicating, the availability of network coverage, data transfer rates and others [25].

3. Standards - referring to the handling, processing and storing of data collected by the sensors. According to the International Organization for Standardization (ISO), "a standard is a document that provides requirements, specifications, guidelines or characteristics that can be used consistently to ensure that materials, products, processes and services are fit for their purpose." [26]. There are two forms of standards, technology standards such as communication protocols, data aggregation standards and network protocols, and regulatory standards usually imposed by government agencies and created to assure the security and privacy of the data collected.

4. Augmented Intelligence - after collecting the data there is a need to extract insight for analysis [27]. Analytics means going through a huge quantity of confusing and conflicting data searching for pieces of insight that can influence better decisions [28]. There are three types of analytics: descriptive (What has happened?), predictive (What could happen?) and prescriptive (What should one do for the desired outcome?) [24].

5. Augmented Behavior - typically considered intelligent actions, meaning the "doing" of an action that results from the preceding stages on the value loop [24]. This can be seen in two forms, the Machine-to-machine (M2M) interface that allows machines to communicate with one another and drive action, or the Machine-to-human (M2H) interface where the machine suggests an action, based on the collected data, to an individual who can take the recommended action or not.

This generic process to implement IoT with some creativity and invention added to make the most of the new ways, which can create value thanks to IoT technologies' new sources and types of information [23], can make all the difference in improving energy systems.

2.3 Energy and a sustainable development

The world's present energy system, which depends highly on the exhaustible fossil energy sources, as mentioned in Chapter 2.1, is not a sustainable system, meaning it cannot last indefinitely [8]. As a consequence, the concept of sustainable development was born, or in other words, a development that can last.

Sustainable development is one that meets the needs of the present without putting in jeopardy the ability of future generations to reach their own needs [8]. Considering the increase of fuel prices, global warming, carbon emissions from traditional fuels in the present time, a danger to the future generations is here [29]. So, there is a growing interest in improving the energy efficiency. One example of savings through energy efficiency is the 66 billion dollars saved over 15 years on energy (gas) if just there is just 1% plant efficiency [30]. Saving energy and generating the energy needed from renewable energy sources (in order to avoid pollution) are a part of the future scenarios for cities [14], but there are many other aspects to do a good and sustainable development of a city that needs to be accounted for, such as citizens demands.

Only focusing on the energy perspective, the spread of use of renewable energy systems has changed in recent years, and as a consequence, our conventional, centralized system of energy generation [31] is most probably going to be replaced by interconnected energy generation systems to be managed in the appropriate way to ensure a good energy performance and considerable energy savings [14].

2.3.1 Developing a smart campus

Managing a significant number of students and services is an enormous challenge for campuses nowadays [32], this means new and improved systems, tools, and processes should be implemented in the campus [33] that will influence its sustainability.

The breaks in technology in the 21st century allowed starting integrating technology for campus sustainability [34], so there was a spread of initiatives worldwide to try to make campuses more sustainable.

It is possible to see sustainability in universities in three categories:

1. Research on sustainability.
2. The sustainability of the university.
3. Teach students to be environmentally responsible citizens.

The second category focuses on the reduction of harmful environmental effects, cutting carbon and energy bills, among other measures. So, to try to make a university campus sustainable, the concept of smart campus arises. Smart campus is one that utilizes resources efficiently and delivers high-quality services to its community, while reducing the operational energy [32]. It is dependent on the information value loop described in Figure 2.4, on the IoT technologies implemented and on the sustainable measures applied.

Actions should be taken with the aim of improving the production, distribution, and consumption of energy in the campus, in order to improve building energy performance, better manage energy and educate students on efficient and sustainable energy use, providing a smart campus with sustainability [35].

2.4 Related Work

2.4.1 Energy Monitoring

In Portugal, some pilot-projects related to consumption monitoring control already exist, for example:

- Galp has developed in 2010 a project of an energy management system called SmartGalp, that monitors the energy consumption through a platform which connects with domestic users. By installing these devices in the houses or cars of the end users, it allowed to follow the effective consumption occurring and define goals to save on the energy bills. By monitoring the results, Galp verified the tool allowed for effective savings, reducing up to 8% in the energy consumption [36].
- EDP created in 2011 the InovCity, a program with the goal of being energetically efficient. Évora was the first Iberian city to test change the way electricity is distributed and produced. The first phase of the program is centered in the automation of electric grid management with the goal to reduce the operational costs, which supports energy efficiency and environmental sustainability [37]. With this grid, an end user can know the exact value of how much energy they consume, all in real time. The program result was about 60% savings in electricity costs, meaning that there was an increase on energy efficiency.
- 'Empresa Parque Escolar', a company responsible for modernizing the Portuguese schools, implemented a program to track and control the energy consumption on the school equipment. The project reduced the use of energy applied to technological equipment in 25%. Additionally, the system has easy readable information presented to encourage sustainable individual behaviour [38].

2.4.2 Smart Campus

There are numerous universities around the world trying to make their campus more sustainable. One of the more important aspects for sustainability that can be explored is smart energy management. Energy wastage in several spaces such as teaching auditoriums, laboratories, computer rooms and others can be found. The energy and environmental impact of universities can be reduced if organizational, technological and energy optimization measures are applied.

European commission is one of the examples, since it created a project to develop services and applications which support a platform that gathers data, integrating real time information systems and intelligent energy management systems that drive a bi-directional learning process such that the user learns how to interact with the building and the building learns how to interact with the user in a more energy efficient way [39]. The program was only applied to specific universities in different cities such as Lisbon, Helsinki, Milan. The project reached 30% in energy savings by using ICT and gamification getting a user behavior transformation on public building users.

This pilot project in Portugal was done in Instituto Superior Técnico, in the Taguspark campus and it consisted in the installation of automation equipment that increased the control of energy usage. It was also created an Intelligent Energy Management System (IEMS) that allowed managing several automated equipment such as lighting, HVAC systems and others, and interact with the users through the web and mobile apps [40]. The pilot had success in IST university, at least 10% of savings were observed but it wasn't scaled to the whole university.

Other universities, all over the world, have their own initiatives created by students, researchers, or due to a sustainable awareness, to increase their energy performance, decrease their carbon footprint and become a more sustainable campus - generally through IoT technologies, meaning, they become smart campus. Universities such as University of Melbourne in Australia [41] or Texas A&M University in the United States [42].

Chapter 3

IoT Prototype for Facility Management

The proposed solution is a prototype, which was designed not only for monitoring energy, but also to monitor temperature and luminosity. Using IoT and data analysis, this prototype allows for useful information to be provided to the stakeholders of the university and measures can be applied, evaluated and validated.

The design for this solution consists in having sensors capturing data, and then, this data transmitted to gateways (Arduino and Raspberry Pi 3), will communicate it through LoRa, using the implemented approach illustrated in Figure 3.1.

The sensor data is transferred through the LoRa network, until it reaches the IBM platform, where it is displayed in a dashboard and stored for later analysis. The dashboard also contains historical data (it is fed by the database).

From Figure 3.1, it is also possible to observe the material, both software and hardware, used for the proposed system. The full list of material used in the system can be seen in Appendix A.

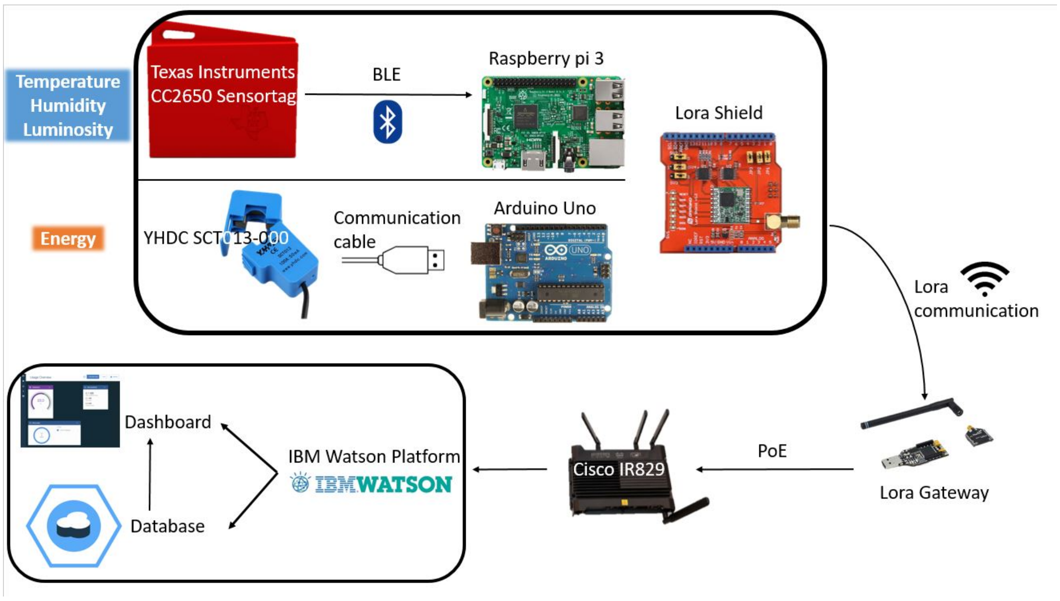

FIGURE 3.1: High-Level Design of the Proposed System

3.1 Data Sensors

As explained before and from the Figure 3.1, the measurements wanted are for temperature, luminosity, and energy consumption. A critical issue is choosing suitable sensors, since there is a high number of sensors currently available in the marketplace for each purpose. The primary goal of this decision process was to have an easy integration and data calibration.

3.1.1 Energy sensor

It is essential to understand the different energy measurements available, in this case, for everyday electricity use, in order to help choose the sensors used:

1. The electric voltage is the potential difference between two points [43], its unit is the Volt (V).
2. The electric current is the ordered flow of electrons in a conductor when subjected to a potential difference. It is the electric current that makes, for example, a light bulb light up. Its unit is Ampere (A). When, the electric

current does not change its direction, or in other words, it is always positive or always negative, it is considered continuous current (DC). When, the current reverses its state periodically, meaning sometimes it is positive, sometimes it is negative, it is considered alternating current (AC) [43]. This is the current that is most commonly used.

3. The electrical power of a circuit is given by the product of the voltage by the current [43] and it is measured in Watts (W).

Since the most common use of current is alternating current, the logic choice is a sensor that can measure this current and which after some calculations we can obtain the voltage and power used.

So, to measure energy we chose the YHDC SCT013-000 non-invasive current sensor, which measures from 0 to 100A AC by electromagnetic induction, useful to measure whole electric power consumption [44]. Its analogue output is received and processed by an Arduino with a LoRa module on top for wireless communication, as it is explained in Chapter 3.2.

3.1.1.1 Connecting to an Arduino

In order to connect the CT sensor to an Arduino in an effective way, there is a need to condition the CT sensor output signal to match the input requirements of the Arduino analogue inputs, meaning positive voltage between 0V and the reference voltage ADC [45]. The scheme to connect the CT sensor is visualized in Figure 3.2.

This conditioning can be done through the use of resistors, a burden resistor and an AC/AC transformer.

The Arduino program written to collect the data from the current sensors and from the AC/AC transformer can be seen in Appendix C.

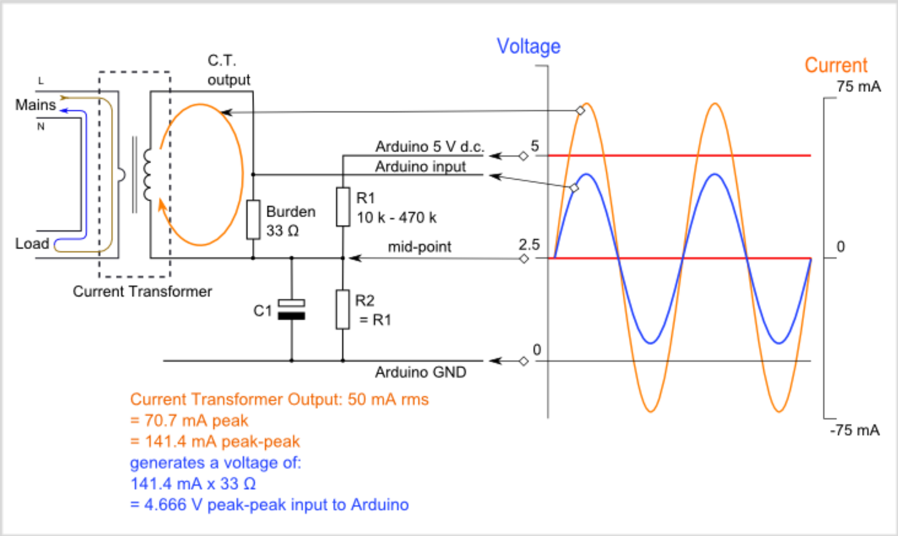

FIGURE 3.2: CT sensor connection to an Arduino with a reference voltage of 5V [45]

As indicated by the program, and also visible in Figure 3.3, the CT sensors on the Arduino analogue inputs 1, 2 and 3 correspond to phase measurements 1, 2 and 3 of the three-phase electrical panel. Analog input 0 corresponds to the AC/AC transformer.

