Smart Auditorium: Development and Analysis of a Power and Environment Monitoring Platform

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Abstract. The Internet of Things (IoT) is applied to many cases on the topic of smart cities. In the scope of this paper, we apply a flexible IoT-Developed platform, using LoRa communication, applied to university auditoriums in order to try and find patterns and/or anomalies in energy consumption and in the interior temperature. This platform enables the interested parties to monitor the energy consumption of lighting, of HVAC (Heating, Ventilation, and Air Conditioning) and if electrical plugs alongside the monitoring of temperatures, aiming to create a report about the efficient, the thermal insulation and the HVAC behavior. Based on the acquired information, a management strategy is applied to find that the lack of certain systems leads to an extreme waste of energy and the lack of proper cleaning procedures can lead to decreasing the efficiency of the HVAC.

Keywords: IoT, Power Consumption Sensors, LoRa, Sensors, Temperature Sensor, Classroom Monitoring, Smart Cities.

1 Introduction

With an increase in the world's population, resource wasting follows closely. Waste of resources originates from a different number of factors including, but not only, the lack of regulations, the misuse of existing regulations and in more extreme cases the complete disregard for those regulations, in both household and enterprise environments. One of many approaches used to tackle the problems related to resource wasting was

the production and improvement of sensorial devices, the means to communicate between them and the analytical information obtained from using these devices, thus giving birth to the Internet of Things (IoT).
These sensors are able to act both independently and with ease of use due to their mostly plug and play features.

Obviously, with the increasing search for IoT devices, the market is already flooded with devices like this, and by 2025 this market will be valued at $6.3 trillion according to McKinsey Global and, in line with this, International Data Corporation (IDC) specified that, by 2025, data load will increase all the way up to 163 zetabytes thus reaching 10 times the value from 2016 [1].

More than 80 million LoRa connected devices are working in tandem between more than 100 countries and with a CAGR for 100% or double each year [2]. This type of device can work as emergency alerts or automation controls with the lowest latency on the downlink.

Considering this scenario, and based on our previous works, we developed a low-cost LoRa sensorial solutions and the respective web server capable of monitoring power consumption and the environment in classrooms with the objective that smart classrooms and campuses may be able to improve learning experiences for students, while also improving operational efficiency. The reason for choosing LoRa was due to the poor Wi-Fi connection in certain environments, as well as the authentication factor that required more than a simple password in order to connect. In this paper, in order to evaluate our work, we also detail the assessment of an auditorium that was described as a heavy consumer of electricity and the interested party wanted to find out why, alongside an evaluation of the HVAC to find out possible improvements.

2 State of the Art

Energy efficiency and energy consumption saving are one of the most popular problems in the world of IoT research. To this end the European Union not only has created several sustainability programs with focus on reducing carbon emissions by 40% and increasing the use of renewable energy by 32% [3], but also created directives with measures that focus on the achieving of 1.5% energy efficiency increase per year by energy distributors and promote energy-efficient renovations by government-owned buildings to an extent of at least 3% of the floor area [4]. Within these initiatives, GAIA (Green Awareness in Action) [5] is one of the main contexts of this paper. It's main objectives focuses on the creation of Information and Communications Technologies (ICT) ecosystems specifically for educational buildings that motivate and support citizens' behavioral change to achieve greater energy efficiency in over 24 educational sector buildings in 3 countries covering North, Central and South Europe leading up to reductions of over 15% on the energy that could be influenced by the end-users.

Stricter regulations lead to an increase in demand for the creation of efficient energy management inside buildings, therefore, leading to the creation of more IoT projects and infrastructures. The work in [6] presents an example of both the positives and negatives of the increasing demand for efficiency measuring platforms for HVACs. It presents an example of how the lack of proper network infrastructure that can be an impediment for efficient measuring. Yet another issue faced by researchers is the lack of standardization for data generated by energy monitoring solutions. Brick [7] proposes uniform schemas that define a concrete ontology for end-devices, subsystems, and relationships among themselves, which would enable portable applications. Edge Computing [8] is also another problem-solver whose main objective is to bring the computer processing as close to the data source as possible, as in, some cases, the end-device itself. This way we're saving finite resources such as bandwidth, server resources and the costs caused by cloud processing while increasing the solution's "awareness" and reducing latency between the time the events occur and when the user is notified.

