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The Impact of IoT- Enabled Energy Management Systems on Hotel Operating Costs and Sustainability Outcomes

Vasco Bizarra Ferreira

Master´s degree in Digital Technologies for Business

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TECNOLOGIAS
E ARQUITETURA

Department of Information Science and Technology

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Resumo

Os hotéis utilizam uma quantidade significativa de energia para numerosas operações, o que tem um impacto negativo no ambiente e aumenta os custos operacionais. O desenvolvimento e a implementação de um sistema de gestão de energia baseado na Internet das Coisas (IoT) para hotéis é o tema principal desta tese de mestrado. O estudo utiliza a monitorização de dados em tempo real, a análise e a automação para reduzir os custos operacionais, otimizar a utilização de energia e melhorar a sustentabilidade. A integração de dispositivos IoT, sensores e métodos de análise de dados é examinada na tese como um meio de fornecer informações úteis e promover decisões fundamentadas de gestão de energia. Os resultados ajudam o setor hoteleiro a adotar técnicas eficientes em termos energéticos, a reduzir custos e a aumentar a sustentabilidade.

Palavras-chave: Internet das coisas, Hotéis, Poupanças Energéticas, Sensores

Abstract

Hotels use a significant amount of energy for numerous operations, which has a negative impact on the environment and raises operational costs. The development and deployment of an Internet of Things (IoT)-based energy management system for hotels is the main topic of this master's thesis. The study makes use of real-time data monitoring, analytics, and automation to lower operational costs, optimize energy use, and improve sustainability. The integration of IoT devices, sensors, and data analytics methods is examined in the thesis as a means of delivering useful information and promoting reasoned energy management decisions. The results help the hotel business adopt energy-efficient techniques, save costs, and increase sustainability.

Keywords: Internet of Things, Hotels, Energy Savings, Sensors

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Chapter 1

Introduction

1.1 Motivation

The Internet of Things (IoT) has emerged as a game-changing technology in recent years with the potential to alter many industries, including the hospitality industry. Energy management systems in hotels are one application where IoT deployment has a lot of potential. The need for sustainable solutions that can reduce operational costs and advance environmental sustainability has been sparked by the escalating energy crisis worries and the outrageous levels of energy usage in the hotel industry. In fact, hotels and other forms of lodging are responsible for 2% of the 5% global CO2 that the tourism industry emits [1].

The current state of the world's energy supply is urgent and requires quick care [2]. The hospitality sector, which is notorious for using a lot of energy, significantly adds to this dilemma. Hotels have seen a large increase in energy usage for heating, cooling, lighting, and other operational needs as a result of rising demand for comfortable and luxurious rooms [3]. In addition to creating environmental problems, this excessive energy use drives up operational costs for hotel owners and management.

A large amount of a hotel's operating expenses is related to energy, and the cost burden is increased by the ongoing increase in energy prices. Striking a balance between giving visitors a comfortable experience and properly controlling operational costs is difficult for hoteliers. Exploring novel technologies and approaches that can optimize energy use, save costs, and improve sustainability is becoming increasingly important.

The development of IoT presents fresh possibilities for enhancing hotel energy management. Hotels can gather real-time data on energy consumption, spot inefficiencies, and adopt focused steps for energy optimization by connecting IoT devices and sensors with existing energy infrastructure. Hotel owners and managers could benefit from granular insights into energy usage trends via IoT-enabled energy management systems, enabling them to make wise decisions and put energy-saving measures into practice [4].

1.2 Context

To understand how IoT can help hotels reduce their costs, it is important to understand what IoT sensors are and how they operate.

The Internet of Things (IoT) has emerged as a transformational technology in recent years, transforming numerous sectors and industries. The hospitality business is one of these areas that has undergone tremendous transformation, and IoT integration in this sector has the potential to increase operational effectiveness, save costs, and improve sustainability outcomes.

In the hospitality sector, operational efficiency and guest satisfaction are key elements in the success of an establishment. In this context, the application of advanced control and management systems plays a crucial role in optimising operations and ensuring an exceptional guest experience. Two systems in particular stand out as pillars of technical and operational management in the hotel industry: SCADA (Supervisory Control and Data Acquisition) systems and TCM (Centralised Technical Management) systems.

SCADA (Supervisory Control and Data Acquisition) systems play a pivotal role in optimizing operations. Real-time monitoring of vital infrastructure, such as HVAC systems, energy and water use, and security systems, is made possible by SCADA systems. Through the provision of centralized control and data collecting capabilities, SCADA systems enable hotel management to prioritize guest comfort while concurrently improving operational efficiency and cutting expenses.

Commercial, institutional, and residential buildings can effectively manage their technical systems with the help of CTM systems, which provide specific platforms. They combine several building systems into a single, centralized platform, including access control, HVAC, lighting, and fire protection. By using a centralized method, building systems may be remotely monitored, controlled, and optimized, guaranteeing peak performance, energy economy, and occupant comfort. Building managers utilize CTM systems to fulfill the varied demands of tenants while reducing their environmental impact through resource allocation, energy conservation, and proactive maintenance.

While both SCADA systems in hospitality and CTM systems in buildings serve the purpose of centralized management and control, they are tailored to different environments and address distinct operational needs and challenges. SCADA systems are geared towards industrial processes and infrastructure within hospitality establishments, while CTM systems are specialized for managing building systems in various commercial and residential settings.

Although specialized communication networks are typically necessary for SCADA and GTC systems to function, the addition of IoT devices can expand their capabilities. IoT sensors, for instance, can be installed in lighting, HVAC, and other systems-controlled devices to provide more information on operating conditions and performance.

1.3 Objectives

This work aims to examine the potential benefits associated with the implementation of IoT-based energy management systems in hotels. Through the analysis and presentation of consumption data in real-time, it is hoped to create environmental awareness in guests, motivating them to adopt more sustainable practices during their stay, generating cost savings for the hotel, and increasing its operational efficiency and sustainable image.

1.4 Structure of the Thesis

Considering the objectives outlined, this dissertation is divided into five chapters, beginning with the Introduction presented in chapter 1, which displays a summary of the issue under investigation as well as the broad study objectives.

Chapter 2 is focused on the literature review. This chapter presents the state of the art on the problems of large energy consumption in hotels and other big buildings and the use and importance of energy management systems.

Chapter 3 presents the proposed IoT system which includes the architecture, data collection, and visualisation in dashboards.

Chapter 4 addresses the execution of the surveys, data analysis, and the results.

Finally, chapter 5 is dedicated to the conclusions of the present study as well as the identification of the challenges to be considered in future work.

Chapter 2

State of the Art

2.1 Hotel consumptions - Use of energy and water-saving systems

Tourism has increased consecutively in the past decades. The data shows that from 1980 until 2022 the number of guests per year in hotels has increased by 603.11%. In 1980 it was registered 2,488,953 guests in hotels in Portugal followed by 6,228,971 in 2000 and finally 17,496,349 in 2022 [5].

The data indicates a steady increase in the number of hotel guests in Portugal over the past two decades, reflecting the growth of the country's tourism sector. Although the number of hotel guests dropped significantly in 2020 (6,764,955) and 2021 (9,359,379), due to the COVID-19 pandemic and the travel restrictions imposed, the growth trend over the years is evident and proven by the numbers of hotel guests in the year 2022 [5].

Hotels are one of the largest consumers of energy in the hospitality industry [6]. Several factors, including lighting, laundry, cooling, heating, ventilation systems, and air quality systems, among others, influence the amount of energy used in hotels which comes at a hefty price to the operations´ financial success [7]. As a result of an increase in tourists and the country's thriving tourism industry, Portugal's lodging activities now consume significantly more energy. When the source of energy used for consumption is examined, 96% of it is electric, 3% is natural gas, and 1% is propane gas [8].