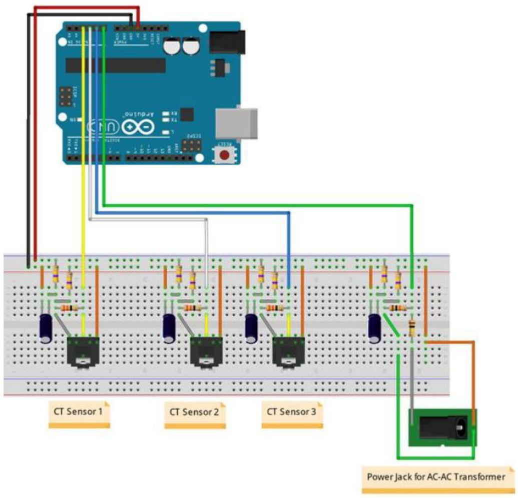

FIGURE 3.3: Breadboard scheme for the Energy Monitoring System

3.1.1.2 Sensor calibration

To have values as close as possible to the real ones, a calibration is necessary. Without this, the values read can have a deviation of around 40% of the real value.

To calibrate the sensor, the current value was measured through a power consumption meter, being this value compared to the one obtained through the program made for the Arduino. In order for the values to match, the value of CURRENT_CAL constant was changed through an iterative process until the value measured by the device was the same as that obtained by the Arduino.

For the calibration of the value measured by the AC/AC transformer, the same instrument was used, but in voltage measurement mode. The calibration process was the same as the one described previously, and the value of the VAL_CAL constant was changed through an iterative process until the values match.

3.1.2 Temperature and luminosity sensor

Temperature and luminosity were measured with the sensor Texas Instruments CC2650 Sensortag [46]. The data collected was transmitted to a Raspberry Pi gateway through BLE, a LoRa communication is then performed with a LoRa shield board.

This sensor has a clear plastic material for infrared temperature and ambient light measurement [46].

3.1.2.1 Configure the Raspberry Pi

To set up the Raspberry Pi, the following steps were followed:

1. Insert the MicroSD card containing the operating system into its Raspberry Pi slot.
2. Connect Raspberry Pi to a monitor/television over HDMI and connect a keyboard and mouse to Raspberry Pi (this is necessary when Raspberry is turned on for the first time).

3. Connect the Raspberry Pi to the transformer for power supply.
4. Installation of the Raspbian operating system (just follow the steps of the installer).

It is also possible to access remotely to a Raspberry Pi through VNC Connect software - explained in Appendix B.

3.1.3 Sensor calibration

As explain for the energy sensor, to have values as close as the ones in reality, there is a need to calibrate the sensors.

The texas sensor provides raw and uncalibrated sensor outputs to the application. It is up to the user to calibrate the sensor through specific calibration implemented directly in the BLE Client - the Raspberry Pi. The calibration was done by comparing the values of temperature and lighting using an application on the phone and the values from the sensor shown on the app.

3.2 Communication Layer

LoRa technology was chosen to provide the wireless data communication within the campus. For this purpose, a Cisco LoRa network had to be installed to allow communication on all grounds from the university campus. The choice of LoRa was based on two main reasons:

1. A long-range coverage, compared to other low power wireless technologies, such as ZigBee and BLE.
2. A low data rate requirements, LoRa data rates range from 0.3kbps to 50kbps [47].

LoRa is a radio Physical layer modulation technology focusing on battery-powered endpoints over long-range radio connectivity [48].

The Cisco LoRa infrastructure is a communications based protocol that is currently transforming the IoT world and as a network from end-to-end like the one shown in Figure 3.4. It is a network that is operator-free, and it allows a single gateway to cover up to 15km radius in open areas, where hundreds of sensors can coexist and communicate. This infrastructure allows real-time data to be gathered from several sensors and to be used in decision support tools, optimizing processes and increasing the quality of life [49].

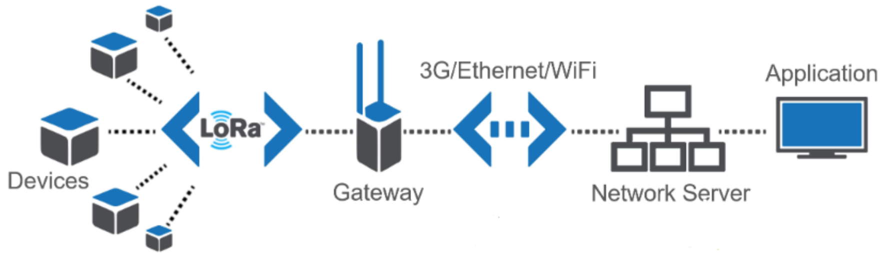

FIGURE 3.4: Lora Network from end-to-end

3.2.1 LoRa Implementation

The infrastructure of ISCTE-IUL LoRa LAB has two Cisco Enterprise Gateways, installed in indoor and outdoor environments to support IT equipment and other tools. The implemented LoRa solution is composed by four layers, seen in Figure 3.5:

1. Lora Antenna: it runs LoRaWAN protocol to communicate with LoRa gateways or sensors.

2. Lora Gateway: it is a router equipped with a LoRa concentrator, allowing tunneling the LoRaWAN MAC frames between an endpoint and an IR829.

3. Cisco IR829: it handles the LoRaWAN MAC traffic, performing endpoint and gateway management.

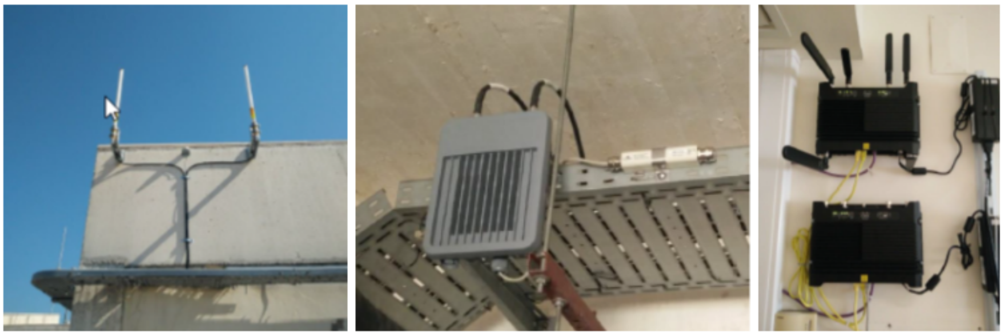

FIGURE 3.5: LoRa network implementation on ISCTE-IUL - outdoor antenna; LoRa gateway: IXM-2; Cisco IR829.

4. Actility ThingPark Platform: it is the application management.

All sensors in this prototype communicate through LoRa using the LoRa shield as seen in Figure 3.6.

FIGURE 3.6: Arduino and Lora Shield connected

To set up the LoRa nodes, there is a need to go through the following steps:

1. Create an account at The Things Network (TTN - https://www.thethingsnetwork.org/).
2. Select the *Console* from the top menu.
3. Select *Applications* to start registration of LoRa node. Devices need to be registered with an application to communicate with.
4. On *Application*, click on the button *add application*.
5. A screen with four fields will appear, as seen in Figure 3.7. For the field *Application ID*, there is a need to choose a unique ID. For the field *Description*,

anything can be entered. For the field *Application EUI*, it can be empty to be automatically generate by TTN. For the field *Handler registration*, the following should be entered *ttn-handler-eu*.

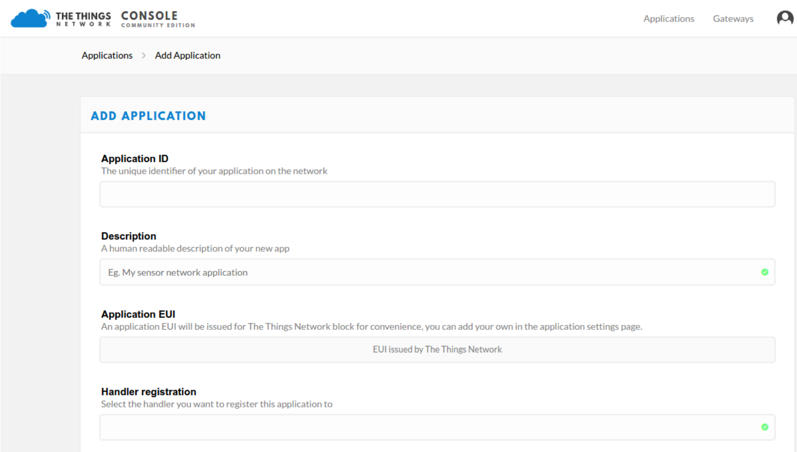

FIGURE 3.7: Applications screen

6. Click on the button *Add application* to finish.

7. Finally, the device can be registered. So, on the *Applications*, go to *Your Application ID* page and scroll down to *Devices*.

8. In the Devices, click on the button *register device*.

9. In registering the device, only the field *Device ID* should be fielded. The remaining - *Device EUI, App Key and App EUI* - will be empty to be automatically field.

10. Click in the button *Register* to finish.

In LoRaWAN, to mantain the data traffic secure, the LoRa node uses Session Keys, provided by the network server to encrypt the content of the sent data. When the data packets reach the server, it will use the session key to identify the owner of the LoRa node. There are 2 types of device activation:

- Over-The-Air Activation (OTAA): a secret key called App Key is generated when the device is registered. It is used to request session keys from network server, where each request will result in different session key [50].

- Activation By Personalization (ABP): the session keys are fixed and are hard-coded on the devices. The device will always use those keys for any data transmission until a different set of session keys is hard coded into them [50].

In this prototype, the type ABP was used, instead of the OTAA. In addition, the LMIC library should be added to change the code.

3.3 IoT Platform

ISCTE-IUL made a partnership with IBM and based on this, the IBM Cloud platform was used in the development of the proposed system. IBM Cloud is a Platform as a Service (PaaS), supporting a range of services and programming languages and allowing DevOps on the cloud [51].

For this particular system, there were four main services used from IBM Cloud:

- Internet of Things Platform (IBM Watson).
- Node-RED.
- Cloudant NoSQL DB.
- IBM Watson Analytics.

3.3.1 IBM Watson

The IBM Watson platform is a hub where we can add, configure and control the connected devices so that the apps can access live and historical data [52].

To use it in IBM Cloud platform, there is a need to create the service first, as described below:

- Search for the service *Internet of Things Platform* through the list of services provided by IBM Cloud.

- Change the name of the service and click on *Create* button, as seen in Figure 3.8.

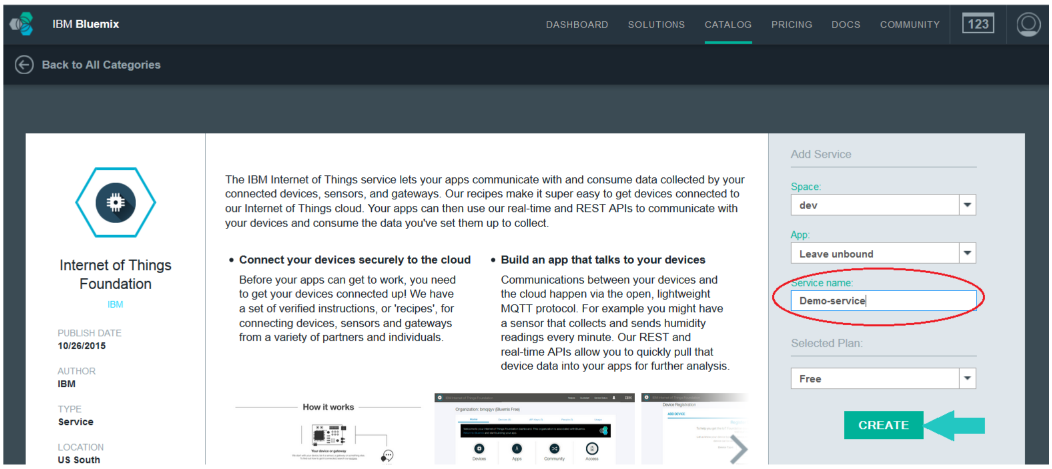

FIGURE 3.8: Creating IBM Watson Service [53]

The second step to follow is to register devices on the platform. There are two different types of devices:

- Gateway - used as access points to the Watson IoT platform for other devices. These have additional permissions over other devices, and can perform several functions, such as register a new device in the platform, send and receive the sensor data directly or on behalf of other devices connected to it. Each gateway connected to the Watson IoT platform is associated with one type of device, which are groups of devices that share characteristics common to each other.

- Device - connection to a device directly.

Both types were created, Gateway type - gwtype - and Device type - SensorTag-Type - as seen in Figure 3.9.

Two devices were added to the gateway type:

FIGURE 3.9: Devices types created for the prototype

1. Gateway01, which refers to the gateway for the energy monitoring system.

2. Gateway02, which refers to the gateway for the temperature and luminosity measurement system.

Both these gateways have in their information the model: Pi3, maker: Raspberry and in the descriptive location where the installation occurred. To the device type was only added one device - the temperature and luminosity sensor - myTIsensor.

To add these gateways and devices, the following steps were followed:

1. On the platform dashboard, click on the tab *Devices* and, then, click *Add device* button.

2. Select the type of device and choose an ID as seen in the screen in Figure 3.10. After this, click on the *Next* button.

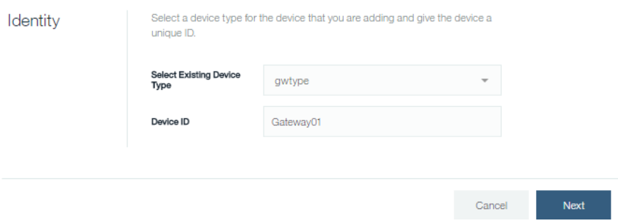

FIGURE 3.10: Example for Gateway01

3. In the next page, it is possible to insert information about the device. All attributes are optional and can also be added afterwards.

