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Gamification in building automation - the Human in the loop in a Cyber-Physical System

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[1] https://github.com/joaomlourenco/novathesis [2] http://www.di.fct.unl.pt

To my famfam

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FCT is love, FCT is life!

Abstract

Nowadays, the number of intelligent environments has been increasing, as have their energy needs. It has become quite common to find buildings with interconnected components and automated systems implemented in order to create an environment with perfect conditions, maximizing the comfort of its users and minimizing energy consumption. However, not all infrastructures are prepared to accommodate such systems, which sometimes leads to the need for human intervention. Unfortunately, due to their lack of interest in achieving the system's goals, the level of reliability of the individuals can be low, which can cause system malfunctions. Nonetheless, there are many examples of systems where human engagement could be improved with gaming techniques. This type of techniques, known as gamification, turn common tasks into engaging activities.

Even though we have found a variety of gamified systems examples, we did not find studies that implemented a building automated systems, with a human-in-the-loop, in a retrofitting environment. Therefore, we created our study to assess if gamified Office Automation Systems can be used to encourage interaction with the system and to improve users' habits.

The final product was LabRats, a gamified system adapted to our environment and tested to determine if gamification techniques can be used to encourage and strengthen the connection to the system, and also to motivate its users to adopt energy saving routines.

With the implementation of LabRats, we can observe that there was an increase in participation, that led not only to a reduction in energy consumption but also to a change in the habits of the occupants.

Keywords: Internet of Things, Cyber-Physical Systems, Building Automation Systems, Human-in-the-Loop, Gamification, Energy Efficiency, Participation, Motivation

Resumo

Hoje em dia o número de ambientes inteligentes tem vindo a aumentar, tal como as suas necessidades energéticas. Cada vez mais encontramos edifícios com componentes interligados e sistemas de automação implementados para conseguirem criar um ambiente com condições perfeitas, maximizando o conforto dos seus utentes e minimizando os consumos energéticos. No entanto, certas infraestruturas não estão totalmente preparadas para este tipo de sistemas, o que por vezes leva à necessidade de intervenção por parte de um indivíduo. Infelizmente, devido à falta de interesse em alcançar os objectivos do sistema, o nível de fiabilidade do indivíduo pode ser muito reduzido, o que pode causar falhas no sistema. Porém, existem vários exemplos de sistemas onde a interacção pode ser melhorada recorrendo a técnicas de jogo. Este tipo de técnicas, conhecidos como gamificação, tornam mais cativantes tarefas comuns.

Embora, tenhamos encontrado vários exemplos de sistemas gamificados, não encontrámos estudos que implementassem um sistema de automação de edifícios, com participação de humanos, num ambiente de retrofitting. Por isso criámos o nosso estudo para avaliar se um sistema gamificado de automação num espaço de trabalho pode ser usado para incentivar a interação com o sistema e melhorar os hábitos dos ocupantes.

O produto final foi LabRats, um sistema gamificado adaptado ao nosso ambiente e testado para determinar se técnicas de gamificação podem ser usadas para encorajar e fortalecer a conexão com o sistema e também motivar seus utilizadores a adoptarem rotinas de economia de energia.

Com a implementação do LabRats, conseguimos observar que ocorreu um aumento de participação que levou não só a uma redução do consumo energético como também a uma alteração dos hábitos dos ocupantes.

Palavras-chave: Internet das Coisas, Sistemas Ciber-Físicos, Sistemas de Automação de Edifícios, Human-in-the-Loop, Gamificação, Eficiência Energética, Participação, Motivação

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Chapter 1

Introduction

In the upcoming sections we will provide an overview of our problem, our motivation to study it and the final goals for this project.

1.1 Context and Description

We live in a high technology world nowadays, there are smart devices everywhere, from our phones to our houses to our cars, millions of different devices available to help us in our daily lives. Sometimes, people do not notice the existence of such complex systems, they have become a part of their lives in an almost untraceable way. The number of Internet of Things' environments and devices is always growing, with companies trying to develop new, better products to release [1]. A new industrial revolution is on the horizon, Industrie 4.0, is set to change the world as we know it [2]. Based on cyber-physical systems, these systems are capable of covering a variety of sectors from healthcare to manufacturing passing through households, smart cities, emergency response and wearables. However, such advanced technologies have some issues associated, such as security, privacy, infrastructure demands and energy costs. While it is important to continue to explore these fields, we also need to keep in mind the limitations of today's world and how we can adapt to the existing conditions.

We are so used to these types of smart imperceptible environments that we become less aware of our surroundings, we forget about the energy consumption and leave our devices on even when we are not using them. Other times, we are so focused on what we are doing we forget to change positions or turn on the lights and proceed to work only with the light the screen irradiates and do not pay attention to the effects that such actions may have in our life. While some structures are already equipped with smart devices that are capable of maintaining good work conditions and save energy, they are not the norm.

The majority of buildings today are not prepared or built to minimize energy consumptions nor to autonomously maintain certain work conditions, and as such a substantial investment would be necessary to install all the technology needed for creating an intelligent system. Nevertheless, there are some examples of systems that try to incorporate these new technologies to efficiently regulate consumptions on these existing infrastructures without disrupting the comfort of its occupants. An example is a building automation system that tries to maintain comfort, save energy and reduce the costs associated with it by monitoring and controlling the indoor settings. However, some of these systems cannot be fully autonomous due to adaptation limitations. Therefore, in some environments, the systems need help from a human to complete a cycle of events. Unfortunately, people are not as reliable as systems, they have emotional states and other concerns that make their participation unpredictable. Thus, the opinion of individuals is very subjective, which in some situations can generate an unsuitable response from the system.

For example, a smart system that controls an air conditioner unit, to know if it needs to adjust the temperature of the room, it asks the user for input. The descriptions of the users may be contradictory, as they are based on individual subjective comfort perception, and might trigger an inappropriate response in the system [3].

So it is of great interest to find ways to increase the reliability of the user and to study how far these methods can really motivate people and change their habits. In this thesis, we approached this problem by implementing principles from one growing successful area, which is gamification. To test our hypothesis we created an engaging system, LabRats, that tries to improve user's reliability and energy consumptions without sacrificing comfort, that was adapted to our case study environment, the NOVA LINCS SmartLab.

1.2 Motivation

We have to be able to keep up with the technological evolution, even in outdated infrastructures. When there is no possibility for remodelling work, we need to adapt and rethink what we have and use the available resources to transform an infrastructure to the idealized innovative space, within the possible limits. We need to take into consideration the people who use the structure, their preferences and routines. They are the ones that occupy the space in a daily basis and who's comfort and health will be impacted. Another important aspect to have in mind is energy efficiency, besides the adjacent monetary cost, it is an environmental worldwide relevant concern.

Reports show the unprecedented changes that human influence has on the climate system [4]. Even though the evidence is indisputable, not everyone takes into consideration the impact of their daily actions on the atmosphere. Some people leave appliances on, they do not turn off the lights and run the air conditioner all day, which increases electricity consumptions and raises emissions of carbon dioxide, contributing to global

warming [5, 6]. Even though carbon dioxide is one of the many harmful greenhouse gases, if we can make a difference in the emissions, it is a step forward to a healthier planet.

To resolve this issue, new systems are being developed to efficiently manage energy consumptions. For instance, systems may include sensors that detect the presence of people in a room and automatically turn off the lights if the room is empty, these techniques save money, energy and also create the appropriate settings to work [7, 8].

Although some systems are capable of performing all the needed actions to manage consumptions and maintain certain indoor conditions by themselves, others require extra help, so a human participant may be requested to assist. Instead of only perceiving the human as a final client, we need to include the human as an active part of the system. Thus, new concerns surface because humans may not be willing to help or may not care about the goal of such task and, in case a task disturbs their comfort, they will not perform it. Relying on human participation has a risk because their behaviour is, most of the times, uncertain. It depends on their mood, current workload, so it is generally hard to anticipate the behaviour of an individual. However, it is possible to design an interaction logic that increases the subject's will to engage with the surrounding components. We can create a system that is captivating, fun and easy-to-use that strengthens the commitment of the user to the system and therefore, to its goals.

A very popular topic nowadays, that tries to tackle this issue, is Gamification, the use of game elements and techniques in a non-game context [9, 10]. Games, whether virtual or physical, include a series of attributes that turn them into an amusing and addictive activity, hence increasing the level of commitment of the player to achieve a certain goal and creating new routines.

We believe that it is possible to boost the participation and reliability of the users, as well as motivate them to save energy by creating an engaging gamified system, that will not disrupt user's comfort, which can ultimately be associated to a CPS in order to change user behaviour and optimize energy efficiency.

1.3 Problem Statement and Final Goals

This thesis aims to demonstrate that the application of gamification principles can raise the engagement within a cyber-physical system and create awareness about healthy office settings and energy consumption, while maintaining comfort levels, which will hopefully lead to an increase of reliability and a change of habits.

With this study we will be able to answer the following question:

> **Can we increase the participation of users, provide a comfortable environment and motivate them to save energy by using gamification in a smart environment?**

This study also gives us the opportunity to answer the following sub-questions:

- Can we increase the user's awareness about the involving environment?

- Will we be able to instil healthier working habits?
- Can we change user behaviour in a manner that really optimizes energy efficiency?

Our final goal was to create a gamified application modelled around the target environment that encouraged users participation and energy efficiency management, keeping the comfort levels. To do so, we analysed the environment and its stakeholders, understood their needs and preferences to find out what kind of gamification elements are appropriate. The developed system, LabRats, results from this analysis.

1.4 Key Contributions

We believe the work we developed provides the following contributions:

- A study of the necessities of a cyber-physical system based on an initial questionnaire;
- A game logic adapted to a cyber-physical system;
- A generic base platform for the implementation of the game logic;
- An implementation of a prototype of the proposed game logic within an existing cyber-physical system;
- An evaluation methodology for gamification in cyber-physical systems;
- An article published in 2019 IEEE 43rd Annual Computer Software and Applications Conference (COMPSAC), which disseminates the developed work [1].

1.5 Document Structure

This document has the following organization:

- Chapter 1 — Introduction: the current chapter;
- Chapter 2 — Background: a description of the concepts involved;
- Chapter 3 — Related Work: in this chapter we will present and discuss various examples of projects developed in the areas of interest;
- Chapter 4 — SmartLab Environment: an introduction to the SmartLab environment and its occupants, as well as their preferences and needs;
- Chapter 5 — Conceptualisation and Implementation: this chapter presents our application, LabRats, its logic, architecture and implementation;

[1] https://ieeexplore.ieee.org/abstract/document/8753912/

- Chapter 6 — Evaluation: a discussion of the obtained results and the occupant's assessments;
- Chapter 7 — Conclusion: the closing chapter of this dissertation, in which we summarise our discoveries and point to possible future directions;

1.6 Summary

This chapter was an introduction to the theme and problem of this preparation. In the upcoming chapter we will provide relevant information regarding these types of systems.

Chapter 2

Background

This chapter will present a detailed explanation of the related concepts to better understand the main body of our work. We will start with IoTs and CPSs, then move on to the subject of gamification.

2.1 Internet of Things

Internet of Things (IoT), which can be also called Internet of Everything, is a network that interconnects physical objects capable of interacting with each other [11, 12]. IoT allows objects to be controlled and recognized remotely, bringing together the physical world, the sensors and actuators with the cyber-space, and consequently improving efficiency, interaction and accuracy.

To understand how it works, we need to learn about its components and networks. Starting with architecture, several have been proposed for IoT, however, no consensus was ever reached [13–17]. Nevertheless, studying all the different proposals we can distinguish four layers, depicted in Figure 2.1. The first one would be the perception layer, which handles the sensing of the physical objects and gathers the data. Next, there is the network/transport layer, which is responsible for connecting the different devices and for the transparent transmission of data through the different networks, using for example, wireless or bluetooth. The processing layer organizes, stores, analyses and processes the incoming data, and also provides services for the lower layers. Finally, there is the application layer, which delivers content services

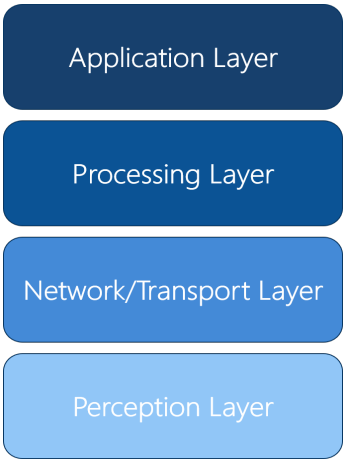


Figure 2.1: The four layer architecture of IoT's.

for various users.

When design an IoT-based product, there are different technologies available, some of the most used are presented below:

- **Aplication software** — provide robust and reliable device-to-device and human-to-device interaction;
- **Radio frequency identification (RFID)** — small device with a reader and a tag, that allows to automatically identify and track objects;
- **Wireless sensor networks (WSN)** — group of spatially dispersed autonomous sensors for monitoring physical and environmental conditions. When used with RFID it can improve readings of location, temperature and movement;
- **Middleware** — software layer that acts as a bridge between software applications and the operating system, provides and facilitates controlled interaction and prevents interference between computations;
- **Cloud computing** — is a model for delivery of on-demand computing resources, it is the ideal back-end solution for handling and storing huge amounts of data.

IoT applications can range from health care systems to smart homes and cities. It can also be used to improve the efficiency of business operations or to manage and monitor environments and resources [18].

One example of a system that is interconnected is inirv[1], a system that enables the user to control their stove from a distance. The system is composed by a gas and smoke sensor unit, a knob and a mobile app. Whenever the sensor detects high levels of smoke or gas, it will send a signal to the knob, which will turn off the burners. Through the app, the user can see the state of the knob and regulate the heat from a distance.

Like any other computational system, IoT has some challenges [19]:

- **Security and privacy** — since it handles the transportation of sensitive data such as users' personal information, purchasing references, it becomes vulnerable to attacks from cyber criminals;
- **Heterogeneity** — the system needs to interconnect a variety of devices that have different characteristics such as communication protocols, functionalities, data types and storage;
- **Scalability** — the amount of data that needs to be stored and processed keeps increasing and storage starts lacking;
- **Network** — the system needs to take into consideration the energy that these devices consume, as well as the distance and amount of data that needs to transmitted.

[1] https://www.kickstarter.com/projects/157070440/inirv-react-make-your-home-smarter-and-safer

2.2 Cyber-Physical Systems

A cyber-physical system (CPS) is a collaboration between computational entities and physical components. Both elements are connected through a network in order to provide control and feedback about ongoing processes [20, 21]. To truly understand CPS, we need to comprehend the interaction between both components, rather than understand them separately.

These principles can be applied to the most diverse areas, from healthcare to traffic management. Since they can be applied to such a broad spectrum, it is an advantage to have a multidisciplinary team working together, composed of diverse branches of engineering [22].

A cyber-physical system can be divided in three parts:

- **Physical plant** — all the parts that are not performed by computer or digital networks. These parts could be chemical, mechanical or biological processes, as well as human operators;
- **Computational platforms** — consists in actuators, sensors or computers. A system can have one or more of the platforms;
- **Network fabric** — provides the necessary mechanisms to connect the different computational platforms.

Figure 2.2 showcases an example of a feedback control loop. In this example, we have a physical plant that provides data to the platform, then there are the sensors who measure and analyse the processes. The sensor sends the data to the control unit who determines which command to send to the actuators, who later, according to the instructions received, will initiate a state change in the physical plant.

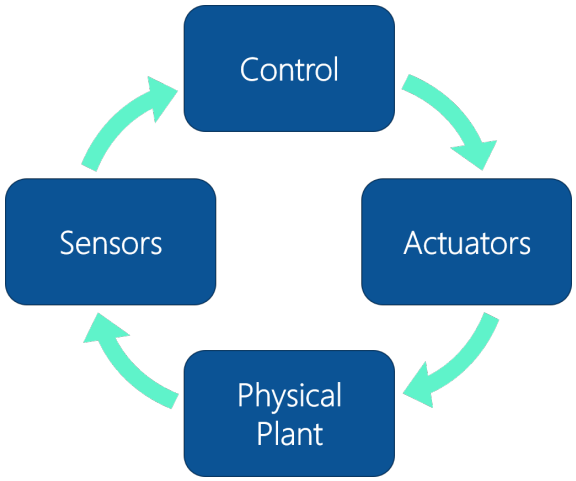


Figure 2.2: The feedback loop of a cyber-physical system. Adapted from [23]

The loops can either be open or closed-loop system [24]. In the first case, the information gathered by the sensors will not trigger a state change. An example would be a

sleep tracking application like Lullaby, which provides the information gathered but it does not act upon it. The opposite happens in a closed-loop, the state of the physical component will change due to actuator action. For example, a room with a smart thermostat that detects the presence of people and tracks their sleep patterns. According to the data gathered, the system will adjust the room settings in order to save energy.

2.2.1 Human-in-the-Loop Cyber-Physical Systems

Human-in-the-loop cyber-physical systems (HiTLCPS), like the name entails, are CPS that require a human participant in the feedback control loop [25].

HiTL applications can be divided into three categories [24]:

- **Human control** — when humans directly control the system. It can either be supervisory control, if the human operator oversees the process and adjusts it when needed; or direct control, if the human issues commands to the system to follow;
- **Human monitoring** — humans are the source of information of the sensors and may be the targets of the triggered response of the feedback loop. The feedback loops, like previously discussed can be open or closed;
- **Hybrid** — it is a combination of the two systems above, humans provide direct input, the system uses it and learns from the data.

The taxonomy illustrated at Figure 2.3 is based on the controls that human-in-the-loop applications employ.

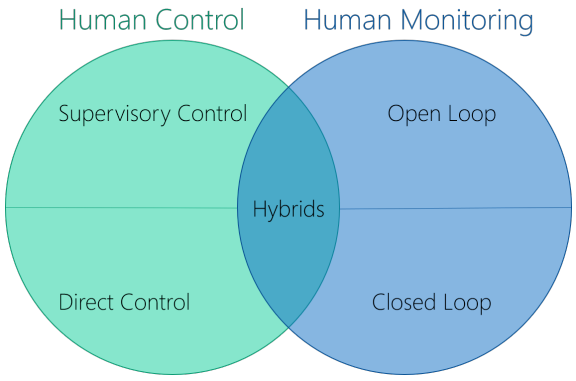


Figure 2.3: Taxonomy of human-in-the-loop applications. Adapted from [26]

In HiTL systems, humans can have different roles regarding [26]:

- **Data aquisition** — humans can either take a role as sensors or as communication nodes. Humans can be seen as sensors whenever they provide information directly or indirectly through their smartphones or wearables. They can also be considered communication nodes due to the devices that they carry such as a smartphone, which can aggregate and store information, and also forward the data to a receiver node when appropriate, hence, saving communication related energy;

- **State inference** — humans can affect directly the response of a system, since the latter is capable of not only measure different human properties, but also recognize activities and psychological states. Humans can also be processing nodes since their devices can process data, thus enabling collaborative work;

- **Actuation** — humans are actuators whenever their actions are triggered by information provided by the system or when their commands are required as specialized help for the system to function.

2.2.2 Building Automation Systems

Building automation systems (BAS) monitor and control the conditions of an indoor environment [7]. The main goal of BAS is to increase energy savings and reduce costs. These types of systems control various functions of an environment, for instance heating, ventilation and air conditioning (HVAC), lighting and shading systems, energy conservation and storage, occupation detection, security and safety systems [27].

A BAS setup is composed by sensors, actuators and controllers. Sensors are the measuring devices, actuators are responsible for changing the state of the devices. Finally, controllers are hardware modules with input and output ports that allow receiving data and sending signals.

Building Automation Systems have three hierarchical levels of functionality architecture [28, 29]:

- **Management** — where all the information of the system is collected. System configurations, visualization and storage also happen at this level;

- **Automation** — this level provides the control functionality, for example execution of control loops and measurements process;

- **Field** — all the field devices belong to this level, such as sensors and actuators.

2.3 Gamification

Gamification is the use of game elements and game techniques in a non-game context [10, 30].

The game elements represent the small pieces that build a game, that give a game structure and make it engaging. For example, in Tic-Tac-Toe, game elements include the tokens, the competitive feature, the notion of blocking the adversary by putting a token in an empty spot, the winning state that consists in one player having three tokens in a row.

Game elements can be divided in a three tiers hierarchy. The base tier is components, which are the specific ways to reach the higher level action that the two top higher represent. For instance, give achievements to the player as a reward or fight the powerful

enemy at the end of a level. Then, there is the mechanics tier, the elements that drive the action forward, like challenges or transactions. At the top, we have dynamics, the implicit structure that provides framing to the game, enriching the experience by applying constraints or creating a narrative.

Game techniques are the set of practices that make the task fun, challenging and addicting. Providing a good experience will dictate if the player will stay engaged with the system.

The users of gamified systems are also known as players, since they are the main focus of the systems. They use the game and have autonomy and control over their actions. The players are not using the system to escape to a fantasy world, this is not a diversion. Gamification is a way to increase the engagement to a product or objective, it transforms a chore into a fun activity.

Gamification, as illustrated in Figure 2.4, can be divided into three categories:

- **External** — when gamification is applied to costumers or potential costumers. For example, to increase sales or improve marketing;
- **Internal** — when applied for the people of an organization or community to enhance productivity or increase motivation;
- **Behaviour change** — extra encouragement for people to change or establish habits, whether it has personal or community benefits. For instance, improve health or reduce waste.

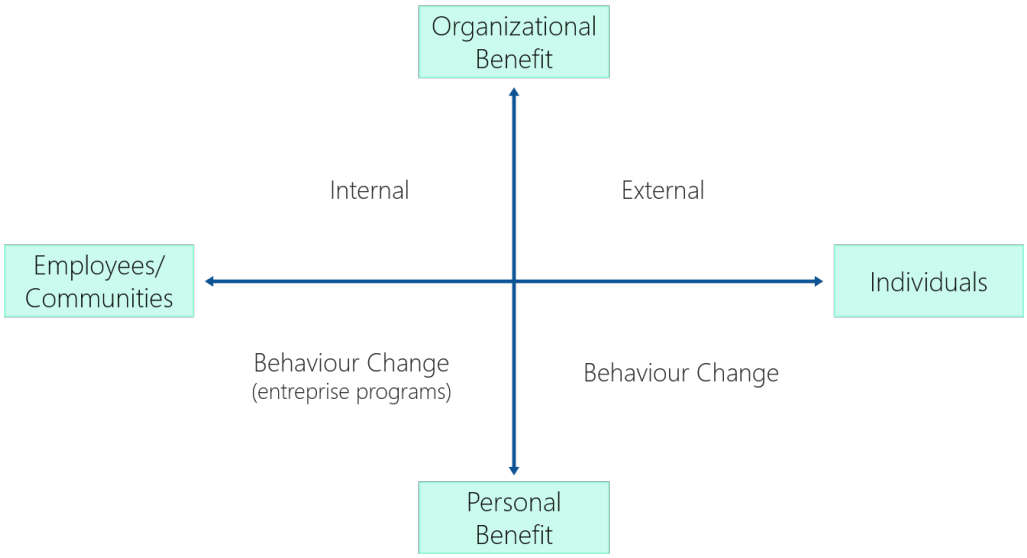


Figure 2.4: Relationship between the different gamification categories. Adapted from [30]

Gamification is a human-focused design. It focuses on the human component, by trying to increase motivation and engagement by creating a pleasant experience [31].

When planning such a system it is crucial to set the goals of the system and the desired behaviours, to know the target audience, understand their drives and desires and to anticipate potential conflicts.

To facilitate the design of gamified systems, a six step design framework (6D) was developed, as detailed in [30], taking into account people's and the business' needs:

- **Define** business objectives — defining the ultimate goals of the desired system will help build a better strategy, it will allow to better understand what the organization wants, if gamification is in fact the answer, and better comprehend what the possible benefits are;
- **Delineate** target behaviours — after having the main goals set, the next step is to identify the desired behaviours from the players to reach said objectives, what are the players expected to achieve and how will these actions translate into successful outcomes;
- **Describe** your players — to design a successful system, the players likes and dislikes have to be accounted for, not everyone has the same taste nor evolves at the same pace, so the system needs to be able to offer appealing and interesting opportunities to all users;
- **Devise** activity cycles — players have to have a sense of progression and return, they need to have feedback after performing some kind of action, such as receiving points or a congratulatory message. They also need to feel they have grown within the system, first steps might be easy, but as the system progresses, missions become more difficult and they have to really master their skills to reach the next phase;
- **Don't** forget the fun — what distinguishes gamified systems is the fun element they provide to the people who use them, it is the reason behind the continuous use of the system, so besides creating a functional system it is also important to make it motivating and, therefore, engaging;
- **Deploy** the appropriate tools — gamified systems entail a certain degree of complexity, which means that its implementation must be performed with this in mind. When developing a gamified system from scratch, it is benefitial to make use of a diverse team with several different backgrounds, allowing for a wider range of viewpoints and ideas. As an alternative, instead of building a system from scratch, we can rely on external companies, which provide tailored gamification solutions adapted to our needs.

Another interesting vision belongs to Yu-kai Chou, who created a gamification framework called Octalysis [32, 33]. He studied different games and identified eight core drives that motivate people to do a certain task in a gamified system. The drives are the following:

- **Epic meaning and calling** — the players feel like they are part of something bigger than themselves, they are an important piece to the system. To exemplify, we have an application called Pain Squad[2], which was developed to track pain on children with cancer. The kids are recruits in a police task force that wants to hunt down pain, to help them they need to report twice a day if they are in pain, where and if they know the cause. It is an easy-to-use application, it displays the reports and it has a graduation structure, so the rookie would be promoted to junior detective and so on. Throughout the app, the children would also receive videos with messages from characters of police series, this way a task that had a negative connotation was transformed into a valuable mission;

- **Development and accomplishment** — the player is progressing within the game, is improving the skills and overcoming challenges. A good example are running apps, like the Nike+ Fuelband[3], a point based system where the user receives performance feedback and is informed about all the short-term accomplishments (Figure 2.5a[4]). Every time the user improves, for example rans an extra twenty minutes compared to last time, the user is notified of the achievement and if a new milestone is reached an avatar appears doing a victory dance. This gives the users a sense of improvement and extra motivation to keep on track;

- **Empowerment of creativity and feedback** — the players use creativity to solve a problem, like in a puzzle, where the players need to test different combinations to see what works and adapt the solution according to feedback. A possible example is Foldit[5], an application that wants its users to solve problems for science. The players receive points and can work in teams to discover the unknown structure of proteins by applying different options;

- **Ownership and possession** — users feel motivated because they feel like they have something of their own, consequently they will want to improve, protect and gain more. Dragonbox[6] uses this core drive, this is an application aimed to help kids learn math. The users have a baby pet dragon that has to eat to grow, but the pet only eats when the floor is empty. At the beginning, the floor has items that can disappear using some math principles, imagine that there are two items on the ground, one is a good robot and the other is a bad robot. If the player joins them, they will cancel each other. Then, the dragon would scan the floor and eat, so the kids would learn math while trying to take care of their dragon and watch it grow;

[2] http://www.sickkids.ca/Research/I-OUCH/Pain-Squad-App/index.html
[3] https://play.google.com/store/apps/details?id=com.nike.fb&hl=en
[4] http://static1.cdn.gadgetreview.com/wp-content/uploads/2012/03/xnike-fuelband-day_goal-650x487.jpg.pagespeed.ic.yoBOHOJkfJ.jpg
[5] https://fold.it/portal/info/about
[6] http://dragonbox.com/about

- **Social influence and relatedness** — this core drive includes social elements like competition, companionship, relativeness, envy and more. The user may be driven by a sense of nostalgia, wishing to have something that was once present in their lives or by envy, the player wants to reach the same level of her friends in order to own the same items. For instance, Opower[7], a company that intents to lower energy consumptions, every month, on the utility bill, would give information about the consumptions of the average and the best neighbour. This created a healthy competition, which led to a behaviour change and a reduction in costs;

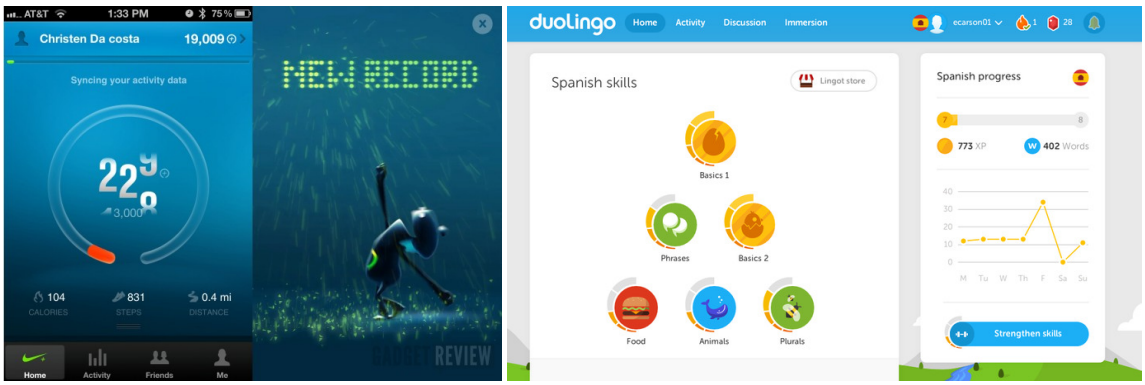
- **Scarcity and impatience** — when there is something that the player cannot have, that idea will keep lingering on the player's mind until it is available, which keeps him motivated to get it. Kickstarter[8] is an good example, the site presents several innovative ideas, but they are only available when the goal is met. When the project's goal is reached, the product becomes available and the site will inform how many units are accessible. Kickstarter keeps people invested because they want to know when they can get the item and if there are many units or not;

- **Unpredictability and curiosity** — the player is curious about what she is going to get, which keeps her motivated. We see this case with a book or a game, when we want to reach the final chapter or level to know how it ends. An example is Yorn Shake it[9] sweepstakes, where the user has to shake the phone in order to receive cards that may be immediate prizes or collectable cards. The prizes range from merchandise to smartphones. The user knows the possible prizes, but cannot predict which one he will get, so he keeps using the system until the desired prize is collected;

- **Loss and avoidance** — the user is driven by the fear of losing something they worked hard for, like previous work. Duolingo[10] has a system that uses this core drive. There are several themes, take for instance animals: as the user learns new words a bar will fill up, until it turns gold (Figure 2.5b[11]). To maintain the status of the bar , the user has to check-in to the application and train the theme. If the player stops checking in, the bar will eventually become empty and the user has to do the work all over again. This system motivates users to visit and train the language every day.

Not everyone thinks or reacts the same way, so it is important to create a system that will appeal to the subject's personality. For some, a meaningful context, a higher purpose,

[7] https://ux.opower.com
[8] https://www.kickstarter.com/about?ref=global-footer
[9] http://www.yorn.net
[10] https://play.google.com/store/apps/details?id=com.duolingo&hl=en
[11] https://i2.wp.com/notesontraveling.com/wp-content/uploads/2015/11/duolingo.jpg?fit=1300%2C975&ssl=1



(a) Nike+ Fuelband. (b) Duolingo.

Figure 2.5: Octalysis core drive examples.

will be sufficient to keep them engaged [34]. For others, a real value reward is what matters.

Rewards can keep players motivated, and lead them to becoming addicted to winning some type of compensation. They are an important aspect of gamification, and can either be tangible, have value in the real world, like money or intangible, a non-palpable value like a badge. Receiving unexpected rewards, does not only help the user feel accomplished, it also triggers a chemical reaction, in this case increases the dopamine levels which act like positive reinforcement and therefore the desire to engage with the system [35]. To receive a reward the player needs to meet certain criteria [30]. If the player gets the reward no matter what, we say it is a non-contingent reward. Engagement-contingent happens when the player starts doing the action and immediately gets rewarded. Completion-contingent when the player is rewarded at the end of the task. Finally, if the player is rewarded according to performance, then it is performance-contingent.

Another important property of rewards is its schedule. Rewards can be:

- **Continuous** – the player is rewarded each time, works for every instance of the action. It is the least interesting;
- **Fixed ratio** – if the activity happens a specific number of times, then for example, every three times the player performs it, a reward is given;
- **Fixed interval** – the player is rewarded based on a time unit;
- **Variable** – these are the most interesting, the rewarding does not have any fixed schedule, it is always a surprise. These rewards can be either competitive/non-competitive, when the player has to win something or reach a specific level; or certain/uncertain, the player does not know which one it is or if she is really going to get it.

Gamification is a promising area, there has been an increase of searches and writings on the topic since 2010 (Figure 2.6) and five years later, in 2015, there was a clear peak of outputs [36, 37]. While some people may associate the theme with computer science fields, Gamification is multidisciplinary subject. As we can see from the examples provided above, gamification can be applied in many areas, ranging from several scientific fields to education and economics.