The hospitality sector prioritizes client comfort and high-quality service. The demands placed on these factors frequently result in significant, sometimes excessive high energy usage [9].

For that reason, energy management is crucial to mitigate environmental problems, lower energy consumption and increase hotels' sustainability. Air conditioning, ventilation, lighting, hot water production, and space heating account for 75% of a hotel's energy use [10].

Additionally, as of July 1, 2021, Decree-Law 101-D/2020 [11] mandates that hotels promote energy conservation and the use of renewable energy sources in their structures. Other measures include:

- Energy consumption rationalization plans must be created and put into effect by hotels with an annual energy consumption of more than 500 toe (tons of oil equivalent).
- Energy certification is required for all lodging establishments with more than 50 rooms. This certification evaluates the building's energy performance and identifies opportunities to increase energy efficiency.
- Energy audits are required every four years for hotels with annual energy consumption of more than 500 toe (tons of oil equivalent).

According to a report by the U.S. Environmental Protection Agency (EPA), hotels spend an average of 2.196 dollars per available room per year on energy costs. This represents about 6% of a hotel's total operating costs, which can have a significant impact on a hotel's profitability [12]. The inefficient use of energy in hotels like energy waste and higher expenses is also a serious problem. Many hotels operate on a 24-hour basis and still make use of antiquated technology, such as ineffective heating and cooling systems, which increases energy usage.

In today's environment, hotels must embrace sustainable practices due to their impact on brand reputation, consumer trust, and guest happiness. Putting money into environmentally friendly operations enhances the customer experience, increasing pleasure and loyalty. From an organizational standpoint, hotel managers understand that in the future, guests will expect hotels to use technology like IoT in smart rooms. Technology can improve services, increase revenue streams, streamline processes, and make better use of customer information. For hotel chains that have integrated intelligent IoT systems, there are chances to translate individualized consumer data into improved loyalty [13].

In a different study, it was possible to demonstrate that interactive dashboards and gamification methods, such as user competition or collaboration, are more advantageous for users and have more potential outcomes. It was possible to reduce energy use by 19.18%, but the most important factor is the observed changes in user behaviour that enabled them to maintain savings over an extended period of 11 months [14].

Additionally, a community study with 208 participants found that 69% of respondents thought the approach was more appealing than solutions currently on the market. 81% of participants strongly or completely agreed that the real-time data offered by interactive dashboards had the potential to affect users' behaviour. For people to see data, comprehend how to use it, and build sustainable behaviours that can spread throughout the community, tools like this system are crucial [14].

IoT systems can enable remote monitoring of water parameters, eliminating the need for manual examination. Using sensors, it offers real-time information on water quality, including pH, alkalinity, and ammonia levels. Big data analytics can be used to evaluate this data in order to get insights and make wise decisions [15].

A study on energy use in 16 high-quality hotels in Hong Kong found that energy consumption was very diverse and that the Energy Use Indices (EUI) produced by each hotel varied significantly. The primary energy source, accounting for 73% of total consumption on average, is electricity, with air conditioning usage being particularly prevalent given the subtropical environment. An extensive regression analysis revealed that the number of guests and the outside air temperature have an impact on how much power is used, with the outside air temperature having the greatest impact. To reduce operational costs and safeguard the environment, it is advised that hotels develop an energy management program highlighting the key elements of this program [16].

Chapter 3

IoT System for Hotel Energy Savings

The hospitality industry has witnessed an increase in understanding of its operations' environmental impact in recent years. Hotels are among the most energy-intensive of all building categories. They can therefore have a significant energy consumption and environmental impact, particularly in well-known tourist locations [17].

Meanwhile, there has been an increasing awareness of the necessity of effective resource management, especially regarding energy usage. Conventional energy management systems are unable to supply the precise, real-time data needed to make decisions that satisfy sustainability objectives as well as lower expenses.

For that reason, the proposed IoT-enabled system operates at the forefront of technology to monitor energy usage patterns in real-time and flexibly within hotel premises. This feature makes it possible to react proactively to variations in demand and identifies opportunities to maximize energy use.

The IoT system used was previously developed by another author as the basis for my implementation. This system, created for the study "Long Term Energy Savings Through User Behavior Modeling in Smart Homes" [14], served as the backbone of this research. However, to enrich the study, innovative elements were introduced such as the integration of gamification strategies and the implementation of surveys.

3.1 Proposed IoT System

Data collection: To track and gather information on energy use, IoT sensors are strategically placed all around buildings or surroundings. These sensors can monitor variables including temperature, humidity, occupancy, light intensity, and power consumption consequences for sustainability.

Data Transmission: For processing and analysis, the gathered data is sent wirelessly or over connected connections to a central hub or cloud-based platform. Various protocols, including Wi-Fi, Bluetooth, and LoRaWAN (Long Range Wide Area Network), can help in communication.

Data analysis: After the data is transferred to the central hub or cloud platform, it is examined using a variety of algorithms and machine learning methods. The analysis helps in finding patterns, anomalies, and chances for energy-saving within the gathered data.

Energy Optimization: IoT-enabled devices can make wise decisions to optimize energy use based on the knowledge gathered through data analysis. For instance, based on occupancy and temperature information, the HVAC (Heating, Ventilation, and Air Conditioning) system of a smart building can be dynamically controlled. In sections that are not inhabited, lights can be automatically adjusted or turned off. Equipment that consumes a lot of energy can be controlled based on demand or consumption trends.

Automation and control: IoT sensors make it possible to automate and manage systems and equipment that use a lot of energy. Energy usage can be optimized in real-time by integrating IoT with actuators, such as smart thermostats, smart plugs, or motor controllers. These devices can be remotely operated or set up to function according to predetermined rules or schedules.

3.1.1 Physical Layer - Data Collection

The proposed IoT system is made up of several parts, each responsible for a certain function and interconnected to create a successful and efficient IoT system. This layer includes sensor devices responsible for gathering information from the environment such as energy and water consumption and temperature. Therefore, in this work, it was used the developed LoRa sensor devices for gathering information about temperature as shown in Figure 2, water consumption as observed in Figure 3, and an amperometric clamp for energy consumption monitoring as illustrated in Figure 4.

Because it contains all the system's functionality, dashboard software, and database information, the Raspberry Pi is the component of hardware that is most important as represented in Figure 1. The data is received and sent to the various IoT system entities by the network layer of the Internet of Things architecture.

Figure 1 Raspberry Pi Model 3 B+

Figure 2 Developed sensor board with temperature and light sensor

Figure 3 Display water flow sensor meter with G1/2 flow sensor

Figure 4 Amperometric clamp for energy consumption monitoring

3.1.2 Application Layer- Dashboard Visualisation

A free home automation program called Home Assistant supported the application layer in this research. This software in which devices can be integrated allows the guests to see information on a dashboard.

Data services, LoRa and Wi-Fi sensor devices gather and supply the system with data, which is then analysed and displayed on dashboards for home assistants. Because savings are carefully tailored for each room, it is feasible to manage energy and comfort from the dashboard in the most effective way. User engagement can alter system efficiency.