4. Then add an authentication token or allow the platform to create one automatically (just click the *Next* button and the token will be generated at the end).

5. Finally, click *Done* and the details of the device registration will be shown.

ID do dispositivo	Tipo de dispositivo	ID de classe	Data de inclusão	Local descritivo
3 resultados				
Gateway01	gwtype	Gateway	12 de Nov de 2017 14:34	Auditorios Afonso de Barros e Silva Leal
Gateway02	gwtype	Gateway	21 de Dez de 2017 20:25	Auditório Afonso de Barros e Silva Leal
myTIsensor	SensorTagType	Dispositivo	21 de Dez de 2017 20:26	

FIGURE 3.11: Devices added to the prototype

After registering the devices in the platform, the boards, and cards for a useful dashboard were created.

Each board can accommodate n number of cards, each card depicting and displaying statistics with varied visualization options. It is possible to create visualization graphics for real time device data, create meters to visualize physical quantities such as temperature, view data consumption and storage of devices, and view the list of registered devices [54].

In order to create and configure the boards, the following steps were followed:

1. In the platform dashboard, click on *Boards* and, then, *Create new board* button.

2. Choose a name for the board and a description and click the *Next* button.

3. This board is created as seen in Figure 3.12 and added to the tab *Your Boards*. By clicking on the board, it is possible to change the settings or add a card.

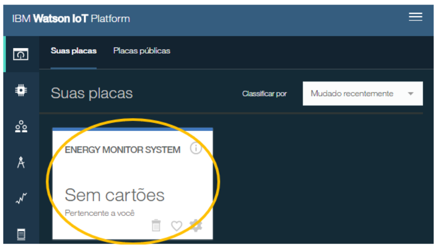

FIGURE 3.12: Example of a created board

To add and configure the cards itself, the following steps were followed:

1. Click on the board where it is supposed to add the card and click on the *Add new card* button.

2. Next, select the type of card (Line chart, bars, ...) and the device that we want to observe the data.

3. For the connection of a new dataset, visualized in Figure 3.13, it is necessary to have already the Node-RED configured. Select the event (input node in the Node-RED), the property, which will be taken from the JSON messages of the device events, give a name to the property, select the data type (text, number, ...) and the SI unit and, finally, the limits of the chosen graph.

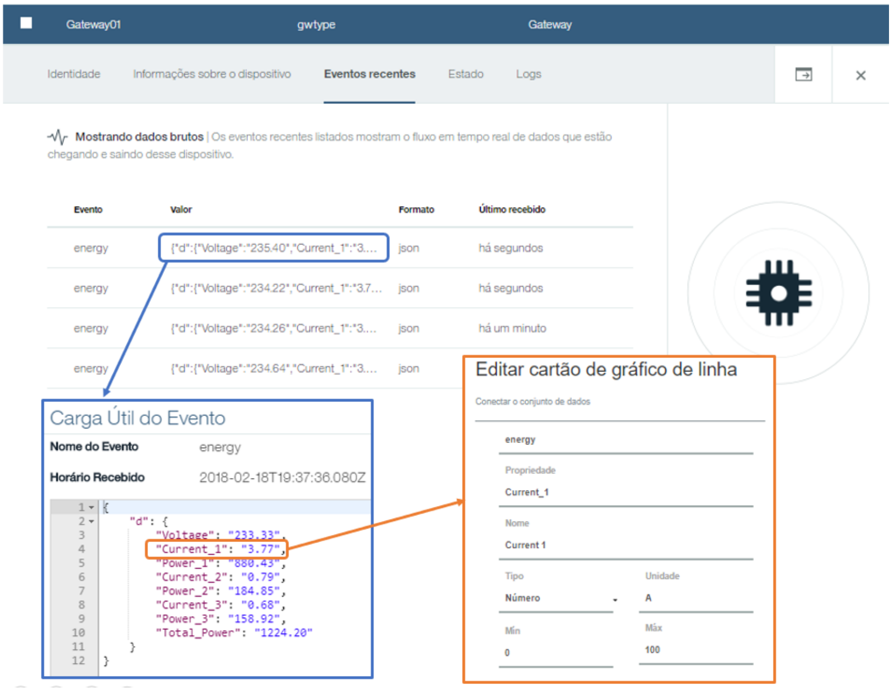

FIGURE 3.13: Example of the connection of a new dataset

4. In the next step, it is possible to preview the card, choosing the size of the card. The name for the card is also chosen and its colour scheme, and click on the *Send* button to terminate the creation process. An example of a card created is seen in Figure 3.14.

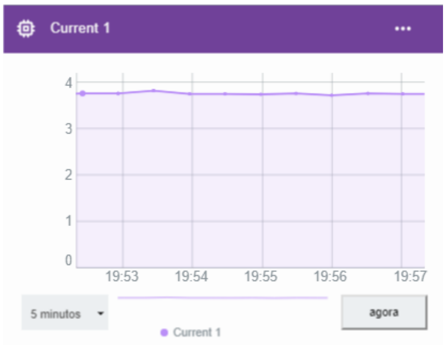

FIGURE 3.14: Example of a card created

For this prototype two boards were created as seen in the Figure 3.15, one two measure temperature and luminosity and, the other, for energy monitoring.

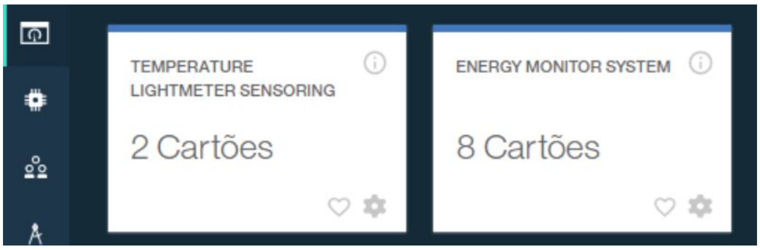

FIGURE 3.15: Created boards for the energy monitoring and temperature and luminosity measurements system

3.3.1.1 Messaging Transport Protocol

Watson platform uses the Message Queue Telemetry Transport (MQTT) protocol, which is a machine-to-machine (M2M) connectivity protocol designed as an extremely lightweight publish/subscribe messaging transport protocol [55]. It is used in several connections, for example connecting with sensors where small memory-sized code is required.

It is an excellent protocol to use with integrated devices since it is asynchronous, with different levels of service quality and this is important in the case the Internet connection is not trustworthy [55]. It sends short messages which is useful when the bandwidth is low.

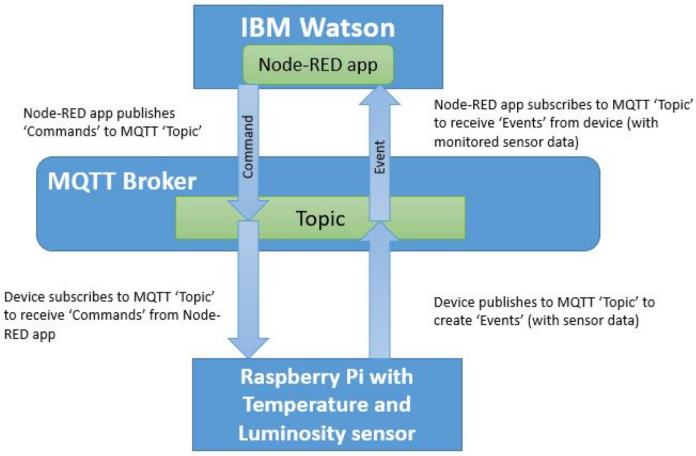

FIGURE 3.16: Diagram of the interaction between a device and an application through an MQTT Broker

Since it does not require a lot of software to implement a client, makes it excellent for devices such as Arduino which have limited memory.

3.3.2 Node-RED

Node-RED allows the development and deployment of JavaScript apps easily. Rules can be implemented in Node-RED to create automatic actions, such as sending an SMS, or an email alert when consumption increases above a predefined value, correlation with external data like weather conditions, among others. So, in addition to the other services, it was necessary to add Node-RED, as one of the services. To do so, the following steps were followed:

1. Go to the IBM cloud console and search for *Node-RED*.
2. Click on *Node-RED starter* and fill the fields App name, Host name, select the plan and click on the *Create* button.
3. After the creation of this service, its state should be *up & running*, and it has a link *Visit App URL*. Click on the link.

4. Define an username and password, and click the *Next* button.

5. Afterwards, several nodes from Node-RED will appear that are currently available and that can be added to the app. Click in the Next button.

6. Finalize the installation and, then, click on *Go to your Node-RED flow editor* to run the editor.

3.3.2.1 Flow schemes

The schemes used on Node-RED can be seen on the Figures 3.17 and 3.18:

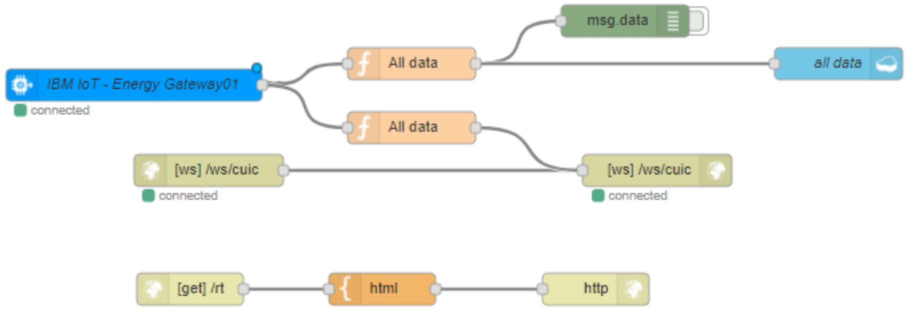

FIGURE 3.17: Node-RED DB schema for Energy Monitoring System

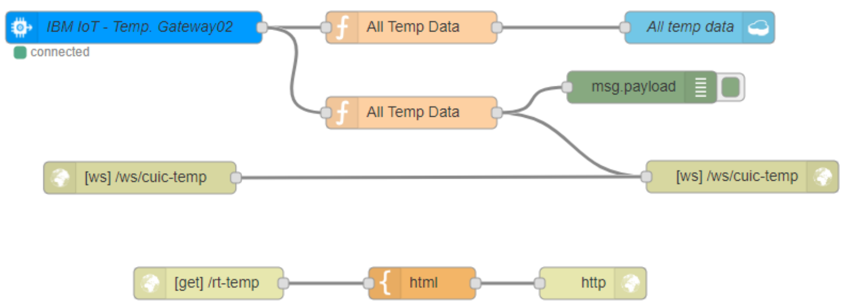

FIGURE 3.18: Node-RED DB schema for Temperature and Luminosity Measuring System

As mentioned before, for energy monitoring system we have the Gateway01, as seen in Figure 3.19. It was chosen as an input type, and the first node for the scheme configured to use the IBM Cloud services authentication. For the temperature and luminosity measuring system, we have the Gateway02 device, it was equally chosen as a first node in its scheme and an input node.

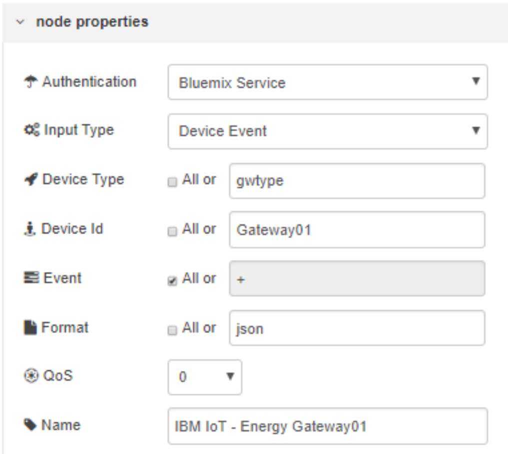

FIGURE 3.19: Example of the node (IBM IoT - Energy Gateway01) properties

The node *All data* has the type function, and it formats the received messages by the node *IBM IoT - Energy Gateway01* in case of the scheme in Figure 3.17, or the node *IBM IoT - Energy Gateway02* for the scheme in Figure 3.18, using the property *msg.payload* which contains the message body, returning a new object. We can see an example for Gateway01 in the Figure 3.20.

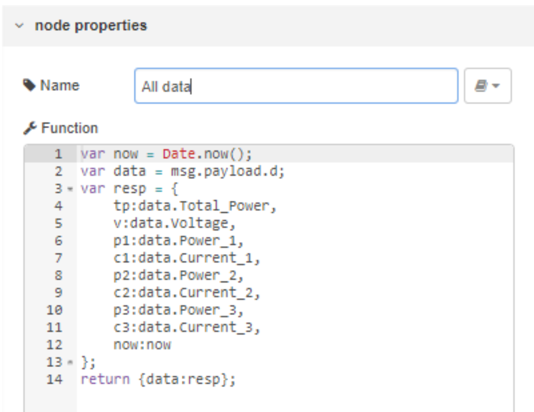

FIGURE 3.20: Example of the function on All data node (IBM IoT - Energy Gateway01)

In Figure 3.21 we observe an example of the message after debug. The node *msg.data* is a debug node to obtain data sent in each node of the process.