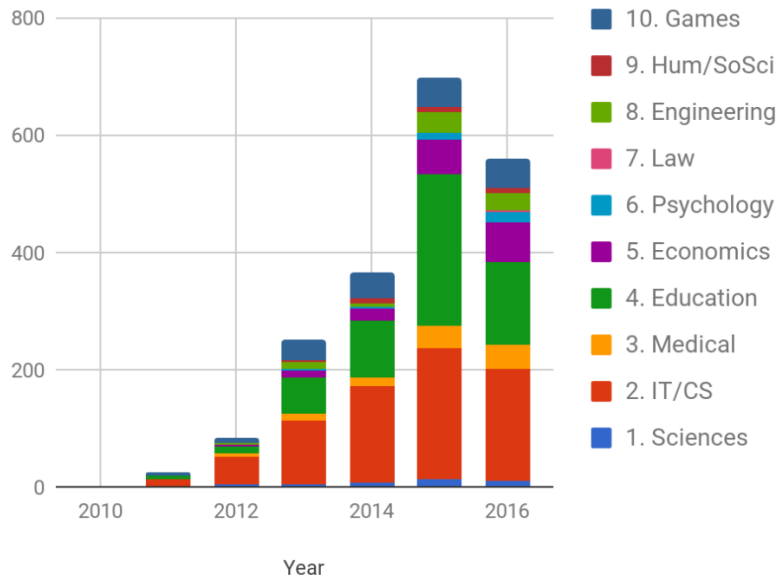


Figure 2.6: Gamification papers from 2010 to 2016 by category. Taken from [36]

2.4 Summary

The previous sections provided the necessary knowledge about the technologies of our domain. In the following chapter, we will review the existing work developed in these areas, providing real world examples of projects and systems that use similar techniques to those presented in this dissertation.

Chapter 3

Related Work

The upcoming sections will detail a few examples of the work developed in the previously mention areas.

3.1 Smart Environments and Objects

We are surrounded by objects that interact not only with people, but also between themselves, such as movement detectors and home assistants. These devices, known as smart devices, can be embedded seamlessly to create smart environments.

3.1.1 Smart Home

Nowadays, smart devices are highly accessible, and there are several relatively inexpensive options, making it possible to easily create a smart home. Many of these devices are able to connect with each other, creating an IoT environment, which allows the user to control and monitor their house from outside. Some of these devices, besides enabling remote controlling, also learn by themselves, by following a persons routine. Smart houses have a variety of sensors for temperature, presence, light, humidity and so on. These smart environments, as we stated before in section 2.1 and section 2.2, also have a controller unit and several actuators, in order to change the systems state.

The user has access to all the information of the house through an user interface, which provides control and the possibility to monitor everything. The user can turn off the lights in a room or pre-heat the oven with the help of a phone or a voice controlled assistant like Alexa[1]. Owners can also monitor the state of appliances and the house itself, they can know if the points of entry are all locked and access security cameras. The house

[1] Amazon's cloud-based voice service. https://developer.amazon.com/alexa

on its own can also change its state, it can turn on the lights when the owner is arriving or turn up the heating around the time residents normally get home.

This type of system is also useful in life-threatening situations, for example if there is a gas leak, the house can sense the high levels of carbon monoxide, so it turns off all the heating and through smart light bulbs sends an alert to residents to inform them. These smart houses can also lower energy consumptions, by turning off the lights when owners leave a room or turn on the laundry machine when the energy demand is low. A company that tries to provide all the devices and functions mentioned above is Nest [2]. They turn the house into a system that can perform some tasks by itself, like turning on the lights, regulate temperature and alert for intruders. Additionally, the house is also capable of acknowledging the surrounding environment and learning behaviour patterns.

LG is another company that is investing in these types of systems, they have a line called SmartThinQ[3], it has refrigerators, vacuums, sensors, hubs, etc. The phone is connected to all the devices, as well as the hub, if it exists. The sensors are placed on the appliances, but can also be used on doors and windows, this way the user can check through the phone if doors and windows are closed. For instance, the fridge has a screen, which provides an user interface on the door that allows the user to watch TV, check for recipes, order groceries and see the family schedule. It also provides a list of all the food inside it and the expiration dates, and it has cameras inside for the user to see what is on the fridge. It also has a power saving feature, if the owner switches on the option vacation on the mobile app, all the appliances go into eco mode.

3.1.2 Smart Conference Room

A group of researchers developed a smart meeting room that was able to detect and track people's presence inside, in order to regulate the room's temperature and change the state of the lights and projector[38]. The system aimed to create an energy efficient environment and to provide both a productive and comfortable space while maintaining its cost at low levels.

The room was equipped with two Microsoft Kinect sensors, facing opposite directions in order to capture all the angles of the meeting table. The system was fully autonomous, being able to track motion within the video stream to then subtract the background and, according to the resulting image, identify people and track alterations regarding their position. Given this information, a decision module would then make control decisions regarding the elements mentioned before. At the end of the meeting, all the room devices would be turned off and a transcript of the meeting would be then created.

[2] https://www.nest.com/works-with-nest/

[3] https://www.youtube.com/watch?v=b9bzLbqgfyg,https://www.youtube.com/watch?v=CBJsCaPVAmo&t=5s,http://www.lg.com/us/discover/smartthinq/app.jsp

3.2 Gamified Systems

In this section we present some systems that implement, in some way, gamification elements and techniques, as discussed in 2.3

3.2.1 Microsoft's Language Quality Game

Microsoft is a company that has several products launching every year, around the world, in different languages. They have large testing groups to assure the quality of the product. However, these groups cannot test all the functionalities in all the languages to make sure the product works well. To resolve this issue they created the Language Quality Game[4], an internal system that relied on the company's employees to volunteer and review several dialog boxes, reporting bad translations or interpretations in their native language.

The system was used worldwide, with Microsoft offices competing against each other. Volunteers could have two distinct roles, they could be players, the users that go through the different screen shots and either give positive feedback or report an issue. In the latter case, a dialog is prompted, and they have to write some observations. The second role is moderator who reviews, resolves and posts bugs related to the submitted issues. Every office worked as a team to elevated their position in the leaderboard, since each team had a score which was the number of bugs found. The goal of the system was to improve the company's software by working as a team and providing feedback, and to be the winner office. This system worked because people were willing to put an effort in improving the company's software, to show their commitment to the company and to belong to the winner office.

Overall, they looked into over half a million of dialogue boxes, found around seven thousand bugs, of which several hundreds were actually real bugs and relied on the help of more than four thousand and five hundred volunteers[5].

3.2.2 Foursquare

Foursquare[6] was location based social network, where the user had to "check-in" at various venues. The goal was to bring people together in an offline world. This system used a points and badges system. Every time the player would check-in in a place or suggested a place, points would be added to the account. If the player had the highest number of visits to a place, the title of mayor would be assigned and displayed at the location. This status introduced a competition element, players competed against each other to became mayor. Another interesting idea was the badges, when the player visited

[4] https://social.technet.microsoft.com/wiki/contents/articles/9299.language-quality-game.aspx

[5] https://www.gamasutra.com/view/news/126763/Serious_Play_Conference_2011_Microsofts_Productivity_Games.php

[6] https://www.coursera.org/learn/gamification/lecture/h9Xrc/3-1-why-gamify

a different kind of place, like a conference venue or airport, a badge would be added to the personal collection. Some badges were limited to a certain area or event. The badges had several levels, the player would win one at the first visit and then a higher level badge if it was the twentieth visit. Foursquare also had a real-world reward, the player could also exchange the points earned for discounts in some affiliated restaurants.

Foursquare combines several elements to create an engaging system, it gave the player a sense of progression and it rewarded the user for various reasons. It had a very strong social component, the players would know where their friends were and could invite them. It also appealed to a protective side by giving titles to the users, which led them to visit the places where they were mayors more often, in order to keep the status. Overall, it was a very successful platform going from fifty thousand users in 2009 to reaching fifty million users later.

Even though Foursquare still exists, the idea has changed, now renamed as Foursquare City Guide[7], is an application that learns the user's preferences and suggests new place to visit based on them. The "check-in" service and location sharing aspects are now incorporated in an application called Swarm[8].

3.2.3 The Fun Theory

The Fun Theory is a Volkswagen initiative that aims to change human behaviour for the better by making it fun. They take ordinary banal tasks and transform them into something fun to attract people attention and modify habits. In the next sub-sections some of the experiments of the Fun Theory are presented.

3.2.3.1 Piano Staircase

In this situation, we have a subway exit in Stockholm, where people can reach the surface level by going up the escalators or the stairs. Not surprisingly, almost everyone chooses the less healthy option, the escalator. So Volkswagen installed musical stairs over the existing ones[9], whenever someone stepped on a key it would play a note, so everyone who went up the stairs would create their own music (Figure 3.1a[10]). The results of this experience revealed that 66% more people chose the stairs over the escalator. This example is interesting because it demonstrates that a simple system that was fun for people to use can change habits.

[7] https://support.foursquare.com/hc/en-us/articles/201015194-What-is-Foursquare-City-Guide-

[8] https://support.foursquare.com/hc/en-us/articles/201908440-What-is-Foursquare-Swarm-

[9] http://www.thefuntheory.com/piano-staircase

[10] https://www.qallwdall.com/wp-content/uploads/2017/12/Volkswagen_FunTheoryPianoStaircaseNumber110.jpg?be8325&be8325

(a) Piano stairs. (b) Speed lottery LED panel.

Figure 3.1: The Fun Theory experiments.

3.2.3.2 Speed Camera Lottery

This is a more complex system compared to the previous on. The goal of this system was lead people into obeying the speed limit[11]. To do so a speed camera was installed at the location and it would snap a picture of everyone who passed by. There was also a LED panel, placed on a vertical sign in the lanes separation, that would inform the drivers of their current speed, either giving them a thumbs up or down (Figure 3.1b[12]). The people who were driving over the speed limit, 30Km/h, would be fined and the money would be put into a stack. Drivers under the speed limit would get an entry to a lottery, to win the stack money. During three days, over twenty-four thousand passed the speed camera and the average speed went from 32 Km/h to 25 Km/h.

This is a fun system with a reward/penalty logic established. It provides instant feedback to the driver, since it shows the current speed and according to that information, it will either reward the driver with a lottery ticket or a fine, the penalty. People were motivated both by the reward and the fear of being caught speeding, and also by the fact that it was a lottery, which is a thing that people enjoy. The feedback played an important part as well, because it made people aware of their speed leading them to slow down.

3.2.4 Energy Chickens

Energy chickens [39] was a serious game, available through a web-based application, that aimed to help reduce the plug-load in a commercial office. The virtual pet game, in which the user had a barn with several chickens, each one corresponding to a device. The health of the animal was affected by the energy consumed by the device, which would then influence the number of eggs laid. If the user saved energy, the chicken would grow and lay larger eggs, otherwise the chicken would become smaller and ill. The eggs could be later traded for accessories for the chickens and barnyard (Figure 3.2).

[11] http://www.thefuntheory.com/speed-camera-lottery-0

[12] https://s3.amazonaws.com/revue/items/images/001/951/900/mail/Spee-Camer-Lotter1.jpg?1494105437

Figure 3.2: Energy chickens.

The study started with a period of data gathering, the daily energy consumption of several appliances was being monitored by wireless plug-load sensors to create a baseline. After this phase, a campaign to save energy was released as well as the game. There were two distinctive groups, one that played the game and the other who were only exposed to the campaign posters and their peers. The posters encouraged people to become aware of their energy spendings and served as reminder to reduce consumption. After some time a new phase started, the posters were taken down and later the game ended, following up this period there was a follow-up similar to the baseline, where the energy consumption was monitored.

There was final compensation for entering this study, the game users who completed the experience, including answering well-being and productivity surveys would earn $100 and there were 5 gift cards to win among all the participants from the two groups.

This game provided feedback by displaying the chicken and its level, and the amount of energy used/saved (compared to baseline). It also had rewards, in this case the eggs that could be used as a currency to buy item in the store. As the game progressed, the store inventory grew and some features were became available, such as the possibility to see the farms of other participants and a graphic with personal energy usage.

In the end of the study, researchers concluded that there was a decrease in energy use (13%) and some behaviours had lasting effects in individuals from both groups.

3.3 Wellness at work

This section details a few examples of programs and applications focused on increasing well-being at work environments, serving as an inspiration for wellness components of the proposed system.

3.3.1 Workplace Fitness Program

Workplace conditions are directly related to the employee's health,. Most of the time, people stay in the same position for hours, only moving a small group of muscles[40]. Due to this fact, MuskuloSkeletal Disorders (MSD) are one of the most commonly reported

issues, with individuals stating especially upper body discomfort. With that in mind, this group of researchers developed a study to better understand the possible benefits of implementing a wellness program. The study took place in a Portuguese enterprise, whose employees had a regular office job, spending most of their time sitting at their desks with usual office materials. This experiment was voluntary, it required the participants to answer a few questionnaires and participate on their designed wellness plan.

They gathered a sample of 50 people which were divided into two groups, a control group (n=21) which only answered the questionnaires and a study group (n=29) that additionally attended the workplace fitness program. The plan was composed by several activities, such as massages, pilates and stretching classes, they could either be individual, paired or in group. The program occurred 3 times per week for a period of 15 minutes. Both groups took a test at the beginning and the end of the experiment to understand their pain perception and evolution during the 8 months. The study concluded that the control group pain perception did not suffer significant alterations, as expected. However the study group felt a substantial reduction, especially in the posterior back, dorsal, lumbar zones and wrists. They also corroborated previous studies observations regarding adhesion: some employees prefer or do not make use of their breaks during work hours; they present some resistance to change; the individuals might also feel insecure regarding their job, fearing negative repercussions, and their bodies, preferring not to exposed themselves. The latter fact might explain the higher adhesion from woman comparatively to men.

3.3.2 WorkRave

WorkRave is a computer application that aims to remind its users to take breaks during the day, as a way to assist and prevent repetitive strain injuries [13]. The application has three different types of reminders: micro-breaks, a reminder to look away from the computer and do small stretches; rest-breaks take by default 10 minutes reminding the user to step away from their desks; and a daily limit. The program tracks keyboard and mouse activity, whenever it is time to take a break a small pop-up window will appear. The application does not disturb the workflow, however if the user constantly ignores the alerts from the system, WorkRave can be configured to completely block the computer after a certain threshold. The user can change the reminder intervals, postpone breaks if desired and follow a simple instructional exercise animation suggested by the application.

3.4 Summary

The presented projects contain interesting examples of the application of IoT systems, gamification in existing applications and wellness integration within the work environment. Some of these systems monitor user activity without relying on user input, while

[13] http://www.workrave.org/

others rely on human interaction. These examples provide an interesting view of subjects within this dissertation's scope. In the upcoming chapter, we present our case study and environment, serving as an introduction for the developed solution.

Chapter 4

SmartLab Environment

In the following sections, we will present the laboratory of our case study, the SmartLab, list all of its components and devices. We will also get familiarized with the inhabitants of the SmartLab, their preferences and opinion on the matter.

4.1 SmartLab

Our case study takes place in the NOVA LINCS SmartLab, a room in the Department of Informatics that has several IoT devices installed both for sensing and actuating. The laboratory has ten workstations, which are used by MSc and PhD students, the target audience of our system. The overall layout can be seen in Figure 4.1, Workstation 3 has a permanent desktop computer that controls the aquarium.

The SmartLab is an intelligent building automation system integrating IoTs, it aims at reducing energy consumptions without sacrificing the comforts of its residents [41, 42]. It has already a variety of components installed, which we will detail in the following subsections [23, 43].

4.1.1 Fish Tank

The fish tank is a subsystem of the laboratory, it is managed by the Open Aquarium[1]. The warm water aquarium has plants and different fishes with their own role in the ecosystem. The tank has its own components, it has to have several sensors, such as temperature, Ph and water level, as well as different actuators to keep the system alive, in this case, we have a heater, a ventilator, a feeder, a light and a water pump. The system

[1] An hardware solution design to control and maintain an aquarium. https://www.cooking-hacks.com/documentation/tutorials/open-aquarium-aquaponics-fish-tank-monitoring-arduino/

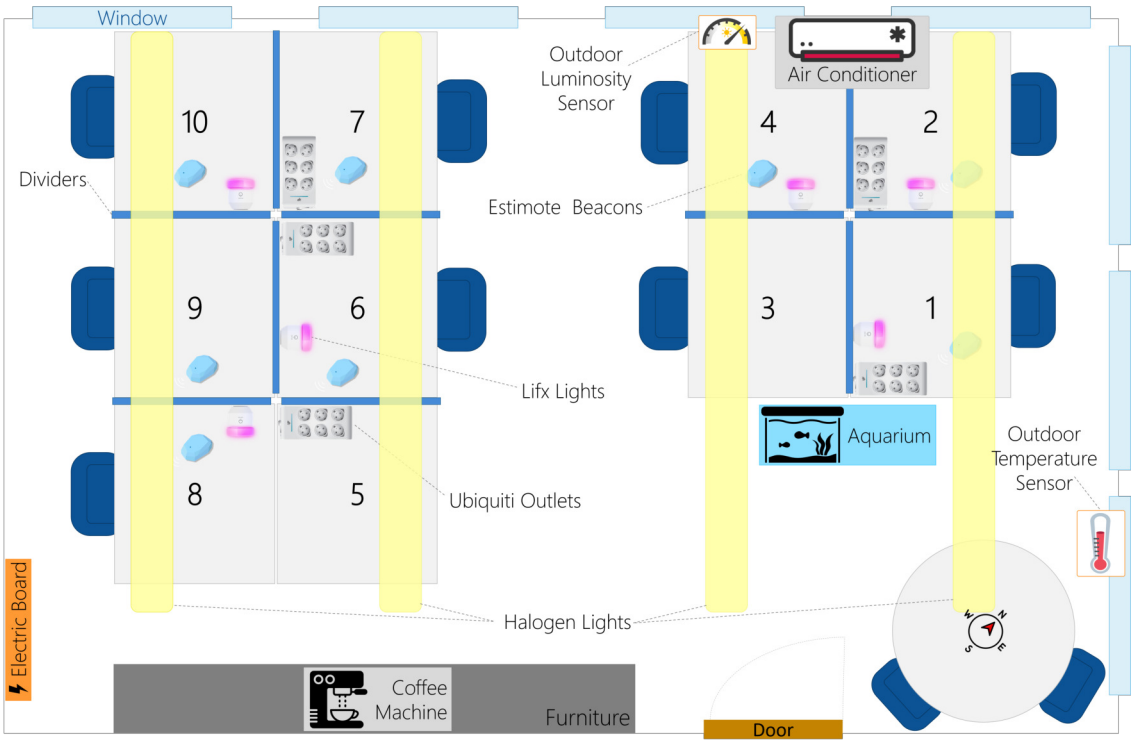


Figure 4.1: Layout of the SmartLab.

only needs human assistance if any of the components fail or if the water of the tank needs to be changed or the feeder needs to be refilled.

4.1.2 Physical Plant

The physical plant is composed of components that interact and are affected by changes of room state. In this case we have the humans, their presence alters the temperature of the room and energy consumptions; the structural elements that have their own properties, we have the furniture, doors and windows; and finally the fish tank that has its own environment, detailed above, and it is affected by the room conditions.

4.1.3 Sensors

There are several types of sensors installed in the SmartLab, they are responsible for collecting information about the room environment and outside conditions. We have Estimote beacons[2] that measure temperature, light and location inside the room, power sockets which allow to measure the power consumption of the outlet, outdoors luminosity and temperature sensors which measure said attributes of the atmosphere, and Microsoft Kinect[3] device that tracks movement.

[2] https://estimote.com/
[3] https://support.xbox.com/en-US/xbox-one/accessories/kinect-sensor-info

4.1.4 Actuators

In order to change the system's state we need actuators, in the room we have: an air conditioner unit, responsible for the climate settings of the room; a coffee machine that provides beverages for the inhabitants; the power sockets offer energy to the residents; the Lifx lights that can be turned on or off and have different properties, such as colour and intensity; and, the ceiling halogen lights which can turn on and off the light for the whole room.

4.1.5 Control

The unit responsible for analysing the data coming from the sensors and triggering the corresponding actions through an API, in this case, the unit is a computer. In order to enable communication between the devices, every device has an IP address.

4.2 Occupants' Assessment

In order to create a good and appealing system for the SmartLab, we need to understand its environment and occupants, who are in this case the target audience. To do the occupants' profile, we made a questionnaire, available in the Appendix A, that can be divided into three parts. The first one, asks them about their habits and preferred workplaces, reasons why they like to work from home and what could be done to improve the SmartLab. In the second part, we assess their opinion about group dynamics and knowledge about gamification. Also, if they knew the concept and liked gamified applications, and which elements were more important to them. The final section talks about the possible outcomes of a gamified system and asks for implementation suggestions.

The form was an important step to our system, considering that our solution has to contemplate the behaviour of end-users. The process provided a deep understanding of their knowledge of the theme, personal drives, opinions, and availability.

The form was accessible to all SmartLab users, including professors. At the end of the experience, we had in total ten responses, which we will analyse through this section.

Around 40% of the studied population works on their academic assignments full-time, and their favourite places to work are at home and at the laboratory, spending more days at the latter. Other places were mentioned, like the library, but in a less frequent manner. Home is somewhat a preferred option since it does not require for the occupant to go to another place, people can multi-task and focus better.

When asked about improvements for the SmartLab, the main requests focused on comfortable office furniture, better climate control and accessible switches, and a revision to the network circuits.

Concerning group dynamics, everyone finds it beneficial, at least in certain situations. The majority of the subjects usually discuss their work with colleagues from the laboratory, however, around 30% does not share this habit.

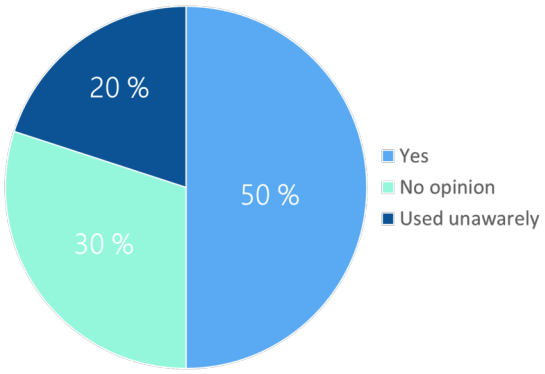


Figure 4.2: Users' enjoyment of gamified systems.

Regarding gamification, we learned that half of the population either had no opinion or were not aware of having used a gamified system before (Figure 4.2). The remaining answers were positive, with interaction, fun and rewards being the main reasons for attraction. Next, we enumerated characteristics from gamified system and as we can observe in Figure 4.3 , the most appealing were performance feedback, social interaction between users and earning rewards.

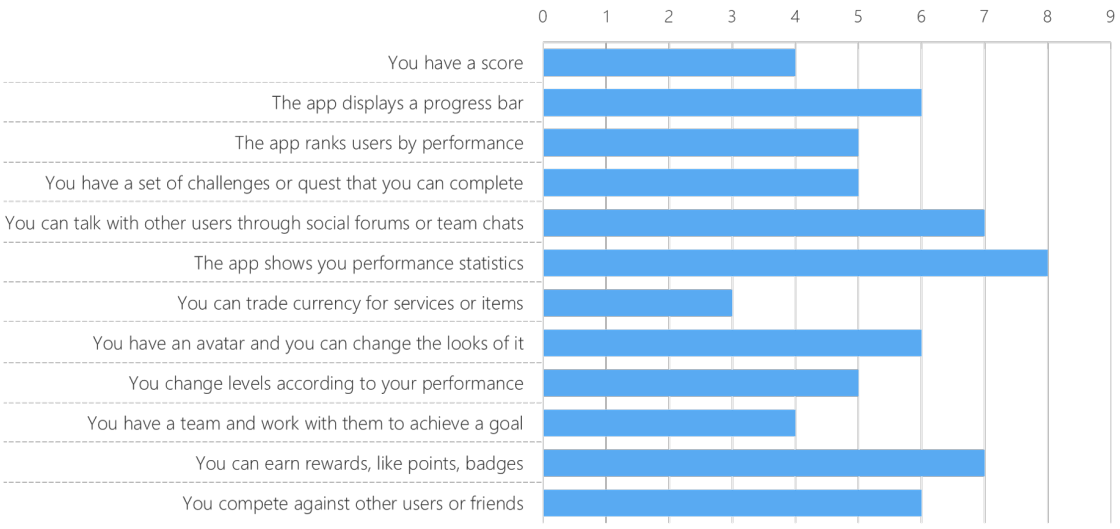


Figure 4.3: Game characteristics that the residents find interesting.

Looking at Figure 4.4, we can see that StackOverflow [4], LinkedIn [5], TripAdvisor [6] and Waze[7] are popular systems. They provide answers to a variety of questions, ways to create a network of people, user reviews and suggestions, and community supported in real time traffic information, respectively. They also show some interest in systems that offer a social and supportive experience. Loyalty programs do not overexcite our subjects.

[4] https://stackoverflow.com/
[5] https://www.linkedin.com/
[6] https://www.tripadvisor.com/
[7] https://www.waze.com/pt-PT/

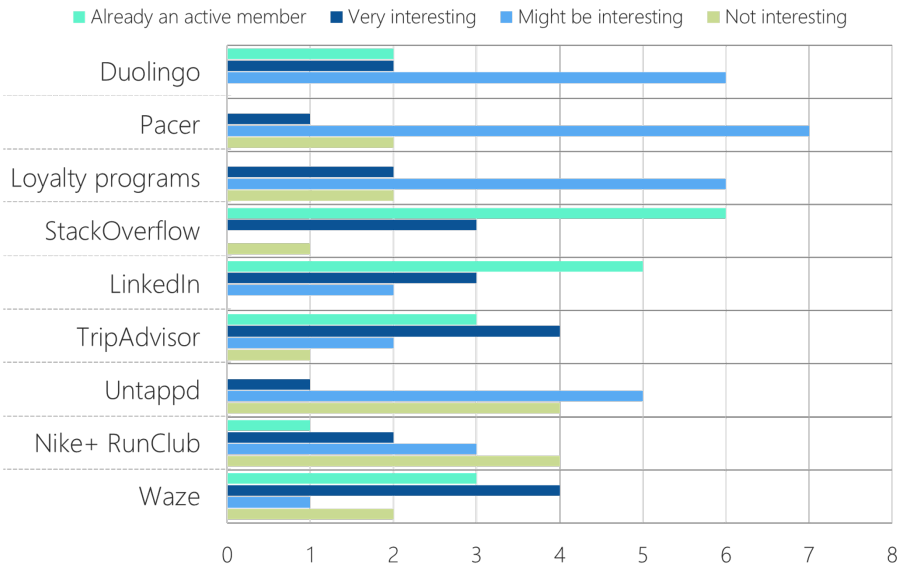
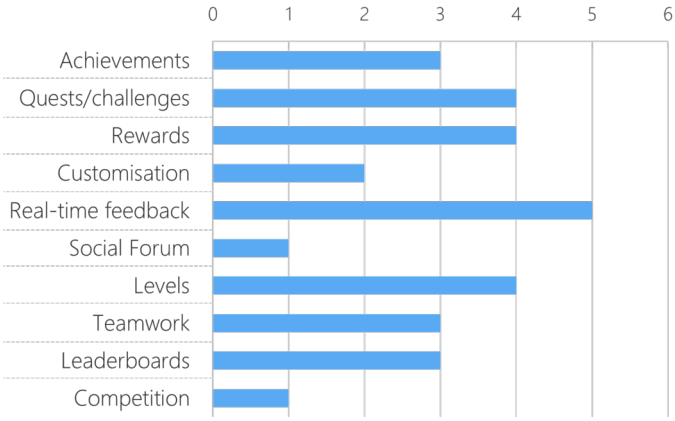


Figure 4.4: Examples of gamified systems for users to classify.

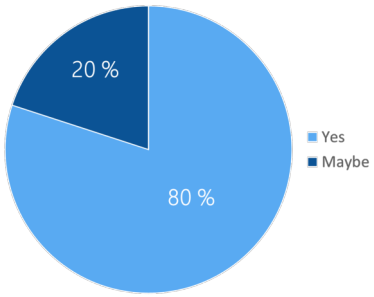
The subjects prefer systems that provide real-time feedback. Rewards, missions like quests and challenges, and placement according to performance were also important components, as depicted in Figure 4.5a.

The entire population knows the importance of managing energy efficiency and the majority believes that a gamified system is capable of executing the task. These results can be verified in Figure 4.5b. Given that our solution would be used by the subjects of this study, we asked them what ideas would they implement if they had to build such a system. They suggested a system that aims to monitor energy efficiency, rewarding the users with points or penalties according to performance and placing the subjects in leaderboards, avatars were also mentioned. However, when asked if the implementation of a gamified system would be a good idea and if it would change occupancy habits, they said it would be a favourable modification if that meant improved equipment and tempting rewards. When asked which rewards they would prefer to have, the majority of the subjects chose the gift card, the following option was a donation in their name to a charity. The least favourite rewards were titles and trophies.

From the previous analysis, we conclude that our subjects enjoy working at the Smart-Lab but have some complaints regarding the conditions of the given space. They are aware of the energy costs linked to BAS and are willing to use a system that aims to reduce these expenses. The majority is familiarized with gamified systems and use several of the kind. Feedback is a relevant component to them, the possibility of getting a real-time report on their performance is extremely appealing. Gaining rewards for the work executed is also important, as well as the ability to compare personal results to the rest of the community, which can be translated in a stimulus to self-improve and a bit of healthy competition. Another important element were rewards. We can also conclude that they appreciate teamwork and find it helpful for the most part.



(a) Important game elements for the users.



(b) Users' opinion about a gamified system contributing to a more planet-friendly laboratory.

Table 4.1: The conclusion drawn from the occupants' responses.

Conclusions
The subjects enjoy working at the SmartLab.
The population is aware of the energy costs and is willing to reduce them.
The individuals use gamified systems and enjoy them.
The subjects value real-time feedback, rewards and competition.
The entire population is receptive to new ideas and is willing to participate

4.3 Summary

In this chapter, we described the SmartLab and all of its components. We also studied our audience and analysed their wishes and opinions. The performed study helped us establish the basic gamification strategies for the system, which we will detail in the next chapter.

Chapter 5

Conceptualisation and Implementation

Based on the discoveries discussed in the previous chapters, we designed and implemented our solution, LabRats. In the upcoming sections, we will describe our system, state the concept behind it, as well as its goals. Additionally, we will detail all the pieces that are part of it and the basic game rules that the users have to follow.

5.1 LabRats Concept

With today's technological evolution, we are have to having devices monitoring our daily routine, to communicate, and to facilitate our life. Given the technology immersion, more and more, we can already expect that a typical user of building automation will demand intelligent behavior: when we enter a building, we want it to be prepared for our presence and customized to our preferences. Potentially the occupant does not want to worry about her or his impact in the space and might not even have the patience nor the time to constantly adjust the settings to her or his preferences. Either the environment is capable of offering our optimal conditions and manage itself, or the occupant just goes on with our work with the available ambience. The great majority of the buildings we have nowadays have been built before this digital era, so they are not fully suitable for this new type of technology that besides benefiting our experience, may also lead to significant energy savings.

Therefore, we need to have means and technology to adapt the existing buildings, to increase our awareness of the involving environment and potentially bring both the space and the users together in an advantageous way for all parts. To achieve that, it might imply to know the limitations of a infrastructure, to design a well thought-out system that, jointly with a set of smart devices, can provide us with both the conditions and desired information, run smoothly and request sporadic intervention from its occupants.

The current occupants concerns fall into the goals of energy consumption and optimal work conditions. However, the previous stated issues may not hold the same relevance for all individuals, so we need to add a new element to the system to increase reliability and engagement.

From this necessity we created LabRats, our gamified application that connects the occupants with the system and aims to increase participation, energy savings and awareness while making it fun, captivating and enjoyable. Another goal of our work was to encourage teamwork within the shared space, we believe this buddy-system enables the possibility of achieving better results, whether be at individual or group level. We want the users to feel engaged, committed to the play and consequently the solution's main goals. Also to work with each other and discuss strategies, creating a stronger group dynamic. Additionally, we want them to embrace better, greener, healthier habits and to start seeking out places that can offer appropriate settings, even if it means they will have to do a little extra work. Our goals are fitted to our case study, a BAS in a retrofitting environment that has energy costs associated with it and hosts a group of active occupants, and supported by the previously discussed results.

LabRats allows its users to interact with the SmartLab changing its state, to know their indoor and the outdoor conditions at any given moment, as well as how much energy their devices consume. If the occupants spot an unused consuming device, they can warn the system. They will also be able to enter a variety of challenges and perform requests for the system, which will later on dictate their placing in a weekly and overall ranking score board. Furthermore, the system alerts you to stretch and provides a more convenient way to turn on and off appliances, such as lights and air conditioners.

During the phase of conceptualization, we also looked into the possibility of implementing a betting system or privilege cards, but upon further reflection, we concluded both ideas would not be viable. The betting system was intended to introduce real money into the logic to create some real-world rewards, but because it required real money and the participation of all residents to be fair, we set the idea aside. The card program intended to be another engaging element, where players would either win or trade points for cards and then use them in their favour against the other players. Cards like "You choose the AC temperature"and "The person who receives this card will only have energy for five hours". Unfortunately, this idea had potential to ruin players stay at the laboratory and consequently drive them away, with the system losing participants.

5.2 LabRats Game Logic

To create the game logic for LabRats we looked into the previously mentioned frameworks and the responses of the users to our initial questionnaire. We designed a point based system that presents several opportunities for the user to be rewarded. It also presents information about various aspects of the SmartLab, such as indoor and outdoor conditions, and places the users in a rank according to their score. We believe these

elements enable some motivational competition, boosting the desire to self-improve and bringing awareness to the setting.