In [9], the authors presented the design and evaluation of the system PTEC, a thermal and energy control prediction system in a data centre. The focus of the study was to verify if the PTEC could efficiently perform monitoring of the data centre with a low cost in the use of power. The system collects data from both the server fans and the air conditioner and checks whether the information on both temperature and consumption are within a margin of safety for the data centre. The evaluation of the system is carried out by means of simulation to verify the efficiency and lability of the PTEC. The PTEC evaluation has shown that it can reduce cooling and circulation energy consumption by up to 34% and 30%.

In [10] a low-cost solution is developed with its main objective being, in a similar manner to ours, the power monitoring in educational buildings with the use of an open-source IoT infrastructure and XBee Devices. This solutional experiment has provided insights based on the data obtained for several power consumers, thus managing descriptive analytics of those consumers. A different approach used in power consumption research mentioned in the article [11] is the use of occupancy sensors in large commercial buildings. These occupancy sensors determine the occupancy in the selected areas and generate patterns that can create a more efficient HVAC schedule patter. This could bring reducing energy consumption up to 38% without reducing thermal comfort.

Aside from research solutions, there are also several commercial devices available in the market, in this paper we present three of the most common: (1) Smart Energy by Develco Products [12], focused on the overall building energy monitoring in an intrusive way, it also allows for the measurement of energy generation created, for example, by photovoltaics, using communication standards such as Zigbee, Z-Wave, WLAN, Wireless M-Bus, and Bluetooth Low Energy. (2) Sense: Home Energy [13], like this work, makes use of amperage clamps or current transformers to measure power consumption, therefore making it a non-intrusive solution. (3) Engage: Efergy [14] is yet another home energy consumption monitoring solution that uses Current Transformer (CT) Sensors to measure energy with the possibility to mix with future energy electrical plugs thus allowing for both intrusive and non-intrusive experience.

In this paper, a similar solution is described. CT sensors will connect to an Arduino MKR1300 and sent power consumption per interval data to an open-sourced web server which will place all data on a MySQL database. The users will then be able to analyze the data using PowerBI.

Table 1 presents the mentioned devices studied.

Table 1 - Related Works table

System	Source	Sensor Type	Communication	Main Use	Commercial
This paper	Open	**Non-Invasive:** CT Sensor	LoRa	Any Power Source	No
PTEC[9]	Closed	**Invasive:** Power Meter **Non-Invasive:** Temperature Sensor	IEEE 802.15.4 Ethernet	Data Center Cooling	No
[10]	Open	**Non-Invasive:** CT Sensor	IEEE 802.15.4	Educational Buildings / Any Power Source	No
[11]	Closed	**Non-Invasive:** Occupancy Sensor	Not specified	HVAC	No
Smart Energy by Develco Products [12]	Closed	**Invasive:** Plugs, Meter Interface	Zigbee, Z-Wave, WLAN, Wireless M-Bus, BLE	Any Power Source	Yes
Sense: Home Energy [13]	Closed	**Non-Invasive:** CT Sensor	Wi-Fi	Any Power Source	Yes
Engage: Efergy [14]	Closed	**Non-Invasive:** CT Sensor **Invasive:** Power Plug (Future)	Not specified	Any Power Source	Yes

WLAN: Wireless Lan, BLE: Bluetooth Low Energy, HVAC: Heating, Ventilation and Air Conditioning,

All of the devices above have at least one form of communication protocol. In order to enumerate some of the key differences between several communication standards used by IoT and the LoRaWAN we are using, the following table 2 is also presented:

Table 2- Overview of Common IoT Communication Standards

Wireless Technology	**Data Rate**	**Max Payload Length**	**Comm. Range**	**Security**	**Strengths**	**Ref**
LoRaWAN **(This paper)**	50kb/s	243 Bytes	~5km Urban ~15km – 20km Rural	128bit AES	(1) Low Power Consumption (2) Long Communication Range (3) Low Cost (4) Secure (5) Easily available	[15] [16] [17]
Sigfox	100 b/s	12 Bytes	~10km Urban ~40km Rural	No Encryption	(1) Long Communication Range (2) Low Power Consumption	[17]
NB-IoT	200 kb/s	1600 Bytes	~1km Urban ~10km Rural	LTE encryption	(1) Large Maximum payload length (2) Low Power Consumption (2) Secure	[17]
Wi-Fi	Top 1Gb/s - IEEE 802.11ac	2034 bytes	1-100m	WPA/WPA2	(1) High Speed (2) Advanced/Mature Standard	[18] [16]
ZigBee	250kb/s@2.4Ghz 40kb/s@915MHz 20kb/s@868MHz	255 Bytes	10-300m Direct Line Sight 75 – 100m Indoor	128 bit AES	(1) Low Cost (2) Low Power Consumption (3) Large number of nodes (up to 65000 nodes) (4) Secure	[19] [20] [21]
Bluetooth 5	2 Mb/s 500 kb/s (Long Range S = 2) 125 kb/s (Long Range S = 7	255 Bytes	Up to 200m +200m (BLE)	L1 – No security L2 – AES 128 L3 – AES and Pairing L4 – ECDHE	(1) Ease of access and setup (2) Simple Hardware (3) Secure (4) Low power consumption (BLE)	[22]
NFC	424 kb/s	$2^{32}-1$ Byte	< 20 cm	Short Range	(1) Continuous evolution (2) Stable technology for short range devices	[23]

AES: Advanced Encryption Standard, WPA: Wi-Fi Protected Access, BLE: Bluetooth Low Energy,

ECDHE: Elliptic-curve Diffie–Hellman Exchange, LTE: Long Term Evolution

3 System Architecture

In short, our system consists of three main layers as shown in Figure 1.

Sensor Layer: End Devices consist of the Environment Sensor integrated with a LoRa Seeduino board and the Power Consumption Sensors integrated into the Arduino MKR WAN 1300 that enables data to be sent through a LoRa network into the closest gateway. End devices are also able to receive messages from the gateway, therefore, communication is bidirectional. These devices are powered by a lithium battery, in the environment sensor's case, or directly by the power plug, such as the power consumption sensor, and their only way of communication is through a LoRa network. Temperature sensors are used for the HVAC evaluation and Power Consumption Sensors are used for the HVAC, Lighting, and Room Electrical Plugs.

Network Layer: Consists of a LoRa Gateway connected to a Cisco's Router that receives Uplinks from several end devices and sends them to the Actility networks management service. This management service routes messages, through an Internet Protocol, to one or more application servers depending on the application they were defined to be sent to, while, also, forwarding messages from those application servers to the respective End Devices, in case there is a need to send a command, or correct the sensor's internal clock.

Knowledge Layer: The Flask web servers/application servers, a scalable solution, receives the data from the gateway and provides the treatment and processing of that data while also sending messages to defined sensors to calibrate their internal clock or provide commands, the MariaDB databases provide the data storage and backup, all while PowerBI provides the dashboard that analyzes and displays the data which is then used to make conclusions.