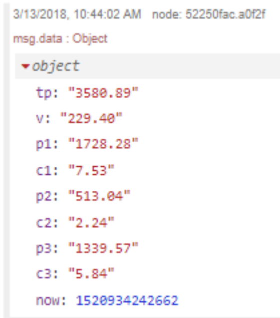

FIGURE 3.21: Example of a message after debug

The different *all data* node, seen in Figure 3.22, with a cloud in the symbol is a cloudant node with a storage type. This node stores the message in a selected database.

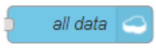

FIGURE 3.22: All data (Cloudant) node

The node *[ws] /ws/cuic* is a web-socket node with input and output type, seen in Figure 3.23.

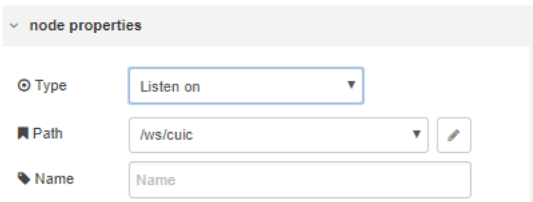

FIGURE 3.23: Websocket node properties (input and output) where real time data is collected

The node *[get] /rt* is a HTTP node with input type. This node creates a HTTP endpoint to create web services.

The HTML node is a template node with a function type. This node represents a page (view) that is sent by the server to the client (browser) with data injected into certain places by the server. For this particular case, the HTML template shown in Figure 3.24 is used in web-sockets, allowing communication between the client (browser) and the server in a continuous way. With this type of protocol, messages appear on the screen, without having to refresh the page, since the socket stays in the open state while the client and server remain connected.

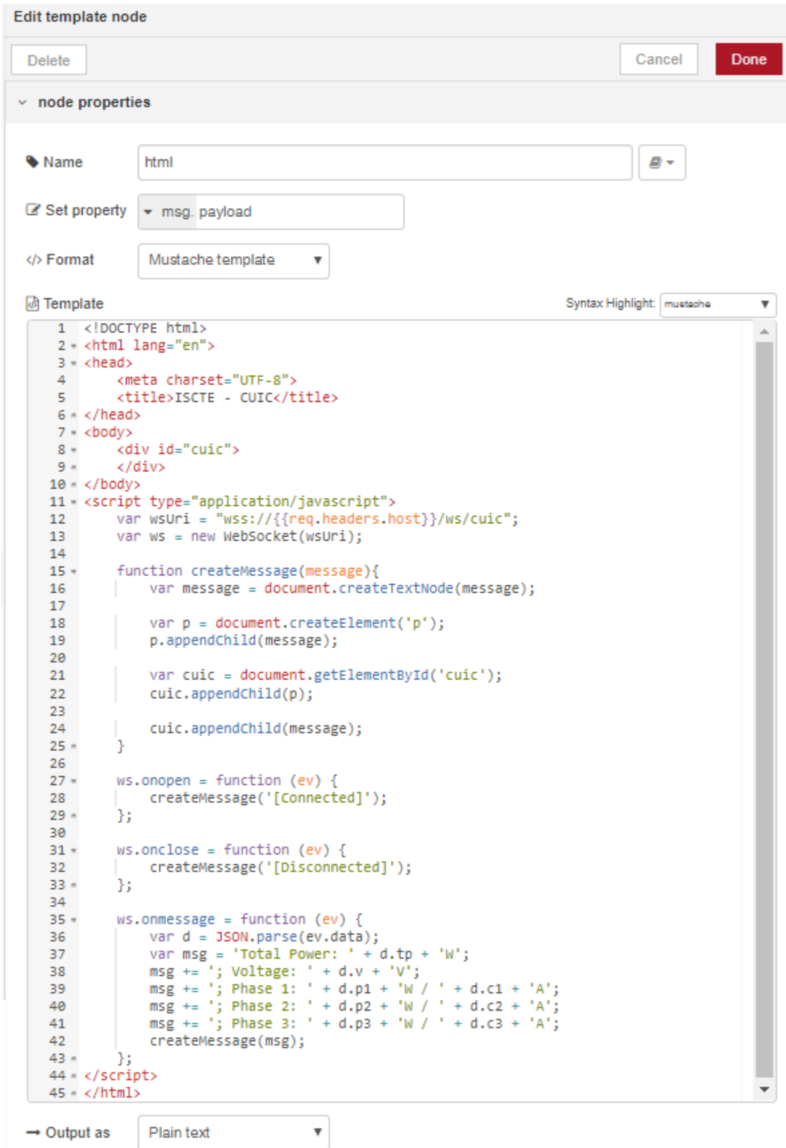

FIGURE 3.24: HTML template to show the data in real time (with the use of web-sockets)

Additionally, to get the external temperature in a specific location, a new flow was created on Node-RED to use the Weather Company API, seen in Figure 3.25.

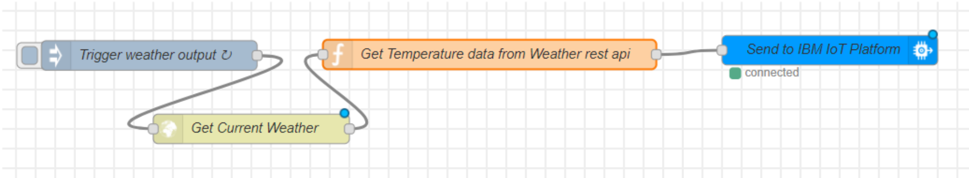

FIGURE 3.25: Node-RED flow to extract the external temperature in a certain location

In the node *Trigger weather output*, the parameters are adjusted to capture data from the virtual device that will get the temperature every 30 minutes, every day of the week.

In the node *Get Current Weather*, the coordinates for the location where the external temperature is wanted was inserted.

In the node *Get Temperature data*, we are connecting to the Weather Company API to create a message with the MQTT protocol in JSON to be sent after to the IBM IoT platform.

Also, in addition to the previous API referring to the external temperature, an API was created and the flow added in Node-RED to verify if the auditoriums were occupied or not through the fenix page.

3.3.2.2 Rules applied

Rules can be created to send notification, for example, when the consumption is too high, or the temperature too low, as observed in Figure 3.27. For this project we created three rules, seen in Figure 3.26:

1. Considering the current sensor only reads values until 100A, warning the user when the values are too high is a must. The overload of the circuit can ruin it. So, an SMS is sent when the current is superior or equal to 100A.

2. When the external temperature is below zero degrees an SMS is sent to the user, so an awareness exists for a higher energetic consumption to heat the buildings.

3. If the current is superior to 90A, the user should already be alerted, so an email is sent every hour while it remains equal to or above this value.

FIGURE 3.26: Rules created and applied

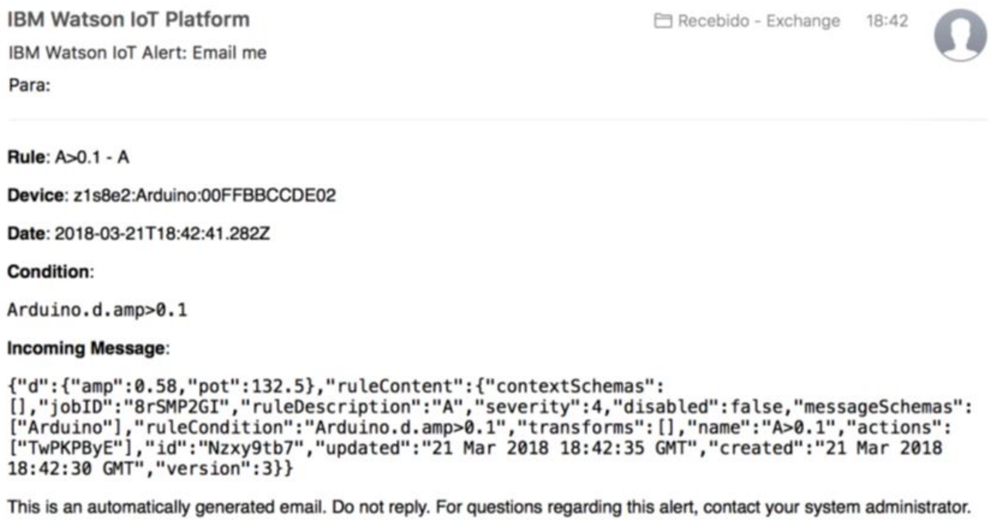

FIGURE 3.27: Example of an alert email when the current is superior to 90A

3.3.3 Cloudant NoSQL DB

Cloudant NoSQL DB is a scalable JSON document database. To analyze the data afterwards, there is a need to have the data stored, and due to the easy integration with the IBM Watson platform, Cloudant NoSQL DB was chosen. So, to store the data, it was necessary to add Cloudant NoSQL DB, as one of the services on the IBM Cloud platform. To do so, the following steps were followed:

1. Go to the IBM Cloud console and search for *Cloudant NoSQL DB*.

2. Chose a name for the service and click on *Create* button.

3. Go to *Service credentials* and click on the *New credential* button.

4. Select the name for the credentials and click on the *Add* button.

5. Click on *View credentials* to visualize the data to access the database.

6. Access to the link *https://cloudant.com/sign-in* and enter the access credentials previously defined.

7. To create a database, just click on *Create Database* and choose a name to identify it.

For this prototype, there were two databases created, as seen on Figure 3.28, one called *cuic* for the energy monitoring system, with a message example on Figure 3.29, and other called *temperature* for the temperature and luminosity measurement system, with a similar message example on Figure 3.30.

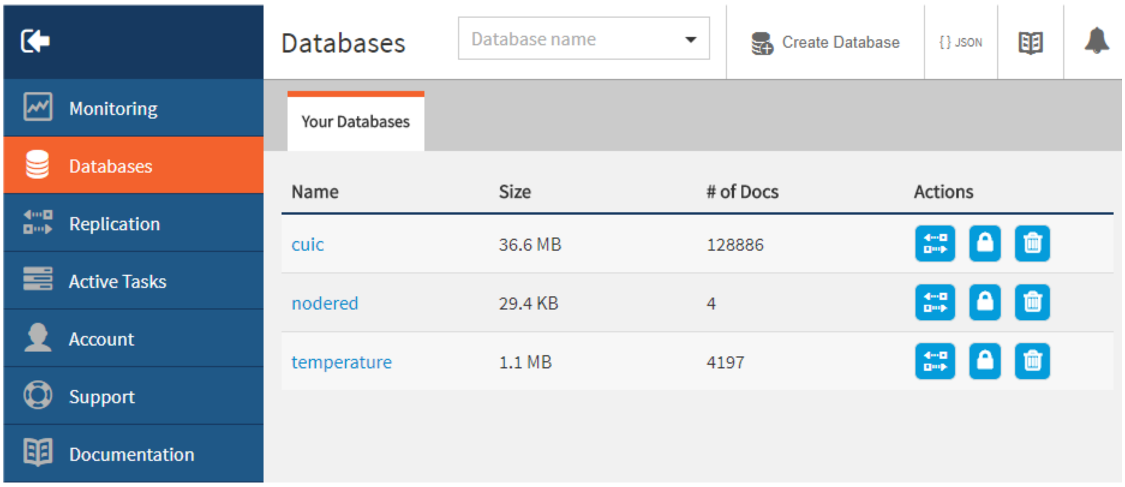

FIGURE 3.28: Databases NoSQL (cloudant) created

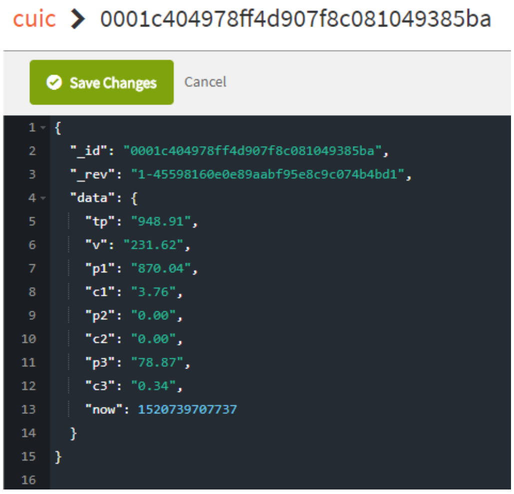

FIGURE 3.29: Example of a saved message in the DB for the energy monitoring system

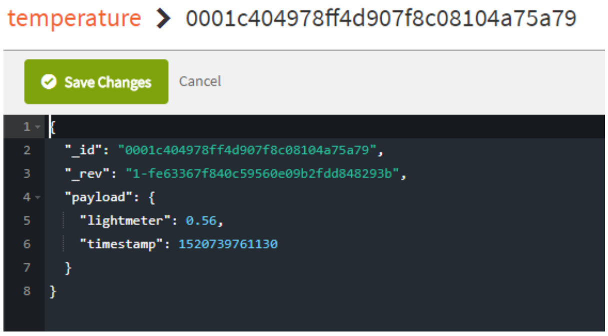

FIGURE 3.30: Example of a saved message in the DB for the temperature and luminosity measurement system

3.3.4 IBM Watson Analytics

The service IBM Watson Analytics allows getting the data collected and do predictive analysis over this data. To use this tool, the following steps were followed:

1. Go to the IBM cloud console and search for *IBM Watson Analytics*.
2. Click on the button *Create*.
3. On the Welcome page, click on the button *New data*.
4. It is possible to upload a file from the computer or search for the files from the Cloudant NoSQL DB.

5. After the new data sets are uploaded, the data can be explored. Click on the tab *Discover* to start exploring the data and generating graphics. The several options are available in the Figure 3.31.