5.2.1 Points

There are a few ways to win points in LabRats. Points can be earned by performing tasks, completing challenges or by creating warnings for the system. Each task and each challenge has an associated number of points. If the individuals execute the requested task, they will earn the compensation. In the case of the challenges, if completed then the earnings will be added. However, if there is a significant improvement the participants will win 10% of the challenge value. Players can also win daily compensation in group challenges. These last two measures were implemented to motivate the occupants and compensate their efforts.

Regarding penalties, there are two situations where points can be deducted: whenever the user forgets to check-in when coming in the SmartLab and when there is a warning about unnecessary devices left on. We believe that having their score at risk, in certain circumstances, can create a lasting impression since we are threatening their assets.

5.2.2 Challenges

Challenges are missions that the players can do to win points. Every challenge is open for a fixed period of time in which the user can join. Every challenge has a duration, so when the time ends and if the goals are met the players will receive the respective compensation. There are two types of challenges, individual and group. The first type will only involve the player and their behaviour, the latter will need the participation of all or a specific group of the occupants of the room.

5.2.2.1 Individual Dynamic

This type of challenge involves the performance of one player. If the challenge is completed, the player will be rewarded with points. Otherwise, the points property will not be altered. Here are some examples of challenges that may appear to the user:

- Arrive at the same time interval for the rest of the week;
- Switch off the coffee machine after using it.

5.2.2.2 Group Dynamic

Group challenges require the effort of everyone, they have to work as a team to reach the final goal. If the challenge is completed the participants will receive a compensation. Otherwise, no benefits are added. Some examples of this component may be:

- Turn of all of the unused devices;

- Minimize the night-time consumption.

Some challenge goals may not be reached. Nevertheless, if there is an improvement in the results, we believe it is important to acknowledge the effort. In order to do so, we will give a percentage of the expected reward.

5.2.3 Tasks

Since the SmartLab is not fully automated, various actions must be performed by the users. As an example, when opening a window is required, the system must enlist the help of the occupants.

Whenever a certain condition is met, the system triggers a task and sends a request to all the present users, the Lifx lights come on green and the individuals that perform the task win a certain amount of points, the rest of the users might win some compensation as well. This rule was designed to keep the point attribution fair and to encourage communication, since some subjects might be closer to the elements in question, this way they can all win something or they can discuss amongst them who will perform the task. If the subjects do not want to perform said task, they will have to provide a reason for it (e.g.: light reflection causes vision problems). In Figure 5.13 is depicted the creation of a system task regarding light.

When designing our game logic we had to take into account the consequences of overloading our occupants with requests [44, 45]. We do not want them to enter a decision fatigue state, in which a person's judgment may lead to poor choices and deteriorate their mood, after being requested to make decisions over a long period. In case the occupant considers the system to be too demanding, they might not fulfil requests and stop working at the SmartLab, therefore compromising the goals of the system. To counter that effect, we tried to not overwhelm them with tasks, only making requests when needed. As an example: if there is only one person in the SmartLab and the system already asked them to open the blinds, however, their light level did not rise to the desired values, the system waits around 30 minutes to ask again, if nothing changes. Also, all of the tasks are direct requests such as: open the windows, blinds or Kinect related (explained below), users do not have to decide what type of action should be triggered given some information, they only need to decide whether they want to do it or not and let the system know.

5.2.3.1 Kinect Task

There is one kind of task that is not a requirement from the system, but it appears to the user as one. The Kinect tasks were idealized as a reminder for the players to stretch and move away from their working space every two hours of being sited. The task requires the users to go to a marked spot near the door, there is a monitor that has an interface with all the workstations, the users have to choose their workstation and then the camera view will appear. The user's task is to raise their arms above their heads three

times, when its done the screen will display a thank you message and return to the initial display.

5.2.4 Warnings

Warnings are alerts the players can give to the system about unnecessary consuming devices. Whenever a colleague leaves an unused device on, if the player believes the person in question will not come back to switch the appliance off, they can create an alert. After receiving the warning, the system will analyse the situation and it can turn off the device. If the warning was a false claim, points will be deducted from the "warner", if not a specific quantity of points will be traded between the two parts involved.

5.2.5 Feedback

Participants have feedback about several components of the environment, they have in-real-time information regarding the outdoor and indoor conditions. They can verify the temperature and luminosity of their workstation space and the outside. The power consumed by their devices is also on display with the appliance discriminated, their challenge statistics are also displayed, differentiating between available, joined, successful. Their current score is also feature.

5.2.5.1 Ranking

There are two ranking in LabRats, the overall ranking and the weekly ranking, which place all the participants according to their score. The weekly ranking resets at the end of the week, as do their scores.

5.3 LabRats Application

The LabRats application, available through a web browser, allows its users to have a personal area and interact with the system, compete with the other occupants, know which devices are assigned to their workstations and verify the overall conditions of the room. Besides the occupants accounts, there is also an administrator, that is responsible for adding new devices, create challenges and define tasks. In the following subsections we will provide a guide of the application for the two different roles. Figure 5.1 illustrates all possible use cases within the application.

5.3.1 Occupant Version

In order to have access to their personal area, the occupants must be registered in the LabRats system. On the registration page, the occupant's name, email and workstation number are requested, as well as a password. If they already have created an account,

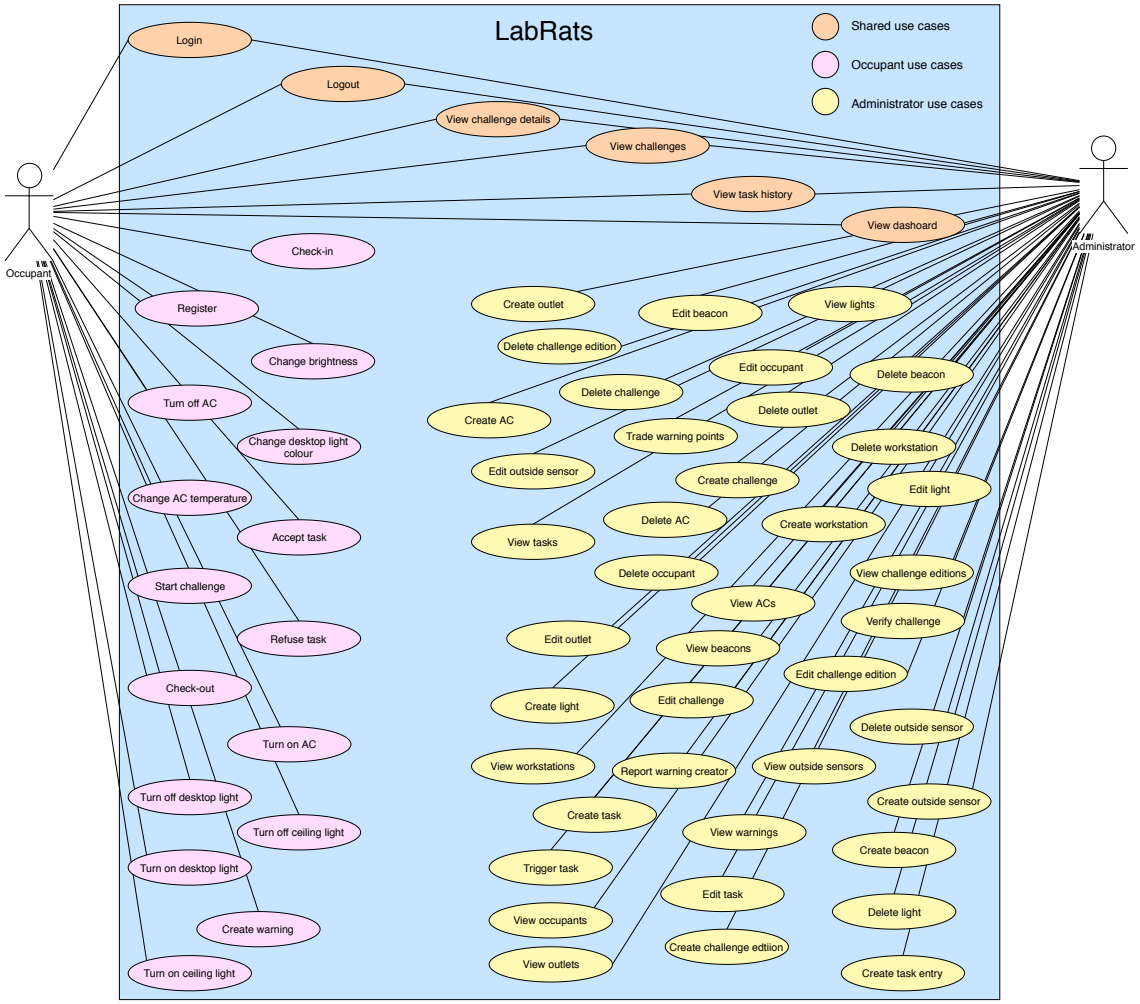


Figure 5.1: LabRats use case diagram.

they must simply login with the credentials, email and password. After submitting the valid information, the user enters their personal area, in both scenarios.

Independently of the page the logged user is on, the left sidebar is always on display, this element presents some basic information about the user, such as the name and the collected points, and also provides a navigation menu and two buttons, the logout button and the presence button. The first button ends the user session and the second serves as a partial presence verification method, when the occupants arrive or leave the SmartLab, other than for a bathroom break, they click the button as a confirmation of the arrival/departure which will save the current timestamp in our database. The text displayed on the button changes according to the expected action, for example when the occupant arrives at the SmartLab in the morning, the text displayed says "I've arrived", when the user clicks on it the arriving time is saved and the text changes to "I'm leaving"(Figure 5.2). The system needs to know when the occupant is present in the room, to do so it relies on a double confirmation method, it checks the state of the occupant's sockets and the presence button timestamps. This way even if the user left the computer on, we are able

to know if they indeed left de room.

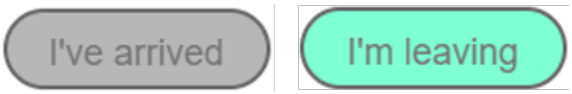


Figure 5.2: The presence button, to check if the occupant is in the room or not.

The navigation menu presents several options to the user, which are the following:

5.3.1.1 Home

Home is the default page for logged users, they are able to view details about their workstation and their overall performance, and also check the conditions of the room and from outside, such as temperature and luminosity level (Figure 5.3). Since the power strips are shared between workstations, this page shows which sockets belong to the workstation and the corresponding devices, and also which row is directly above the space, in case the user wants to turn on the lights. They can also check how much power their devices are consuming and their challenge statistics, how many challenges are available, completed successfully and participating in. Additionally, there are two leaderboards with the ranking of the participants overall and of the current week, this way whenever the users log in they will immediately see their position, in this page they can also view the requested tasks from the system and notify the system if they have done it or not.

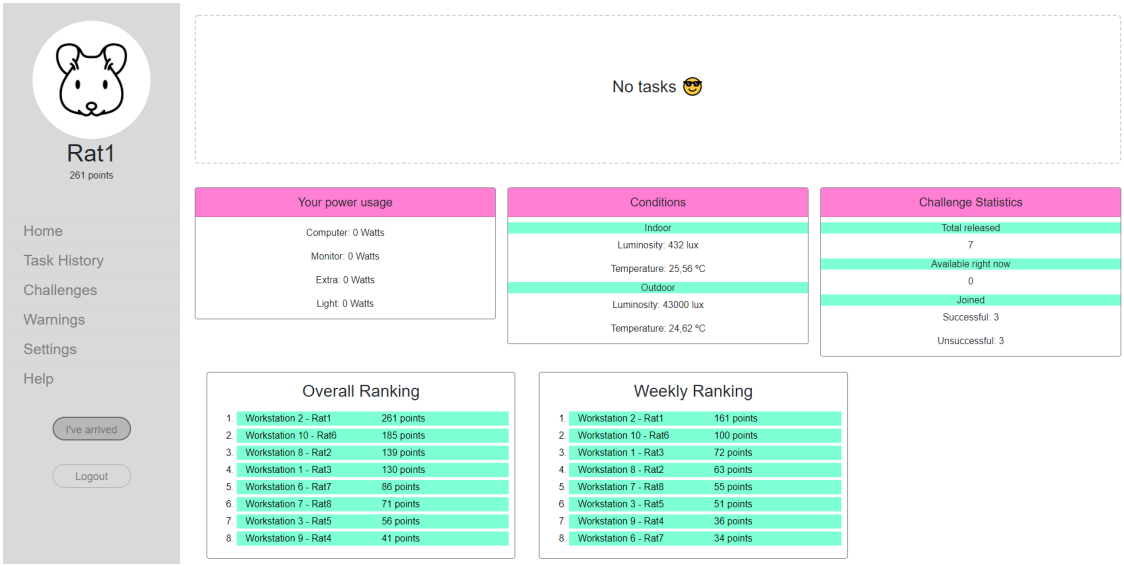


Figure 5.3: Occupant's Home page.

5.3.1.2 Task History

This tab shows the history of all the tasks performed by the user, displayed in Figure 5.4.

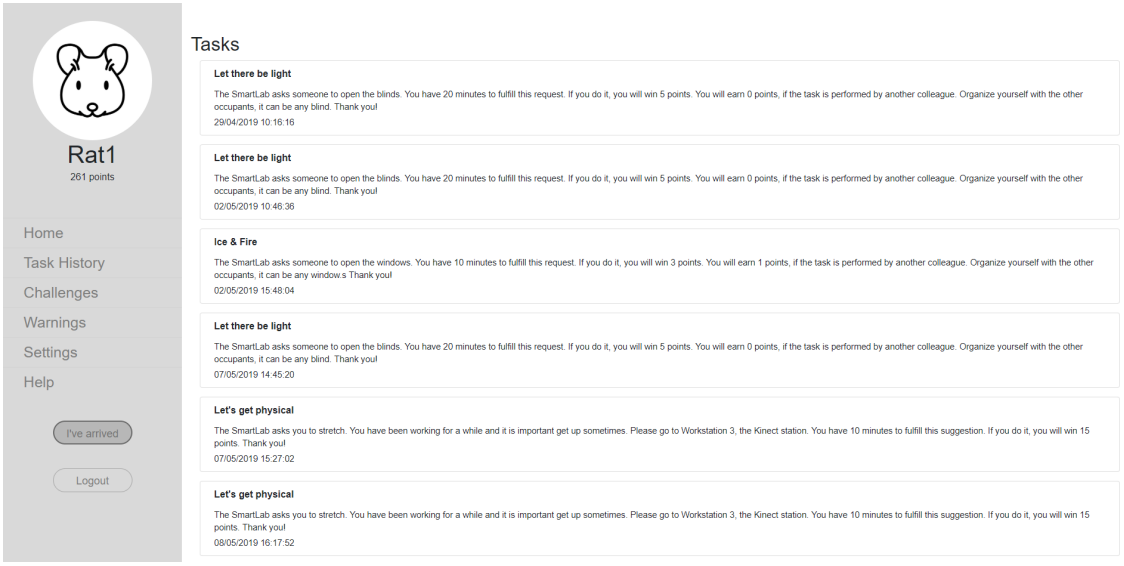


Figure 5.4: Occupant's task history page.

5.3.1.3 Challenges

In this page, depicted in Figure 5.5, a quick view of all the occupant's challenges is shown, independent of the state phase. The previewed information varies with the phase of the challenge, if it is an upcoming challenge only the release date is shown. The other three phases of challenges (available, in progress and completed) have the same basic set of attributes: the name, point earnings, state, plus a specific detail each. The available shows the last day to join the challenge and duration, in progress ones display the days left to end the mission and finally, the completed has the start and end dates.

Apart from future challenges, which are only shown for the purpose of boosting enthusiasm, all the others are clickable, this action shows the specific challenge page, as shown in Figure 5.6. The user is able to see all the information, such as: name, description, release dates, state, points, duration, start and end dates if applicable. Besides these attributes, if it is a group challenge the name of the other participants will show, this way they can communicate and join forces to complete the mission. If the user has not joined the challenge, a button to join is displayed.

5.3.1.4 Warnings

In the Warnings page (Figure 5.7), there is a guide for the user to follow to know if a warning should be created, and a form to complete. The form requests the workstation number and the device type that was left on. Once those are filled the user can submit.

5.3.1.5 Settings

This page allows the players to change the light and temperature settings, turning on or off the ceiling, desktop lights and the air conditioner. It also displays the current

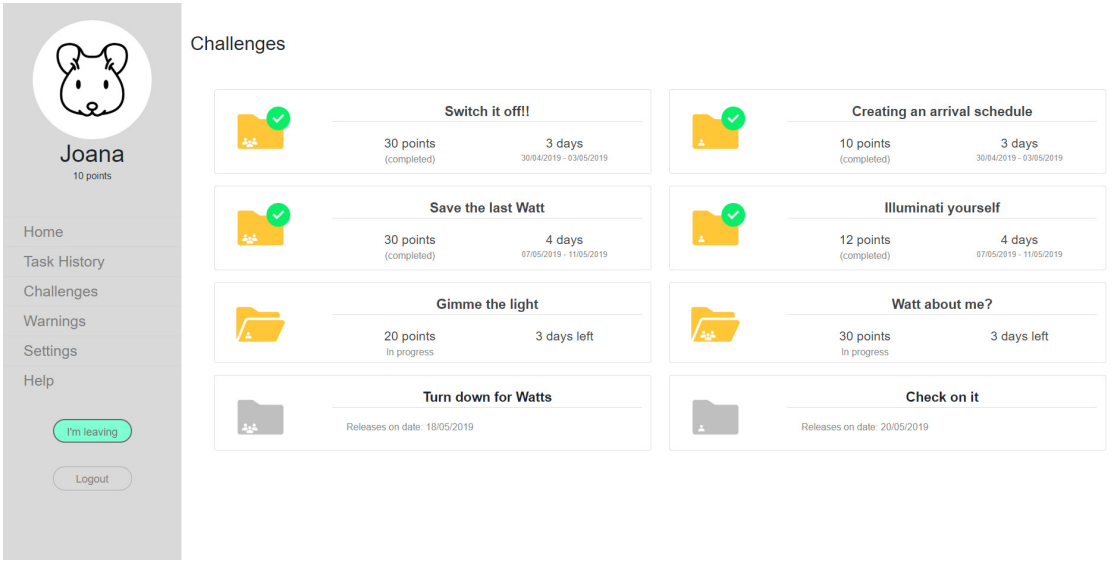


Figure 5.5: Occupant's Challenges page.

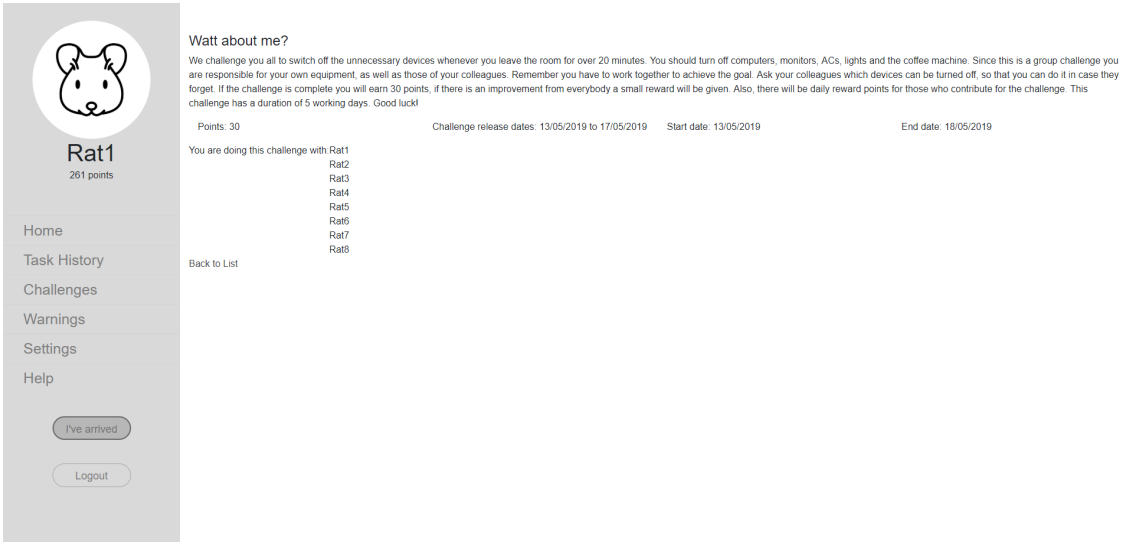


Figure 5.6: Occupant's challenge Details page.

brightness of the desktop light, which can be altered if the user desires it, as depicted in Figure 5.8.

5.3.1.6 Help

An easy guide for the users, it offers an overview of the system functionalities and the overall rules, displayed in Figure 5.9.

5.3.2 Administrator Version

Like all systems, ours also needs an administrator, someone that deals with sensitive information, manages the SmartLab components, and also ensures and adjusts the game

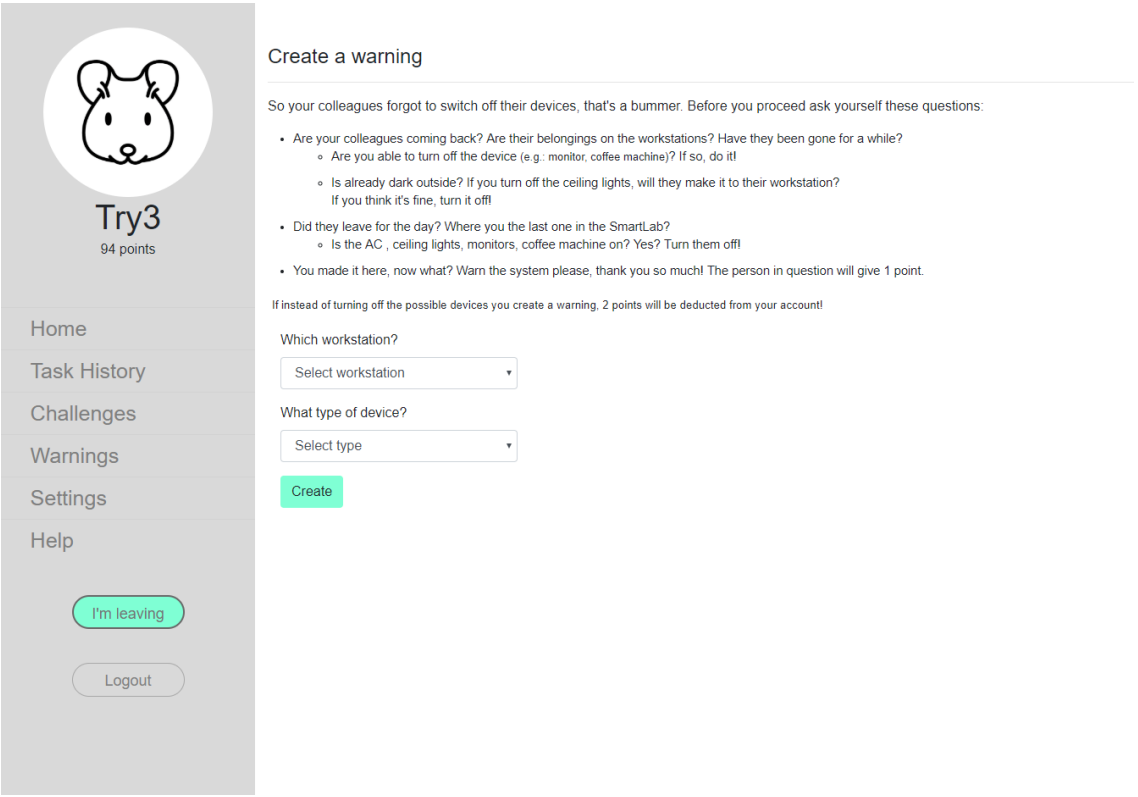


Figure 5.7: Occupant's Warnings page.

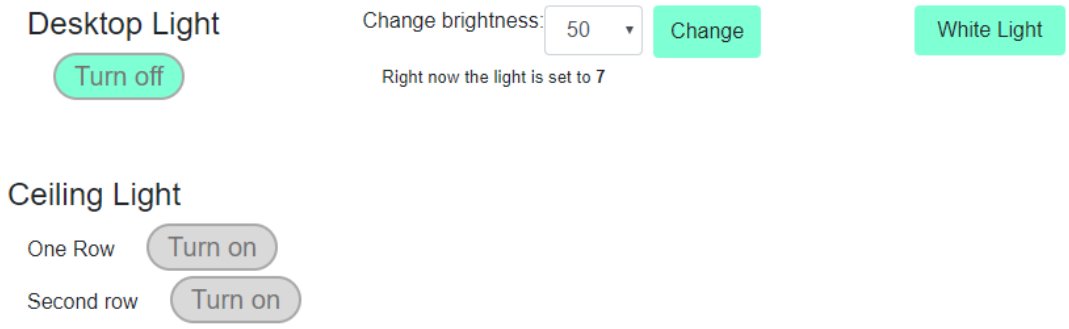


Figure 5.8: Light settings on Occupant's Settings page.

logic if necessary. The administrator credentials are already defined in the system, whenever the administrator logs in the homepage will be displayed. Just like the occupant's version, on the left there is a sidebar with a navigation menu, and in this case a logout button. The administrator is the only user that can insert, edit or delete devices, challenges and tasks. Similar to the occupant's version, this role also displays the sidebar the log out button and the following menu options:

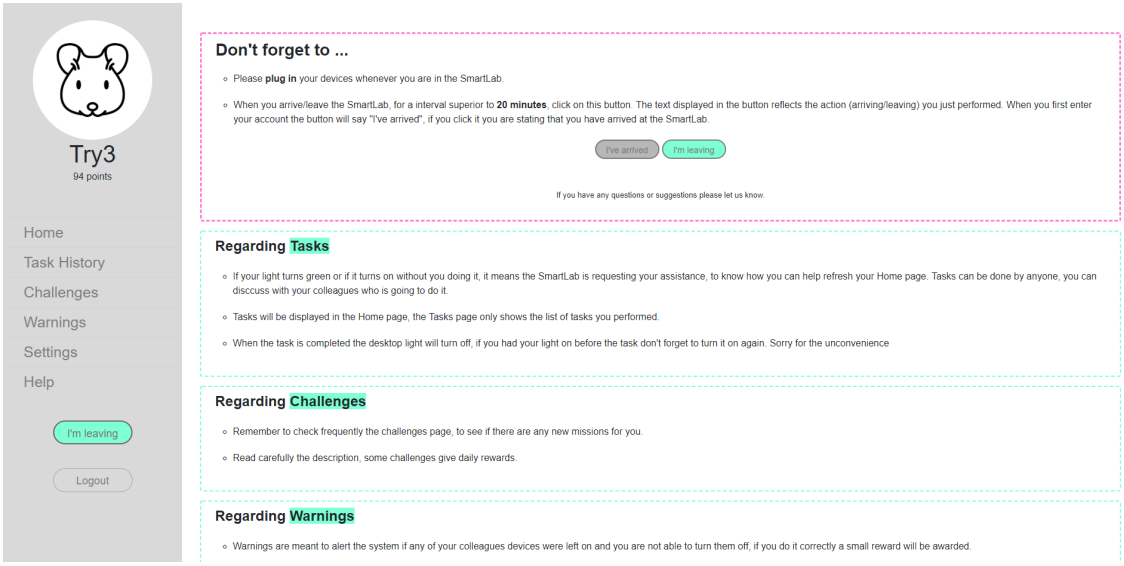


Figure 5.9: Occupant's Help page.

5.3.2.1 Home

Offers a quick overview of the system's composition, it lists all the workstations with the respective devices (sockets, lights), current consumption and occupant's information, as shown in Figure 5.10. It also displays the indoor and outdoor temperature and luminosity values. If the workstation is not occupied then it will say available. In this page, both of the rankings are also shown.

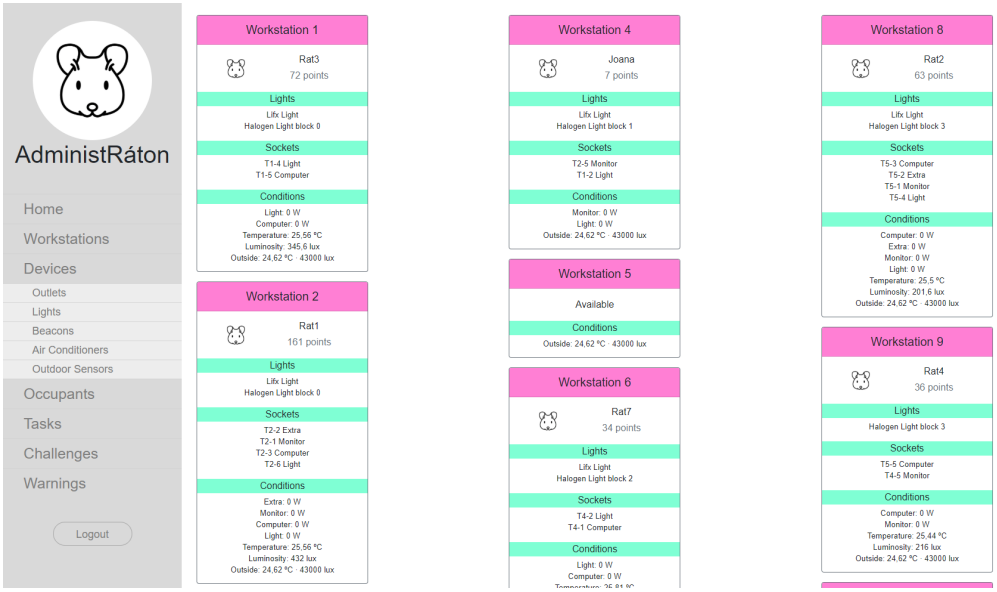


Figure 5.10: Administrator's Home page.

5.3.2.2 Workstations

This page shows an index of all the existing workstations in the SmartLab, plus states if it is occupied. It also allows to create a new workstation and in each row of the list there are two options: details and delete. The Details page shows the devices that belong to the workstation, outlets and lights, and the occupant's information (name, points and email). Options to add or remove devices and clear occupant. If we click delete, the workstation will be removed from the system.

5.3.2.3 Outlets

The outlets page displays all the electric sockets, specifying their outlet block, socket number, the device connected to it and to which workstation does it belong. The administrator can create new entries, in case a new outlet is added or a socket gains purpose, and can also edit the socket's device and/or workstation, if it changes. To create a new socket, the administrator must insert the unique identifier, block and number of the socket, the device that is going to be connected and to which workstation corresponds.

5.3.2.4 Lights

In this page (Figure 5.11), the administrator can add a new light by clicking on the link and check two lists, one for Lifx lights and the other for the halogen ceiling lights. To create a new light the type of light must be specified, if it is an halogen light, an identifier, row and number must be inserted; in the case of being a Lifx light, an identifier and the workstation number to which it belongs to is required. Once submitted, the page returns to the indexes. As stated in the previous chapter, a row of halogen lights have a specific identifier and are directly above a set of workstations, in the ceiling lights list besides the type of the light and the number block, there is also a field that states which workstations are under the light. The list of desktop lights presents the type of light once again and in which workstation is the light on, the administrator can also edit this last field.

5.3.2.5 Beacons

The beacons page is very simple it lists all the beacons with the associate workstations number, which the administrator can change in the edit option. The administrator can also create a new one, edit or delete a beacon.

5.3.2.6 Air Conditioners

This is the page where all the the air conditions available are listed, a new entry can be created or deleted.

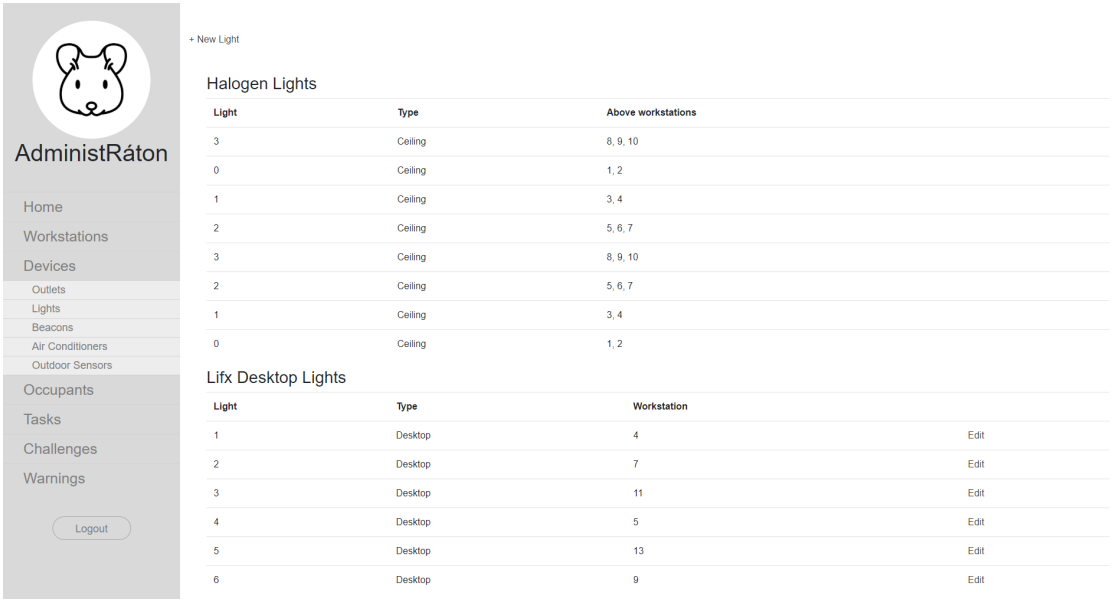


Figure 5.11: Light indexes in the administrator version.