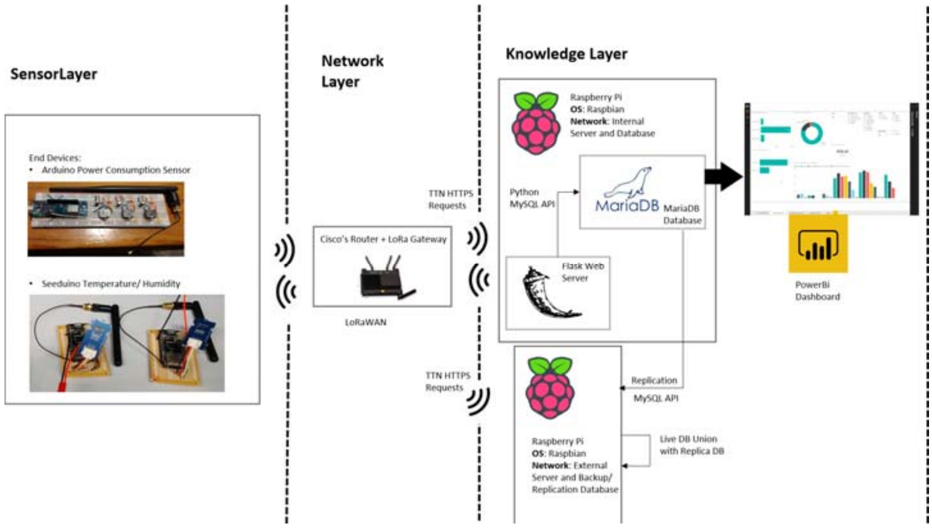

Fig. 1. - Developed System Architecture

3.1 Sensor Layer

Power Consumption Sensor. Power consumption sensors (See Figure 2) were placed in auditoriums in phases corresponding to the Lighting, HVAC and Electrical Plugs, each of them formed by 3-phased power distribution. These prototypes use an Arduino MKR 1300 connected to a set of Current Transformer (CT) sensors with accuracies that will vary depending on the power consumption passing through the main cable at the time:

- With values close to the expected rating of the CT Sensor we can expect ∓ 3% error [24].
- When measuring values that are very close to zero we can see errors up to 10% [24]
- However, if we go above the expected maximum rating by a large factor we risk obtaining error results up to 70% due to saturation [24].

Each sensor is able to connect to three-phases simultaneously, read each phase individually, and sum the values (kWh per reading interval) received from the phases. The sensor sums the value with each read and resets that sum every time it sends the data (as long as the data was received by the server), while also waiting to receive any message from the server. The LoRa limitation comes from the fact that it can only receive messages right after sending data to the server due to the way the device is defined. The type of message this sensor can receive can come in two forms:

- A single command, to change a variety of settings such as the interval of power reading or data sending.
- A corrective message sent automatically by the Application server. This message has the single purpose of correcting the end-device's Real-Time Clock (RTC) when it gets out of sync with real-time.

Environment Sensor. The environment sensor, see Figure 3, used to analyze the HVAC alongside the CT sensor, uses LoRa32u4 II cards based on the Atmega32u4 microcontroller connected to a temperature and humidity sensor SHT31, which has an accuracy of ± 0.3°C. As these sensors are designed to be portable and easy to place anywhere in the Auditoriums, they are powered by 2400 mAh lithium batteries, the durability of which is extended by code optimization and sleeps between submissions.

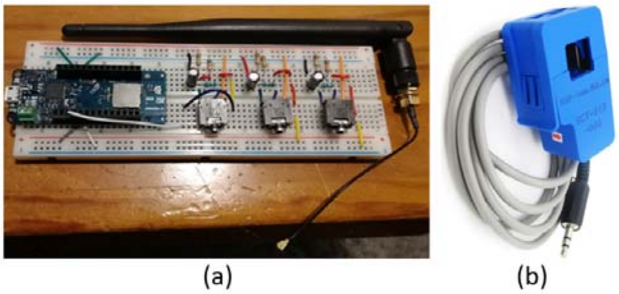

Fig. 2. Developed power consumption sensor board (a) and the CT sensor (b) that is connected to the jacks.

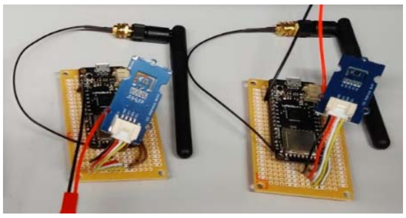

Fig. 3. Developed environment sensor

3.2 Network Layer

The entire system depends on 2 wireless communications protocols:

- The LoRaWAN protocol. Establishes a connection between the end-devices and the LoRa.
- HTTPS connects the LoRa gateway to the WebServer/Application Server.