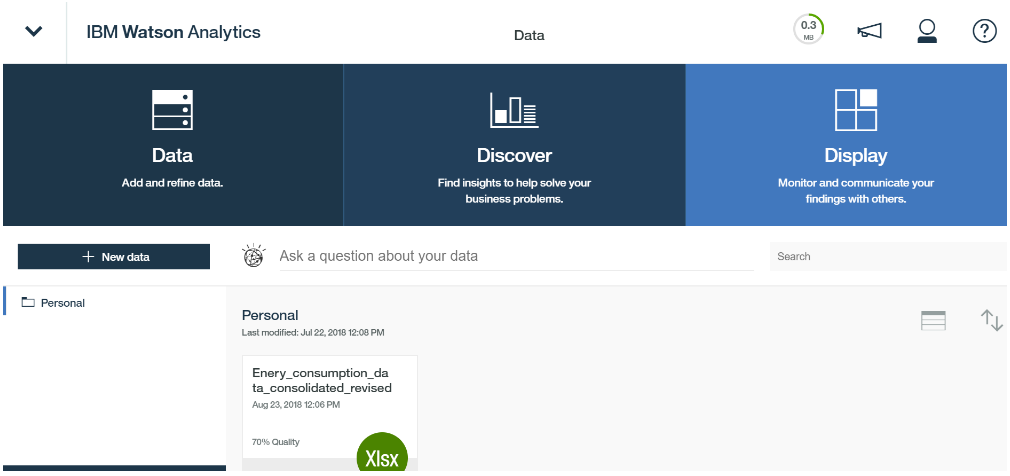

FIGURE 3.31: IBM Watson Analytics - Welcome page

Chapter 4

Prototype Installation

The prototype was installed in the ISCTE-IUL university in Lisbon, Portugal. A university composed by 9283[1] students (undergraduate, master, PhD and post-graduate programs), and that had in 2016 a budget of 42.2 million euros where only 43,8% were financed by the State budget.

The campus in itself is composed of four main buildings but for this prototype, only the building *Ala Autónoma* was used, chosen by the university due to unrelated motives to this thesis.

ISCTE-IUL started in 2018 strategically betting in sustainability. A formal board was created so several projects could be implemented, namely:

1. Campus operations, such as water, energy and waste management.
2. Core activities, like research and education.
3. Outreach to the community, meaning in this context, activities to connect to society.

With the implementation of the sustainability project, the university considers savings of one third on the energy consumption and CO_2 emissions will occur. In

[1] Data from 2016.

order to accomplish here this goal, a need to study energy efficiency and monitor energy consumption arose. If these devices are implemented and with the complement of analytics in the cloud, exploring IoT, we can save ISCTE-IUL significant financial resources by optimizing processes.

To implement the proposed system in this campus, we took into consideration that this is a city in a country with a heating and cooling climate, and as such, there is a need to balance HVAC equipment for heating and cooling in response to the external conditions. Also, this is a service building, with a particular characteristic from universities, which is seasonality [56] - meaning that usually when ISCTE-IUL has more capability to produce energy (through renewable sources - solar energy), it is also when there are fewer people in the building.

The installation of the sensors to acquire data was done in dry places, regulated to environment temperature and kept out of reach for third parties, as observed in Figure 4.1.

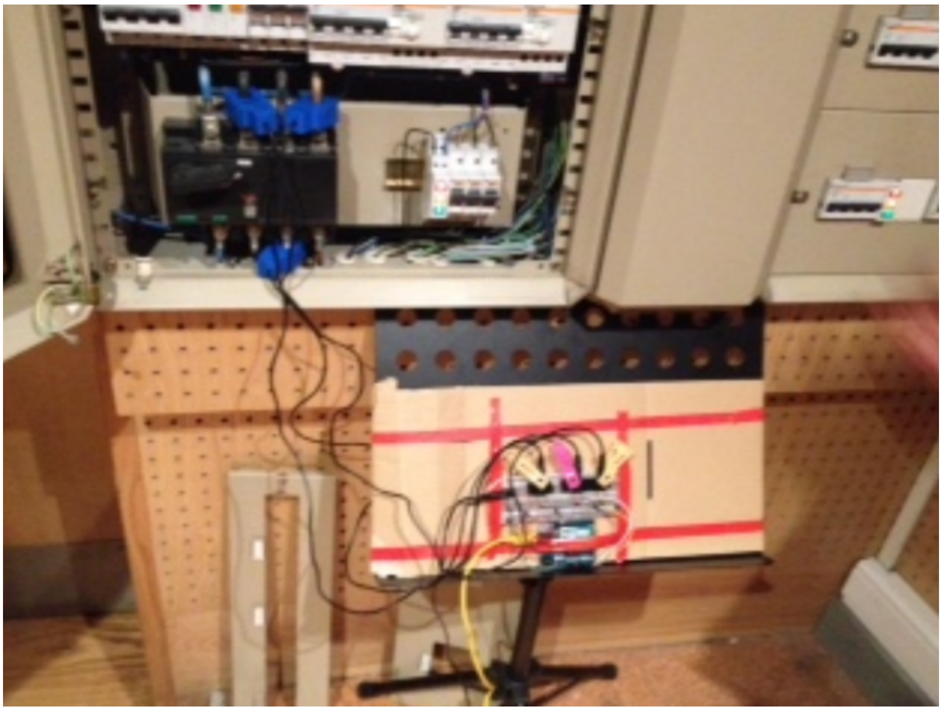

FIGURE 4.1: Implementation on the electric board - Ala Autónoma

4.1 Data Collected

The overall data collected for the energy monitoring system is related to the period from 16^{th} December 2017 to 20^{th} March 2018. The reason for more data not being collected, and even the data collected having gaps, is because LoRa network had a limitation of memory, which was only understood when the server was out of space and data was no longer being stored. This was improved by an algorithm that allows collecting data every 30 minutes or only when a significant change occurred, in order to reduce the number of messages sent and, as a consequence, the space occupied, as explained in Appendix D. In addition, some connections problems happened throughout the project, since the LoRa network was installed recently and was in an initial phase of implementation.

Through the temperature and luminosity measurement system, data was collected for the period from 10^{th} to 16^{th} March 2018, corresponding to only one week of data. More data couldn't be collected for the same reason as the energy monitoring system, due to lack of servers to keep the data. In addition, most of the hardware took four months to arrive.

There were other limitations established by the university, one of them being the energy monitoring prototype could not be in the electric board since wires were out of the board, so eventually the prototype was removed all together due to security reasons and lack of space on the cloud.

To compare the data, we used weeks were we had full data over, such as the following and hence forward mentioned only as following:

- Week 1 - 18^{th} December 2017 to 24^{th} December 2017.
- Week 2 - 25^{th} December 2017 to 31^{st} December 2017.
- Week 3 - 1^{st} January 2018 to 7^{th} January 2018.
- Week 4 - 12^{th} March 2018 to 18^{th} March 2018.

4.2 Data Analysis

To analyse the data collected, the IBM Watson Analytics was used, as mentioned in Chapter 3.3.4. Four cases were analysed, as shown in the following sections.

4.2.1 Total consumption per hour

For the total electric consumption per hour, an average per hour was used for each complete week of data. These graphics per week can be observed in Figures 4.2, 4.3, 4.4 and 4.5.

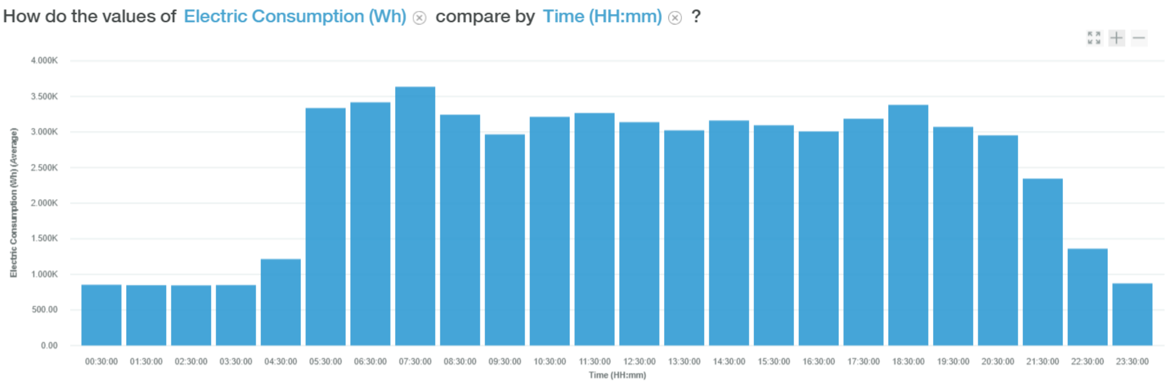

FIGURE 4.2: Electric Consumption per hour for Week 1

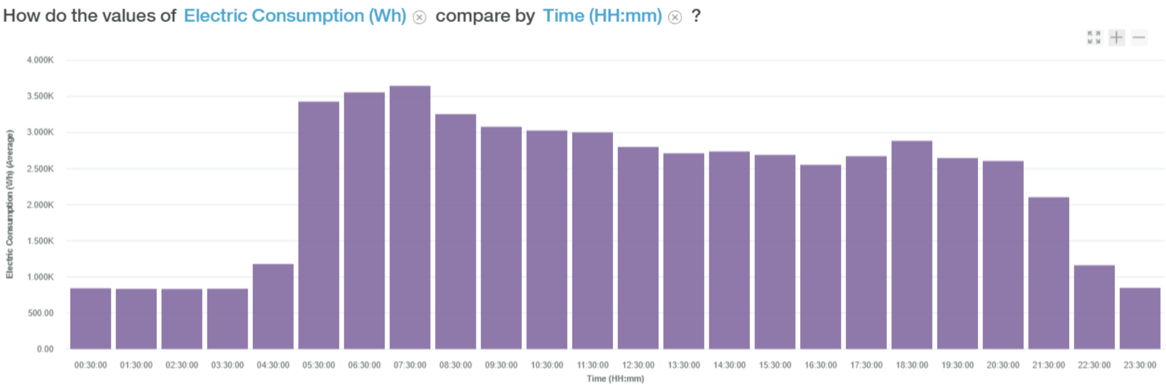

FIGURE 4.3: Electric Consumption per hour for Week 2

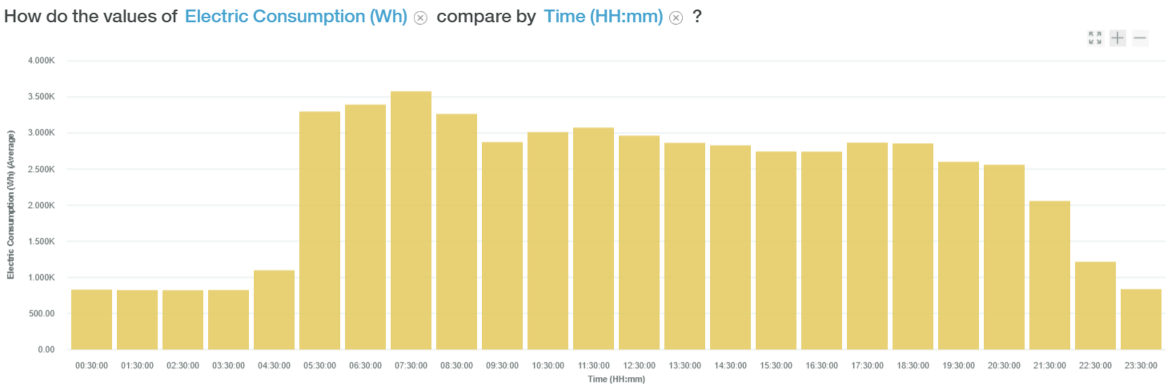

FIGURE 4.4: Electric Consumption per hour for Week 3

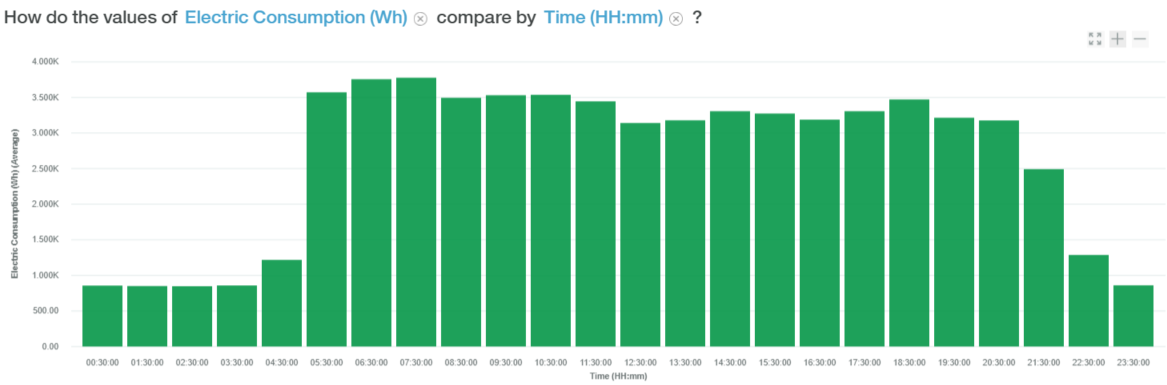

FIGURE 4.5: Electric Consumption per hour for Week 4

From these graphics, it is possible to get the following information:

- There is a waste of energy consumption during the morning.
  Between 5am and 6am the lights are turned on, although classes can only start from 8am. This two hours of consumption are a waste of energy that should be eliminated and that can allow saving a great amount of money to the university. One way to prevent this is having this energy monitoring system sending an SMS to the security, for example, warning of high consumption while there are no classes occurring, in order to have saving measurements applied.
  Due to the investigations done in order to understand this consumption values, efficiency measures were actually applied already in the cleaning and security routines to save energy, being one of the measures removing the permission to the cleaning company to turn on and off the lights as they please.