5.3.2.7 Outdoor Sensors

All the outdoor sensors are listed in this page, stating what environmental element they measure. If there is a new device to add, the administrator can create a new sensor by inputting the unique identifier and the what does it measure. The sensors can also be edited or deleted.

5.3.2.8 Occupants

Just as the section above, this page lists all the participants of LabRats, by displaying their name, email, points and workstation number (Figure 5.12). The administrator can edit the occupant's points and workstation or delete the user.

5.3.2.9 Tasks

Tasks is the index of all the different kind of tasks that are present in the system. It displays the name, the feature involved (aquarium, luminosity, electricity, temperature and health), followed by the number of points the doer of the tasks and the rest of the occupants earn. The administrator can add new tasks to the system, also view task history, edit details, delete and check the details of a task. When adding a new task (Figure 5.13), the subject it relates too must be specified since available task options vary. Some of the input fields can be updated by the administrator in the edit option. The task is triggered whenever the defined condition is met, which means that one task can be called several times, so the option to view the call history is available, showing the date, state and doers of said task.

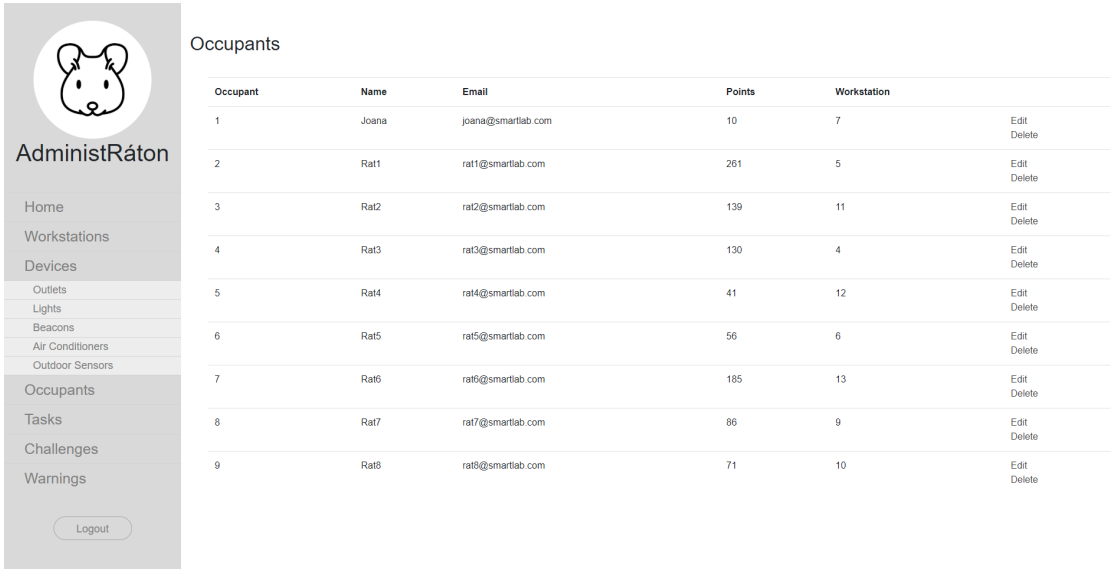


Figure 5.12: Occupant index in the administrator version.

5.3.2.10 Challenges

The next tab has the challenges, once again a new challenge can be created in this page and a list of all the different challenges is shown. Each row is a challenge with a name, a goal, the type (individual, group or all), it displays the number of editions the challenge has had, the mission duration and the points earned once completed. The details option lists all the editions of a challenge and it allows the creation of a new edition, the administrator only has to set the release dates. At the top of the page shows more in detail information of the challenge. Each edition on this list has a field for the release interval, the start and end date of the challenge, its state and the users that participated. If the challenge has not been started by any user, the administrator may change the duration or the points it repays, and can also delete said edition.

5.3.2.11 Warnings

The final option displays all the warnings the occupants created, displaying the time, the creator, the device and workstation in question.

5.4 System Architecture

Our solution can be divided in two parts: the gamified application, LabRats and the already available SmartLab system, as shown in figure 5.14

The LabRats application hosts all the logic behind our system such as: the game logic, requests to the database and to the SmartLab system, and it also offers an interface for the users to interact with, allowing them to check several details regarding the SmartLab

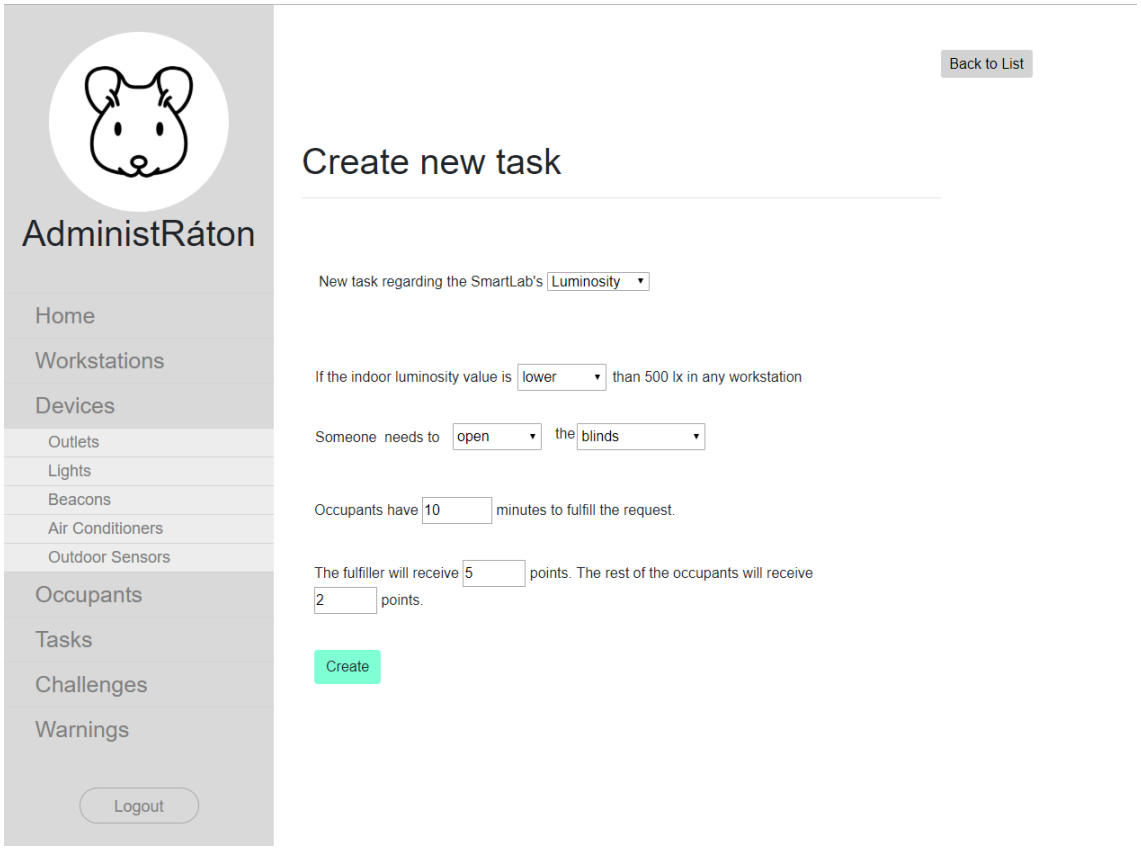


Figure 5.13: Form to create a new system task.

and their progress. Additionally, there is the Kinect module, which has the kinect logic and provides an user interface, that communicates via API with the main application.

The SmartLab system, which is composed by several sensors and actuators, was previously implemented by other SmartLab collaborators, being currently available [23, 43]. They chose to implement an WSO2 IOT server platform[1] that stores data in a MySQL database[2]. For the devices, either the manufacturers provide plugins or such work was developed by the collaborators, this material been deployed previously on the SmartLab. These plugins enable the usage of simple APIs that facilitate the interaction with the devices. As an example, the Lifx lights mentioned previously provide access to methods that allow the individual to change the state or colour of a light.

5.5 Implementation

LabRats is a web application developed in C #, which makes use of the Microsoft MVC .NET framework and a relational database. The tools used were Microsoft Visual Studio, an integrated development environment, SQL Server and SQL Server Management Studio, a database managing system and a graphical user interface program respectively.

[1] Platform that enables management of IoT devices and mobiles for enterprises. https://wso2.com/iot
[2] Database management system. https://www.mysql.com/

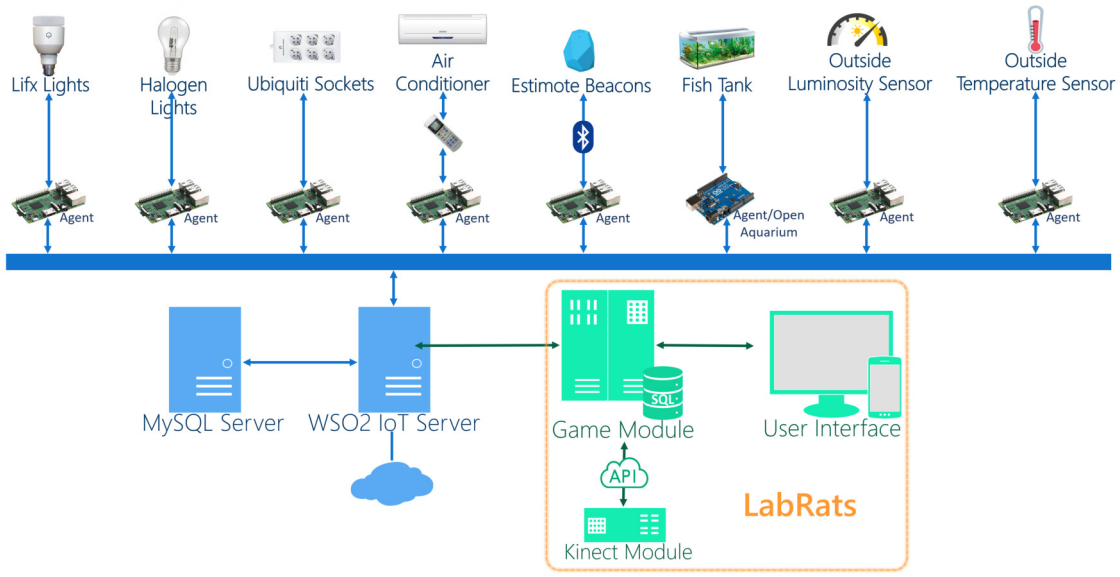


Figure 5.14: The designed system architecture.

Additionally, as mentioned above we work with a Kinect device that tracks movement, this feature is locally implemented in the permanent desktop of the SmartLab. It is a C# application developed in Visual Studio as well. This application provides the logic and user interface for the Kinect tasks, if the task is done correctly it will create a JSON object with the status details and workstation in question, this information is then requested by the LabRats application through an Web API.

As stated, LabRats is an MVC (Model-View-Controller) project, which is an architectural pattern that separates the user interface (View) from the data (Model) and the application logic (Controller). The class diagram is shown in Figure 5.15.

- **Model** – it is an abstraction of an entity of the application;
- **View** – it is what the user sees and interacts with;
- **Controller** – it connects the Model with the View and it is responsible for the application logic and for the communication with the database and the SmartLab's devices;

To better understand the pattern, we will provide the following example: in our application the system administrator can create new challenges, so in our View we have a button that says "Create new challenge", when clicked the create method (type GET) from the Challenges Controller is called and it returns the View to create a new challenge. After the administrator inserts all of the requested information in said View and submits, the create Post method is called. This method receives an object with the filled information and proceeds to create a new object based on the Model that defines a challenge, then it adds a new entry in our Challenge table.

The information regarding our various application elements is stored in a SQL database, from occupants information to all the editions of all the challenges, a schema is depicted in Figure 5.16.

In order to present information regarding overall conditions and allow interaction with the various devices, the application has to communicate with the existing SmartLab system that controls and monitors all the equipment. The system's REST API offers a variety of requests according to the device in question, the application only has to start an HTTP client and place a request to a certain URL, then if all goes well it will receive a JSON response with the data.

In order to better understand the workflow of our solution, we have two examples, the first is the administrator creating a new challenge edition and second explains how the user knows and performs the Kinect tasks.

We will start with the new individual challenge edition (Figure 5.18), the administrator is on the Challenges Index page where all the challenges are listed, the administrator spots the challenge that needs the new edition and click on "Editions". This action will call the Challenges Controller, more specificity the GET method Editions that takes a challenge identifier as a parameter. The Editions page display the name, description and list the existing editions, so the Controller has to ask the Model for this information to proceed, once the Model returns the requested data, the Controller returns the View (Editions). On this page the administrator will click on "New Edition", once again the Controller is called, this time it is the CreateEdition method (GET), to return the respective page the controller must communicate with the Occupants Model to get occupants information to display on the view. After this step the View is return and now the administrator must choose a user for this edition, insert a date stating when will the edition be release and when does it the release period end, then clicks submit. At this point, the CreateEdition POST method is called to add this new entry to the database, when creating the entry, the controller will set the user and release dates by communicating with the ChallengeEdition Model. The controller followed the implementation and know that id done, it will return the Editions View.

The Kinect tasks are triggered every two hours the occupant has been sited, because sometimes people do not check in, the administrator is the one that triggers the tasks, as shown in Figure 5.17. It starts with the administrator with the Task Index View open, spots the task and clicks on Trigger, this will call a POST method with the same name from the TaskEntriesController, there will be communications established with the WSO2 server to change the colour (green) and brightness (maximum) of the respective individual Lifx lamp. The user sees the lamp and opens the app and clicks on refresh, this action will call the GET method from Home Controller to return the the page. In order to do that the Controller needs to request the Task Model for details to proceed, when returned the page is loaded. The user now reads the task, goes to the Kinect mark and chooses their workstation, after the interface will change and the user can proceed to do the requested exercise. The Kinect application tracks the movement and after confirming the

movement was repeat 3 times, shows a thank you message. At this point the user goes on with their routine and the Kinnect application creates a JSON with the exercise details (date, workstation and state) and sends it to the Kinect API, which will then proceed to communicate with the WSO2 to once again change colour (white) and brightness (0) and with the TaskEntry Model to set the date, state and user id , and the Occupant Model to add the points to the user.

We chose to develop a web application since it is accessible from any type of device and it is practical for general use. And since the SmartLab has a permanent desktop computer, there is always a way for the occupants to access the application if they do not have any devices with them. In order to make the application available to the users, we deployed it to Microsoft Azure, a cloud computing service which serves as a hosting platform for our application. To establish communication between the main application and the Kinect program, we also deployed our Web API to Azure, ensuring the availability of the communication between the two components.

5.6 Summary

This is our solution, based on our research we created a system that is suited to the target environment and audience. Next, we will explain our testing phases and discuss the obtained results.

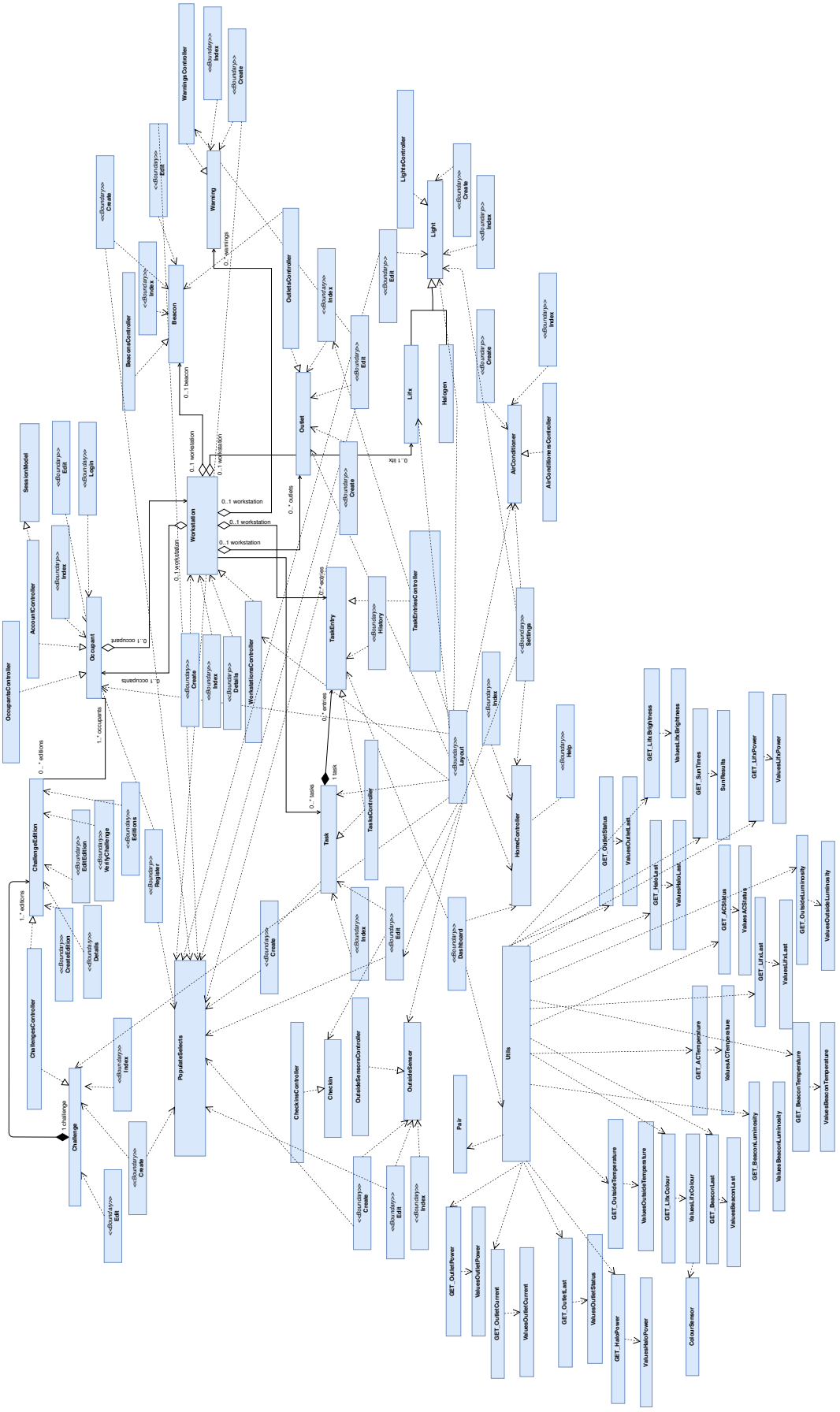


Figure 5.15: LabRats class diagram. The full diagram can be seen in Annex I.

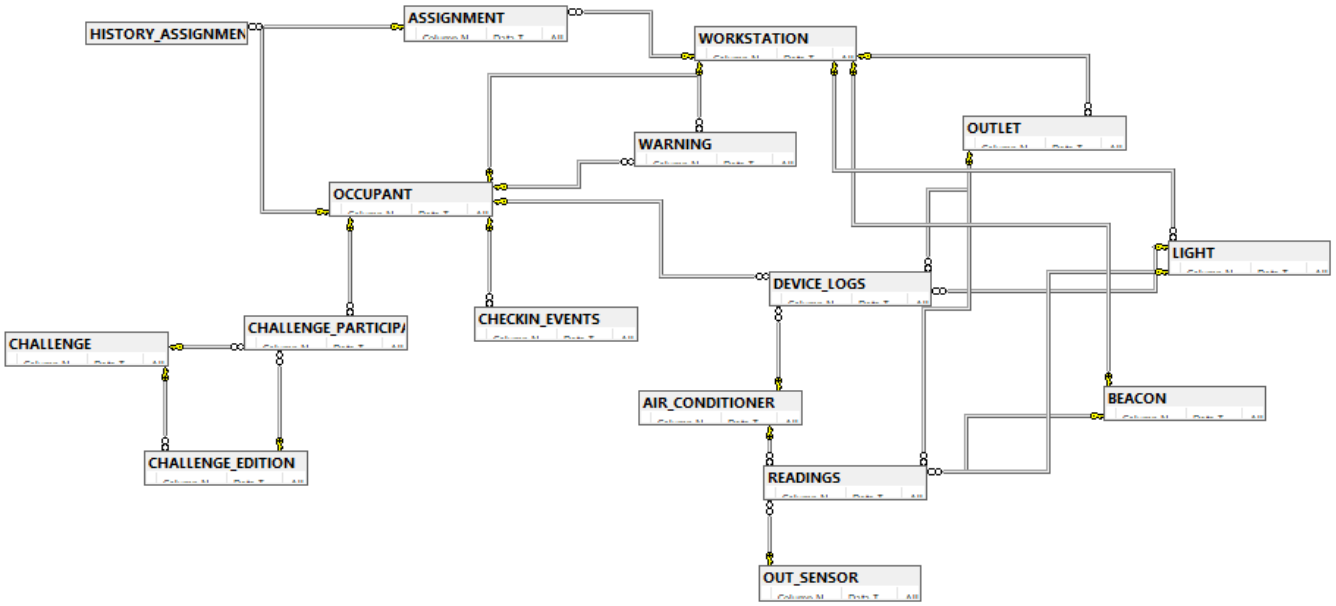


Figure 5.16: Database Diagram.

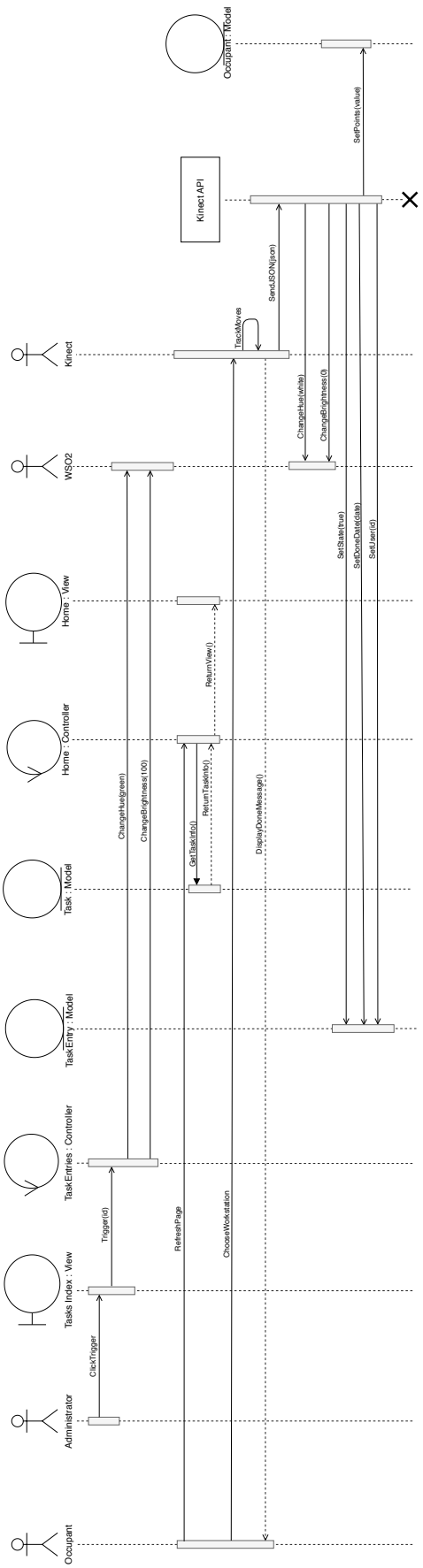


Figure 5.17: Kinect task sequence diagram.

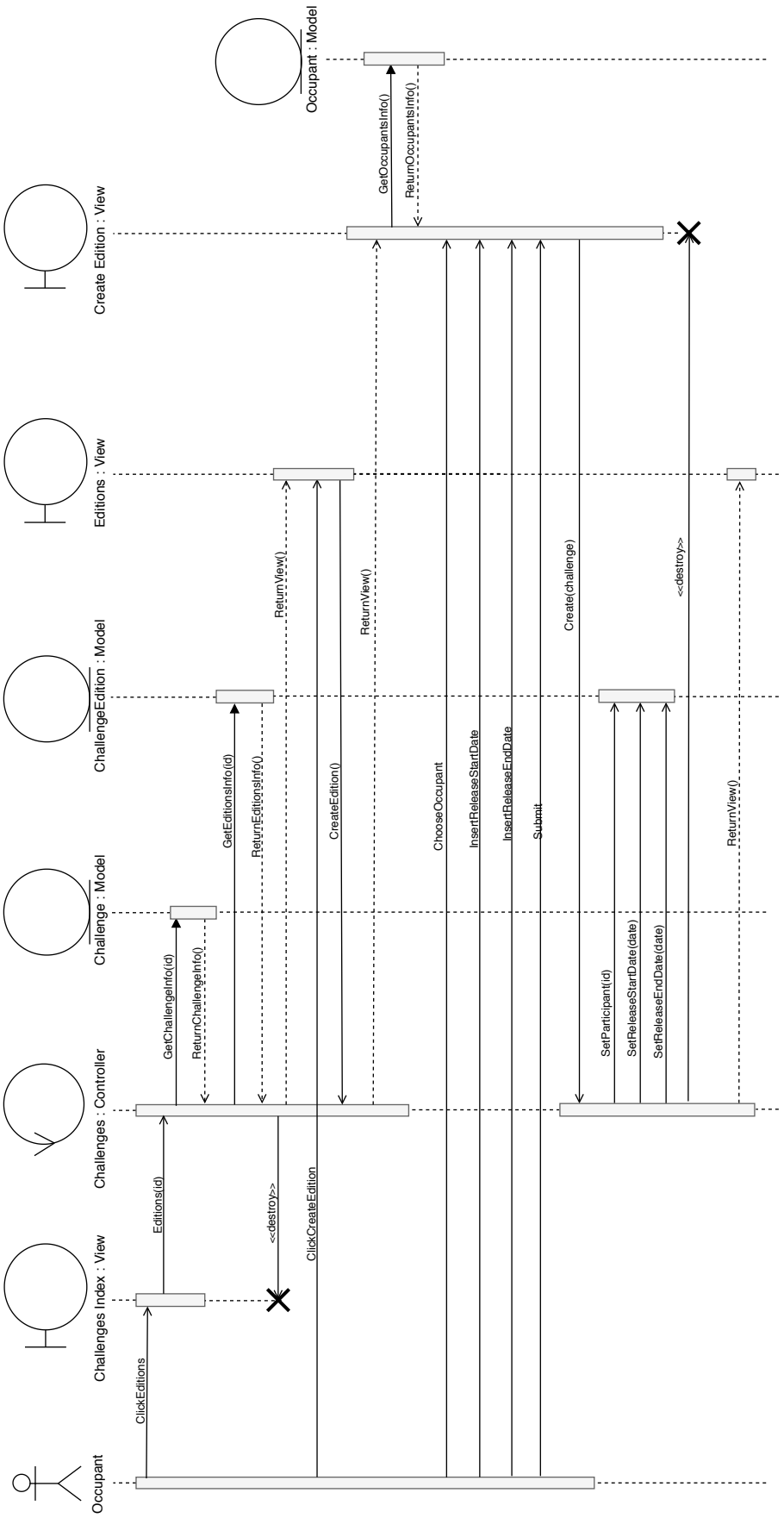


Figure 5.18: New individual challenge edition sequence diagram.

Chapter 6

Evaluation

In these sections we present diverse scenarios, followed by a comparison and discussion of the respective results. We also analyse the feedback given by the occupants after each period.

6.1 Evaluation Notes

In order to corroborate our theory we have to put our solution to the test. We had seven distinctive testing periods, started with basic consumption, so our first period of testing regards the room performance without any occupants. We will then follow with the usual occupant's routine period and a healthy luminosity 500lx period. Next, we have three weeks of LabRats testing, some features change between weeks, and finally the aftermath of LabRats week. The occupants were requested to answer a questionnaire, after certain periods, in which we evaluate their comfort and study their suggestions. During our testing phases we acquired data regarding the overall room and socket consumption, indoor and outdoor luminosity and temperature conditions, we also have data regarding the participation.

Ideally, all the test phases would be the same length and have similar atmospheric conditions, as well as the same number of people, this way we could recognize more clearly points of interest and establish a relation between meaningful elements. However, it is not possible to maintain all the variables constant, we can not control the weather nor the occupants availability. Therefore, LabRats testing phases will present data from a superior number of days. Also, we are only presenting data relatively to work days, as mentioned above our occupants are students that do not have strict schedules and have no obligation to be present.

We will analyse the performance of all occupants of the SmartLab, however for some testing periods, such as basic consumption, routine and 500lx, we will only focus in three

different workstations, to us they are the most interesting data wise. Workstation 1 catches all the incident light beams; Workstation 2 is in the corner of the room, surrounded by windows and Workstation 8 is on the opposite corner, with furniture and no windows around (Figure 4.1). During all cycles, we gathered data from the indoor devices, as well as the outdoor sensor regarding light and temperature, to examine the impact of the atmospheric conditions on the indoor environment.

It is also important to state that these are Computer Science students, so they spend majority of their time working on their computers. In terms of consumption, only using the browser and writing a thesis will use less energy than someone who is writing code and compiling programs, also power intake varies according to the device hardware. Not all of them have the same availability to be at the SmartLab, since they have classes, projects to do and jobs outside the university.

6.2 Basic Consumption Period

This phase analyses the SmartLab's performance without any human intervention, during this period the room was empty. We tested from the second to the fourth of March of 2019. As we can see in Figure 6.1, the air conditioner (orange coloured line) stayed at a constant zero kW/h (kiloWatt per hour) as expected since there was no one in the room. The top green line represents the two elements that are always running, the aquarium arduino and the desktop computer of Workstation 3 which has aquarium related programs. It has some oscillations but stays in between the 100-175 kW/h, we can consider this a low consumption, that is essential for proper functioning and survival of the aquarium species.

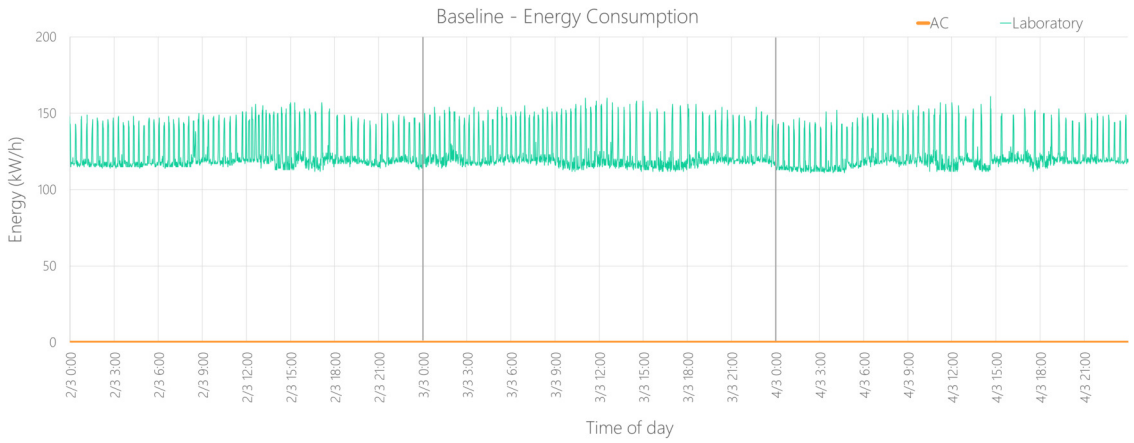


Figure 6.1: Baseline phase - General energy consumption and AC consumption.

6.3 Routine Period

The routine phase refers to the period between 11 and 13 of February of 2019, in which the subjects demonstrated their daily routines and habits. This period had maximum temperatures between 16° and 19°C and minimum values at 8°/9°C. From Figure 6.2, we can observe that the air conditioner has very high consumptions, especially comparing to the green line which represents the overall room consumption, which encompass the computers, monitors, lights and other small devices. Two other devices that rank up the energy consumption are the personal heaters from the subjects present on Workstations 9 and 10, these peeks can be observed on the second day and third days and are accompanied by a drop on the energy consumption of the air conditioner. We can also notice that the air conditioner was left on all night, from the second to the third day, the last subject leaving the room forgot to turn it off, which made the room temperature more stable and it did not require a boost from the air conditioner on the third day morning. Another device that also causes short interval peeks is the coffee machine.

The overall temperature of the room also influences the energy the aquarium consumes. As we can see in Figure 6.2, the night the AC was left on, the energy oscillations were minimal since the aquarium required less energy to regulate the water temperature.