As a co-founder of the LoRa Alliance, Actility is a worldwide project with over 30000 gateways interconnected, with a focus on the creation of a secure IoT network based on LoRa technology and LoRaWAN protocol. Each end-device is inserted into the network using the Actility console that provides an interface to enable flexible device management. It also allows the integration of a variety of services such as HTTP, MQTT, and cloud services such as Azure or AWS, however, the Application server used connects directly to Actility using HTTPS.

LoRa communication allows the device to work in a different variety of environments even when Wi-Fi is not available due to its low frequency. Low frequency also means that obstacles such as sturdy walls in building basements are also not an issue.

3.3 Knowledge Layer

Application Server. The application server has one main responsibility, to receive data from the LoRa server through HTTPS and then save it onto a database. In order to do this a web server was created with Flask, a python web framework. This web server is kept running full-time on a Raspberry PI configured with the Raspbian OS. Flask was chosen due to its lightweight capability. It is an un-bloated and simple framework which means it does not occupy a lot of computational resources to run.

The server processes HTTPS post requests with UPLINK data packets. It creates specific objects according to the type of end-devices that sends them. It then sends those objects unto a database running on the local IP. As mentioned above the server will also send corrective messages to the end-devices when their RTCs get out of sync with real-time

The data collected is inserted into individual tables in a SQL database so that they can be further analyzed, consulted and, in case there is a need, exported.

While power consumption sensors provide consumed kWh per time interval, the environment sensor will provide temperature data. In the database temporal information is inserted alongside data such as the location of the sensors, auditorium occupancy, etc.

Dashboard. To create the dashboard PowerBI was used. It's a Windows OS only tool. Based on well the database is prepared for business intelligence it will provide a simple way to create interactive visualizations with pre-defined filters created by the developer. PowerBI, however, is mostly used for non-real-time business indicates, but even then the developer can achieve near-real-time updates while also connecting to different APIs and web services. It also allows the capability of using scripts from common programming languages such as R or Python

PowerBI connects locally to a MySQL database. Temperature, power consumption and other variables for each auditorium are acquired and stored on the same device. This allows for data extraction alongside the displaying of gathered information using gauges, bar, line, and circular charts.

In Figure 4 we can see an example of the monthly report (a), that can be filtered for each month, Type of consumption (Lights, HVAC, Plugs), Room, Weekday, Period of Time and even hour of the day, enabling, for example, to find anomalies such as computers that are left ON overnight leading to power waste.

Fig. 4. Monthly Report on PowerBI

In Figure 5 is presented an example of the reporting for the Auditorium C103, alongside this image, while not visible, we can also filter by the several devices in the room including an interval of dates.

Fig. 5. Daily Auditorium C103 report

4 Results

In order to evaluate our work, we ran our solution in several auditoriums, but one particular was chosen for analysis because of its particular high power consumption. The solutions ran for 3 months and we decided to pick May as our main evaluation month since it was the month with no school holidays. Overall the total energy consumption for the 3 months in this evaluated auditorium was 1710 kWh with May consuming 44% of that total, 755 kWh. In general for the month of May, and in all the other months the biggest consumer was, in fact, Lighting, reaching over 85% of the total (See Fig. 6 (a)) or 642 kWh overall (See Fig. 6 (b)).

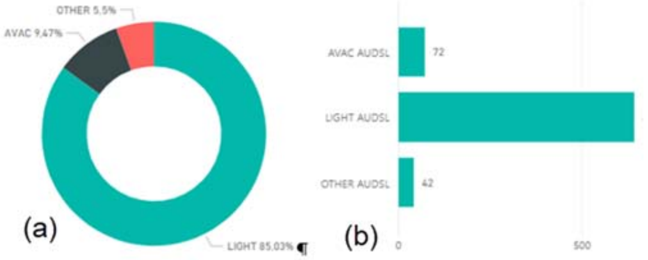

Fig. 6. The ratio of the total energy consumed per type of device in percentage (a) and the total value consumed in kWh (b)