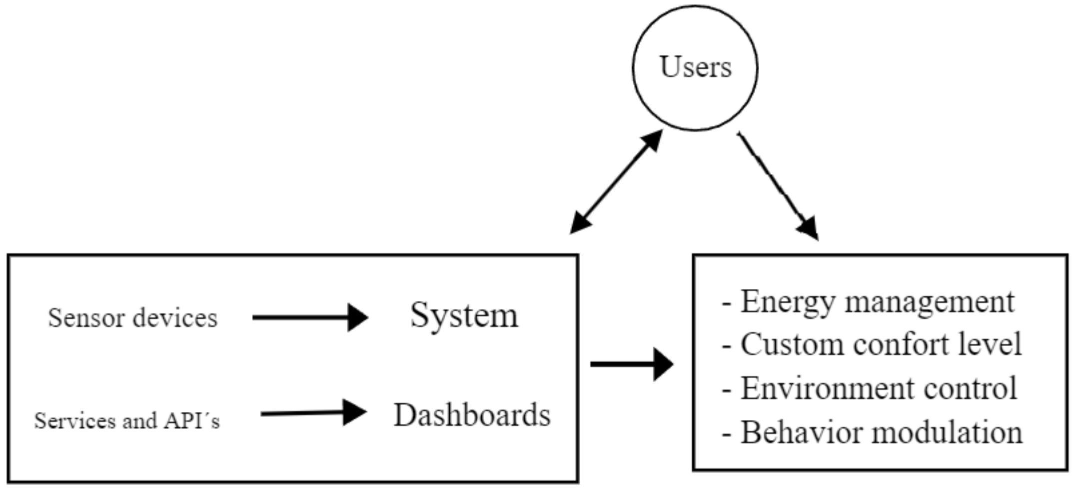

Figure 5 Schematic of system interaction schematic between each key

3.1.3 Network Layer

In this layer, the information gathered from the sensors is safely transmitted to the destination. LoRa is a low-power, low-cost technology intended for low data rates and a large transmission range that can connect with hundreds of sensors installed in hotel rooms through a single gateway.

This technology works well for sensor applications where battery-powered devices are easier to set up because they require low power and have good coverage.

Since Wi-Fi is now widely used in hotels, sensor devices don't need to be portable but need to gather data frequently or have easy access to the main power source for then be able to connect with apps and web services using this technology.

3.1.4 Gamification and Social Engagement

Calculating monthly and daily costs per customer is of paramount importance to hotels for several crucial reasons. Firstly, it provides a detailed overview of the direct financial impact of each guest on the hotel's operations, allowing for a more accurate analysis of the expenses and revenues associated with each stay. The calculations provided a precise overview of the costs in euros, consumption in kilowatt-hours (kWh), and litres (L) associated with each client, forming a solid basis for effectively managing financial resources, optimizing prices, and maximizing profitability.

Additionally, by knowing the costs associated with each client, hotels can adopt smarter and more personalized pricing strategies. These calculations also make it possible to identify areas of waste and greater inefficiency, driving the implementation of resource management measures, which in turn contributes to environmental sustainability and the hotel's image of corporate responsibility. The analysis of monthly and daily costs per client is a fundamental strategic tool for the efficient management of hotel businesses, benefiting both financial performance and the hotel's sustainable reputation.

Two hotels located in the city of Lisbon were analysed using real cases. Using data provided by the two hotels, in a proper working system, the average monthly and daily water and energy costs were calculated over three months.

The results of this analysis were used to show the actual water and energy average costs that hotels have per guest per day, per guest per month, and the total of all guests over a whole month. Therefore, in a later stage of this work, alongside with the data obtained through the survey, it was possible to calculate the real savings the hotel can make by using an IoT system that allows data to be visualised in real-time.

All the calculations presented were calculated using the formulas below and all the values shown were, as mentioned above, provided by two hotels located in Lisbon, who, at their request, have asked to remain anonymous.

Energy

$$Average\ consumption\ perguest\ per\ day = \frac{Average\ daily\ consumption\ (Kwh)}{Average\ number\ of\ guests\ per\ day} \quad (1)$$

$$Energy\ consumption\ of\ the\ stay = \ Average\ energy\ consumption\ per\ guest\ per\ day \times length\ of\ stay\ \times nº\ of\ guests \quad (2)$$

Water

$$Average\ consumption\ per guest\ per\ day = \frac{Average\ daily\ consumption\ (L)}{Average\ number\ of\ guests\ per\ day} \quad (3)$$

$$Water\ consumption\ of\ the\ stay = Average\ water\ consumption\ per\ guest\ per\ day \times length\ of\ stay\ \times nº\ of\ guests \quad (4)$$

***Hotel* A**

Energy - January

$$Average\ consumption\ per guest\ per\ day\ in\ January = \frac{3\ 210\ Kwh}{107\ pax} = 30\ Kwh$$

Water - January

$$Average\ consumption\ per guest\ per\ day\ in\ January = \frac{26\ 000\ L}{107\ pax} = 242.99\ L$$

Energy - February

$$Average\ consumption\ per guest\ per\ day\ in\ February = \frac{3\ 446\ Kwh}{208\ pax} = 16.57\ Kwh$$

Water - February

$$Average\ consumption\ per guest\ per\ day\ in\ February = \frac{38\ 000\ L}{208\ pax} = 182.69\ L$$

Energy - March

$$Average\ consumption\ per guest\ per\ day\ in\ March = \frac{3\ 576\ Kwh}{231\ pax} = 15.48\ Kwh$$

Water - March

$$Average\ consumption\ per guest\ per\ day\ in\ March = \frac{44\ 000\ L}{231\ pax} = 190.48\ L$$

***Hotel* B**

Energy - January

$$Average\ consumption\ perguest\ per\ day\ in\ January = \frac{1\ 100\ Kwh}{65\ pax} = 16.92\ Kwh$$

Water - January

$$Average\ consumption\ perguest\ per\ day\ in\ January = \frac{18\ 129\ L}{65\ pax} = 278.9\ L$$

Energy - February

$$Average\ consumption\ perguest\ per\ day\ in\ February = \frac{1\ 020\ Kwh}{85\ pax} = 12\ Kwh$$

Water – February

$$Average\ consumption\ perguest\ per\ day\ in\ February = \frac{19\ 000\ L}{85\ pax} = 223.53\ L$$

Energy - March

$$Average\ consumption\ perguest\ per\ day\ in\ March = \frac{1\ 024.94\ Kwh}{106\ pax} = 9.67\ Kwh$$

Water - March

$$Average\ consumption\ perguest\ per\ day\ in\ March = \frac{22\ 000\ L}{106\ pax} = 207.55\ L$$

The tables below summarise the average costs per customer per day and customer per month.

Table 1 Average daily consumption per person in Hotel A

Hotel A	Energy (kWh)	Water (L)
January	30	242.99
February	16.57	182.69
March	15.48	190.48

Table 2 Average daily consumption per person in Hotel B

Hotel B	Energy (kWh)	Water (L)
January	16.92	278.9
February	12	223.53
March	9.67	207.55

Examples of accommodation rates:

What would be the total consumption costs for Hotel A in March?

$$Total\ cost = (Electricity\ (kWh) \times Avg.Cost\ €\backslash kWh) + (Water\ (L) \times Avg.Cost\ €\backslash L) \qquad (7)$$

$$Total\ cost = (110\ 859\ (kWh) \times 0.0664\ €) + (1{,}379{,}000\ (l) \times 0.0041€) = 13\ 014.94€$$

What would be the real cost of a stay at Hotel B for 3 guests for 14 days in January?

Average energy consumption per guest per day in January = 16.92 kWh

kWh cost = 0.15 €

$$Total\ energy\ cost = 16.92\ kWh\ \times 0.15€\ \times 3 \times 14 = 106.6\ €$$

Average water consumption per guest per day in January = 278.9 L

L cost = 0.0019€

$$Total\ water\ cost = 278.9\ l\ \times 0.0019€\ \times 3 \times 14 = 22.26€$$

$$\underline{Total\ cost = 106.6€ + 22.26€ = 129.2€}$$

After a detailed analysis of individual energy and water consumption costs per customer at these hotels, the next step is to understand how guests are willing to adopt more sustainable behaviours during their stay.