- There is a residual energy consumption throughout the night.

  It is visible throughout these four weeks that there is a residual consumption with a value of approximately 1000W/h. This is too high of a value to just be ignored. As such, other graphics[2], seen in Figures 4.6, 4.7 and 4.8 were made to analyse if these values were related to a particular phase or distributed through the three present phases on the electric board.

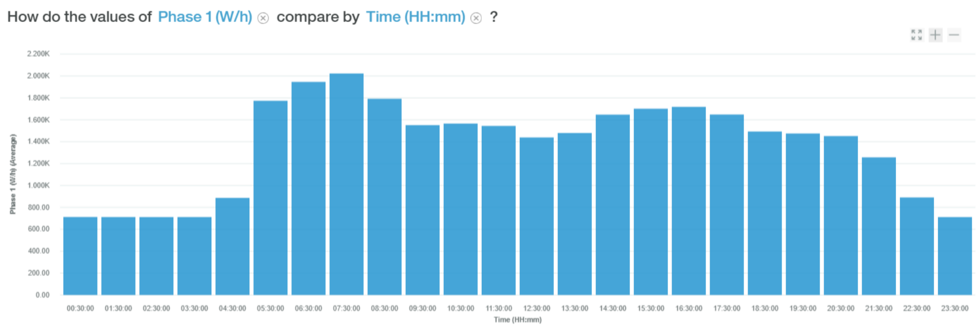

FIGURE 4.6: Consumption for Phase 1 of the electric board per hour for all the data collected

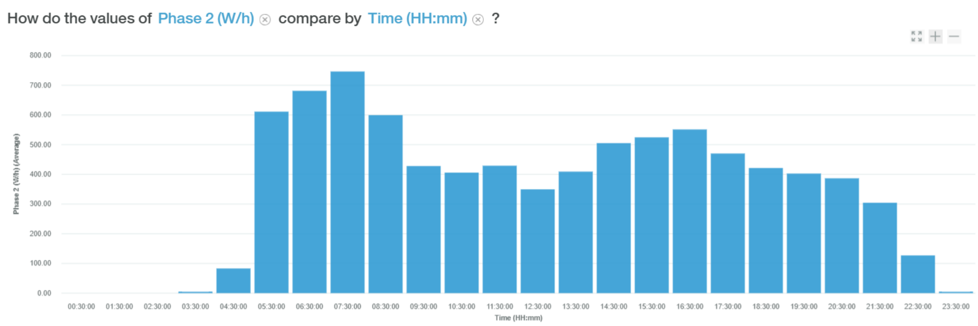

FIGURE 4.7: Consumption for Phase 2 of the electric board per hour for all the data collected

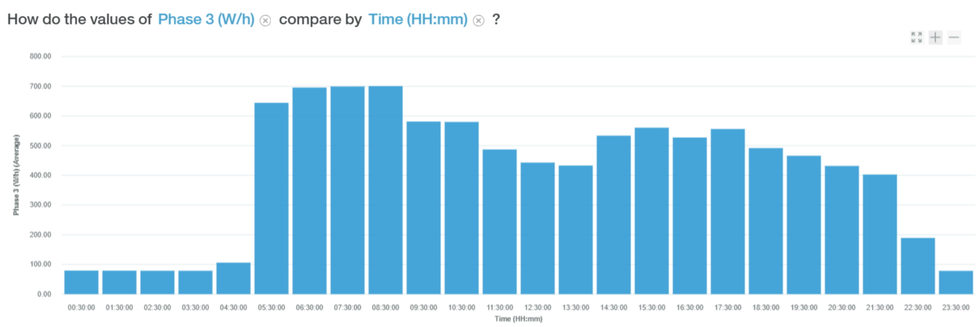

FIGURE 4.8: Consumption for Phase 3 of the electric board per hour for all the data collected

[2]Please note that for Figures 4.6, 4.7, 4.8, the y axis scale is different.

From the analysis of this graphics, it can be verified that the consumption is higher in phase 1, which indicates that there is a greater number of equipment linked to this phase. Concerning phase 2, it can be verified that during then night the values are zero, which shows that there is a time where no consumption exists at this stage. Phase 1 and phase 3 always have values higher than zero, meaning they have residual consumption present.

In special, phase 1 has a residual consumption of approximately 800W/h. After some investigation within the university, the two electric boards in this building have either the air conditioning running continuously or the computer room within the auditorium. One of these is creating the residual consumption verified in the data. These consumption patterns cannot be improved, since there is a need to have this consumption actively occurring. The only measurement of improvement would be to get better equipment which would consumed less energy.

- There is a visibility of the seasonal aspect of the university, even if only slightly. The next graphic shows this situation better, as for each day we can see the average of electric consumption, which is higher during the classes period compared to the exam or break periods.

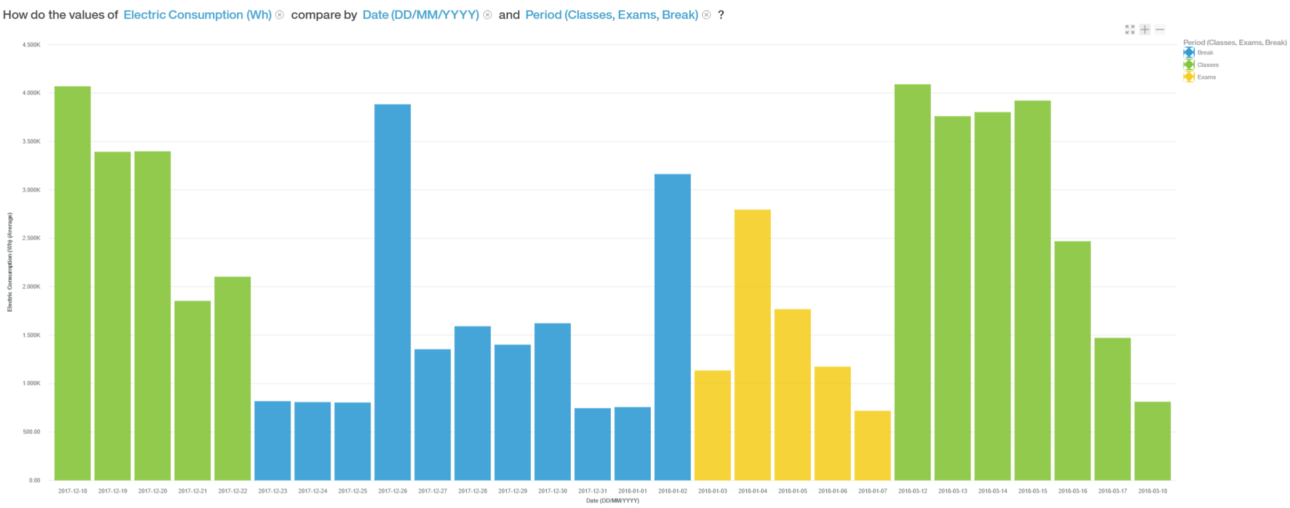

FIGURE 4.9: Consumption per day and period

4.2.2 Total consumption per person

For the electric consumption per person some limitations were present, since a motion sensor was not assembled with this system and no access was permitted to the card system in each auditorium. So, it was considered an average of 30 people per auditorium. This means that if both auditoriums were occupied, we counted with 60 people in it, but if, for example, only Auditorium Afonso de Barros was occupied, we counted only 30 people.

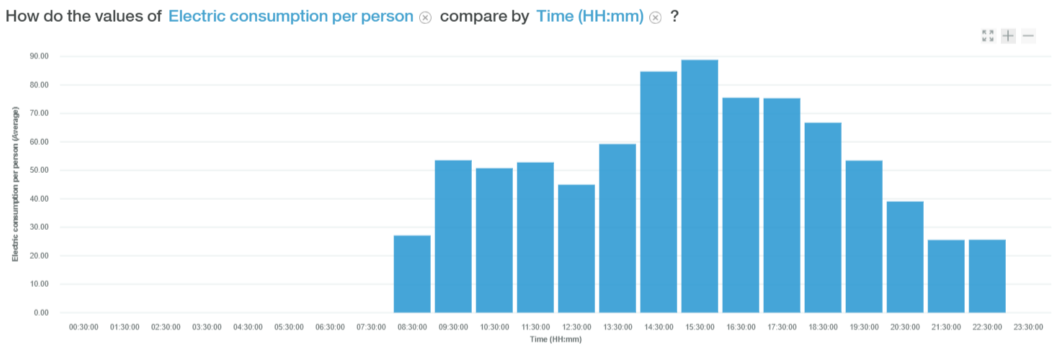

FIGURE 4.10: Consumption per person by hour for Week 1

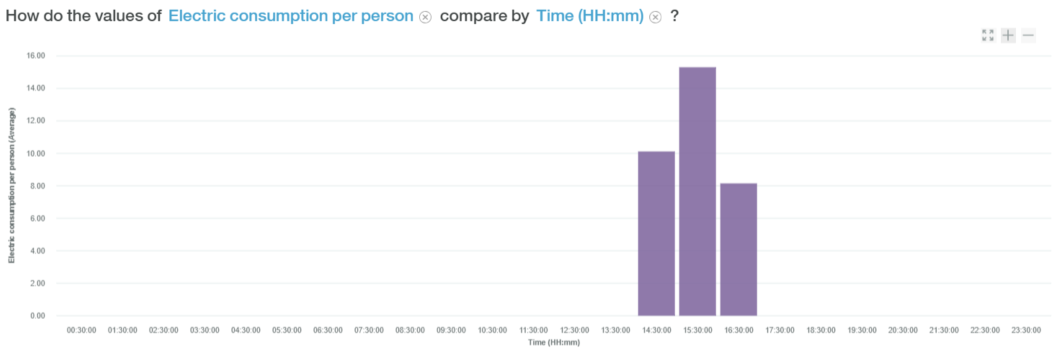

FIGURE 4.11: Consumption per person by hour for Week 2

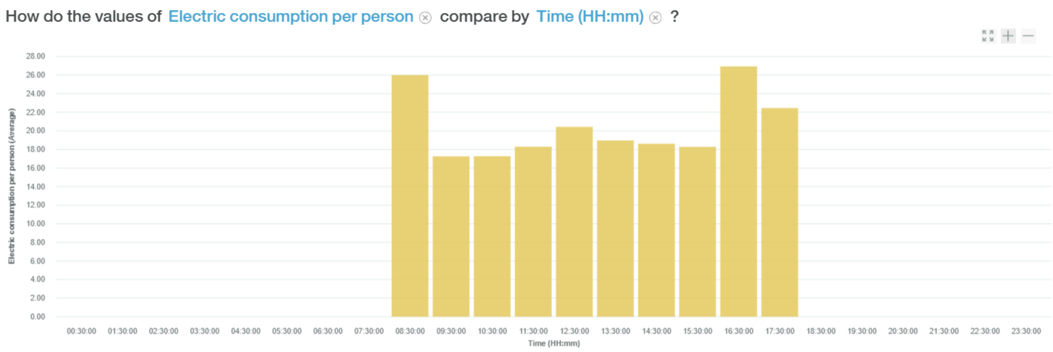

FIGURE 4.12: Consumption per person by hour for Week 3

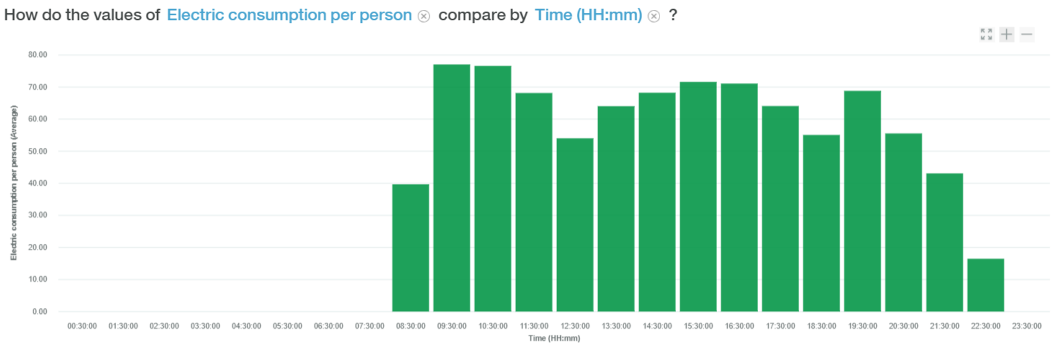

FIGURE 4.13: Consumption per person by hour for Week 4

From these graphics[3], it is possible to take the following observations:

- Looking only to the Week 1 and Week 2, we can see a high peak of approximately 90W/h on Figure 4.10, while in Figure 4.11 the peak is only 15W/h. Having in consideration that we are only considering when the auditoriums are occupied, it is simple to observe that the energy consumption per person was lower in the Week 2. This might be due to the seasonality of the university, considering the Week 2 is a period of break where no classes or exams are occurring.