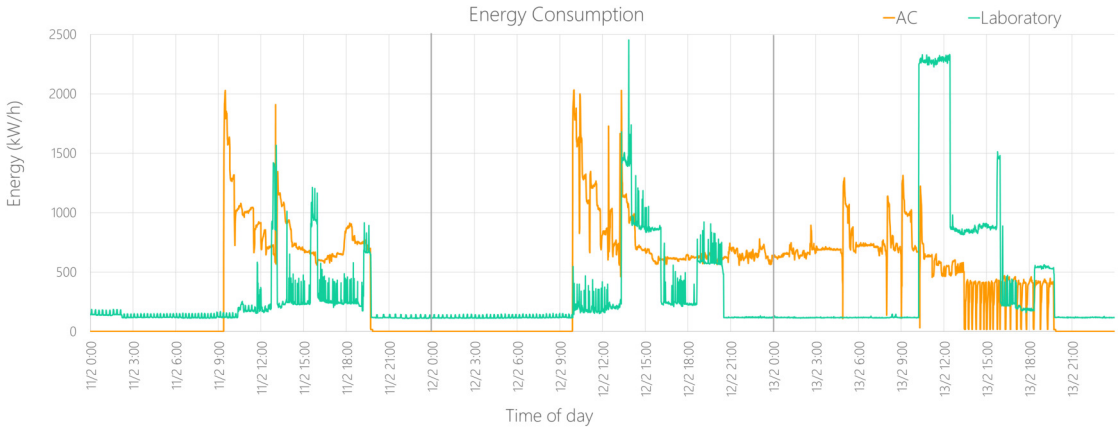


Figure 6.2: Routine phase - General energy consumption and AC consumption.

6.4 500lx Period

After observing the normal routines and habits of the occupants we reached the conclusion that the occupants do not really pay attention to room lighting. This might happen due to the fact that they work with computers, which radiate light and some of them even have lighted keyboards, meaning no exterior light source is needed in the immediate surroundings to see what they are doing.

With this new discovery in our study, we though it would be of great interest to observe the effects of keeping a 500 lux level at their workstations, as suggested per

offices spaces by European and international norms[8, 46]. During a period of three days, we requested our participants to check and maintain the luminosity level at the given value as they pleased. We used a mobile application, from 20th to the 22nd of February of 2019, develop by a SmartLab collaborator, that displayed the current value read by the workstation's beacon[23]. During these days the weather had relatively medium temperatures, with the maximum values between 17° and 20° Celsius, the minimum temperatures reaching the 10°C.

Starting with Workstation 1 verifying the data we collected (Figure 6.4), we can observe that although it suffered some oscillation and sometimes it was bellow 500lx, the space was able to reach the 500lx during the day. Interestingly the individual would only turn on the desktop light in the afternoon, except the first the day in which the desktop lights were not on. Meaning that the space was able to reach the 500lx with the natural incident light, having some peeks when the halogen lights were on, without being a major difference and whenever the desktop light was on the values increased over the suggested level.

Majority of the day, Workstation 2 luminosity level is above the 500lx as seen in Figure 6.5, this is the workstation with the highest values amongst the sample, since it is in the a corner surrounded by windows it catches light from the East (sunrise) and West (sunset) side which explains the values. Considering the exposure angle, it is natural that the light reflection may cause undesirable conditions, in this case it did and the occupant decided to lower the blinds, this movement was performed in the first two days before midday. In the second day it had a more pronounced drop because the outdoor level was around 10000lx versus the 5000lx from the day before (Figure 6.3), but after the occupant's action the indoor level in both situation was around 500-600lx. These similar end results can be related to the degree of incidence of the light beam, which will have consequences on the level of the blinds and the number of stages the objective has. In the final day, we can observe a accentuated decrease, at this point the lux level dropped from 600/700lx to 200lx, probably the occupant moved an object that blocked light from the beacon for around one hour. The individual from this workstation was the most active throughout this test period, having performed several adjustments along the days to keep the requested level.

In Figure 6.6 we can see that Workstation 8 did not have much oscillation, comparing with the other two elements, this might be because of the location of said workstation, it does not catch any direct light beams. Whenever the light level surpassed the 400lx mark, the desktop and ceiling lights were turned on. Over 600lx the two rows of the halogen lamps were switched on. On the second day we can recognize a significant drop in the middle of the afternoon, this decrease was caused by turning off the lights, and even though there was light incising in the room it was not sufficient. Analysing these results and compared to others, Workstation 8 without any artificial illumination is rarely at the 500lx mark, which is the recommended level by the international commission.

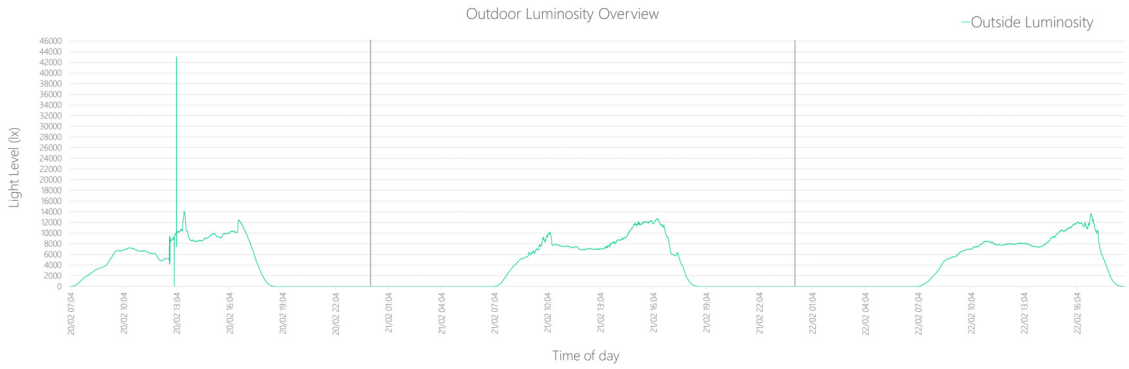


Figure 6.3: 500lx phase - Outdoor luminosity level

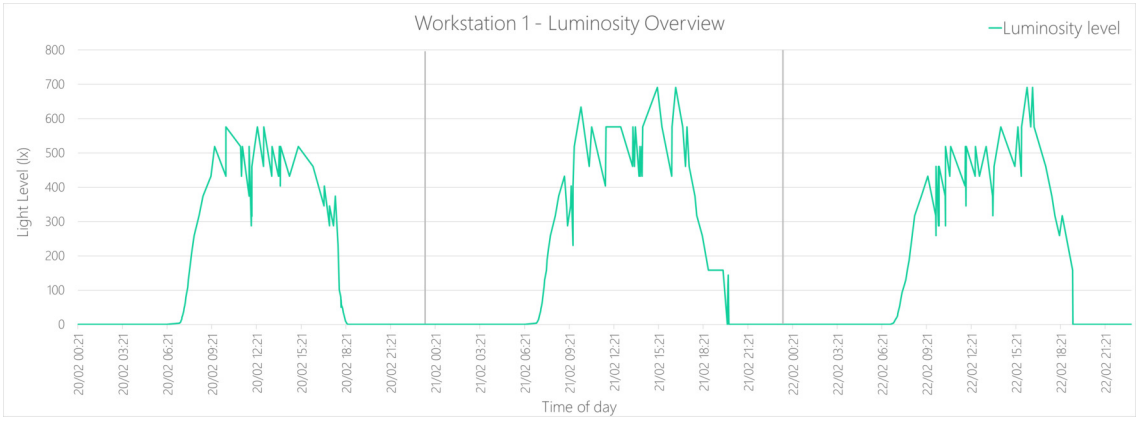


Figure 6.4: 500lx phase - Luminosity level of Workstation 1

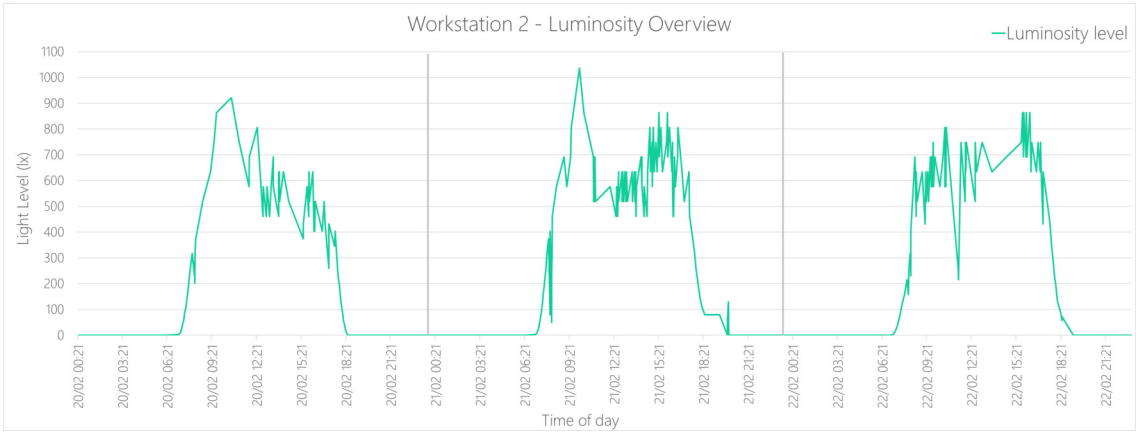


Figure 6.5: 500lx phase - Luminosity level of Workstation 2

6.4.1 Recommended Luminosity Assessment

At the end of the testing period we asked the participants to answer a few questions regarding their comfort, the form is available as Appendix B. We wanted to know if having a constant recommended light level had any effect on their work. We had four responses, the number of people present in the SmartLab during this experiment, who occupy workstations in opposite place of the room. Since they were asked to maintain

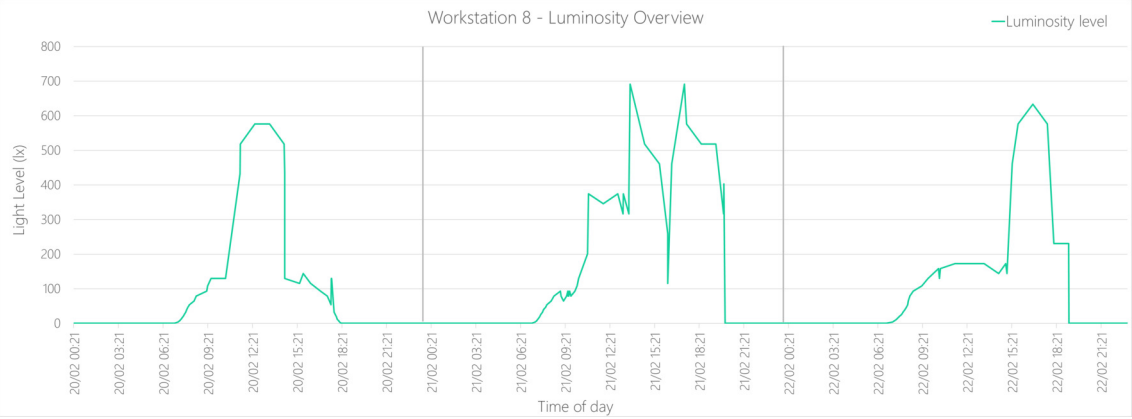


Figure 6.6: 500lx phase - Luminosity level of Workstation 8

a 500 lx in their workstation, we needed to understand if such task was to much time-consuming and complicated to achieve. We started by asking if it was difficult to find ways that would change the luminosity level to the desired value, 75% said no, while one person that answered sometimes. The occupant in question is near one of the corners of the room that has no near windows and furniture surrounding, which might be absorbing and blocking the light.

Their main resource were the desktop lamps, some subjects also used the ceiling lights or opened the blinds. This preference was not surprising due to two factors, the desktop light cause a more significant difference compared to the ceiling (measured with a luximeter) and the ceiling switch which is on the electric board is far from some workstations, as depicted in Figure 4.1.

Next, we inquired them about the attention they dispensed on maintaining the 500 lux, given that the indoor luminosity level is sensitive to changes in outdoor luminosity and dependent of the disposition of the participant's workstation, the player may need to do more or less light adjustments, which can disturb the workflow. In a scale from one (not disruptive) to five (highly disruptive), half of the population considered it a 2, one player said 3 and another gave it a 4.

Since the luminosity affects the eyes' health, we asked them if they had any eye related conditions (e.g.: eye strains, headaches), over half the population suffers from myopia[1], one of those individuals also has astigmatism[2]; and one other subject of the population suffers from keratoconus[3]. Besides this question, we also wanted to know if the subjects experience any side effects from working long hours on low light environments in front of

[1]Myopia is a common vision condition in which you can see objects near to you clearly, but objects farther away are blurry.https://www.mayoclinic.org/diseases-conditions/nearsightedness/symptoms-causes/syc-20375556

[2]Astigmatism is a vision condition that causes blurred vision. https://www.aoa.org/patients-and-public/eye-and-vision-problems

[3]Keratoconus is a disorder of the eye which results in distorted vision and increase sensitivity to light.https://www.mayoclinic.org/diseases-conditions/keratoconus/symptoms-causes/syc-20351352

computers, 50% said no, 25% said sometimes and the rest answered with a yes. For those individuals that had suffered the effects of such settings, we asked if sustaining the 500 lux had helped reduce/weaken the symptoms, in a scale from 1 (worsen) to 5 (helped) all of the respondents evaluated it at a 4.

We needed to know if these new light settings had affected their productivity, so we questioned them to quantify the outcome, if the new workstation conditions had helped (5) or on the contrary damaged (1) their work rate. Three-fourths of the population gave a neutral answer (3) and one element answered with a 4.

Given that we performed this test phase to see the impact the lighting had in the occupant's well-being and productivity, our final question inquired them about the relevance of this issue, to which they responded with relevant (50%) and highly relevant (50%).

6.5 LabRats Period

This phase occurred from the 30th of April to 24th of May, four consecutive weeks. We can divide the LabRats period into two different phases: the application testing and the aftermath of the use of the platform. The first phase had a duration of three weeks, during this time there were weather oscillations and some adjustments to the system were made. At the end of each week, we would send an email with the rankings and notes about new features if needed. Since we have deadlines, the aftermath lasted a week and its purpose was to verify if some of the behaviours prevailed.

After the first, third and last weeks, we asked the occupants to answer a small questionnaire, to comprehend their experience with the system and overall opinion. These forms had several types of questions, from open answer, checkboxes to a 1 to 5 scale (Strongly disagree to Strongly agree).

6.5.1 Week One

This was our first week testing LabRats, it started on April 30 and ended May 3, the 1st of May was a holiday. During these days the temperature was relatively high, ranging from 23°C to 28°C, maximum values and minimum around 12°C.

Figure 6.7 shows the overall consumption of the room, without the holiday data. As we can see, there are several peaks in energy (green line), reaching 1000 kW/h, caused by the coffee machine, we cross-referenced the data and reached this conclusion. Each peak does not correspond to a coffee, normally the occupant turns on the machine and after a while makes the coffee and turn the machine off. However, on May 3 the occupant, who drank coffee twice, took a little longer to make the first beverage and forgot to switch it off after. Thus, the high number of peaks because the longer the machine stays on, the more frequently it has to heat up the water to be prepared to deliver a coffee.

This week the electric panel where the air conditioner is connected broke and therefore the AC could not be turned on, we were informed at the end of the week. Given the

relatively high temperatures, there were days when the room got really warm reaching 26°C in some workstations, which is unpleasant. However, none of the occupants, who were not aware of the situation, tried to turn on the AC. The Warnings and Kinect features were not available at this time.

There was group challenge on going this first week, in which the occupants had to try to reduce their device consumption and should turn off unnecessary devices when out over 20 minutes. As displayed in Figure 6.8 the occupant from Workstation 1 did not turn off the computer in neither of the days at lunchtime which was around 2 p.m. and 12 p.m. respectively. The occupant from this workstation also had an individual challenge which required the occupant to arrive at the SmartLab around the same time the following days, which was not achieved since said workstation had no activity on the last day.

The monitor of Workstation 2 had been left on from April 29 and was only switched off when the occupant left the next day for lunch, as shown in Figure 6.10. However, at the end of the day, when the individual went home, the monitor was on once again consuming around 1 Watt every other few seconds and it kept the energy intake until the occupant left for the day on May 2. Although the device does not consume a lot of energy (around 1 Watt), it is still unnecessary consumption that could have been prevented. All the other devices were turned off when unnecessary.

The occupant from Workstation 6 this week only used the computer, which was left on when the individual left around 2:40 p.m. on May 3, and the monitor very briefly, depicted in Figure 6.12.

Users from Workstations 7 and 10 always turned off their devices when they left for over 20 minutes, as shown in Figures 6.13 and 6.17.

The Workstation 8 occupant had several devices on, but they were all off when the occupant went home, as displayed in Figure 6.14.

The individual from Workstation 9 was at the SmartLab, however as we can see in Figure 6.16 only used the devices for a short period.

The occupants from Workstations 1, 2 and 8 never reached a healthy luminosity level when present in the room, as we can see in Figures 6.9, 6.11, 6.15 respectively, the desktop lights were only turned on for task alerts.

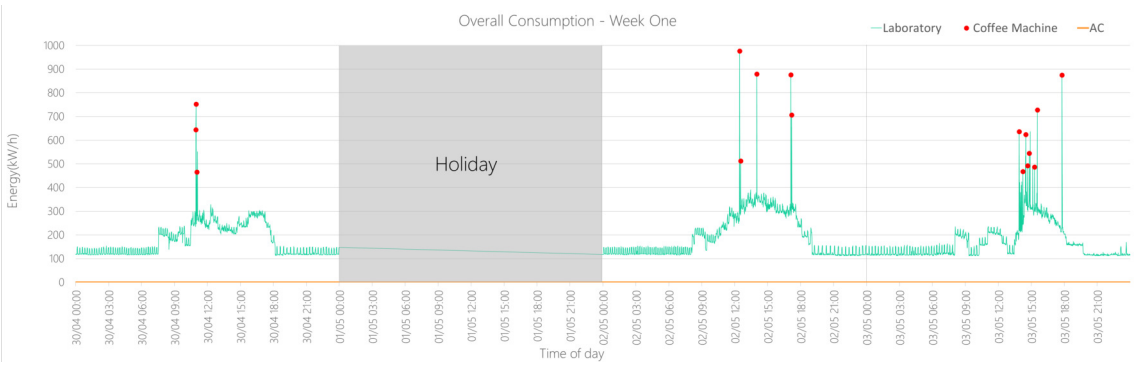


Figure 6.7: Week One - General energy consumption and AC consumption.

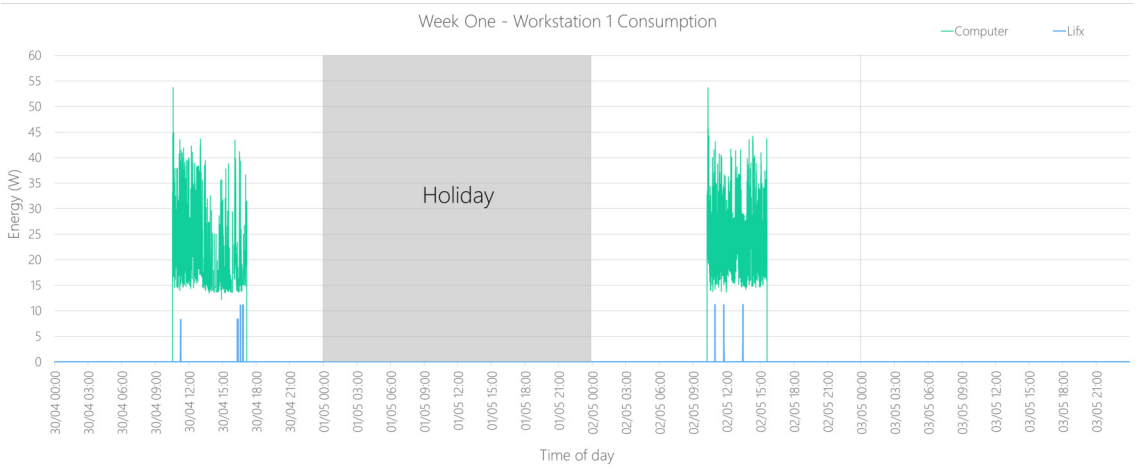


Figure 6.8: Week One - Workstation 1 device consumption.

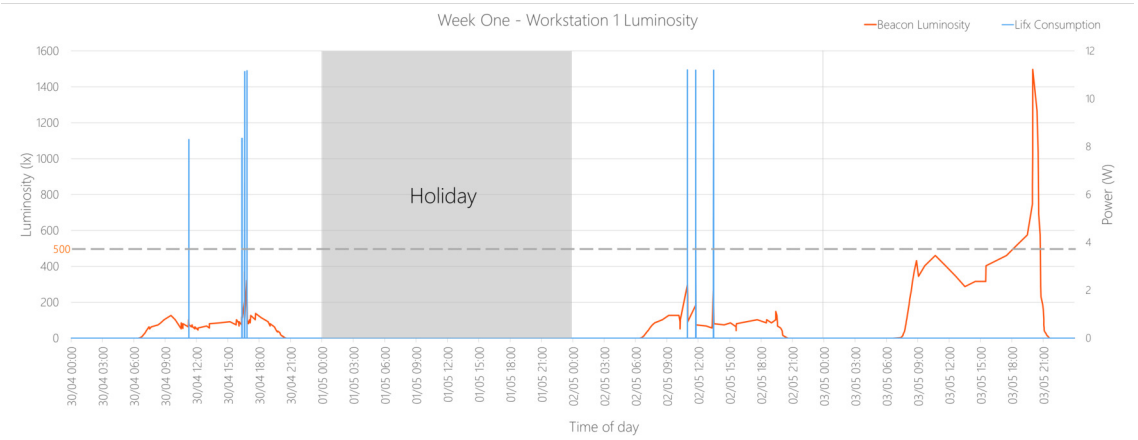


Figure 6.9: Week One - Workstation 1 luminosity level and Lifx consumption.

We can see in Table 6.1 that on the first week the system triggered 16 tasks total. The majority of tasks were completed (13), except three: two of them were refused by the users due to reflections on screen and being too busy to help; and there was one missed task, the user was away from the the workstation in question, therefore unable to see the lamp light up. Table 6.2 displays the challenges that were available that week, a total of 6 challenges, only three were successful, all of them individual. This week, majority of the individual challenges were about creating a regular arriving schedule, excluding one which was created with a user in mind, the occupant works in a company during the day so the time they pass on the SmartLab is limited. Since this individual usually drinks coffee, the challenge goal was for the user to switch off the machine after using it, as we can see from Figure 6.7, the coffee machine creates power peaks whenever it is heating, this was completed successfully.

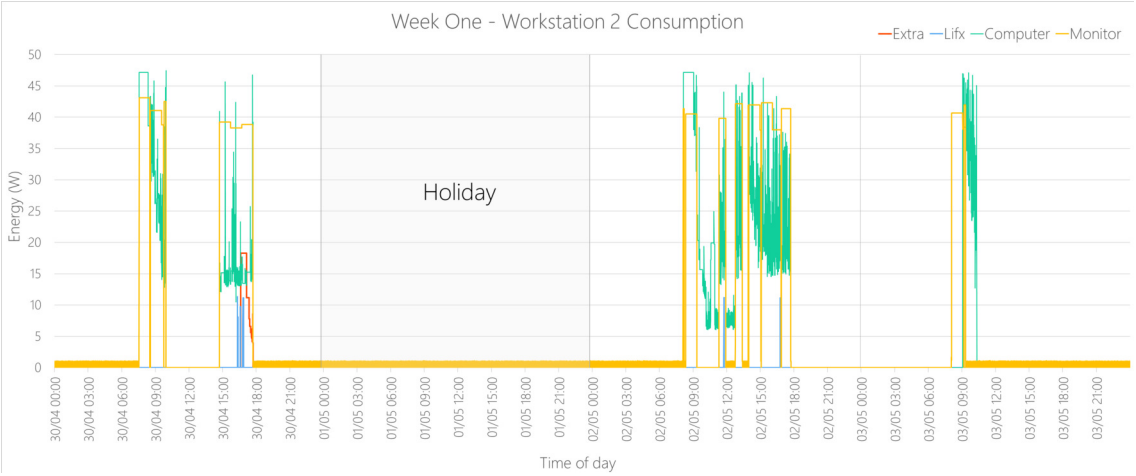


Figure 6.10: Week One - Workstation 2 device consumption.

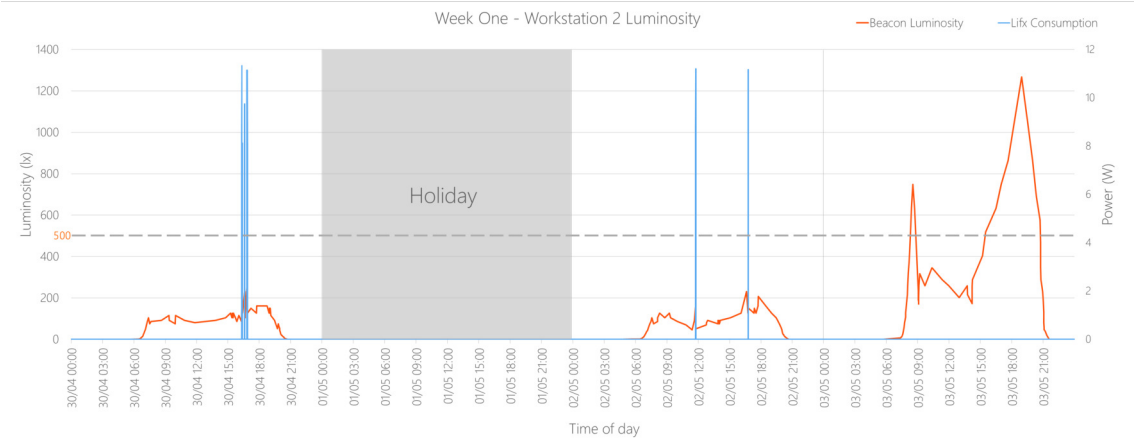


Figure 6.11: Week One - Workstation 2 luminosity level and Lifx consumption.

6.5.1.1 Week One Assessment

After our first week of testing LabRats, we wanted to know what the occupants thought of the system, so we asked then to respond to a questionnaire composed by 13 questions and had 6 answers, the questionnaire is available as Appendix C. The first

Table 6.1: Overview of the tasks requested on week one.

			Workstations								
			Wskt 1	Wskt 2	Wskt 3	Wskt 6	Wskt 7	Wskt 8	Wskt 9	Wskt 10	**Total tasks**
Week One	April 30	Completed	2	0	0	0	0	0	0	1	5
		Refused	0	0	0	0	1	0	0	0	
		Missed	0	1	0	0	0	0	0	0	
	May 2	Completed	1	2	0	0	0	1	0	1	6
		Refused	0	0	0	0	0	0	1	0	
		Missed	0	0	0	0	0	0	0	0	
	May 3	Completed	0	0	0	1	0	1	0	3	5
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	Total	Completed	3	2	0	1	0	2	0	5	16
		Refused	0	0	0	0	1	0	1	0	
		Missed	0	1	0	0	0	0	0	0	

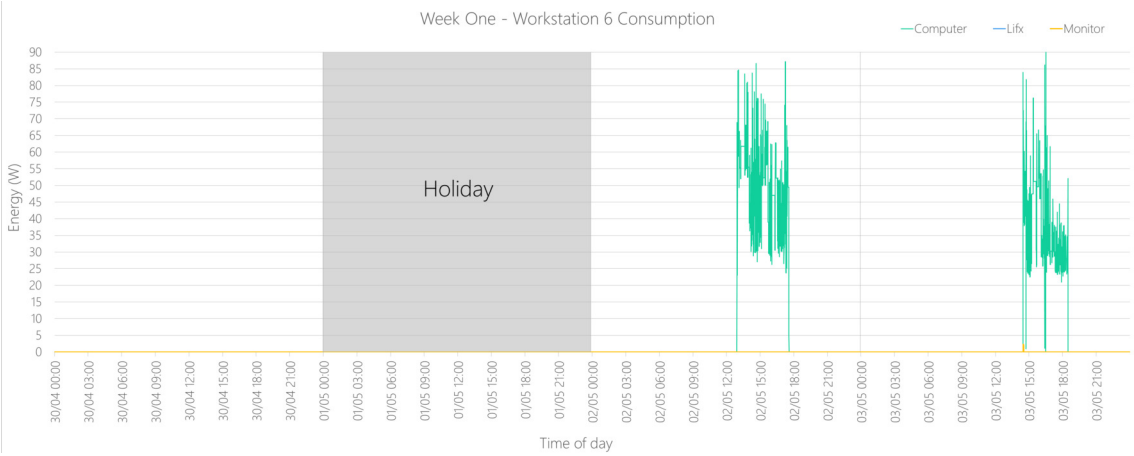


Figure 6.12: Week One - Workstation 6 device consumption.

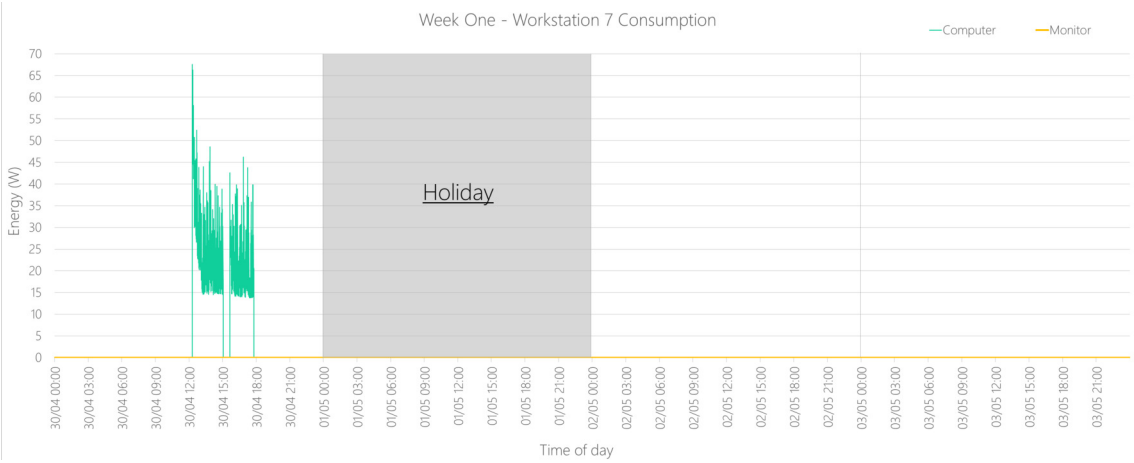


Figure 6.13: Week One - Workstation 7 device consumption.

Table 6.2: Overview of the challenges performed on week one.

		Challenges		
		Individual	Group	Total
Week One	Successful	3	0	3
	Unsuccessful	2	1	3
	Total	5	1	6

10 questions were from the System Usability Scale (SUS) which allows us to measure usability, LabRats scored 85.41 points which equals an A grade. Additionally, we enquired if they thought the system was fair, to which four people said they strongly agreed (5) and the other two agreed (4) with the statement. When asked if the system disrupted their workflow 50% gave it a 1 (strongly disagree), two individuals answered with a 2 (disagree) and one was neutral (3). We asked if they had suggestion, comments or improvements but had no responses.

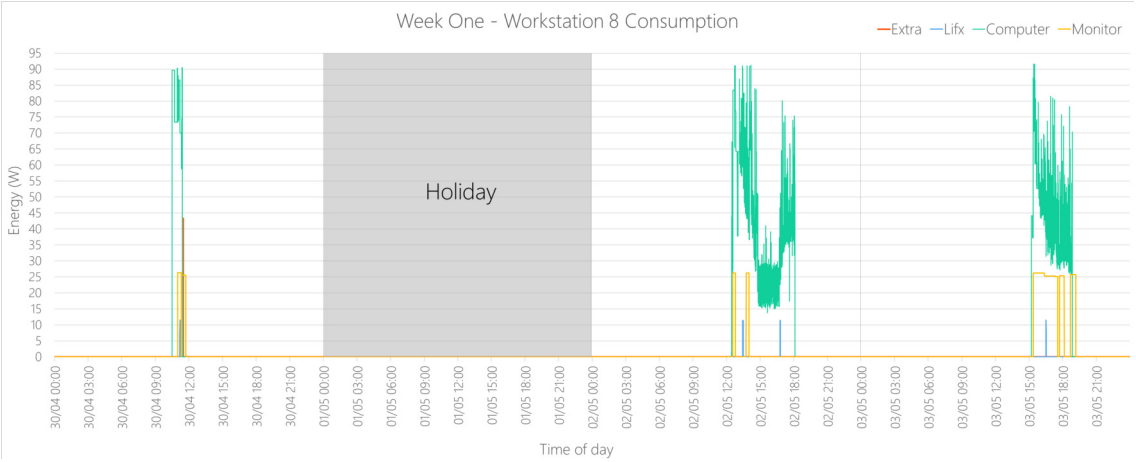


Figure 6.14: Week One - Workstation 8 device consumption.