Therefore, in the following part of this work, a survey was conducted with the aim of getting a better understanding of water and energy-saving habits, as well as the viability of implementing an IoT system in hotel units. In addition, this survey also aimed to identify trends and patterns in the population and, on this basis, provide a better basis for making strategic decisions.

Chapter 4

Survey results and analysis

A survey was conducted to find out if visitors would be interested in seeing their consumption in real-time in their hotel rooms. The purpose of this survey is to better understand consumption patterns while also looking for ways to promote eco-friendly and more productive behaviours. Through guests' responses, it is hoped to discover ways to promote environmental awareness and engagement in resource conservation actions, contributing to a positive impact on both the environment and the guest experience.

With the calculations previously made, the survey also aimed to find out what percentage of respondents would be willing to reduce their consumption with an incentive from the hotel and consequently make a real simulation of the amounts that the hotel could save.

The survey is made up of 17 mandatory questions, covering a variety of topics relevant to the subject under study. This survey was made available online and, since the target was any type of person who frequented hotels, it was aimed at the general population, without any restrictions.

Following the submission of the survey by 204 participants, an in-depth examination and some conclusions were made.

The survey respondents are mostly women (62.7%), and participants' ages range between 18 and 65+ according to the following distribution as illustrated in Figure 6.

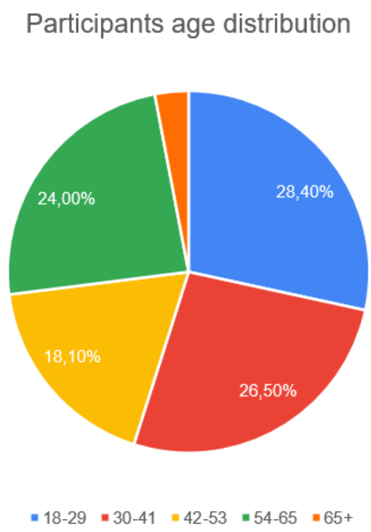

Figure 6 Participants age distribution

Preferences for the number of nights spent in vacation rentals differ significantly, according to the survey: 54.4% of respondents choose stays between 0 and 10 nights annually, followed by 31.4% between 10 and 20 nights, 10.8% between 20 and 30 nights, 2.9% between 30 and 40 nights, and only 0.5% for stays exceeding 40 nights. Hotels are the most preferred option for lodging, according to 79% of respondents. Though preferences differ, 10% of respondents choose hostels, 16% resorts, 24% aparthotels, and 48% local accommodation.

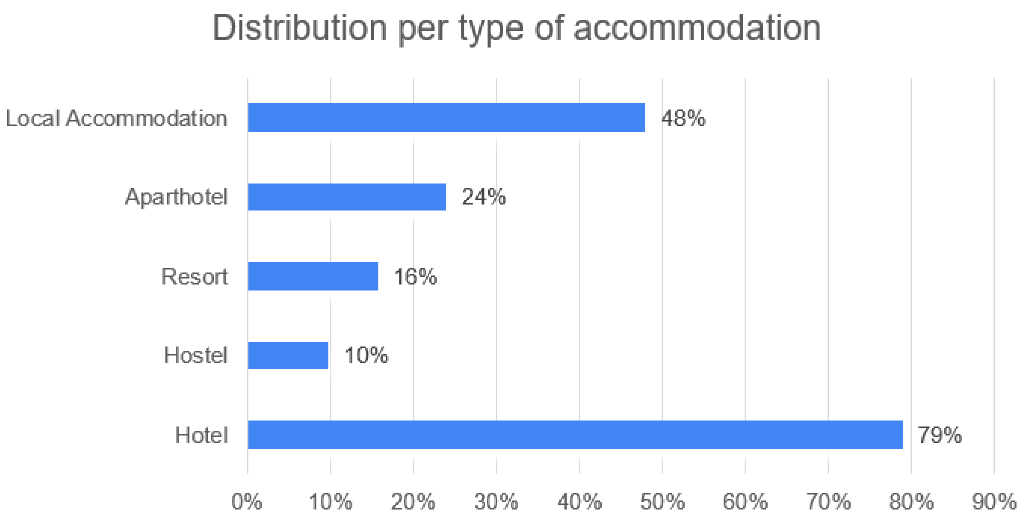

Figure 7 Distribution per type of accommodation

The collected data indicates that (5.4%) of the respondents were technology experts, (31.4%) were advanced, the majority had moderate technology knowledge (53.9%), and (9%) had basic knowledge. Regarding energy-saving habits, (42.7%) of the respondents reported frequent to very frequent energy-saving habits, and (43.6%) of respondents reported moderate habits. Only (13.8%) claimed minimum to no saving habits at all.

In terms of water-saving practices, the majority (47.5%) reported moderate practices and 43.2% reported frequent to very frequent practices. Only (9.4%) stated they had minimal or non-existent saving practices.

Participants were given two images as illustrated in Figures 8 and 9 to rate on a scale from 1 to 10. One picture of an energy management system and one of a water management system to evaluate in terms of attractiveness, utility, and probability of changing habits by watching real-time data. The pictures show the instantaneous consumption per minute of water and energy, as well as a representation showing what has been spent in kWh and Litres over the last 15 minutes, 1 hour, and 12 hours.

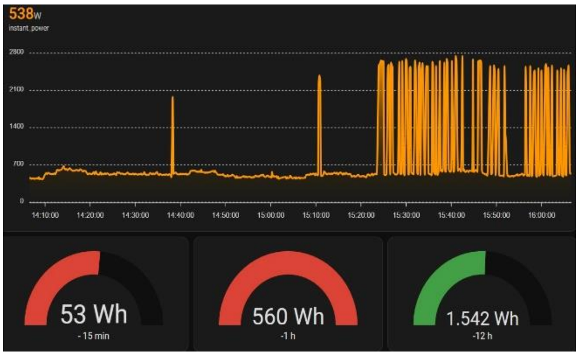

Figure 8 Dashboard showing real-time energy consumption

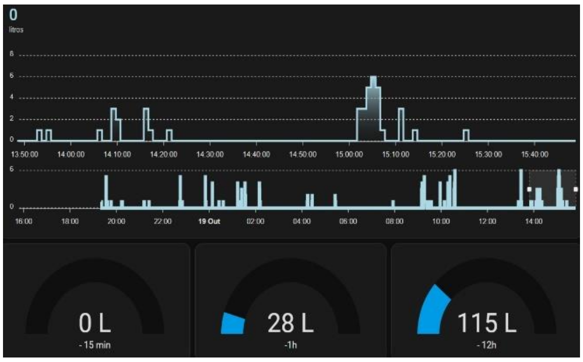

Figure 9 Dashboard showing real-time water consumption

On a scale of 1 to 10, with 1 being "not attractive at all" and 10 being "extremely attractive", the results for both images were quite diverse. For the energy management system, the majority (46.1%) voted between 4 and 7, while for the water management system, it was the 8 to 10 range that got the most votes (47.5%).

Regarding the relevance of the system, using a scale of 1 to 10, with 1 being "nothing relevant" to 10 being "extremely relevant" it is possible to identify that most participants consider the system very relevant, with 65.2% and 72% of responses classifying it between 8 and 10 in the energy management system and water management system respectively.

Again, using a scale of 1 to 10, with 1 being "never" and 10 being "definitely", the respondents were asked whether viewing their energy and water consumption in real-time would make them change their consumption habits. In both systems, the range of answers between 8 and 10 obtained a total of 76%.