- Between Week 1 and Week 4 we can see the consumption is higher than the other two weeks, since these two weeks correspond to a period of classes.

- Since we are observing only the consumption when the room is occupied, we can assume the following statements:

  1. Only the projector is on, this is equivalent to a lower consumption - approximately 5 to 15 W/h per person.
  2. In addition to the previous equipment, the lights are on in the auditoriums and perhaps some devices are charging, which is equivalent to a medium consumption - approximately 15 to 60 W/h per person.
  3. If besides all the previous equipment being connected, the air conditioning is also on, then the consumption is high - approximately 60 to 90 W/h per person.

[3] Please note that for Figures 4.10, 4.11, 4.12, 4.13 the scale for the y axis is different.

4.2.3 Total consumption per square meter

Similar to the consumption per person, the square meters used are related to the room occupation, meaning, if both auditorium were occupied the consumption was divided by the sum of their area. But if only one auditorium was occupied, it would be divided by its area. Important for this analysis was obtaining the area for the auditorium:

- Auditorium Silva Leal - 99,5m^2
- Auditorium Afonso Barros - 151,2m^2

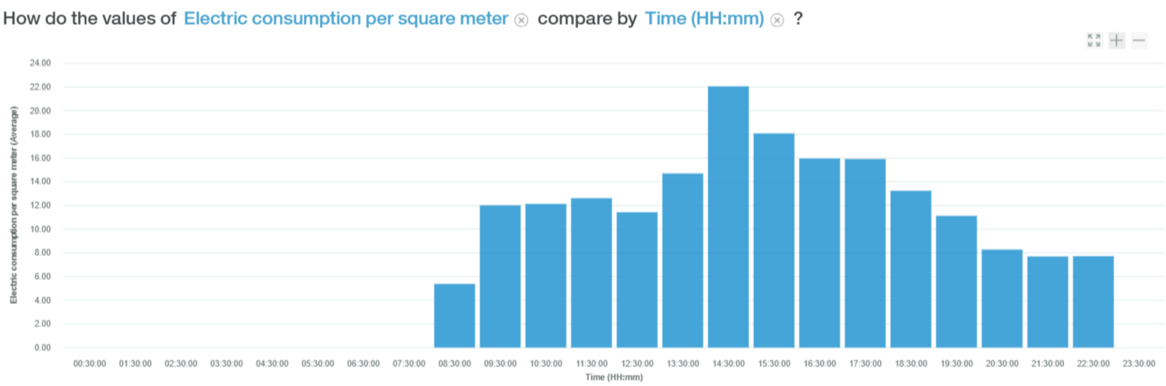

FIGURE 4.14: Consumption per square meter by hour for Week 1

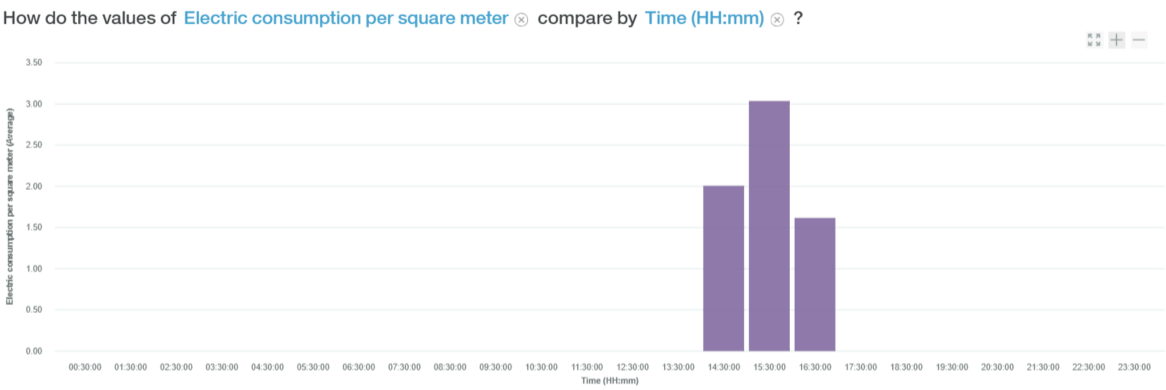

FIGURE 4.15: Consumption per square meter by hour for Week 2

We analyzed this case with the graphics presented in the Figures 4.14, 4.15, 4.16 and 4.17 but no different conclusions could be taken compared to the Section 4.2.2.

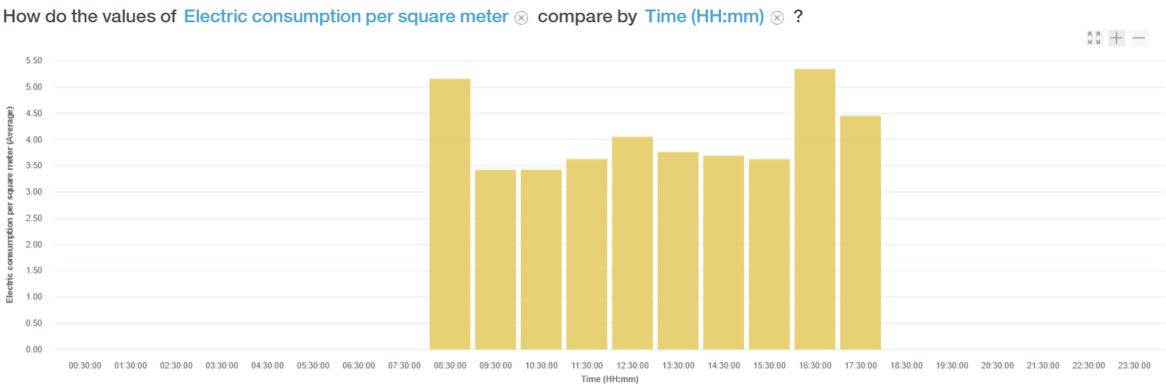

FIGURE 4.16: Consumption per square meter by hour for Week 3

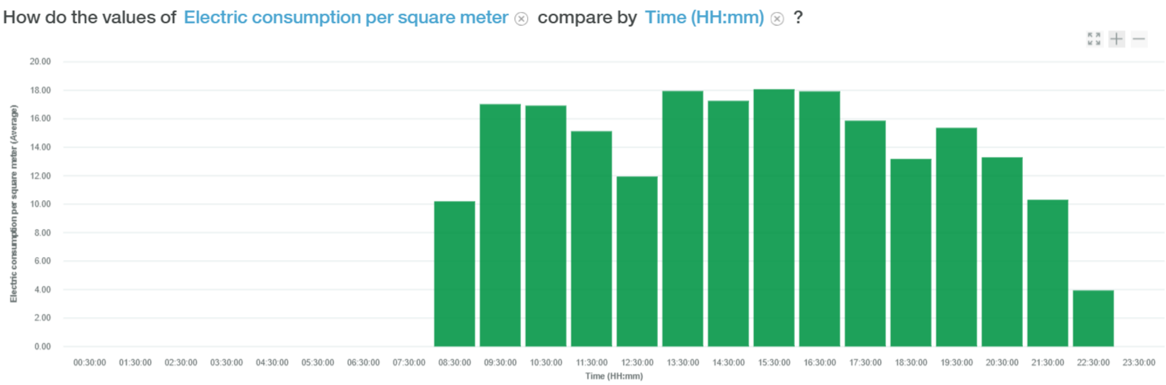

FIGURE 4.17: Consumption per square meter by hour for Week 4

4.2.4 Total consumption and Consumption in the occupation period

The analysis done through the assembly of these graphics on Figure 4.18, 4.19, 4.20 and 4.21 is with the purpose of understanding the energy inefficiency present at the moment in the university.

It is possible to observe from the graphics, that there is a lot of inefficiency moments. The inefficiency is when we have consumption without having the auditoriums occupied.

In terms of operational building management, this difference presented in the graphics, shows what consumption can be attributed to the operational activities of the building and which cannot.

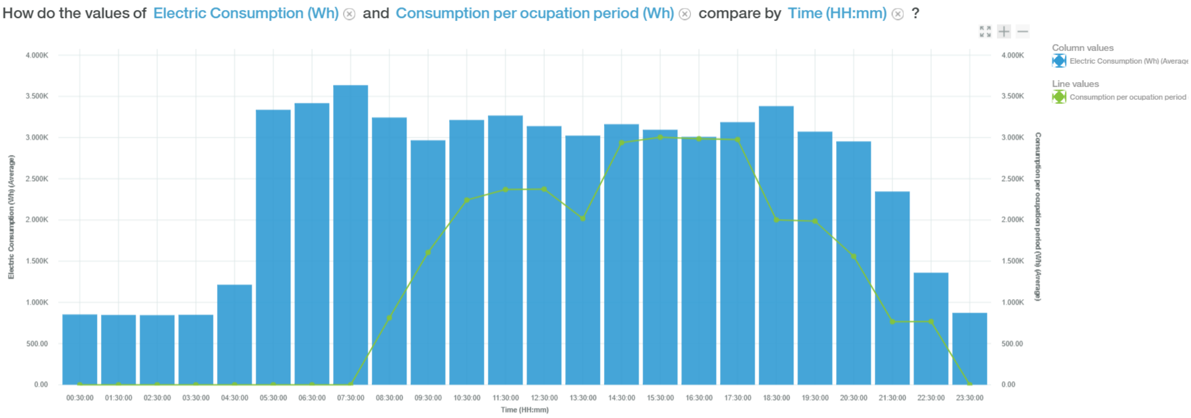

FIGURE 4.18: Total Consumption and Consumption during the occupation period of the auditoriums by hour for Week1

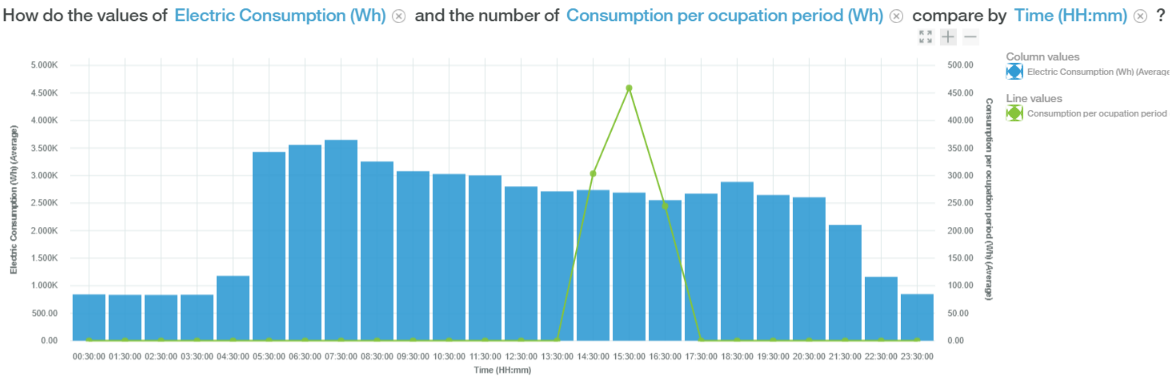

FIGURE 4.19: Total Consumption and Consumption during the occupation period of the auditoriums by hour for Week2

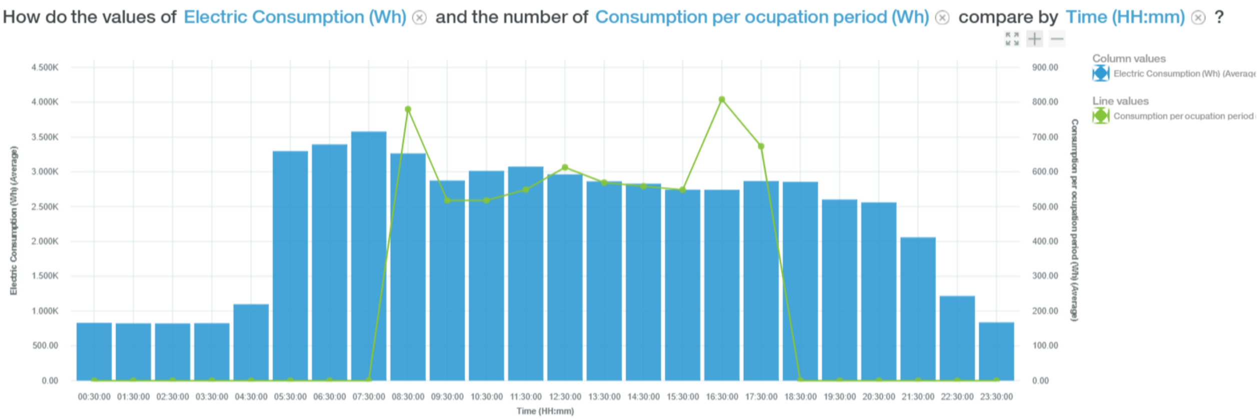

FIGURE 4.20: Total Consumption and Consumption during the occupation period of the auditoriums by hour for Week3

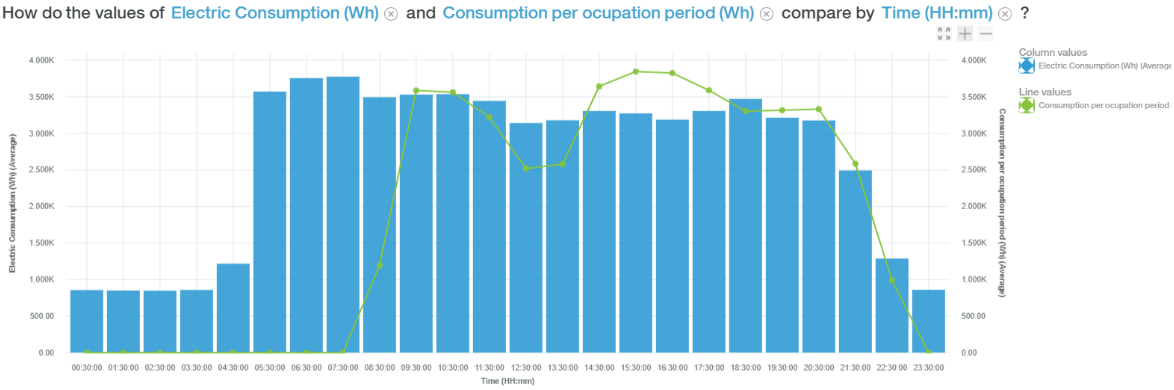

FIGURE 4.21: Total Consumption and Consumption during the occupation period of the auditoriums by hour for Week4

4.3 Recommendations

In this chapter we focused on the data analysis part to demonstrate the importance and usefulness of this project. The prototype, with the purpose of studying the energy efficiency, was installed on an electric board related to two auditoriums in one building of the university. Unfortunately, the prototype ended up removed due mainly to security reasons, but it still provided insight with the data captured.