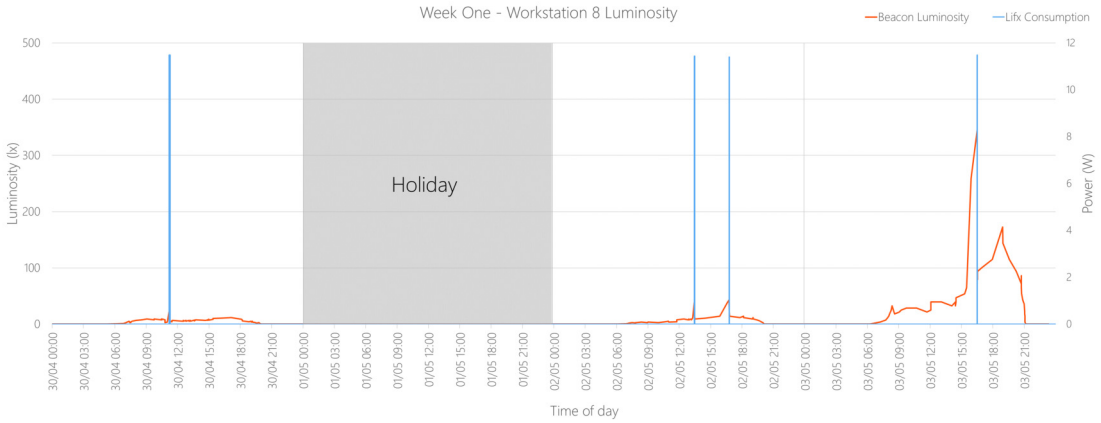


Figure 6.15: Week One - Workstation 8 luminosity level and Lifx consumption.

6.5.1.2 Week One Observations

During this week, we observed some interesting behaviours, such as:

- Individuals did not take the group challenge seriously, forgetting to switch off devices when they left and there was not a strong group dynamic present, individuals only checked the devices that belong to them. We believe this might be due to the phrasing of the challenge, not emphasizing enough that they should help each other by checking the colleagues' devices;

- During one of the hot days, the system asked for the windows to be opened, however there was a barbecue happening close to the building, it was too noisy and they decided to close the window to block the sound;

- People forgot to check-in and check-out when they arrived or left the room for over 20 minutes, as asked. It is an easy action to forget, they were not used to it and they do not have to do it to be able to enter or leave the room. Thus, since they are

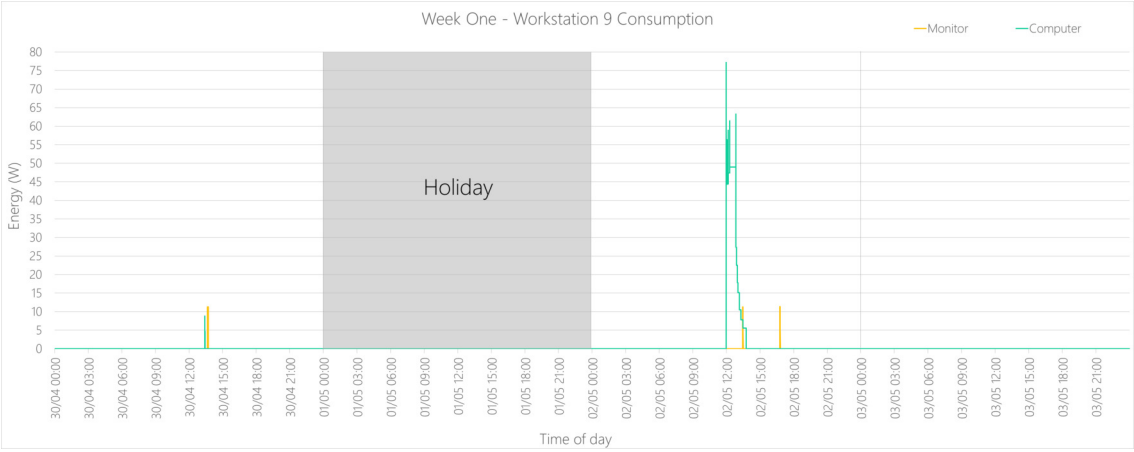


Figure 6.16: Week One - Workstation 9 device consumption.

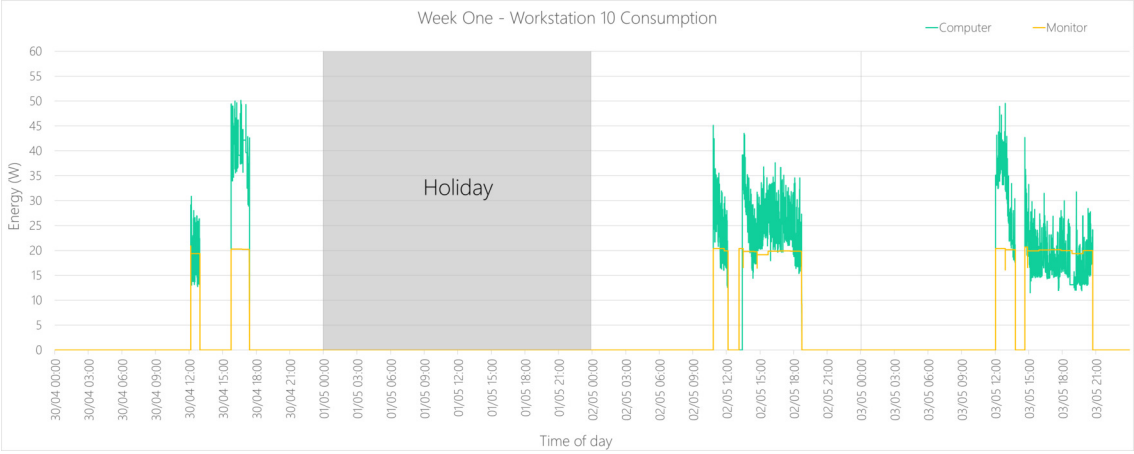


Figure 6.17: Week One - Workstation 10 device consumption.

working on their computers, the LabRats window will not be in the forefront, so there is not an active element showing to remind them;

- The challenges have to be more fitted to the person's availability, for example the schedule challenge that requested the users to arrive around the same time they did on the first day, did not have positive results. We need to keep in mind that these are individuals that attend classes or work, and do not have any obligation to be there or schedule to follow. Another possible observation that we can make from this point is that what they received in return was not worth their presence in the room;

- The system only sent tasks to individuals who are present in the room, but it was pointed out to us that the occupants could only see the light turning green if they are sited at their desk. Otherwise, they will not be aware;

- Even with uncomfortable indoor temperatures, the occupants did not turn on the

AC, which can either be because they did not wanted to jeopardize their consumption challenge or they were unaware they could do so.

6.5.2 Week Two

The second week started at May 7 and ended on May 10. Opposite to the week prior, week two suffered a temperature reduction, it was very cloudy throughout the days, however, indoor luminosity readings reached higher values. We do not know if is due to surface reflection, that allowed more rays of light to enter, or if since it was cloudy there was not intense screen reflection, therefore allowing the blinds to be completely open without causing any discomfort. Regarding temperatures, maximum values were between 18°C to 21°C with a minimum of 14°C.

Given the conclusions reached on week one, we started the week by sending an email where we very innocently mentioned they had the liberty to use anything in the room and to discuss any strategies.

We started this week with only two people in the room, which explain the lower energy levels, the next three days the attended increase with around 4 to 5 individuals present. As we can observe in Figure 6.18, occupants drank coffee on days 8 and 9 of May.

On the 8th of May, we discovered the AC problem was resolved when one of the occupants tried to turned it on to check if it was working on not. The AC remained on for about 20 minutes, after a discussion amongst them they decided there was no need for it to be consuming energy. Similar to last test week, we had the same group challenge, we modified the text to be straight to the point in a very clear way in hopes that the teamwork dynamic would strengthen. Also, this week new features were added, the Kinect tasks for the occupants to stretch every two hours, which had a very positive outcome, and the overall ranking, since the weekly resets at the end of each week.

Shown in Figure 6.19 is the energy consumption of Workstation 1, as we can observe on May 8 the occupant forgot to turn off the computer at lunch time, around 12 p.m., but later when the individual left the room the computer was off. As mentioned before these cloudy days displayed very high luminosity values, Figures 6.20 and 6.22 depict the luminosity values for Workstations 1 and 2, easily reaching values in the thousands. The same can not be said for Workstation 8 (Figure 6.27), which has a high difficulty to achieve 500 lx with natural lighting.

Looking at Figure 6.21 we can observe that the occupant from Workstation 2 really followed what was asked, switching off all appliances when they are not needed. The Lifx light was turned on a few times (Figure 6.22), some were alerts, others were to reach the healthy value and answer the individual challenge that was on going.

Workstation 6 occupant also answered the group challenge, turning off devices when leaving the room (Figure 6.23). This occupant did not have the healthy light conditions but did not turned the light on when needed, as we can see on Figure 6.24. The peak presented on May 10 was caused by a maintenance test on the outlets.

In Figure 6.25, we can see the occupant from Workstation 7 followed the challenge when present in the room. During the morning of May 10, an individual outside the study used the workstation's monitor.

Workstation 8 worked the afternoon at the SmartLab (Figure 6.26), with the computer and light turned on, the latter to be able to reach the 500lx (Figure 6.27).

The occupant from Workstation 9 turned off the unnecessary appliances on May 10, however, on May 9 the same did not happen. We can see in Figure 6.28 a significant drop on energy around 2 p.m., so when the individual left the computer was still consuming, possibly entered on stand-by mode which explains the lower values.

Finally, the user from Workstation 10, similar to before the person remembered to turn off all devices when not present (Figure 6.29). The energy consumed from 8 a.m. to almost 10 a.m. was not consumed by the usual occupant of this workstation. As stated previously, the SmartLab is a shared open space used by several people, on this day an individual external to this study was present in the room and occupied this space.

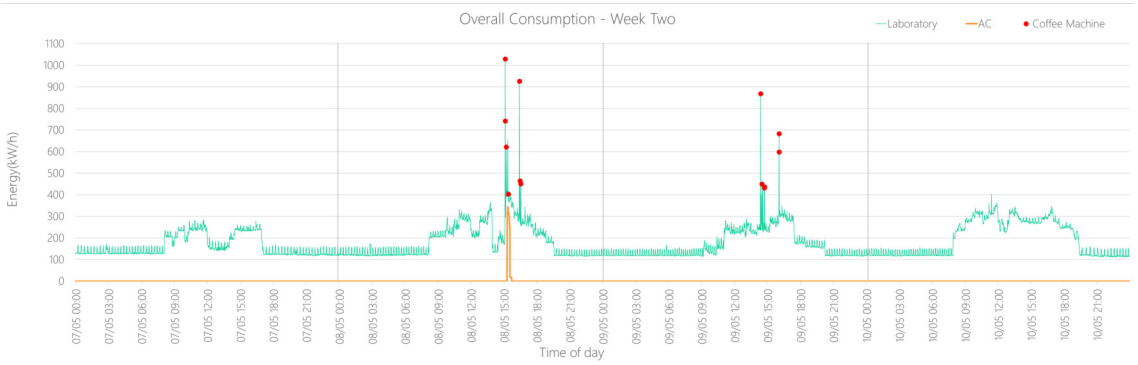


Figure 6.18: Week Two - General energy consumption and AC consumption.

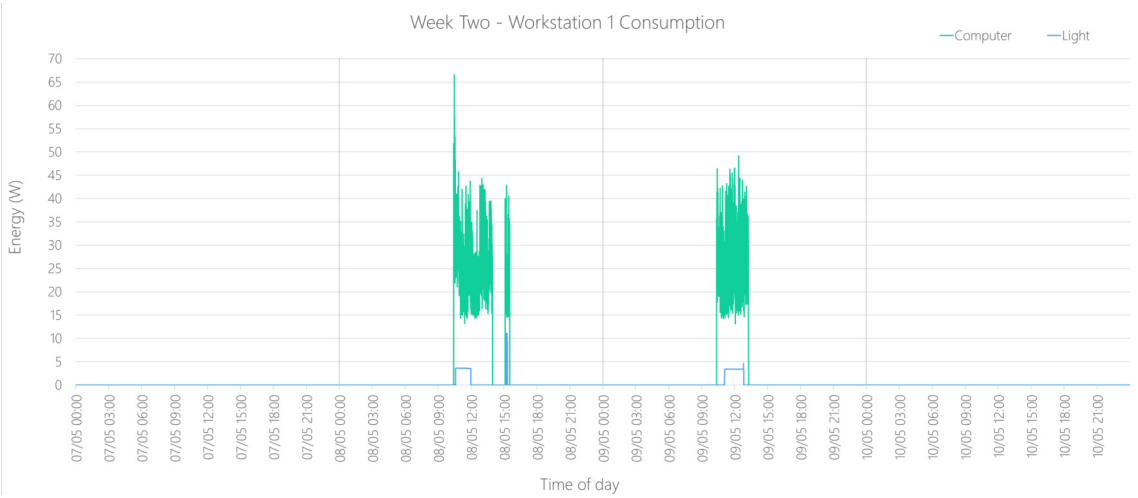


Figure 6.19: Week Two - Workstation 1 device consumption.

On the second week, the system requested the users to perform 17 tasks, 13 of which were Kinect tasks. This week the individual challenges asked the users to try to keep 500

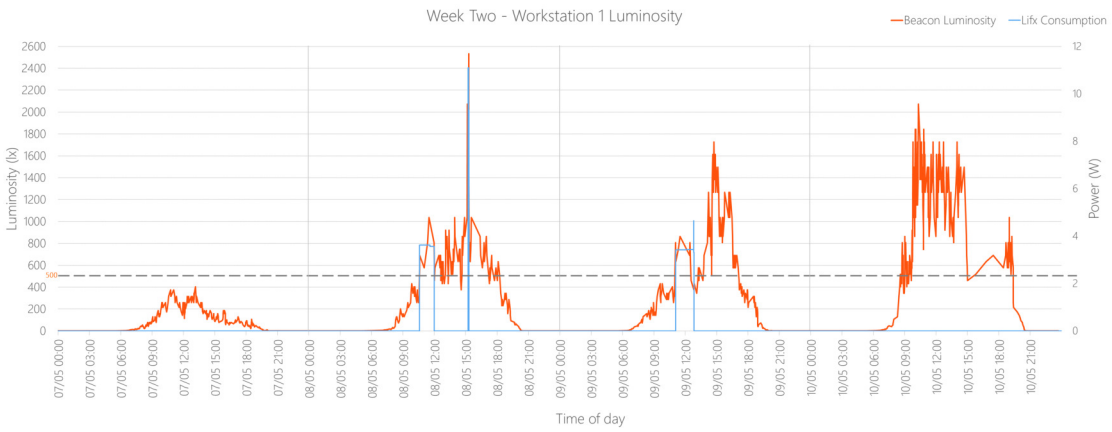


Figure 6.20: Week Two - Workstation 1 luminosity level and Lifx consumption.

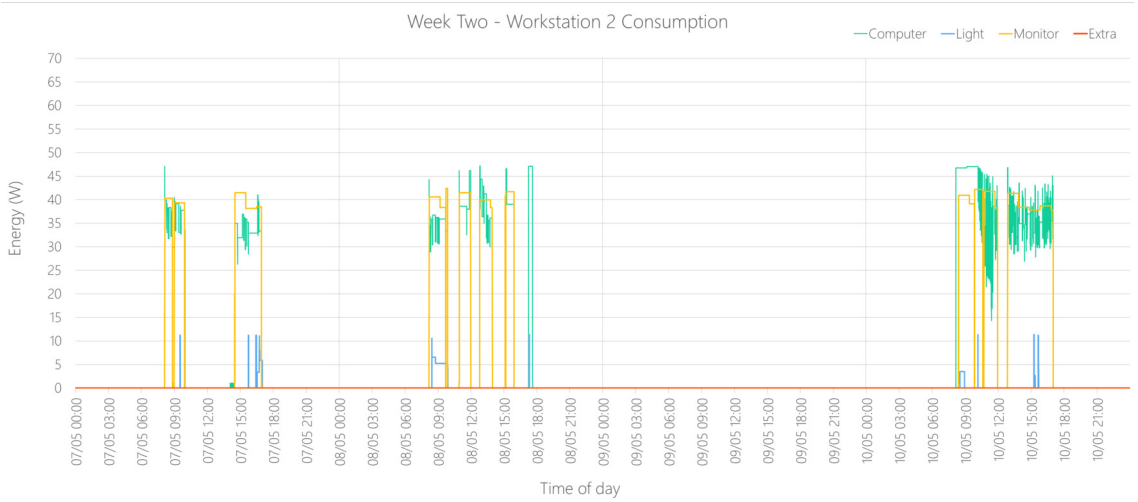


Figure 6.21: Week Two - Workstation 2 device consumption.

lx on their workstations. For this reason there were fewer tasks requesting the occupants to open the blinds. All the tasks were fulfilled by the occupants, as shown in Table 6.3. As for the challenges, we can observe on Table 6.4 there was only one successful challenge, the coffee challenge mentioned previously, all of the other individual challenges, that requested the users to maintain a healthy luminosity level, were incomplete. The group challenge, identical to last week's group challenge, suffered alterations in the description based on the observation from the first week, however, it was not enough for the challenge to be completed.

6.5.2.1 Week Two Observations

In our second week we detected identical issues to week one and found some new interesting facts:

- People still forget to check-in on LabRats;

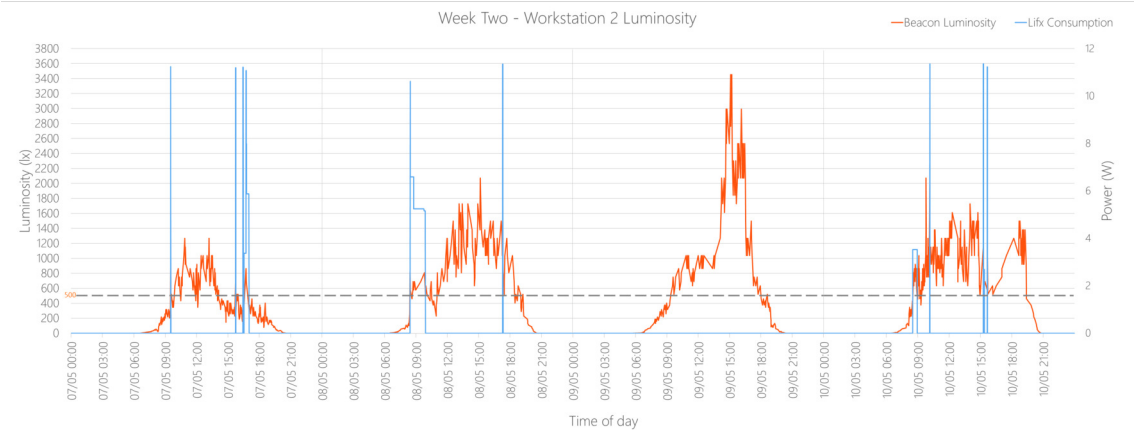


Figure 6.22: Week Two - Workstation 2 luminosity level and Lifx consumption.

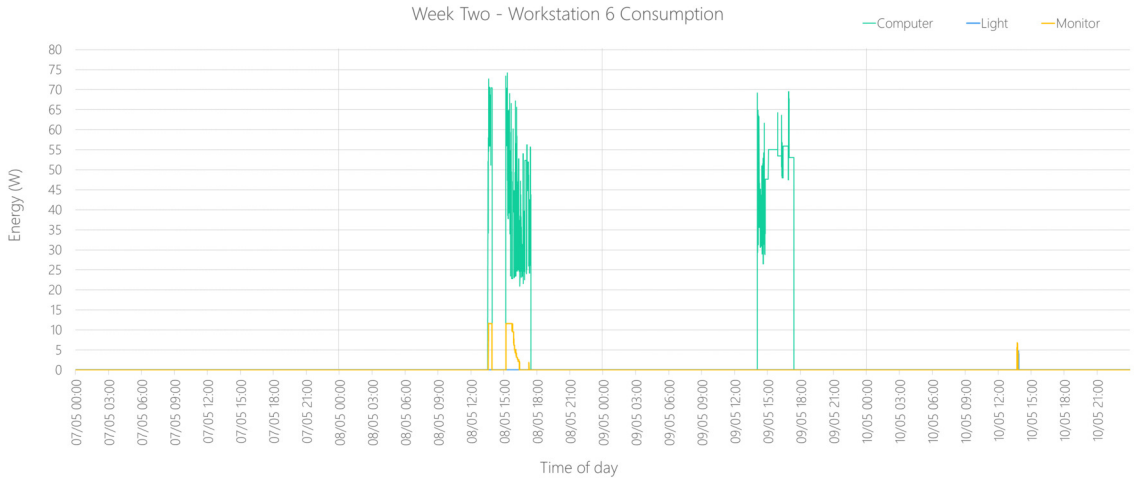


Figure 6.23: Week Two - Workstation 6 device consumption.

- Cloudy days allow for the blinds to be open without interfering on the workflow and reach easily higher lumens on the workstations near the windows. The resulting indoor light was still not sufficient to guarantee 500lx on some workstations;

- Some occupants do not check the Challenges page as instructed, since it is the only way to know if there are new challenges. This fact might be due to a lack of interest from the individuals, possibly LabRats has not caught their attention as much. We do believe that this situation can be resolved either with new gamification elements or a simple alert, maybe change of light colour or screen display in the SmartLab;

- The group dynamic improved when they all discussed if they AC should be on or not, however, the occupants still did not check their colleagues workspace in search of forgotten turned on appliances;

- While some occupants follow the challenges request, others do not and consequently compromised the result of group activities;

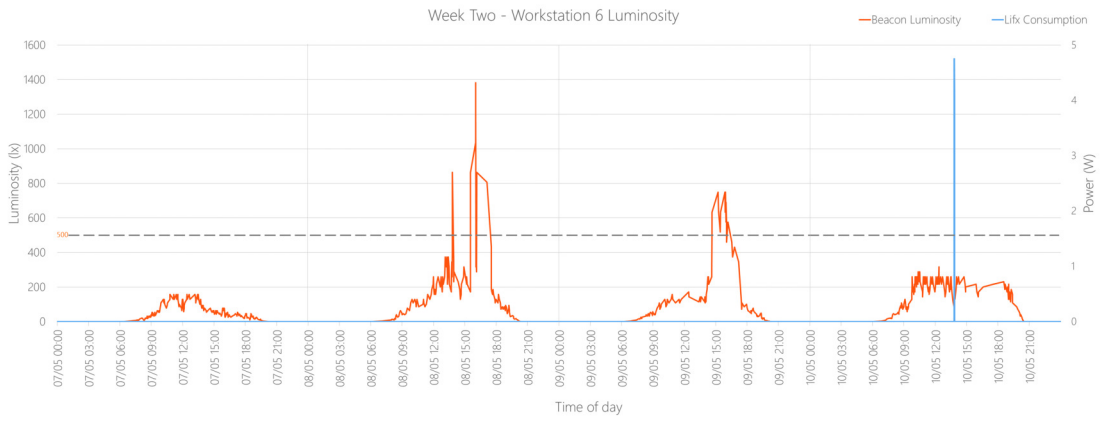


Figure 6.24: Week Two - Workstation 6 luminosity level and Lifx consumption.

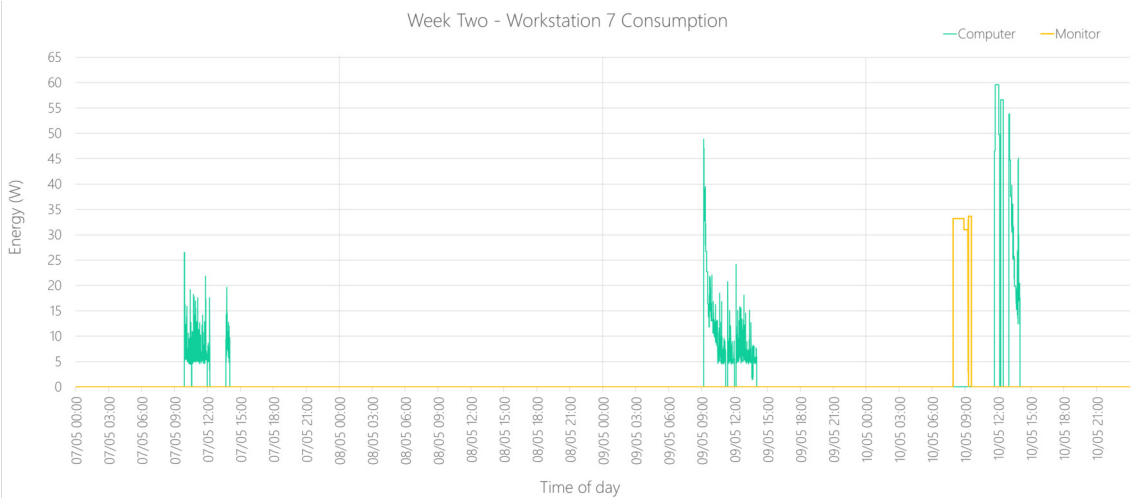


Figure 6.25: Week Two - Workstation 7 device consumption.

- The subjects paid more attention to their devices and surroundings, remembering most of the times to turn off the devices;
- We tried to create challenges more participant oriented, taking into account their availability;
- We had some problems regarding equipment, some outlets were not responding, so we needed to test our fixes which created some peaks of energy.

6.5.3 Week Three

The final week of our LabRats testing phase, went from the 13th of May to the 17th of May. This week reached very high temperatures the first few days with a maximum of 34°C, later it dropped to 20°C. The minimum values were around 13°C/19°C. Given the room's sun exposure, on the hottest days the indoor temperature was between 24°C and almost 30°C.

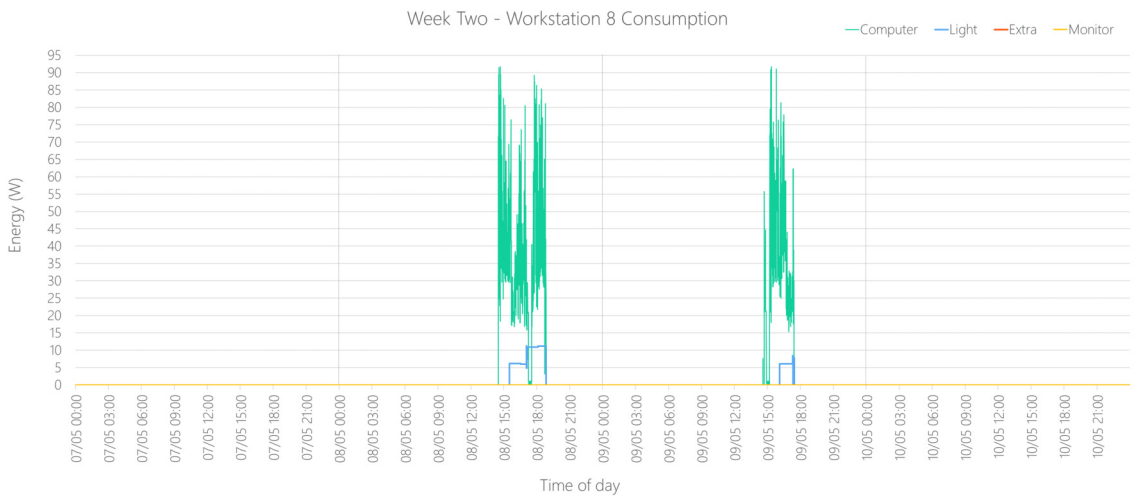


Figure 6.26: Week Two - Workstation 8 device consumption.

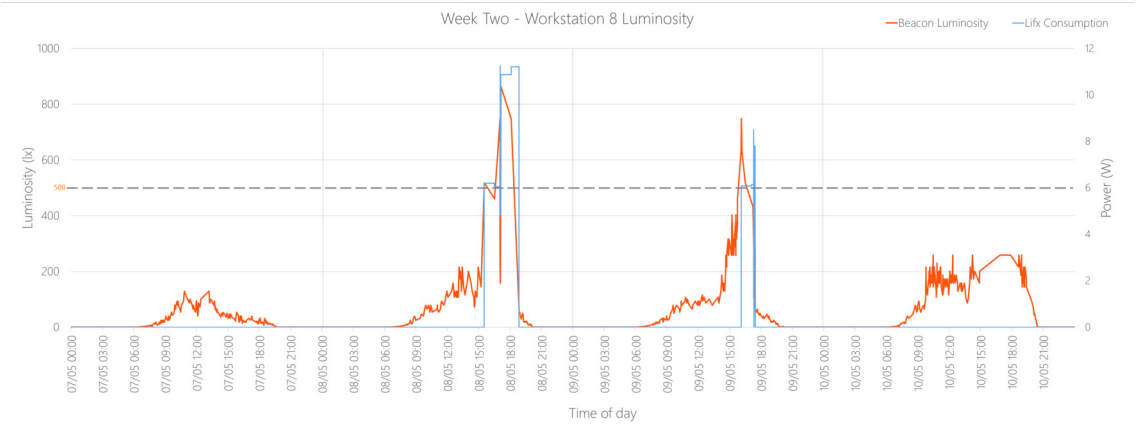


Figure 6.27: Week Two - Workstation 8 luminosity level and Lifx consumption.

Taking in consideration the observations from the previous week, we decided to add new elements to the logic. Since we noticed that occupants do no check the state of the appliances besides their own, we presented the Warnings, a way to notify the system that a certain device, that the occupant can not turn off, was left on. There are a few guidelines the user has to check first, if the alert is legitimate the reporter will get 1 point from the forgetful person, otherwise 2 points are deducted. Unfortunately, no warnings were created during this experience. We also added two new rules, if the user would forget to check-in or check-out 3 points would be deducted from their account. The second rule was thought as a appreciation of the occupant's daily effort in group challenges, if the individual has done what is requested in the challenge then 2 points will be added to their account each day the condition applies.

Displayed in Figure 6.30 is the overall consumption of the room for the interval stated, we can see that on the third day (May 15) the AC was on and suffered some oscillation, as well as the laboratory consumption. The SmartLab case study is unique and generates curiosity to the general public, therefore demonstrations are organized to show university

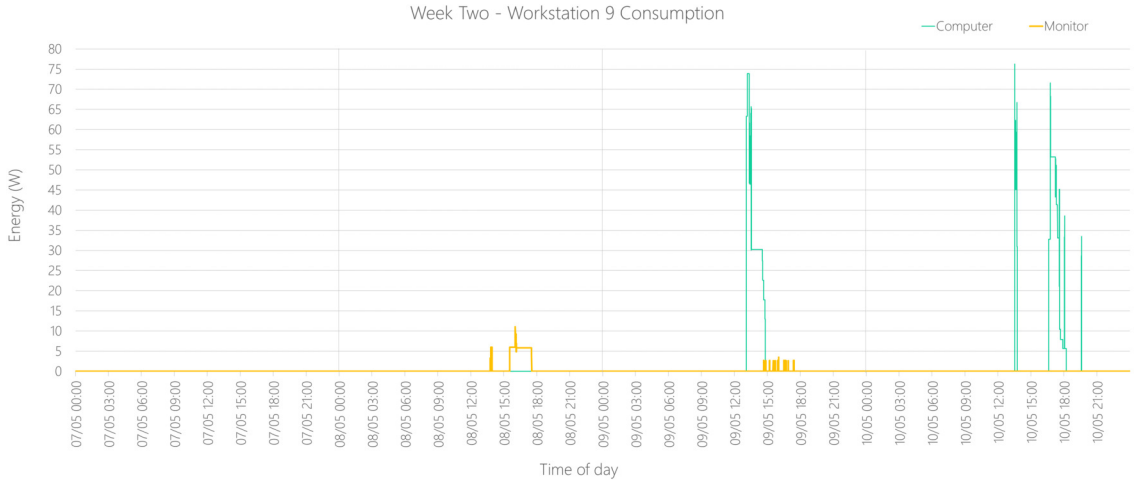


Figure 6.28: Week Two - Workstation 9 device consumption.

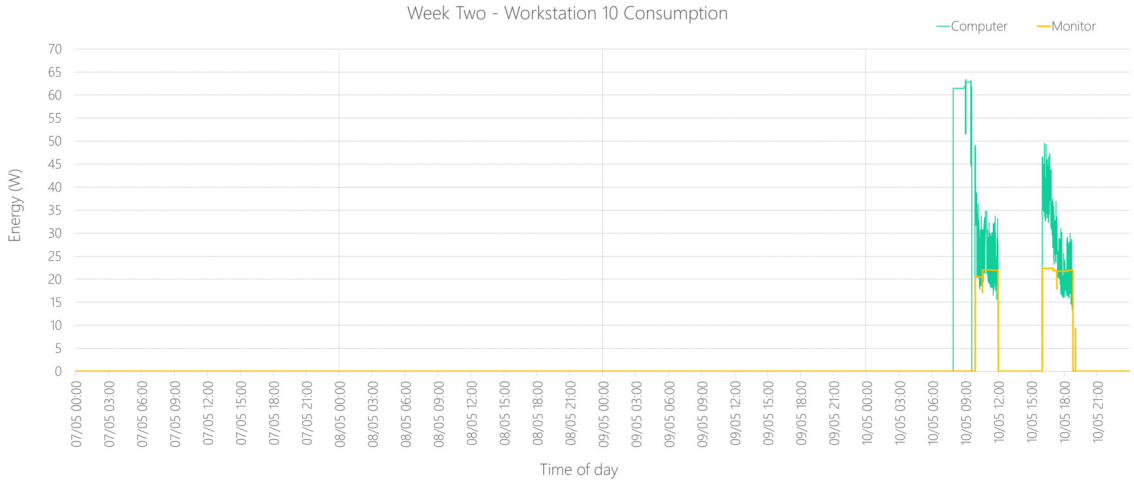


Figure 6.29: Week Two - Workstation 10 device consumption.

guests the system functioning, which was what happened on this day and explains the variation on consumption. After the visit had ended, the occupants discussed between them if they should turn on the AC or not, they ended up doing it around 1 p.m., sadly due to internet issues some data was lost. This week had similar challenges to last week.