Later, two other types of real-time consumption visualisation were shown. Figure 10 provides methods of comparing consumption levels with a more familiar consumption unit and Figure 11 shows guests' consumption during their stay compared to the hotel's overall average. In the next two questions, participants were asked to rate it on a scale of 1 to 10, 1 being “never” and 10 being “definitely” whether the two new visualisations, firstly, were easier to read and, secondly, whether they could influence consumer habits.

Figure 10 Consumption levels with a more familiar unit

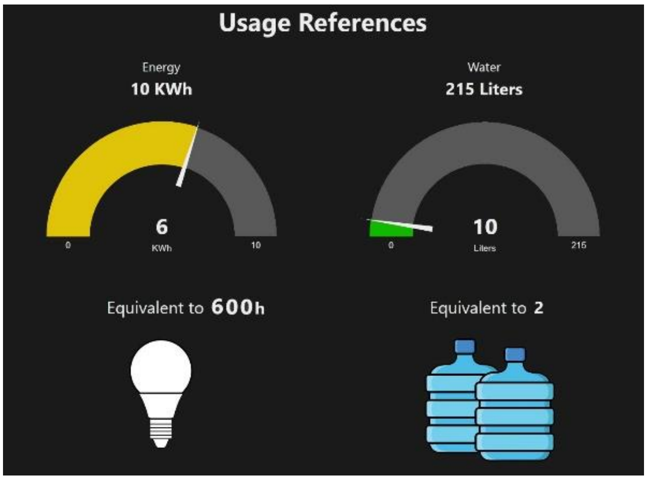

Figure 11 Consumption compared to the hotel´s overall average

Regarding ease of interpretation, 76.9% of the participants rated between 8 and 10, meaning that they find it easier to read and analyse compared to the previous visualisations, and when asked if the new visualisations presented could lead to behaviour changes, the majority (75.6%) also rated between 8 and 10.

To understand the reasons that prevent the adoption of sustainable behaviours it was asked the participants to choose from a predefined list of options or add another one. Results are presented in Figure 12.

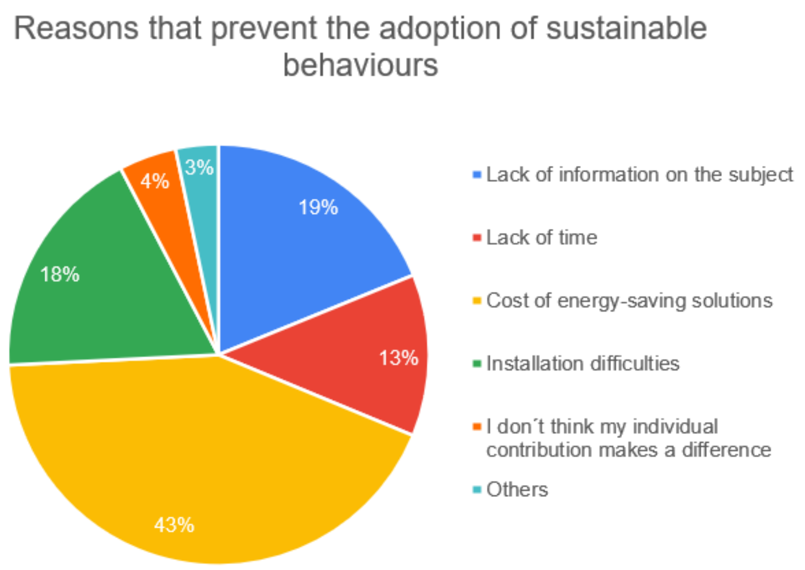

Figure 12 Reasons that prevent the adoption of sustainable behaviours

Unlike households, where costs and lack of knowledge can be significant barriers to adopting energy-saving technologies, hotel guests don't have to worry about such obstacles. In a hotel, they don't need to possess specialized information about water and energy-saving solutions and don't face installation challenges, providing a more sustainable guest experience without imposing any financial or technical difficulties.

In the survey, the following example was given: the amount of energy and water saved in relation to the customers' average values is rewarded with a voucher to use in the bar, restaurant, or another outlet of the hotel.

The introduction of a reward system for those who save energy and water during their stay in hotels is an innovative and highly motivating approach. As proof, 78.4% of the participants in the survey gave it a rating between 8 and 10 on a scale of 1 to 10, 1 being never and 10 being definitely, demonstrating a high level of acceptance and enthusiasm for the idea.

On the one hand, this system creates a virtuous circle, encouraging guests to adopt more sustainable practices during their stay, while at the same time enjoying tangible benefits such as discounts and rewards. On the other, the hotel reduces its costs and helps promote the hotel's image and environmental responsibility.

Correlating data is fundamental, as it makes it possible to discover hidden relationships and significant patterns between variables, offering valuable insights for making informed decisions. These correlations can reveal connections that would not be apparent when analysing each variable alone.

Firstly, it was analysed the preferred type of accommodation and the average number spent on tourism accommodation per year to see if the places where people spend the most nights are the types of accommodation that consumed the most.

Of the 111 participants who answered that they spent an average of between 0 and 10 nights in tourist accommodation, 77 chose "hotel" as one of their main preferred types of accommodation. Also, of the 64 participants who chose between 10 and 20 nights, the option "hotel" received the most votes with 58 out of 64.

This shows that, in addition to hotels being one of the most consuming types of accommodation [6], they continue to be the preferred type of accommodation. It is therefore necessary to implement measures and new practices such as water and energy management systems in order to improve the efficiency of hotels.

Secondly, the correlation between age and technological knowledge was analysed to see if there was any age group that stood out in any way in terms of their savings habits. Figures 13 and 14 show the data distribution and was not possible to draw any relevant conclusions from this analysis, since the results were very similar for the various age groups.

In both water and energy-saving habits, in all age groups, most habits are moderate and frequent.

Figure 13 Age group vs Energy-saving habits

Age	No energy saving-habits	Minimum habits	Moderate habits	Frequent habits	Very frequent habits	Total
18-29	3	12	27	12	4	58
30-41	1	8	22	19	4	54
42-53	0	2	18	14	3	37
54-65	0	1	21	17	10	49
65+	0	1	1	4	0	6
Total	**4**	**24**	**89**	**66**	**21**	**204**

Figure 14 Age group vs Water-saving habits

Age	No water saving-habits	Minimum habits	Moderate habits	Frequent habits	Very frequent habits	Total
18-29	3	6	32	12	5	58
30-41	1	6	28	15	4	54
42-53	0	2	17	14	4	37
54-65	0	1	18	21	9	49
65+	0	0	2	4		6
Total	**4**	**15**	**97**	**66**	**22**	**204**

Thirdly, understanding the relationships between technology proficiency and energy and water conservation practices is essential to developing an in-depth understanding of the dynamics influencing sustainable behaviour. Regardless of their level of technological knowledge, the participants in this study showed an equal level of water and energy-saving habits with moderate habits and frequent habits being the most common responses.

Figure 15 Technological knowledge vs Energy-saving habits

Technological knowledge	No energy-saving habits	Minimum habits	Moderate habits	Frequent habits	Very frequent habits	Total
Advanced	1	10	25	19	9	64
Basic	1	1	11	3	3	19
Expert	0	2	5	3	1	11
Moderate	2	11	48	41	8	110
Total	**4**	**24**	**89**	**66**	**21**	**204**

Figure 16 Technological knowledge vs Water-savings habits

Technological knowledge	No water-saving habits	Minimum habits	Moderate habits	Frequent habits	Very frequent habits	Total
Advanced	1	3	34	17	9	64
Basic	1	1	8	6	3	19
Expert	0	0	7	3	1	11
Moderate	2	11	48	40	9	110
Total	**4**	**15**	**97**	**66**	**22**	**204**

Lastly, it was analysed the correlation between saving habits and the likelihood that viewing water and energy consumption in real-time could influence habits. On a scale from 1 being never and 10 being definitely, it was possible to see that those who have moderate, frequent, or very frequent habits are also those who are more willing to change their saving habits after viewing consumption in real-time, as can be seen in the figures below.