From this analysis, we can take some recommendations:

1. The high morning consumption done during the cleaning of the auditoriums can be diminished with an SMS warning the security guard that high consumption is occurring during a period without classes.

2. There could be an analysis of the equipment used in the auditoriums to understand their value and if with these values of consumption they should or should not be replaced for lower consumption equipment.

3. Take advantage of the seasonal aspect of the university to save money on the break periods by implementing these efficiency measurements.

4. Between classes the lights should not be left on, so measurements as an SMS to the security guard or to a professor, should be implemented to make sure this consumption is reduced or eliminated.

Chapter 5

Conclusions and Future Work

In this dissertation, we focused on building a prototype to measure both energy consumption and temperature and luminosity, and study the energy efficiency in the university. The prototype installed only in one building to test the solution presented the results in the previous chapter and throughout this dissertation it is possible to understand how it is mounted from hardware to software.

The temperature and luminosity measuring system was built and installed for one week, but this did not allowed for enough data to be collected to do a proper analysis but should be done as future work in the university with the energy monitoring system implemented in other electric boards so energy efficiency can be studied and improved throughout the university. Also, with the available information regarding external weather conditions and correlated with the electric boards of the HVAC, can be used to predict near-future thermal comfort constraints. Correlating this set of data with data collected by sensors provides beneficial management information to predict future needs regarding heating and cooling. It is, therefore, possible to manage better the relationship between energy supply and demand, taking more advantage of renewable energy produced on-site.

A motion sensor should also be added to the prototype to have an exact value if the room or auditorium is occupied or not. This allows for a more accurate study of the energy efficiency.

As explained in the previous chapter, this solution had already an impact on the university, since with the investigations done to understand the residual consumption during the night, measurements to reduce the consumption during the morning period while no classes occurred was implemented.

In the end, with this dissertation we achieved mainly the goals initially proposed by assembling an IoT prototype able to measure both energy consumption and temperature and which is scalable to the entire university campus, and studied the energy efficiency for the two auditoriums as much as possible, without the correlations with the temperature (explained before the reasons).

So, in spite of the project not going as expected, there is important data that can be used in future dissertations within the university and practical data that already had an impact on the energy efficiency measurements of the university, and if scaled to the entire university, has the potential to be useful for the university sustainability.

Appendices

Appendix A

Requirements

A.1 Hardware requirements for energy monitoring system

Installation of the voltage meter:

- 1x 9V AC-AC transformer
- 1x 100kOhm resistance to lower the voltage division
- 1x 10kOhm resistance to lower the voltage division
- 2x 470kOhm resistance
- 1x 10uF capacitor
- 1x 5.5mm DC jack connector welded to breadboard connection pins to allow connection of the AC-AC power adapter to the breadboard circuit

Installation of the current sensor:

- 1x CT sensor YHDC SCT-013-000
- 1x burden resistor of 33Ohm for 5V supply voltage

- 2x 470kOhm resistance for the voltage divider
- 1x 10uF capacitor
- 3x 3.5mm audio jack (TRS) connectors welded to breadboard connection pins to allow connection of CT sensor to the breadboard circuit

Other components required for the system installation:

- 1x Arduino
- 1x Breadboard
- 1x Laptop

A.2 Hardware requirements for temperature and luminosity measurement system

- 1x Sensor TI CC2650 Sensortag
- 1x Raspberry Pi 3
- 1x MicroSD card with Raspbian operating system
- 1x Raspberry Pi3 transformer
- 1x Keyboard
- 1x PC mouse
- 1x Monitor/Television with HDMI input
- 1x HDMI cable
- 1x Laptop
- 1x Ethernet Cable (RJ45)

A.3 Software requirements

It is needed an IBM Bluemix account (IBM licensing) and access to VNC Connect software.

Appendix B

Raspberry Pi connection to a VNC

Through VNC Connect software it is possible to access remotely to the Raspberry Pi.

To do so, the following steps were done:

1. Create an account and follow the instructions in:
   http://www.realvnc.com/pt/raspberrypi/#sign-up

2. In the Raspberry Pi, open the main menu and select *Preferences* and, then, *Raspberry Pi Configuration*. It will open a new window, select the *Interfaces* tab and choose the *Enable* option related to the VNC interface. Afterwards, press the *OK* button to save the changes and restart the Raspberry Pi;

3. In the Raspberry Pi, select *Licensing* from the VNC Server menu and put in the account's credential.

4. On the computer, run the VNC Viewer and enter the credentials;

5. In the VNC Viewer a connection to the Raspberry Pi will automatically appear under the group name. Click once or twice to connect;

6. In order to complete a direct connection or through the Internet, authentication is required on the VNC Server. Put the username and password used for authentication in Raspberry Pi.

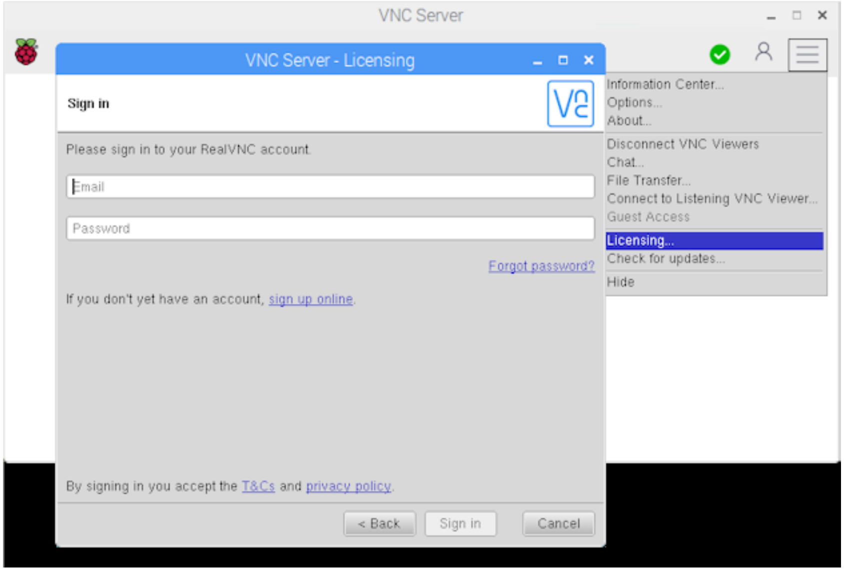

FIGURE B.1: VNC Server - Sign in window

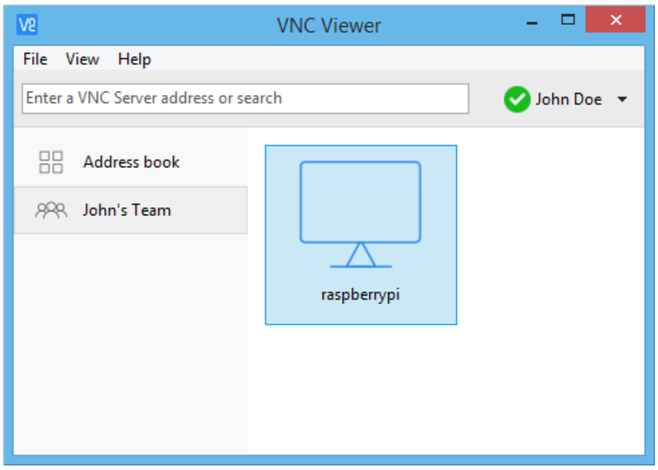

FIGURE B.2: VNC Viewer

Appendix C

Code embedded in the Arduino

```
#include "EmonLib.h"              // Include Emon Library

#define VOLT_CAL 205.08
#define CURRENT_CAL 60.6

EnergyMonitor emon1;              // Create an instance
EnergyMonitor emon2;              // Create an instance
EnergyMonitor emon3;              // Create an instance

void setup()
{
  Serial.begin(9600);

  emon1.voltage(0, VOLT_CAL, 1.7);  // Voltage: input pin, calibration, phase_shift
  emon1.current(1, CURRENT_CAL);       // Current: input pin, calibration.
  emon2.current(2, CURRENT_CAL);       // Current: input pin, calibration.
  emon3.current(3, CURRENT_CAL);       // Current: input pin, calibration.
}

void loop()
{
  emon1.calcVI(20,2000);          // Calculate all. No.of half wavelengths (crossings), time-out
  emon2.calcVI(20,2000);          // Calculate all. No.of half wavelengths (crossings), time-out
  emon3.calcVI(20,2000);          // Calculate all. No.of half wavelengths (crossings), time-out

  float currentDraw_1             = emon1.Irms;             //extract Irms into Variable
  float supplyVoltage_1   = emon1.Vrms;                     //extract Vrms into Variable
  float currentDraw_2             = emon2.Irms;             //extract Irms into Variable
  float currentDraw_3             = emon3.Irms;             //extract Irms into Variable
  float totalWatts = (currentDraw_1 * supplyVoltage_1)+(currentDraw_2 * supplyVoltage_1)+(currentDraw_3 * supplyVoltage_1);

  Serial.print("Voltage 1: ");
  Serial.print(";");
  Serial.print(supplyVoltage_1);
  Serial.print(";");
  Serial.print("Current 1: ");
  Serial.print(";");
  Serial.print(currentDraw_1);
  Serial.print(";");
  Serial.print("Power 1: ");
  Serial.print(";");
  Serial.print(currentDraw_1 * supplyVoltage_1);
  Serial.print(";");
  Serial.print("Current 2: ");
  Serial.print(";");
  Serial.print(currentDraw_2);
  Serial.print(";");
  Serial.print("Power 2: ");
  Serial.print(";");
  Serial.print(currentDraw_2 * supplyVoltage_1);
  Serial.print(";");
  Serial.print("Current 3: ");
  Serial.print(";");
  Serial.print(currentDraw_3);
  Serial.print(";");
  Serial.print("Power 3: ");
  Serial.print(";");
  Serial.print(currentDraw_3 * supplyVoltage_1);
  Serial.print(";");
  Serial.print("Total Power: ");
  Serial.print(";");
  Serial.println(totalWatts);
  //Serial.println("\n\n");
  delay(5000);

}
```

FIGURE C.1: Initial code embedded in the Arduino

Appendix D

Analysis of the number of messages sent by Arduino

In a long term way, too much data is sent to the Cloud system, which has really strict space/memory limitations. In order to reduce the impact of having this great data quantity and due to the lack of space occurred during the project, an algorithm was implement in the Arduino code to only send data when significant changes would occur, such as a change of 0.05A in the current sensor. In case this change in correct does not occur, then no reading is sent to the cloud. All this confirmation is happening every 10 seconds.

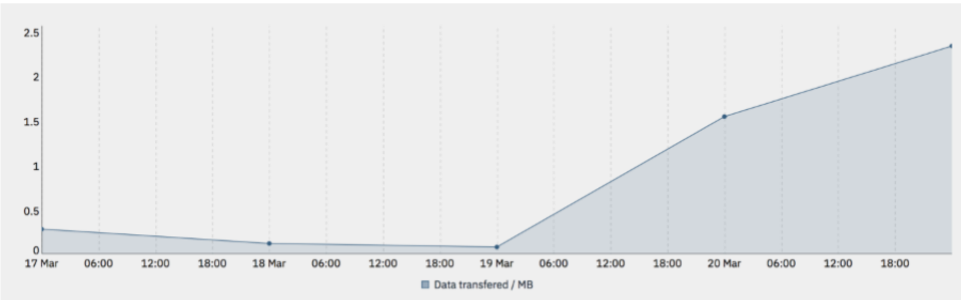

FIGURE D.1: Transferred data between 17th March and 21st March

As it is possible to verify on Figure D.1, there is a significant change in space occupied depending on the algorithm used.

Between 17 to 19 of March only data with significant changes were sent. The following values were registered: 0.28MB, 0.12MB and 0.08MB, making a total of 0.48MB. While between 20 to 21 of March data was sent with a periodicity of 30 seconds. For this case, the values observed were between 1.54MB and 2.33MB, making a total of 3.87MB, representing a much higher quantity in data. Based on this analysis and comparison, we can conclude that sending data only when considerable changes occur, implies a highly significant low value in terms of data stored, being this good for the user and the network.

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