The main reason for these values is an issue where light switches are in a hard-to-reach location within the auditorium, therefore the only people allowed to turn that switch on or off are the security guards for the building. This, in turn, leads to heavy power consumption since the security guards won’t bother turning the lights off when no classes are occurring in the auditorium / between classes. The automated scheduled classes also have partial blame, since security guards are to be told that classes were going to occur in the auditorium but then no one would show up. In this auditorium, out of those 642 kWh used for lighting, approximately 248 kWh were wasted, which corresponds to 38% of the total lighting consumption and 32% of the overall power consumption in the month of May. The best solution for this issue would be to add a new light switch accessible to all users which would make sure they would be able to turn the lights on and off when they please. Figure 7 shows the difference between wasted power consumption in an auditorium with a normal light switch (b) and this auditorium (a). The residual daily consumption we see in the second auditorium is related to cleaning schedules that happen every day except Sundays.

Fig. 7. The daily difference in wasted power between the evaluated auditorium with out-of-reach light switches (a) and one with user-moderated switches (b).

Still on this same topic and already within the values above, we also can see that lights are turned on too early, by which we mean that between 7 AM to 8 AM we have lighting consumptions values of 43.96 kWh in the evaluated auditorium while in the normal auditorium those values barely reach 8 kWh, which is used for cleaning duties (See Fig. 8, highlighted square). In this figure we also note the difference in hourly variation; while in the evaluated auditorium (a) the values tend to be higher and more close together between each hour with slight variations, the normal auditorium (b) seems to have bigger variations between each hour, which can clearly be seen between lunch hours (12 AM block).

As for the auditorium's environment first, we decided to compare the daily maximum and minimum temperatures inside the auditorium with the outside temperature (See Fig. 9). The auditorium temperature was measured starting in April and it's still running to this day.

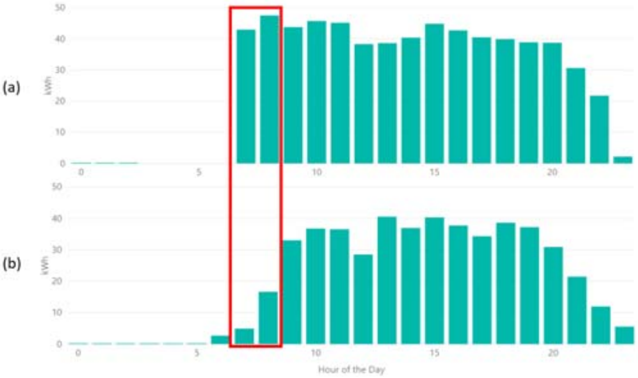

Fig. 8. The hourly difference in the sum of daily power consumption between the evaluated auditorium with out-of-reach light switches (a) and one with user-moderated switches (b). Power consumption within hours 6 AM to 8 AM exclusive marked.

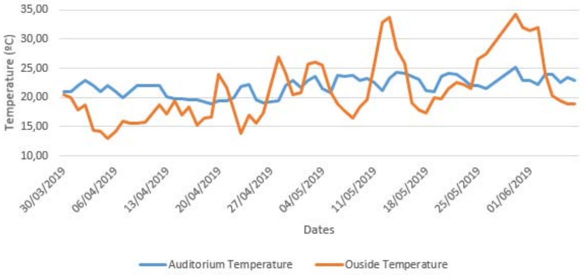

Fig. 9. The difference in daily maximum temperatures and daily minimum temperatures

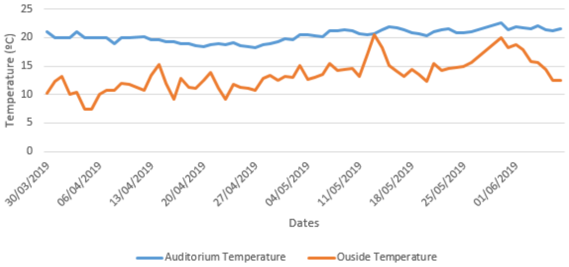

Fig. 10. The difference in daily maximum temperatures between the outside temperature and the temperature inside the auditorium.