Figure 17 Energy-saving habits vs likelihood of changing habits

Energy-saving habits	Average
No energy-saving habits	6,5
Minimum habits	7,5
Moderate habits	8,2
Frequent habits	8,0
Very frequent habits	9
Total	**8,1**

Figure 18 Water-saving habits vs likelihood of changing habits

Water-saving habits	Average
No water-saving habits	4,8
Minimum habits	7,7
Moderate habits	8,3
Frequent habits	8,1
Very frequent habits	9,2
Total	**8,2**

As previously stated, on a scale of 1 to 10, with 1 being “never” and 10 being “definitely”, 85.3% of respondents answered between 7 and 10 in the likelihood of changing their consumption after viewing consumption in real-time in addition to a reward system. In this way, and as also calculated above, it is possible to verify the inherent benefits for the hotel.

To demonstrate it was used the total costs for the month of March as previously calculated for Hotel A which was 13064.44€. Assuming that of the 85.3% who were willing to change their consumption the average percentage reduction in water consumption was 10% and energy consumption was also 10%, it can be concluded that this 20% reduction resulted in monetary savings for the hotel of 2228.80€ as can be seen from the calculations below.

$$13064.44€ \times 0.853 = 11143.97€$$

$$11143.97 \times 0.2 = 2228.80€$$

Other hotels can benefit from using Hotel A's proven cost-saving strategy, which is based on a 20% reduction in energy and water consumption. Even though knowing that these values vary from hotel to hotel, the benefits are undeniable. The potential for significant financial savings is made clear by using Hotel A's example which came to 2228.80€ saved. By extrapolating this outcome to further hotels, it is evident that implementing such resource-efficient procedures can result in substantial financial gains for the hotel sector.

Chapter 5

Conclusions and Future Work

The purpose of this master's thesis was to investigate the possible advantages of integrating Internet of Things-based energy management systems in hotels. The main objective was to demonstrate that these kinds of applications go beyond simple cost-cutting and instead promote sustainability and operational effectiveness. Using an in-depth investigation and display of real-time consumption data, the thesis aimed to bring the spotlight on the numerous benefits linked to visitors increased environmental awareness.

The results of this study offer compelling evidence that integrating IoT technology in hotels not only could reduce costs but also greatly encourage visitors to adopt sustainable behaviours. The results of the survey demonstrated how important real-time consumption data is in favourably impacting visitor behaviour. After learning more about their energy usage patterns, participants indicated a greater readiness to adopt more sustainable practices. This discovery not only supports the first hypothesis of the thesis but also emphasizes how IoT systems can act as drivers for significant change in the hospitality sector.

The findings of this study provide a useful road map for hotels as they keep navigating the difficult balancing act between economic viability and environmental responsibility. By utilizing IoT technologies to encourage environmental awareness, hotels can improve their operational effectiveness, cut expenses, and project a more sustainable image all at once. This study's demonstration of the integration of technological innovation and guest engagement not only conforms to modern standards for ethical business conduct but also opens the door for a more strong and sustainable future for the hospitality industry.

Examining how IoT-based energy management systems interact with smart building technologies creates opportunities for further study aimed at improving sustainable hotel management practices. The intended objective is to create a smoothly functioning ecosystem that maximizes energy efficiency and elevates visitor experiences. Further study efforts could investigate the complex structure of this integration, emphasising the interaction among occupancy sensors, HVAC technology, and lighting control systems. Assessing the instantaneous adaptability of these systems to variables like room occupancy, the presence of natural light, and aligning temperature control with guest preferences and external factors might provide valuable information regarding the possibility of substantial energy conservation.

Establishing precise measurements, gathering and aggregating data, and computing relative savings are all necessary to develop a hotel rating system based on energy and water savings. First, measurements are defined, such as kWh for electricity and cubic meters for water, using information gathered from utility bills or monitoring devices. In order to ensure fair comparisons between hotels with varying sizes and occupancy rates, normalization is essential. The percentage of water and energy saved in relation to each hotel's baseline consumption is computed after the data has been normalized, enabling standardized comparison.

The next step is to assign points or scores based on relative performance; larger savings percentages equate to higher ratings. From that, hotels are rated according to their overall scores, with the best-performing hotel holding the top spot. Based on the ranking, vouchers are given out to encourage the saving of water and energy. Frequent evaluations and modifications guarantee that the ranking system stays current, and open sharing of outcomes encourages ongoing development amongst the involved hotels.

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Appendix

1- Idade *

- 18-29
- 30-41
- 42-53
- 54-65
- 65+

2- Género *

- Masculino
- Feminino

3-Em média, quantas noites pernoita, anualmente, em alojamentos turísticos ? *

- 0-10
- 10-20
- 20-30
- 30-40
- 40+

4-Quais das seguintes tipologias opta para as suas estadias? *

- [ ] Hotel
- [ ] Hostel
- [ ] Resort
- [ ] Aparthotel

5- No geral, como considera os seus conhecimentos tecnológicos? *

- Sem conhecimentos
- Básicos
- Intermédios
- Avançados
- Especialista

6- Como considera serem os seus hábitos de poupança de energia? *

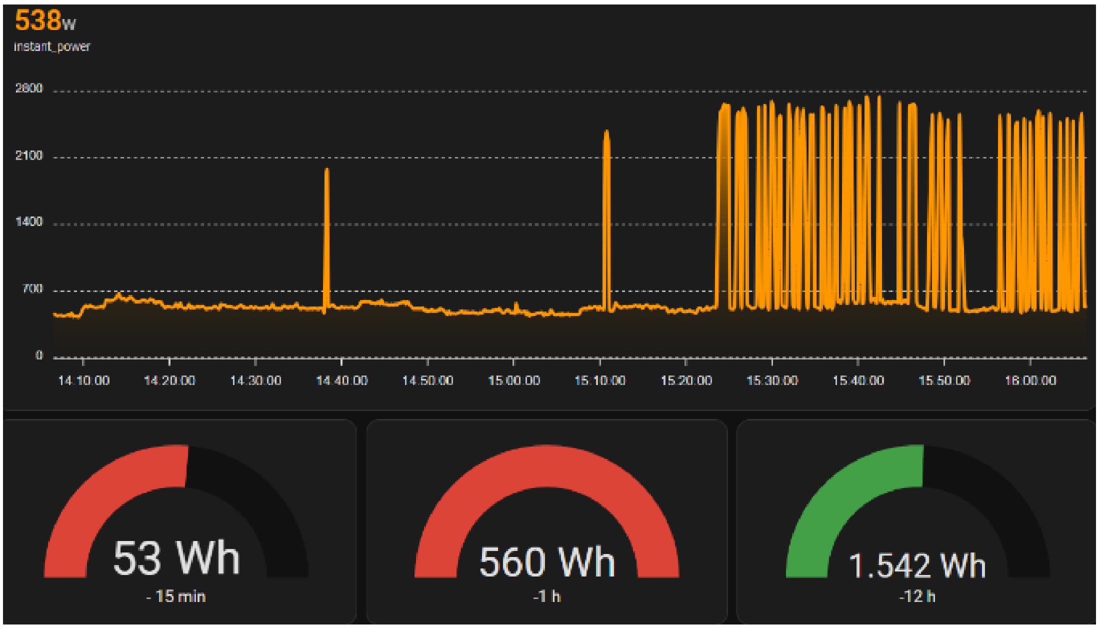
- Sem qualquer hábito de poupança de energia
- Hábitos mínimos
- Hábitos moderados
- Hábitos frequentes
- Hábitos muito frequentes

7- Como considera serem os seus hábitos de poupança de água? *

- Sem qualquer hábito de poupança de água
- Hábitos mínimos
- Hábitos moderados
- Hábitos frequentes
- Hábitos muito frequentes

Em relação a sistemas de poupança de energia:

Considere que existe um tablet colocado numa parede do seu quarto de hotel onde é possível visualizar o consumo de energia em tempo real.