Overall, we can see their behaviour changed, almost every occupant that left the room turned off their equipment (Figures 6.31, 6.33, 6.35, 6.39), except the occupants from Workstations 7 (Figure 6.36), who forgot on the 15th. The users from Workstations 8 and 10 only left the room to go home (Figure 6.37, 6.40).

Regarding luminosity, as we have seen before is extremely difficult to reach the 500lx of the health challenge on Workstation 8 (Figure 6.38), with the Lifx light being the only option, Workstations 1 (Figure 6.32) and 2 (Figure 6.34) can easily achieve the healthy luminosity level with natural lighting, only needing the desktop light in certain situations.

The final week had more tasks than the previous ones, with a total of 22 requests. Identical to the week before, all the tasks were executed. The system requested for

Table 6.3: Overview of the tasks requested on week two.

			Workstations								
			Wskt 1	Wskt 2	Wskt 3	Wskt 6	Wskt 7	Wskt 8	Wskt 9	Wskt 10	**Total tasks**
Week Two	May 7	Completed	0	2	0	0	0	0	0	0	2
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	May 8	Completed	1	1	0	1	0	1	0	0	4
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	May 9	Completed	1	0	0	1	1	1	0	0	4
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	May 10	Completed	0	3	0	0	0	0	0	4	7
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	Total	Completed	2	6	0	2	1	2	0	4	17
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	

Table 6.4: Overview of the challenges performed on week two.

		Challenges		
		Individual	Group	Total
Week Two	Successful	1	0	1
	Unsuccessful	7	1	8
	Total	8	1	9

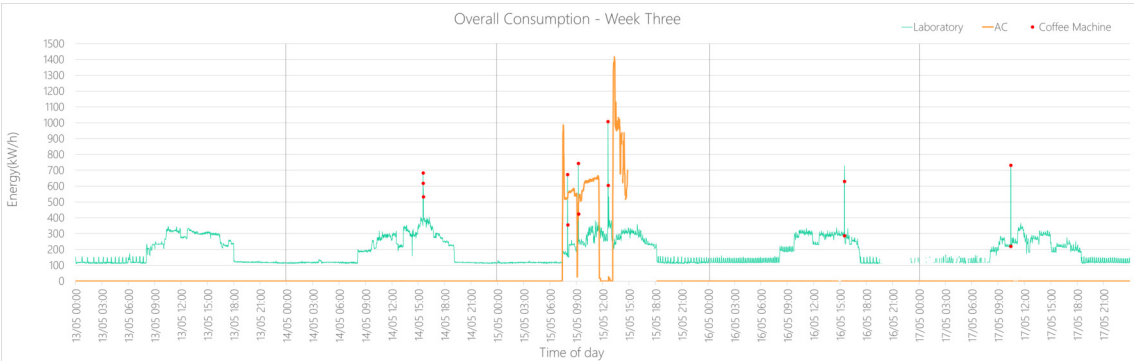


Figure 6.30: Week Three - General energy consumption and AC consumption.

occupants to open and close the windows, also asked for the blinds to be open and triggered several Kinect tasks (Table 6.5). Concerning challenges, there were a total of 9, one group challenge and 8 individual. The group challenge is accounted for as a successful challenge in Table 6.6. Although it did not have 100% success rate, we awarded 10% of the possible score in order to reward the existing improvement.

6.5.3.1 Week Three Assessment

Given that the experience with LabRats had come to an end, we asked our participants to respond to a form (Appendix D). We had a total of 8 responses.

The form can be divided in four parts, the first one is about the application, the second inquires about the lighting, the next part is about indoor conditions and finally well-being.

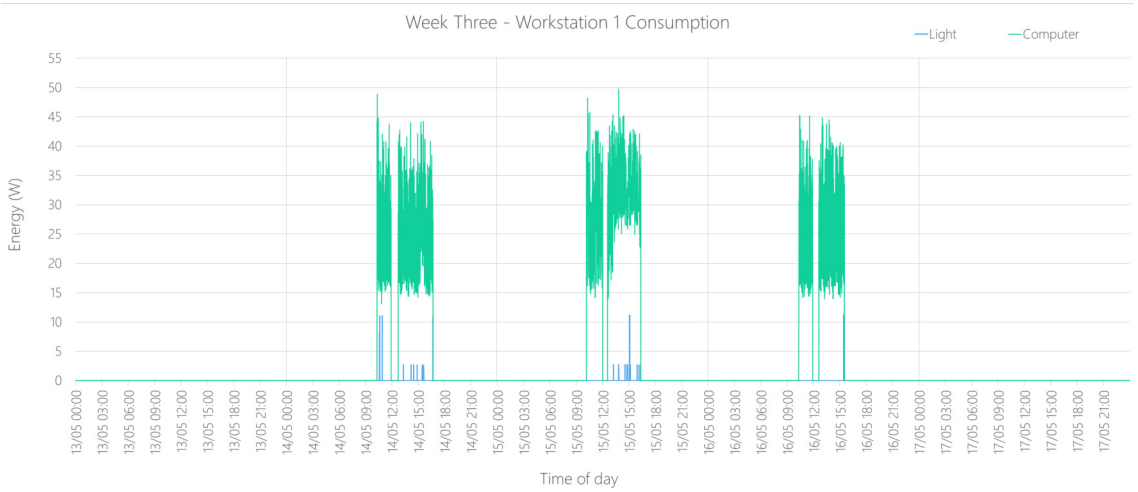


Figure 6.31: Week Three - Workstation 1 device consumption.

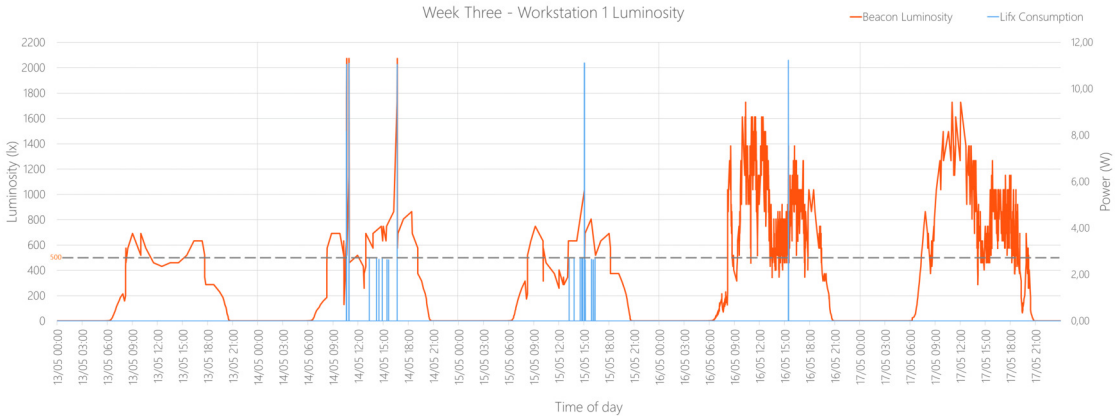


Figure 6.32: Week Three - Workstation 1 luminosity level and Lifx consumption.

On the first part we asked them if they found the system helpful, since it gave feedback on how much each device was consuming and they were able to know luminosity and temperature levels. Five individual gave it a 5, so they strongly agreed with the phrase, and the remaining three gave it a 4. They found the concept of LabRats interesting, seven participants strongly agreed (5) and only one agreed (4).

Six people enjoyed participating in the challenges and tasks (strongly agree - 5), while the two remaining gave it a 4 (agree). Regarding if they felt motivated to work as a group, the answers were two neutral, five agree (4) and one strongly agree (5).

We wanted to know if they found the challenges easy to complete, from the 8 participants one of them did not started any individual challenges, it was only part of the group ones by default. The six other participants assign a 5 (strongly agree) and the another one gave it a 4 (agree). Given the following statement "The system requested too many tasks.", five users strongly disagreed (1) with the affirmation, one disagreed (2) and another other had not done any, so had no opinion. We also wanted to know if they felt the system had disrupted their workflow, half of the population disagreed (2) and the other half strongly

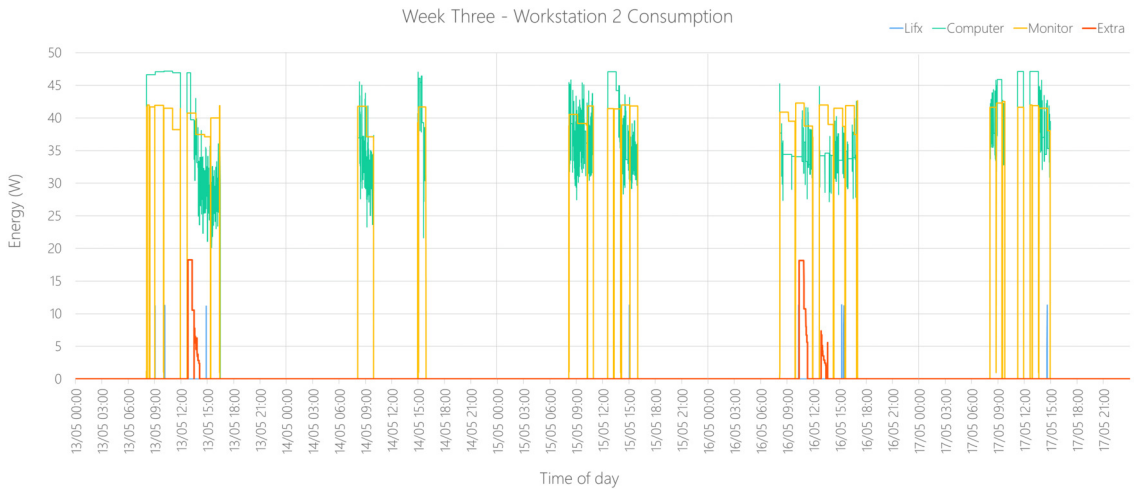


Figure 6.33: Week Three - Workstation 2 device consumption.

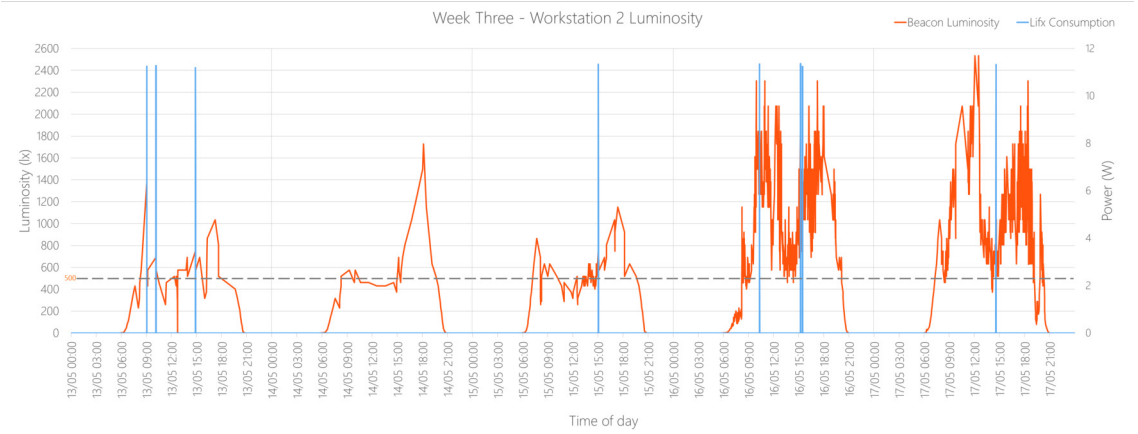


Figure 6.34: Week Three - Workstation 2 luminosity level and Lifx consumption.

disagreed (1).

When asked if they could change anything about the system, one responded that would like to have more opportunities to receive more tasks, and therefore earn more points.

Next, we enter our lighting section, we asked if it was easy to reach the suggested luminosity level of 500lx, the responses ranged from 2 (disagree) to 5 (strongly agree) with one person giving a 2, another a 3, four users gave it a 4 and two assign a 5. Following this question, we questioned them if they thought maintaining said level (500lx) required too much attention. Two people gave a 4 (agree), one said 3 (neutral) four said 2 (disagree) and one answered with a 1 (strongly disagree). We also asked them which methods they thought were better to maintain the 500lx, the winner was opening the blinds (6 votes), followed by desktop lights with 5 votes. Since some occupants were not able to reach the 500lx, we asked them why and they said they had to be constantly on LabRats to verify the level, because the difference is not perceptible to the naked eye.

Our third part is about indoor conditions, there were days where the temperatures

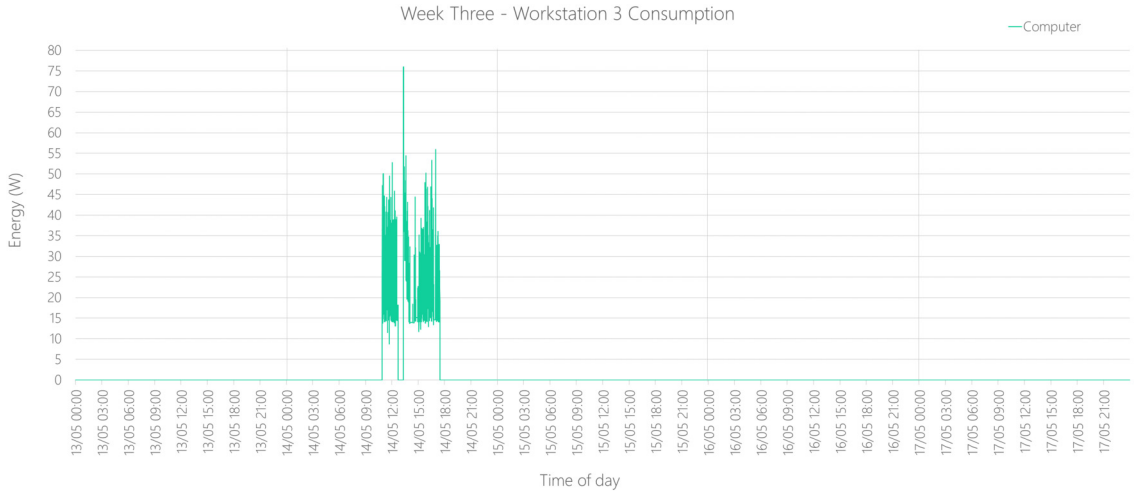


Figure 6.35: Week Three - Workstation 3 device consumption.

Figure 6.36: Week Three - Workstation 7 device consumption.

were extremely high. When asked if there were moments were they felt uncomfortable, three gave it a neutral response (3), another three gave a 2 (disagree) and the remaining two gave it a 1 (strongly disagree). After this question we asked them to describe these situations, all of them complained about the temperature, it was too hot in the warmer days, even though for some it cooled and was acceptable. For another participant it was too hot, when the windows were closed and the AC off, and was uncomfortable when the AC was on too low.

We noticed, in the heated days that no one would turn on the AC, we asked them to give us a reason why. Three said they did not want to ruin their chances to complete the challenges (3 individuals), other were not present (3 participants). Two felt observed and another two liked the temperature. They also said that turning on the AC provokes discomfort (1 person) and that as a group they decided it was not worth it. As mentioned above, there were some noisy parties near the room, we asked them if their concentration

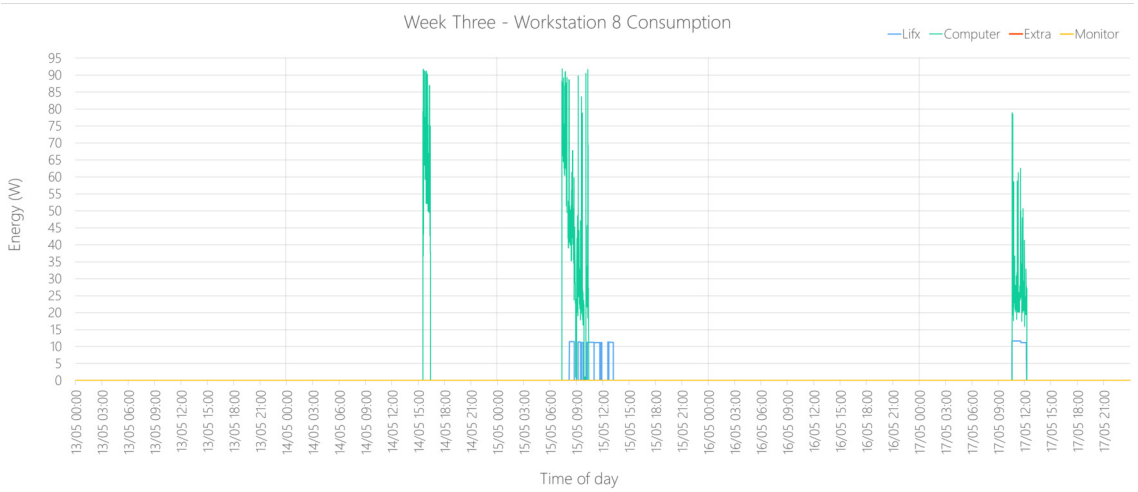


Figure 6.37: Week Three - Workstation 8 device consumption.

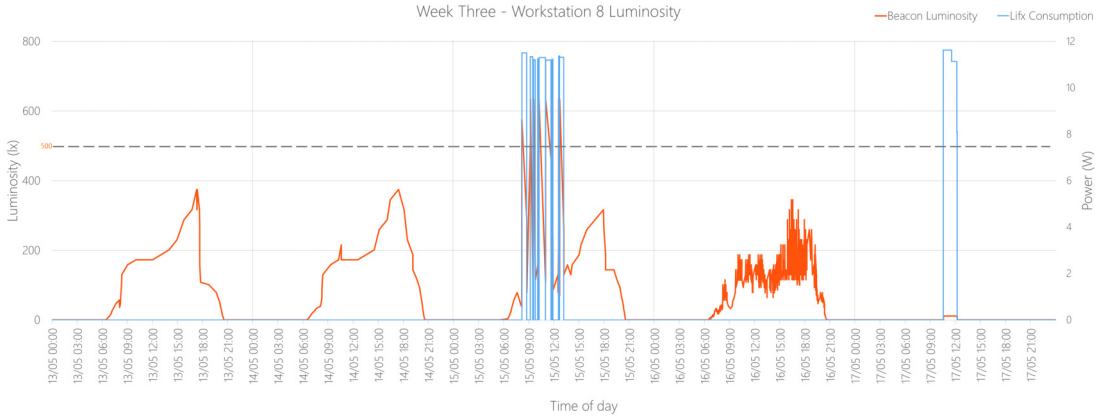


Figure 6.38: Week Three - Workstation 8 luminosity level and Lifx consumption.

was disturbed by it, three agreed (4), four strongly disagreed (1) and one had a neutral response.

The final question of the questionnaire were regarding well-being. We wanted to know if maintaining the luminosity level at 500lx was uncomfortable, five gave it a 1 (strongly disagree), two assigned a 2 (disagree) and one gave a neutral response (3).

We enquired them about the Kinect tasks, if they thought it was a good way to decompress. Four strongly agreed with the affirmation (5), two gave it a 4 (agree), one said neutral and the other remaining participant did not perform any tasks. These tasks were every two hours of the participant being sited, we asked them if they thought they were highly frequent three disagreed (2), two gave a 1 (strongly disagree) and another two gave it a 3 (neutral).

When we asked if they believed the prior two weeks with the Kinect tasks have had a positive impact on themselves and their overall health, one answered with a 5 (strongly agree), three agreed (4). Another three gave neutral responses (3) and one assigned a 1 (strongly disagree).

Figure 6.39: Week Three - Workstation 9 device consumption.

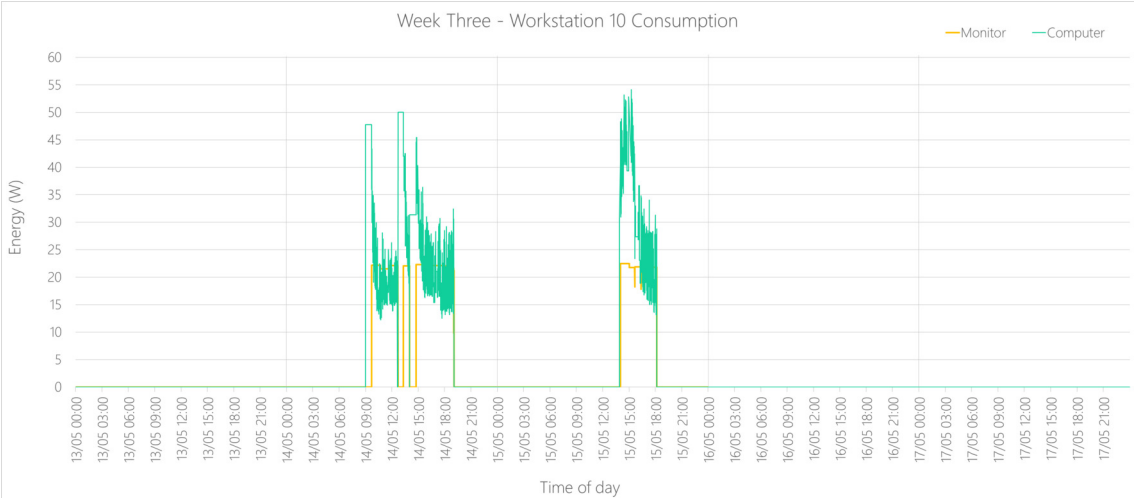


Figure 6.40: Week Three - Workstation 10 device consumption.

The two final questions were open response, the first asked what they would like to see implemented in the future on LabRats and the other any asked if they had any suggestions or comments. For the first question we receive responses asking for automated blinds with control through LabRats, a set of diverse exercises to do with the Kinect (exercises for the legs since they stay majority of they time on a chair). They also suggested a poll system to decide if certain devices should be turned on/off, more team bonding activities, mini prizes for points or reached levels. A customizable avatar where you could trade points for items for the creature, this avatar could also represent them on a group chat and you could do little actions with it, like flying or running. As for comments, they said they liked the system and really enjoyed the Kinect activities.

Table 6.5: Overview of the tasks requested on week three.

			Workstations								
			Wskt 1	Wskt 2	Wskt 3	Wskt 6	Wskt 7	Wskt 8	Wskt 9	Wskt 10	**Total tasks**
Week Three	May 13	Completed	0	3	0	0	2	0	0	0	5
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	May 14	Completed	2	0	1	0	0	0	0	3	6
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	May 15	Completed	1	1	0	0	0	0	0	1	3
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	May 16	Completed	1	3	0	0	0	1	0	0	5
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	May 17	Completed	1	0	0	0	0	2	0	0	3
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	
	Total	Completed	5	7	1	0	2	3	0	4	22
		Refused	0	0	0	0	0	0	0	0	
		Missed	0	0	0	0	0	0	0	0	

Table 6.6: Overview of the challenges performed on week three.

		Challenges		
		Individual	Group	Total
Week Three	Successful	2	1	3
	Unsuccessful	6	0	6
	Total	8	1	9

6.5.3.2 Week Three Observations

In this final week we had a better overall understanding of the impact of our game logic and the users behaviour, such as:

- To minimize the effects of the warm indoor conditions, the occupants opened the windows near them, even though there was just a slight breeze. This action had minimal impact in the indoor conditions, however to them it felt enough to instantly feel less heat;
- The high unbearable temperatures led some of the occupants to leave early, 1 to 2 hours before their normal leaving time. They preferred going home instead of turning the AC on;
- They get excited and enjoy doing the Kinect tasks, maybe because it is interactive or they feel more relaxed after stretching;
- There were no warnings created, either they did not understand the concept, did not check the new feature or they thought it was too complex;
- This week there was no strong wind, so opening the windows had little effect on the indoor temperature. Another factor is the direction of the wind, as we can see in Figure 4.1 our windows face Northwest and Northeast, so to create an air current effect the wind has to have certain directions. Furthermore, the building does not

offer the isolation or characteristics needed to provide a fresh ambience in days like these, being the only option the AC;

- There are three workstations that do not have a desktop lights, so to reach the 500lx from the individual challenge they could only rely on the blinds and the halogen ceiling lights. However, with the ceiling lights they cannot reach the 500lx, and they abstain themselves from turning them on because the lights turn on in pairs and affect the other individuals in the room. The occupants are aware of the impact of their actions in the rest of the people and know that certain situation make them uncomfortable;
- This was the week with the higher number of tasks. Given the feedback, the occupants did not felt overwhelmed by the requests of the system and really enjoyed stretching throughout the day;
- This week we can clearly see the behaviour change, almost all occupants remembered to switch off unnecessary devices and tried to keep their space well illuminated.

6.5.4 Aftermath

After the prior LabRats testing weeks, it was of great value to check if any of the behaviours acquired continued present on the daily routine of the occupants. The participants had been told the study had ended. It was a warm week with temperatures between 23°C/26°C with a minimum of 14°C. We noticed a decay in presence this week, the first day had five people, which we had before, however the rest of the week had around 2 to 3 individuals present and not all of them plugged in their devices (Figure 6.41). This might be due to personal work or since there was no current testing at the room they felt they did not have to go there. This was a short period to securely confirm behaviour changes, ideally this phase would last longer, unfortunately we did not have the time. We were looking for energy related changes, as well as luminosity level modifications, and also, because we are present in the room, we tried to notice if there were differences in their daily motion.

We start with Workstation 1, we can see that the computer was never unplugged or turned off when the individual went to lunch or outside, as shown in 6.42. On the third day (May 23) a new device was added to the workstation set, a monitor which was left on after the user left for the day, however this may not be the participant's fault, the power button of the device is broken so pushing does have no effect on the device. Regarding the light, the lamp was never on but the incident natural light had high values, the space was able to reach over 500lx most of the time, except for the May 22. We also noticed a slight increase of back and arm stretches, however always sitting down.

The individual from Workstation 2, depicted in Figure 6.43, had a promising start, on the first day the devices were turned of when the individual left, there were times

however the monitor went into stand-by with the user present, maybe was not connected with the computer. For the next three days the individual forgot the monitor on when leaving the room, with it consuming on and off 1 Watt, yet the user always switch it off at the end of the day. During lunch break on this day the computer was also left on, as it was on the following day. On the 24th of May the individual remembers again to switch off the computer when going to lunch, but forgets the monitor on. Regarding the light, as stated before this is a well lit space, easily reaching above 500 lx with the blinds half-way down with a small gaps, but there were some days with lower values which might be due to the angle of sun ray incision. We would also like to point out that this individual made an effort to get up from their seat, walk around the room, which was unusual and stretched more often.

Next, we can see in Figure 6.44 that Workstation 3 has power consumption almost at noon, however it was not from the respective occupant, another user mistakenly plugged in their device for around 3 minutes before noticing it and changing sockets. The Workstation 3 user did not leave the SmartLab until it was time to go home, however around 2:30 p.m. we can see that consumption reached 0 Watts, this might be caused by momentary detaching of the cable from the computer. The interior workstations do not have the best lighting, partially because the blinds were almost always half-way down and there are dividers between workstations, therefore reaching 500 lx is rare.

The individual from Workstation 9 arrived at 2:40 p.m., turned on their devices but we noticed the socket where the monitor was plugged in had issues and was not monitoring power consumption (Figure 6.45). This socket has had problems previously, so we said to the user to use a different one as we were going take advantage of the fact that the tests ended to try to fix it. We can also observe that the computer was turned on half-hour after the monitor and it was never off even when the individual left and switched off the monitor.

Workstation 10 did not leave the room, so the devices were always plugged in, around 12:25 p.m. the individual opened the blinds which slowly increased the space lighting throughout the afternoon (Figure 6.46). This workstation is the last window on the Northeast side so it only begins to really catch direct sunlight a while after noon, which explains the low levels of light and also justifies the peaks of the 3000 lx, since it is sun expose all afternoon until the sun goes down. We also notice a change in activity from this user, now they would get up, walk and stretch, a couple times during the day, which was not usual.

6.5.4.1 Aftermath Assessment

Since it passed a week from using LabRats we wanted to know if the experience has had any impact in their routines and if they missed any elements from the application. We created a small form with 3 questions and a follow-up open answer (E). We gathered 8 responses, so the total number of participants in the study, however not all of them were

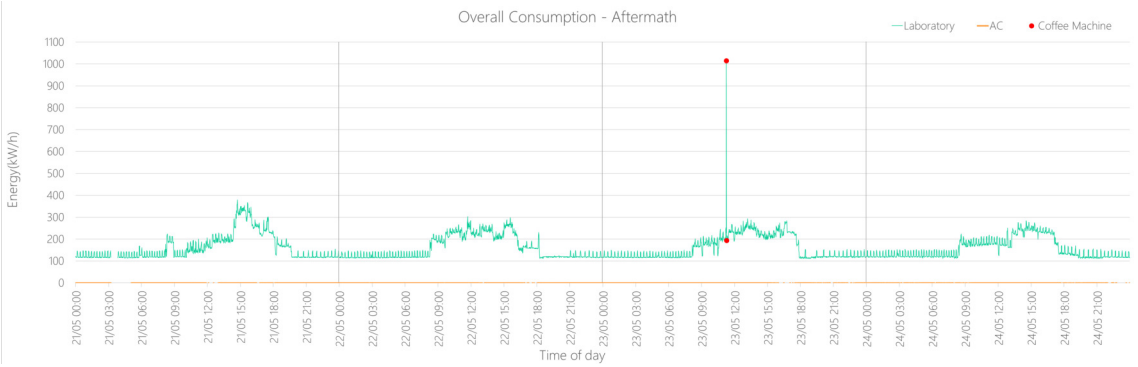


Figure 6.41: Aftermath - General energy consumption and AC consumption.

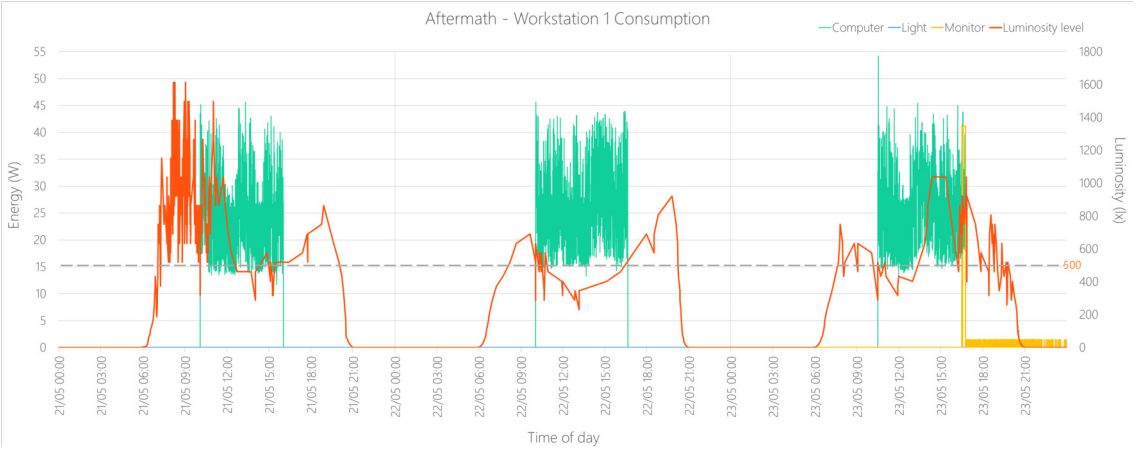


Figure 6.42: Aftermath - Workstation 1 device consumption and luminosity level.

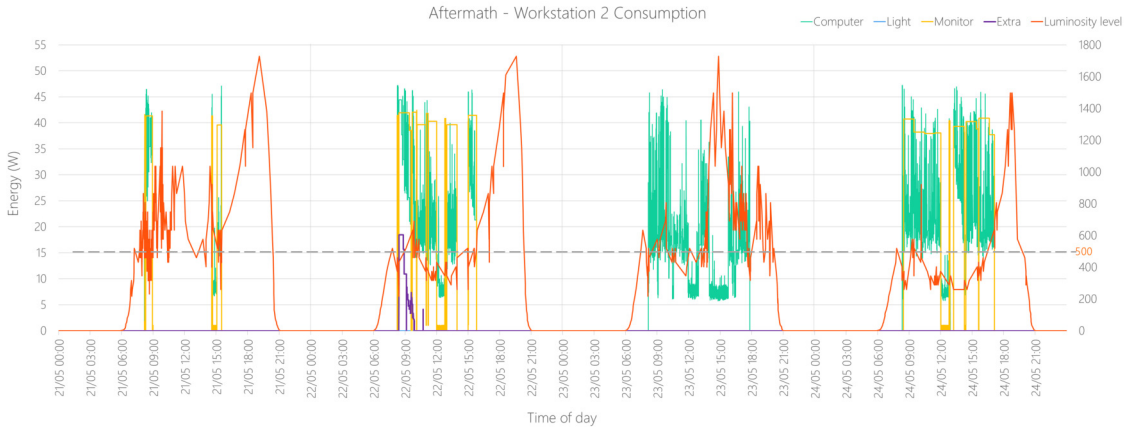


Figure 6.43: Aftermath - Workstation 2 device consumption and luminosity level.

in the SmartLab this week, but knowing if it affect their home routine was also important to us.

We started by asking if they missed being able to track indoor and outdoor conditions, to which they responded with: one disagree (2), two neutrals (3), four agrees (4) and one strongly agree (5).