In Figures 9 and 10 we see that, while the outside temperature tends to vary quite a bit, the temperature inside the auditoriums is always relatively constant, never below 18ºC but also never above 25ºC, whereas temperatures outside reached less than 13ºC and went over 34ºC. In order to analyze how the people feel inside the auditorium we tried to correlate the temperature inside and when the AC is turned on and how long does it run for, the results can be seen in Figure 11.

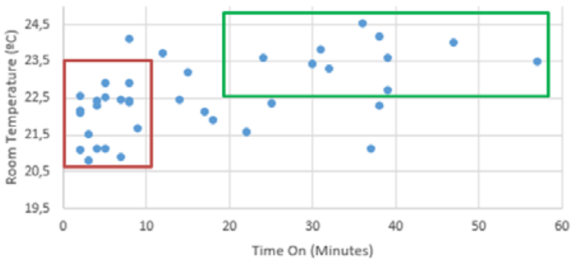

Fig. 11. The relation between the temperature inside the auditorium and how much time the Air Conditioning (AC) is turned on.

The first thing we noticed is that the AC is never started up with temperatures below the 20.5ºC (although after being turned on for a while it does reaches temperatures below that level) and while we clearly see that temperatures below 22.5ºC tend to warrantless AC time (Fig 11 red outline), we also see that most of the times where the AC is on for over 20 minutes the temperatures tend to be above that value, 22.5ºC (Fig 11 Green Outline). The number of times the AC was started up over the course of 2 months is also pretty low, only reaching 38 times overall, so it's pretty safe to say that the auditorium has a good thermal insulation that helps keep the room cool when the outside is hot and vice versa which means, as also presented in Figure 6, that the HVAC's power consumption isn't really an issue. In Figure 12 we see how efficient the AC is, the results tell us that in most cases a slight consumption will lead to very small reductions. In order to reduce the temperature by at least 1ºC, normally, it will require at least a total consumption of 1 kWh over a continuous time period. Overall we think that the AC efficiency could be improved by a proper condenser and vents cleaning since it takes quite a lot of electrical power to receive a small decrease in temperatures for the auditorium. However, this data does not account for the number of people in the room, which can increase the consumption required to reduce the temperature.

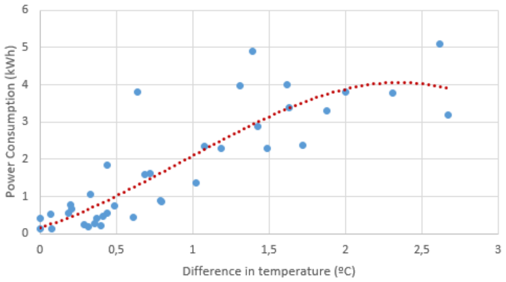

Fig. 12. The relation between the decrease in room temperature and the power consumption while the AC is turned on.

5 Conclusions

In this work, we applied a developed IoT solution with a dashboard to a classroom monitoring system, which can have effects on factors such as energy waste management, comfort levels, and operating costs. With the developed system, it is possible to determine not only anomalies but also to create clean dashboards that can help on reporting how each classroom/auditorium is being used and who are the biggest offenders when it comes to power consumption. With the use of the server, it is also possible to apply alarm applications that could potentially warn interested parties when classrooms are using more/any power when not supposed to. The environment monitoring can also find issues when it comes to HVAC disaster management and reporting, i.e., usage of power without temperature reduction overall, or simply prepare the auditoriums to receive more students without leaving aside the comfort of those students with technologies such as HVAC automation. LoRa communication also proved itself a viable solution to the lack of a proper Wi-Fi network in the evaluated auditorium. Finally, in this work, a management strategy was applied to find anomalies in the auditorium. With the auditorium measured we managed to find out that the lack of proper light switches leads to a considerable waste of energy every month, and the HVAC seems to require quite the electricity consumption in order to properly control the environment inside the auditorium.

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