8- Classifique quanto à atratividade *

	1	2	3	4	5	6	7	8	9	10	
Nada atrativo	○	○	○	○	○	○	○	○	○	○	Extremamente atrativo

9- Considera a apresentação dos dados do sistema de poupanças de energia relevante? *

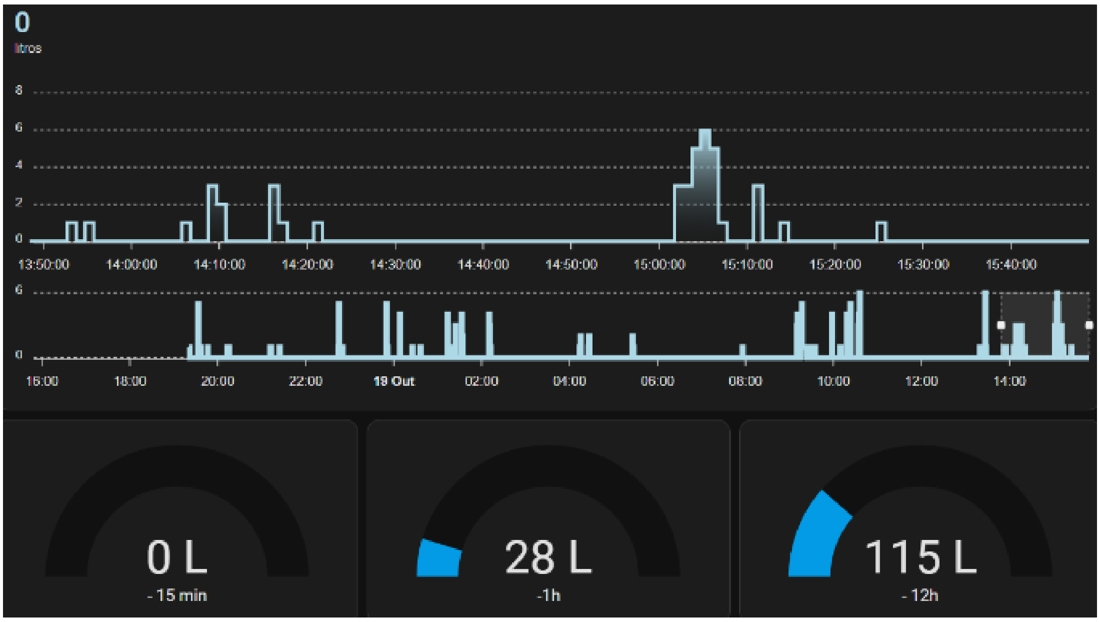
	1	2	3	4	5	6	7	8	9	10	
Nada relevante	○	○	○	○	○	○	○	○	○	○	Extremamente relevante

10- Considera que a visualização dos consumos de energia em tempo-real poderia influenciar os seus hábitos de consumo? *

	1	2	3	4	5	6	7	8	9	10	
Não, nunca	○	○	○	○	○	○	○	○	○	○	Sim, definitivamente

Em relação a sistemas de poupança de água:

Considere que existe um tablet colocado numa parede do seu quarto de hotel onde é possível visualizar o histórico e consumo instantâneo de água, recorrendo a sensores.



11- Classifique quanto à atratividade *

	1	2	3	4	5	6	7	8	9	10	
Nada atrativo	○	○	○	○	○	○	○	○	○	○	Extremamente atrativo

12- Considera a apresentação dos dados num sistema de poupanças de água relevante? *

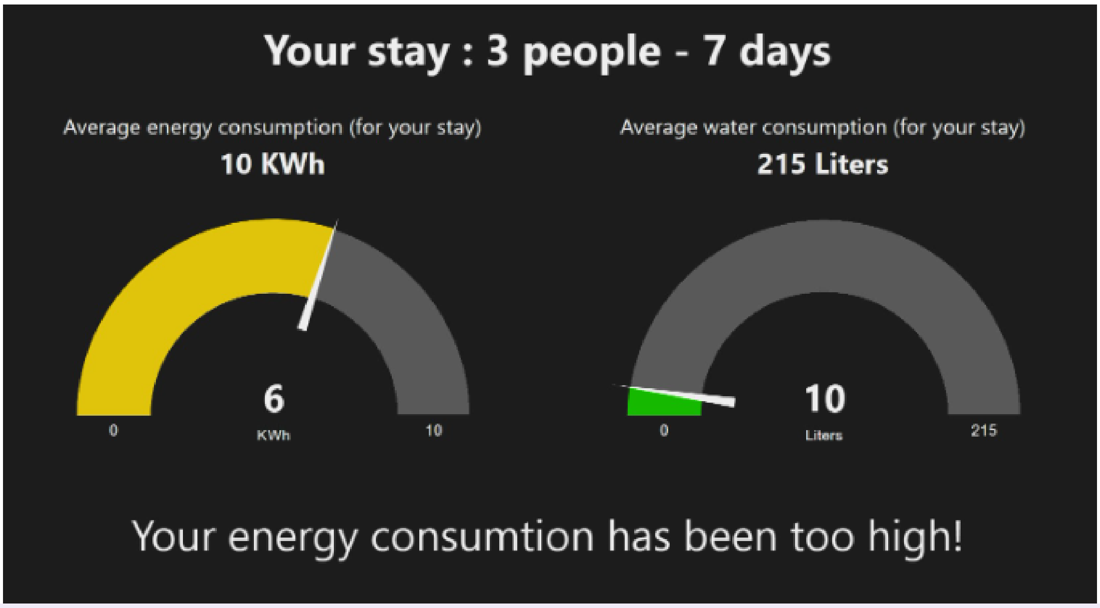
	1	2	3	4	5	6	7	8	9	10	
Nada relevante	○	○	○	○	○	○	○	○	○	○	Extremamente relevante

13- Considera que a visualização dos consumos de água em tempo-real poderia influenciar os seus hábitos de consumo? *

	1	2	3	4	5	6	7	8	9	10	
Não, nunca	○	○	○	○	○	○	○	○	○	○	Sim, definitivamente

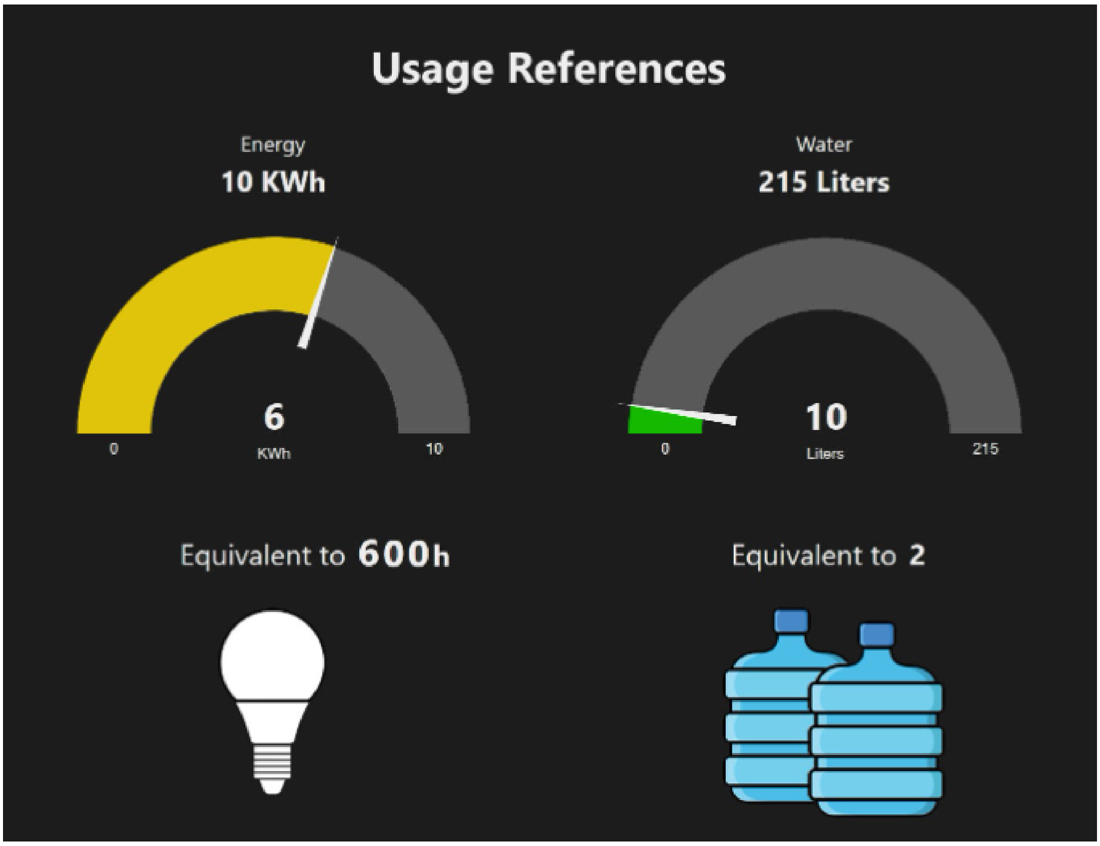
Nas seguintes figuras encontram-se exemplos de outros tipos de visualização de consumos em tempo real.

Neste exemplo, o consumo dos hóspedes durante a sua estadia é comparado com a média global do hotel.
As cores dos indicadores vão alternando à medida que os níveis de consumo sobem e se aproximam (ou ultrapassam) a média.
São também apresentados avisos em texto quando é detetada uma subida acentuada de um dos indicadores (energia ou água).



São também disponibilizados métodos de comparação entre os níveis de consumo e uma unidade de consumo mais familiar.

- No caso do consumo de energia, este é comparado com o consumo de uma lâmpada LED durante X horas.
- No caso do consumo de água, este é comparado com a quantidade de água num garrafão (5 litros).



14-Considera que esta visualização permite uma leitura mais fácil e de melhor compreensão em relação às figuras anteriores? *

	1	2	3	4	5	6	7	8	9	10	
Não, nunca	○	○	○	○	○	○	○	○	○	○	Sim, definitivamente

15- Considera que os modos de visualização de consumos apresentados poderiam influenciar os seus hábitos de consumo ? *

	1	2	3	4	5	6	7	8	9	10	
Não, nunca	○	○	○	○	○	○	○	○	○	○	Sim, definitivamente

Em sistemas de poupança de água e energia é comum haver perda de interesse ao fim de algum tempo. *

16- Que motivos o(a) impedem de adotar comportamentos sustentáveis de poupança de energia e água? (escolher os que considera mais relevantes)

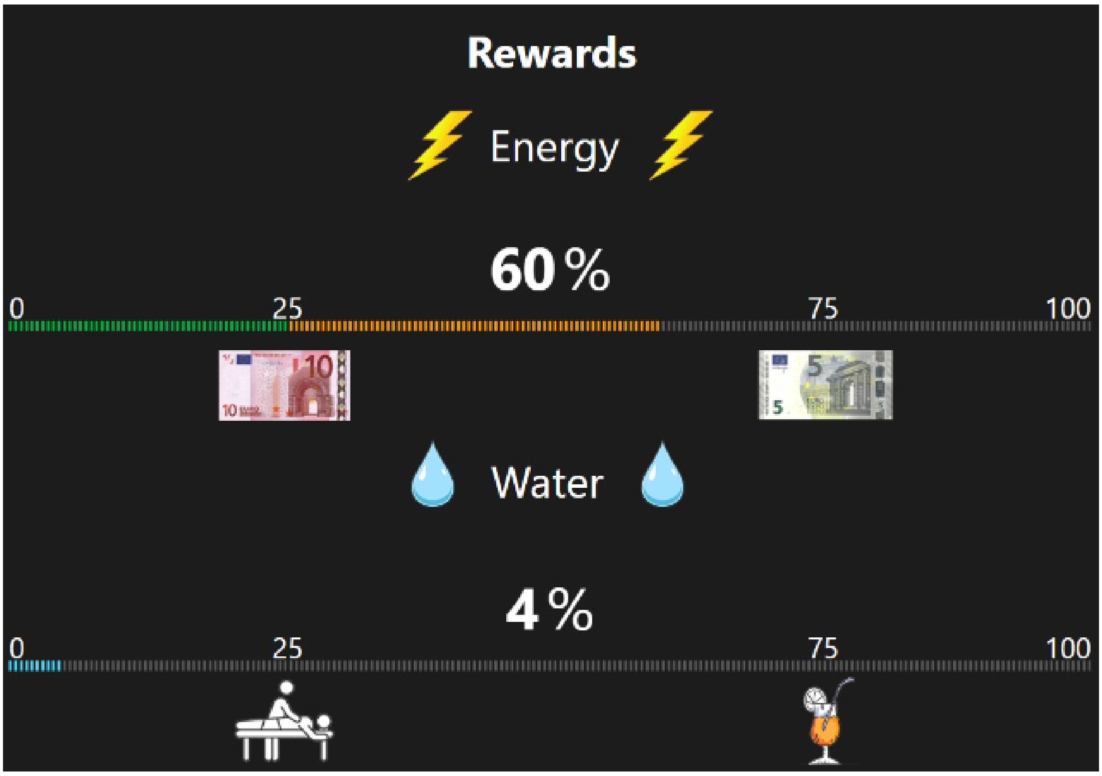
- [ ] Falta de informação sobre o assunto
- [ ] Falta de tempo
- [ ] Custo de soluções de poupança de energia
- [ ] Dificuldade de instalação
- [ ] Não considero que a minha contribuição individual faça a diferença
- [ ] Outra opção...

17- Imagine que, durante uma estadia num hotel, a quantidade de energia e água poupadas em relação aos valores médios dos clientes, é recompensada através de um *voucher* para usar no bar, no restaurante ou num outro *outlet* do hotel, ou seja, quanto mais poupar, melhor é recompensado. *

Por exemplo:
Redução do consumo de energia em 25% - Vale de 5€.
Redução do consumo de água em 25% - Voucher de uma bebida no bar.

Na seguinte imagem encontra-se um exemplo da visualização de recompensas associadas à quantidade de energia e água que consumiu até ao momento, relativamente à média.

Tendo em conta este mecanismo de recompensa, estaria disposto a adotar comportamentos mais sustentáveis?



	1	2	3	4	5	6	7	8	9	10	
Não, nunca	○	○	○	○	○	○	○	○	○	○	Sim, definitivamente