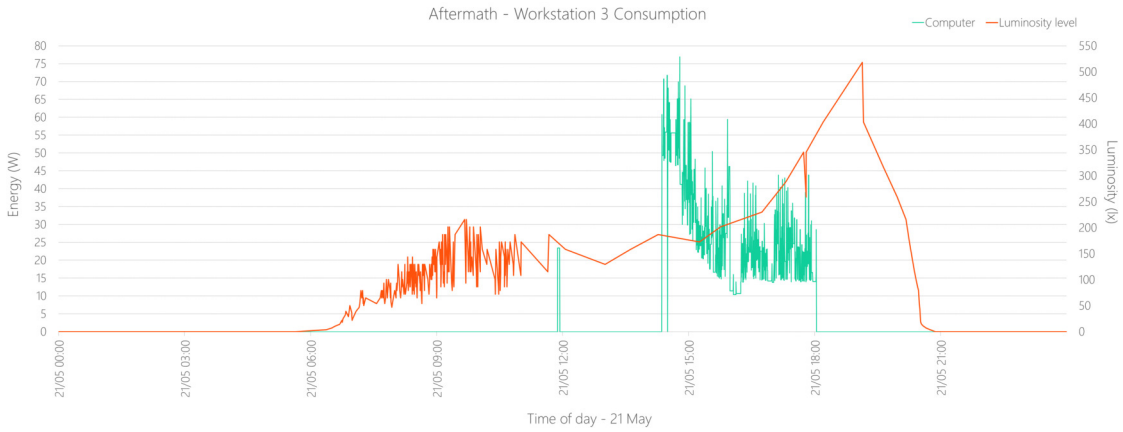


Figure 6.44: Aftermath - Workstation 3 device consumption and luminosity level.

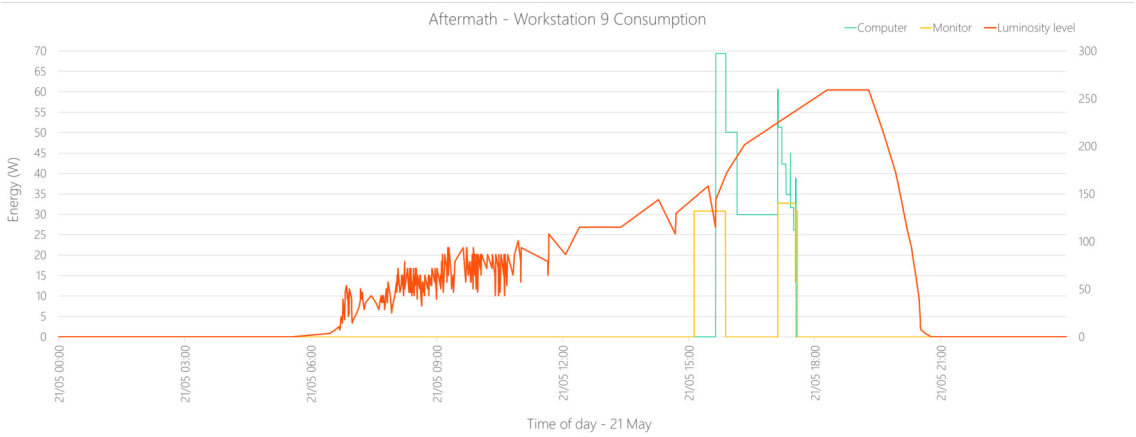


Figure 6.45: Aftermath - Workstation 9 device consumption and luminosity level.

The next questions was about their comfort, if they noticed any differences between the LabRats testing weeks and the aftermath week. This was an open answer question, three people said no, another individual stated that they weren't present, two users complained that the light conditions were worst. Another interesting answer was given by one participant that said that they ended up staying more time sited and forgetting to get up from time to time, the last individual responded saying the comfort levels from the aftermath week were a bit lower compared to the previous. Some also noticed differences but would not say it translated to a noticeable variation.

The final statement asked if they believed this experience with LabRats had changed their daily habits, five people assigned a 5 (agree) and three save 3 (neutral). This question had a follow-up in which we asked them to state which habits did it change, the most popular answer involves light. The users said they now tried to monitor and make sure their workplace is well illuminated, one of them stated that they knew sometimes the lighting was insufficient but because they were in shared spaces they would abstain from taking action. Another frequent answer was that they now tried to turn off the equipment when they left the room, especially at lunch time, however, sometimes they forgot and

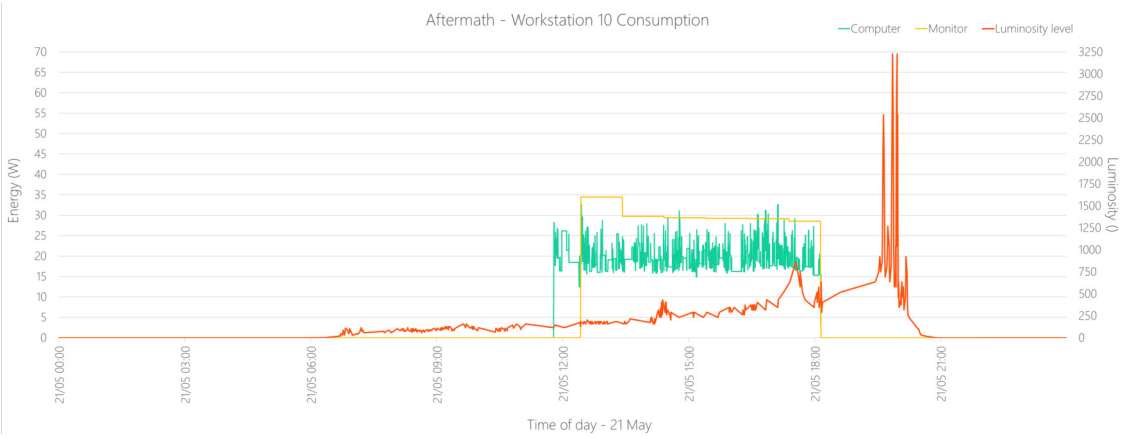


Figure 6.46: Aftermath - Workstation 10 device consumption and luminosity level.

said LabRats reminded them to do so. Also, LabRats was useful because it had tasks that "forced"them to move a bit, this person said while they now tried to move more, they would forget to turn their devices off. One user discovered their computer was super efficient and did not consumed energy when on sleep mode or when it is not charging, so they did not unplug the device when leaving.

6.5.4.2 Aftermath Observations

The aftermath period gave us a different view of the impact of LabRats, we noticed:

- The users were more often in the SmartLab during testing phases, which could be linked to their will to help gather data and/or they felt engaged with the system, wanted to participate and win points;

- Some occupants felt differences regard lighting but their behaviour did not change, they would not turn on the lights (ceiling or desktop) and never opened the blinds fully, with only a few people adjusting them. The latter might be due to reflection or direct heat source;

- They tried to remember to unplug/turn off their devices, sometimes they would forget or maybe they did not bother to do it. An important point to make is that not all occupants left the room, so we do not have data to state if they left they would do it or any indications that they adopted this behaviour at their other working places. In spite of these facts, we can also denote that some remembered to unplug and while they might not have done it with all the devices, at all times, when they left for the day all the devices would be off (except the broken button monitor);

- Users tried to be more active and take breaks while working, an increase of awareness that could have developed from the Kinet tasks;

- Faulty equipment can be a cause to unnecessary energy consumption, even though in our case it was not a high value that was consumed, all these amounts accumulated at the end cause an impact and it requires a simple action to change it;

- The participants missed the system, it served as a reminder for them to unplug and stop their work for a few minutes to move and change positions.

6.6 Threats to Validity

During our testing phases we came across some aspects that posed a threat to our research, consequently influencing our results, however some of them are out of our control.

- **Beacon** – this device is on the table surface and sometimes the occupants cover it with their items, which leads to random very low values and at the moment the only solution is for the occupant to notice. Another issue is that they operate with batteries, which means that when the load end they stop working and therefore create a lack of data for a unknown period;

- **Outdoor luminosity sensor** – this device is very sensitive to alterations and light reflection, as you can see in Figure 4.1 it is next to a window. Plus it has to be in an angle to get accurate readings, to achieve this there is an improvised structure that unfortunately it is not sturdy, so any disturbance can change the position and therefore compromising our data. It is also important to state that the room is at a forward edge of the building and this sensor monitors the light on one side, there are workstations that are affected by the windows perpendicular to the sensor and that have a part of the building creating some shade, which might influence the indoor luminosity levels and comparisons between indoor/outdoor;

- **Network/Energy** – our IoT system needs energy and internet to function, so if there is a communication problem or an blackout we might lose connection, meaning the system might need to be reconfigured and some data might be lost;

- **Occupants** – to conduct these type os studies we need to have participants that are present in the room in order for us to gather data, inconstant presence and low number of subjects does not allow us to connect dots amongst the data or reach secure conclusions. Another factor that threatens our results is not following the rules set up by the study, in this case we asked them to plug in their devices to the outlets whenever they were in the room, for us to know they arrived, and they also forgot to click on the check in button. The subjects do not check the outlet feedback, to confirm whether the data is being obtained or not. These two factors might compromise presence validation and result in a lack of consumption data.

Also, occupant's participation and actions might be influenced by the fact that they know they are being monitored and because they want to help the tester;

- **Room devices** – our system its dependent of several devices that can at any time stop working or stop communicating with their agent, which means we will not get the data or we will not be able to change their state, for example an outlet stops returning data or the AC stopped working. This type of events might go unnoticed and force a do-over on testing, so either a possible occupant notices it when it happens or the administrator when performing a verification routine;
- **External people** – this is a shared space, new people can enter the room's list without the existing occupants being aware, the new users might not become part of the study and start using the room as they please without acknowledging the limitations they face. This type of behaviour jeopardizes the information that is being collected and therefore the overall study. Additionally, the cleaning team is another element to keep in mind, they are not aware of the equipment, sometimes cleaning something falls on the floor or the cable disconnect, which will put the study in danger since there will be gaps on the data and might force a do-over. In order to minimize the risks, we talked to the cleaning team and placed a sign on the door with brief instructions, we also had several notes around the room stating "Do not touch"and "Occupied";
- **Atmospheric conditions** – to be able to fairly compare different scenarios, ideally we needed to be in similar weather conditions to safely compare daily impacts, given that there might be a time limit.

6.7 Summary

In the previous sections we discussed the results of the different phases of our research, we also stated some threats to our system. In the following chapter, we will sum up our discoveries, contributions and discuss future work.

Chapter 7

Conclusion

These are the final sections of this dissertation, we will close with a summary, state our contributions and present the possible future directions of this research.

7.1 Summary

In this dissertation, we proposed a gamified application that aimed to establish better communication between the occupants and the system to increase occupant's engagement with better reliability and energy habits. We studied the behaviour of the occupants, their profile and preferences. We have also observed the performance of the room as a system to have a better insight. Given this information, we created our game logic and developed a platform that was able to communicate with the previously implemented SmartLab system, which gathers information about the indoor and outdoor conditions. Besides being functional and capable of establishing communication with the other room components, we had to make sure the application was intuitive and appealing. After a long period of research and various optimizations, we reached our final product, LabRats, a functional web application available to all the SmartLab occupants.

We tested different scenarios in the SmartLab, we started with tests to gather initial data for comparison and then moved forward to LabRats specific data. All of these phases allowed us to better understand what we wanted, what could be added and how our occupants operate daily. Based on all of the information we analysed, we drawn our conclusions and discusses the possible future adjustments that can be made and new elements that should be add to enrich the solution.

After analysing, we can observe a learning effect, followed by a change of habits with some behaviours being adopted by the individuals after the end of the testing phases. We can also see that the tasks were a success, specially the Kinect tasks. We also believe the

occupants become more aware of their space, conditions and actions. They tried to seek healthier conditions, pay more attention to their devices, and also take more breaks and stretch more.

From the data and feedback we were given, we can also say the suggested healthier conditions and activities still provided a comfortable environment from the occupants perception. The occupants also enjoyed using the system and did not feel like it was too demanding or disruptive. Given all the information gathered, we can verify an increase in participation and interaction with the system, which led to a reduction in energy consumption.

To conclude, although with some threats, our solution showed a positive tendency in the people's engagement and in energy savings.

7.2 Contributions

The main contributions of this research are the developed game logic, one of a kind for Home Automation Systems with the Human-in-the-loop. The logic was thoroughly examined, and the resulting analysis of our tests regarding luminosity conditions and user comfort. Throughout this document, we presented various systems and frameworks, that can be used as comparatives to other future systems or even serve as a foundation to a new one. Our system, even though it is adapted to work with the existing WSO2 platform, it is developed to be easily integrated with others, requiring only to the change endpoints.

We believe the reliability was increased with our game logic, for the time tested, majority of the participants responded to the system's requests.

We reached some important conclusions concerning user awareness, regarding healthy workplace settings and consumption. As stated in Subsection 6, some occupants began to move more and stretch throughout the day and when questioned they felt differences when the LabRats ended and tried to adopt healthier behaviours in their daily routine. It is also important to mention that, as shown in the Chapter 6, occupants started to pay attention to their energy usage, unplugging/turning off their devices when not in use.

We were also able to point out the the effects that the room's layout has in a shared workplace environment, as well as consequences of the infrastructures and state of the material.

Our work also allowed us to have a published paper in the 2019 Computer Software and Applications Conference Proceedings.

7.3 Future Work

In the future, we would like to improve the user interface technology and enrich the game logic in the same scenario. It is a dynamic environment and the evolution of the

users' behaviour pattern, as well as the dynamic change of the setup of the room, might bring us more insights.

We think it would also be important to test the solution in different scenarios and contexts with varying gamification features and compare the outcome, analyse which scenarios achieved better results and how does it relate to the different types of occupants' personalities and usage patterns. The developed game logic has a set of gamification elements that are based on the feedback of the current occupants of the room. However, an effort should be made to generalise it to other users and contexts. It would be interesting to explore a solution that can be ready to adapt dynamically, either triggered by the changes in the context or the potentially perceived loss of engagement with time.

We are also curious to see the evolution of the system throughout the four seasons, how does the behaviour change and we would be able to better assess the long-term results of using such a system.

Furthermore, we think there are elements that need to be improved in the current system, regarding material, presence and engagement. We would like to implement new features, for example badges. Badges represent user's achievements. They are an additional way to reward good performance. An achievement could have several stages and according to it, the corresponding badge will change. For example, there is an achievement for point build-up, if the player reaches ten points, a stage one badge will be added to the collection. The player wins a second stage badge when fifty points are collected and finally the third badge for one hundred, this is shown in 7.1. We believe the implementation of badges would have a positive impact in the adoption of new habits, since they would want to reach the next level and in some cases to do so they would have to have a constant behaviour (e.g.: number of consecutive days of switching off the monitor). The user is supposed to collect all the badges available and upgrade them to the highest stage. The collection will act as a portfolio of conquests, a way to corroborate player's skills and achievements. It would be also interesting to have a set of special badges, as "easter eggs"[1] for collectors, these would be special items that celebrated a certain event.

Besides the badges, we have two other ideas. The first one is a quizz, the user would have answer to questions related to environmental issues, good practices or general culture to win some points. The points could have a fixed value or awarded according to the speed of the answer, for example every user has 15 seconds to respond if they answer with 10 seconds left, they would win 10 points.

We also might have a solution for the check in/check out problem, we could use sensors that read the student's card to know if they are present or not. Passing the card alone will not solve the problem because sometimes people enter with their friend or someone who is leaving opens the door, for this idea we needed two sensors. One sensor is already in place, the one that opens the door, we needed one inside near the door which they would have to use to get out and ,in case they forgot to pass on the entry sensor, they

[1] An intentional inside joke, hidden message, or secret feature of a work.

would have to pass to give their devices power to function. If they do not pass the card, they will not have energy and therefore will not be able to work, and all of it requires a simple swipe on a sensor.

During the testing phases we found that the success of the challenges was compromised because the users would not be at the SmartLab for the entire duration of the mission. We believe the system would benefit from knowing when the occupants are going to be there, so adding a feature that allows the user to choose the days they will be present would make it possible to create custom challenges for each user. If for some reason the occupant knew they would not be able to be there, they could alert the system, which would split the challenges into intervals.

Regarding wellness at work, we would like to move forward and create a more complex system with a variety of exercises, involving the whole body, and that follows established regulations. We would also like to add a more aggressive approach, throughout the day the participants could delay the exercise request a fixed number of times or for a certain period, when that limit is reached and they try to delay again, their devices would freeze forcing them to get up and move.

We also have some ideas to facilitate and assess the good functioning of the SmartLab. Starting with maintenance tasks that aimed to distribute and more efficiently take care of the room components, these tasks would display a different lamp colour for the users to distinguish. The tasks could be check aquarium's water level, clean the aquarium, check and change batteries or simply check if all of their workstation devices are returning values. These would be high reward/heavy penalty tasks, this is a share space, a well functioning system is of everyone's interest so who refused to do it would be greatly penalized. Additionally, the occupants could spot strange device behaviour so they should have the opportunity to report malfunctioning to the system, they would only have to state the issue and then someone would analysed and fix it. Another useful idea is having alarm functions for the devices, whenever the server recognized odd values, it would start an alert protocol that would send an email alert and if there were people in the room, it would start flashing the desktop lights, or if the system was capable of resolving the issue by itself, it would ask an administrator for permission to proceed. Just to give a few examples of possible situation, imagine we were on the middle of the day with high luminosity values and all of the sudden very low lumens or there was a power break and the light's agents stop working or the connection to the server was lost.

Figure 7.1: The badges for every stage of the point build-up achievement.

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Appendix

A

Questionnaire

Laboratory Users

Hello!
This questionnaire is part of my MSc thesis about interaction with gamified systems and aims to learn more about the habits and preferences of the users of the Laboratory.
This form is completely anonymous and the information gathered will be used as a case study for the thesis.
Thank you very much for your help =)

P.S.- All the questions are about the work you do related to the university, like working on your dissertation.

* Required

1. **Age** *
Mark only one oval.

- ◯ 18 - 22
- ◯ 23 - 27
- ◯ 28 - 32
- ◯ 33 - 40
- ◯ > 40

2. **I work on my dissertation ...** *
Mark only one oval.

- ◯ Part-time *Skip to question 5.*
- ◯ Full-time *Skip to question 3.*
- ◯ I'm not a student *Skip to question 8.*

3. **How many days per week do you spend working on your thesis at ...** *
Mark only one oval per row.

	0 days	0.5 - 2 days	2.5 - 4 days	4.5 - 6 days	6.5 - 7 days
Home	◯	◯	◯	◯	◯
Laboratory	◯	◯	◯	◯	◯
Other places	◯	◯	◯	◯	◯

4. **If you work in other places, please tell us where**

_____

_____

_____

_____

_____

Skip to question 6.

5. **Do you have availability to work from the Laboratory more often?** *
Mark only one oval.

- ◯ Yes *Skip to question 7.*
- ◯ Mabye *Skip to question 7.*
- ◯ No *Skip to question 8.*

6. **What are the main reasons that lead you to work from home?** *
If you don't work from please choose the Other option and write NONE.
Check all that apply.

- ☐ It's more comfortable
- ☐ Everything i need is at arm's reach
- ☐ I can focus better
- ☐ No costs
- ☐ I can do other tasks (not work related)
- ☐ I can do all my work from home
- ☐ I'm too lazy to move
- ☐ Other: _____

Skip to question 7.

7. **What could be done to improve the Laboratory?** *
Please write all your suggestions (e.g. more comfortable chairs, quiet environment)

_____

_____

_____

_____

_____

Skip to question 8.

8. **Do you find beneficial working in a group dynamic?** *
Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Sometimes

9. **Do you normally discuss your work with your colleagues from the lab?** *
Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Sometimes

Skip to question 10.

10. **Do you like to use gamified systems?**
Mark only one oval.

- ◯ Yes *Skip to question 11.*
- ◯ No *Skip to question 12.*
- ◯ Never used one *Skip to question 13.*
- ◯ No opinion *Skip to question 13.*

11. **Tell us what do you like about them?**

_____

_____

_____

_____

_____

Skip to question 13.

12. **Tell us the main reasons that lead you to dislike gamified systems**

_____

_____

_____

_____

_____

Skip to question 13.

13. **Do you use a system with any of the following characteristics?** *
Check all that apply.

- ☐ You compete against other users or friends
- ☐ You can earn rewards, like points, badges
- ☐ You have a team and work with them to achieve a goal
- ☐ You change levels according to your performance
- ☐ You have an avatar and you can change the looks of it
- ☐ You can trade currency for services or items
- ☐ The app shows you performance statistics
- ☐ You can talk with other users through social forums or team chats
- ☐ You have a set of challenges or quest that you can complete
- ☐ The app ranks users by performance
- ☐ The app displays a progress bar
- ☐ You have a score
- ☐ Other: _____

Skip to question 14.

14. **Which of the following gamified systems do you find interesting or are you already a member?** *

Mark only one oval per row.

	Not interesting	Might be interesting	Very interesting	Already an active member
Waze - receive real-time information about traffic and change your avatar.				
Nike+ RunClub - Track your runs, get coaching that adapts to you and compare your performances.				
Untappd - Discover and share great beers, breweries, and venues with your friends, while earning badges for exploring beers of different styles and countries.				
TripAdvisor - share your experience, level up and trade some points.				
LinkedIn - expand your network, check the progress of your profile page and get some advice.				
StackOverflow - earn points, badges while helping others.				
Loyalty programs - get access to special offers, discounts.				
Pacer - your walking buddy and fitness coach, track, join a group, compete with your friends and try to stay at the top of the leaderboard.				
Duolingo - learn a new language, unlock subjects and set goals.				

15. **Are you a member of another gamified system? What's it called?**

16. **Which of these elements are more important to you?** *

Please choose 3 elements
Check all that apply.

- [ ] Competition, where the user is allowed to compete against other users or a group of friends
- [ ] Leaderboards, where the user can see how well he/she is doing comparing to others
- [ ] Teamwork, when the user has to join a group and work with the team to achieve goals
- [ ] Levels, according to the performance, the user may level up or down
- [ ] Social Forum, a place where the user can talk with other members
- [ ] Real-time feedback, the system displays charts analysing the user's actions or small messages about performance
- [ ] Customisation, the user can change the looks of an avatar
- [ ] Rewards, after doing some tasks, the user earns some rewards (e.g. points)
- [ ] Quests/challenges, the user has a couple of missions to complete
- [ ] Achievements, after doing missions or reaching a certain point, the user conquers an achievement
- [ ] Other: _____

Skip to question 17.

17. **In your opinion, is it important to manage energetic efficiency?** *

Mark only one oval.

- ◯ Yes
- ◯ Maybe
- ◯ No

18. **Do you think we can achieve a more planet-friendly lab with the use of a gamified system?** *

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Maybe

19. **What kind of ideas would you implement if you had to do a gamified system for the lab?** *

_____

_____

_____

_____

_____

20. **What do you think about establishing a gamified system in the laboratory? Would you work there more often?** *

21. **What type of rewards would you like to get for participation and good performance?** *
Check all that apply.

- [ ] Gift Card
- [ ] King/Queen of the Lab title
- [ ] Unlock special items
- [ ] Special priviledge card
- [ ] Entry for a giveaway of a special prize
- [ ] Points for trading
- [ ] Trophy
- [ ] Donation in your name to a charity
- [ ] Other: _____

APPENDIX B

Luminosity Level Assessment

Luminosity level

The aim of this form is to better understand your experience these past few days, trying to maintain the luminosity level at 500 lx.
Thank you so much for participating!

* Required

1. **What's your workstation?** *

2. **What's your age gap?** *
   Mark only one oval.
   - 20 - 24 years old
   - 25 - 29 years old
   - 30 - 34 years old
   - 35 - 40 years old

3. **Was it difficult to find ways to increase/maintain the luminosity level?** *
   Mark only one oval.
   - Yes
   - No
   - Sometimes

4. **To achieve the suggested level of luminosity, what did you do?** *
   Check all that apply.
   - Open the blinds
   - Turn on the ceiling lights
   - Turn on the desktop lights

5. **Did you find that maintaining the suggested luminosity level (500 lx) required too much attention?** *
   Mark only one oval.

	1	2	3	4	5	
Not at all						It was very disruptive

6. **Do you have any eye related problems? If so write it bellow**
   e.g.: myopia, astigmatism, etc

7. **Do you suffer any side-effects from working long hours in front of a computer in low light environments?** *
   e.g.: headaches, eye strain, etc
   Mark only one oval.

   - ◯ Yes *Skip to question 8.*
   - ◯ Sometimes *Skip to question 8.*
   - ◯ No *Skip to question 9.*

Untitled Section

8. **Do you think that maintaining the light at 500 lx helped reduce/weaken the experienced side-effects?** *
   Mark only one oval.

	1	2	3	4	5	
No, it got worse	◯	◯	◯	◯	◯	Yes, it helped a lot

Untitled Section

9. **Do you think the proposed luminosity level (500 lx) helped your productivity?** *
   Mark only one oval.

	1	2	3	4	5	
On the contrary	◯	◯	◯	◯	◯	Definitely

10. **From 1 to 5, how relevant do you believe maintaining a healthy luminosity level at the work place is?** *
    Mark only one oval.

	1	2	3	4	5	
Not relevant	◯	◯	◯	◯	◯	Highly relevant

APPENDIX C

WEEK ONE ASSESSMENT

Test Phase One

The aim of this form is to better understand your experience with LabRats in the first phase of testing (30 April - 3 May).
Thank you so much for participating!

* Required

1. **I think that I would like to use this system frequently** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

2. **I found the system unnecessarily complex** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

3. **I thought the system was easy to use** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

4. **I think that I would need the support of a technical person to be able to use this system** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

5. **I found the various functions in this system were well integrated** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

6. **I thought there was too much inconsistency in this system** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

7. **I would imagine that most people would learn to use this system very quickly** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

8. **I found the system very cumbersome to use** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

9. **I felt very confident using the system** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. **I needed to learn a lot of things before I could get going with this system** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

11. **I thought the system was fair** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

12. **i think the system disrupted my workflow too often** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

13. **Any suggestions, comments or improvements leave them down below**

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APPENDIX D

WEEK THREE ASSESSMENT

LabRats Experience

Hello!
During the last three weeks you have been using LabRats, a system create as part of a MSc thesis.Now that the testing phase is over we would like to better understand your experience and your thoughts on the subject.
This form is completely anonymous and the information gathered will be used as a case study for the thesis.

Once again thank you so much for your help !

* Required

1. **Age** *
   Mark only one oval.

   - 18 - 22
   - 23 - 27
   - 28 - 32
   - 33 - 40
   - > 40

2. **I found using LabRats helpful, it allowed me to know how much i was consuming and my workstation conditions.** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

3. **I found the concept of LabRats interesting.** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

4. **I enjoyed participating in the challenges and the tasks.** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

5. **The system motivated us to work more as group.** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree						Strongly agree

6. **I think the challenges were easy to complete successfully.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

7. **The system requested too many tasks.** *
e.g.: opening the blinds or windows, stretching
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

8. **The system disrupted my work flow too often.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

9. **If i could change anything about the system, I would...**

Regarding the lighting

10. **It was easy to reach the suggested luminosity level (500 lx).** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

11. **I think that maintaining the suggested luminosity level (500 lx) required too much attention.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

12. **Which methods do you think were better to maintain the 500lx?** *
Check all that apply.

- [ ] Desktop Light
- [ ] Ceiling Lights
- [ ] Opening the blinds
- [ ] Other: _____

13. **If you weren't able to keep up the 500lx, tell us why**

_____

_____

_____

_____

_____

Regarding the indoor conditions

14. **During the testing phase, there were times where the indoor conditions were uncomfortable.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

15. **Please share with us the moments you felt uncomfortable**

_____

_____

_____

_____

_____

16. **Last week the inside temperature was extremely high and opening the windows had little effect, however the AC was never turned on. What was your reason for not switching on the AC?** *
Check all that apply.

- [ ] I didn't want to ruin the chances of completing the challenge
- [ ] I felt i was being observed
- [ ] I liked the temperature
- [ ] I wasn't present
- [ ] We discussed it and reached the conclusion it wasn't necessary
- [ ] Other: _____

17. **My workflow and concentration were disturbed by the outside noise.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

Regarding well-being

18. **Keeping my workstation with 500lx made me uncomfortable.** *
e.g.: headaches, eye strain
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

19. **I think the Kinect tasks were a good way to decompress.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

20. **The Kinect tasks were highly frequent.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

21. **I believe that the last two weeks had a positive impact in me and my overall health.** *
Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

22. **After the LabRats experience, is there anything that you would like to see implemented in this system in the future?**

23. **Any suggestions, comments or improvements leave them down below**

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APPENDIX E

AFTERMATH ASSESSMENT

LabRats Aftermath

Hello once again!

As a final request, to close our LabRats Experience, we kindly ask you to answer this quick questionnaire. We are curious to know how was your experience this last week(20-24 May), the first week without LabRats.
This form is completely anonymous and the information gathered will be used as a case study for the thesis.

Thank you so much for your help !

* Required

1. **1. I missed being able to keep track of the indoor/outdoor conditions.** *
   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

2. **2. Did you notice any differences in your comfort levels between the LabRats weeks and this past week(20 - 24May)?** *
   If you did please share with us your observations, tell us in which areas did you felt the differences

   _____

3. **3. I believe the LabRats Experience changed my daily habits.** *
   Mark only one oval.

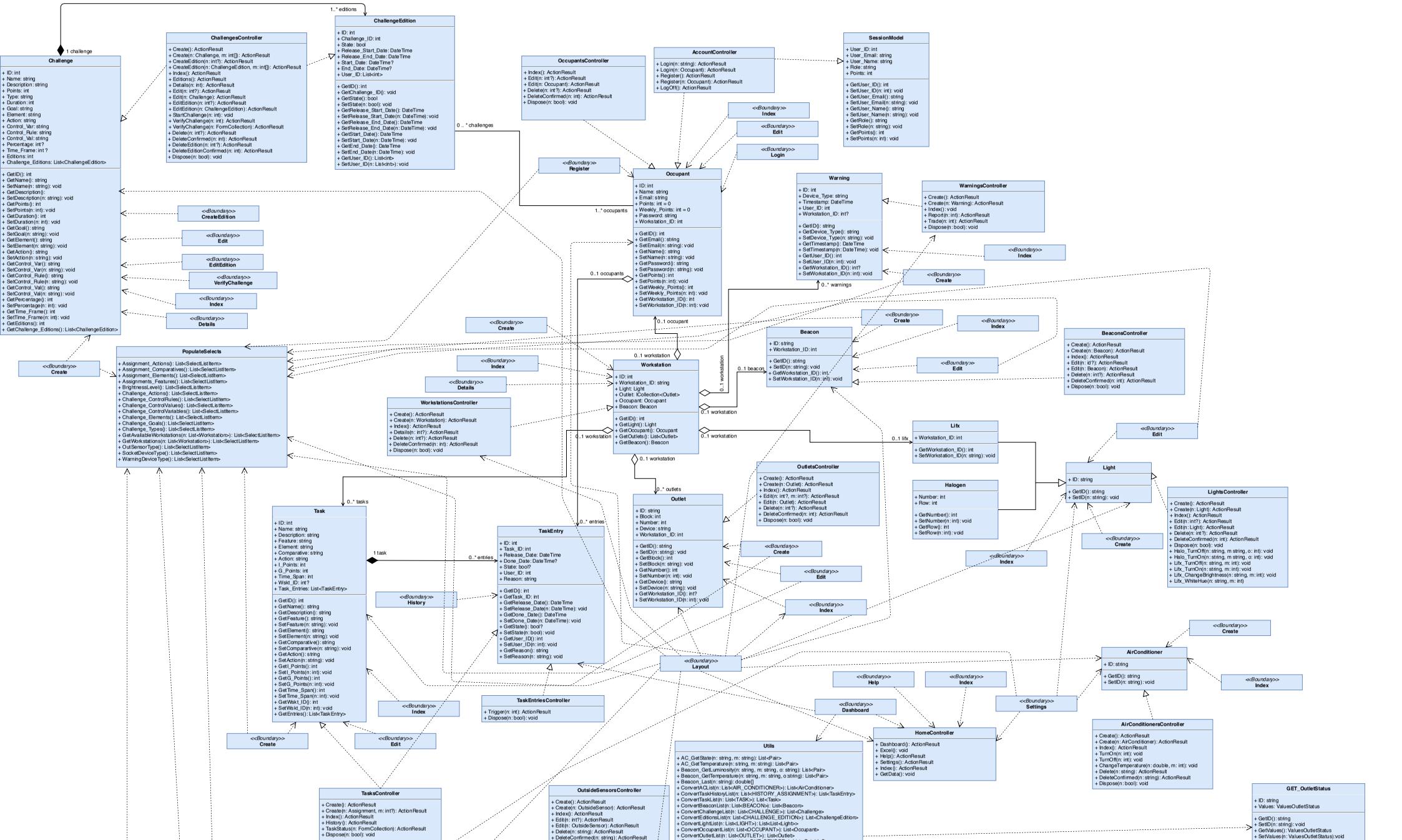
	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

4. **If it did, which habits did it change**

   _____

ANNEX I

LabRats Class Diagram


Challenge
+ ID: int
+ Name: string
+ Description: string
+ Points: int
+ Type: string
+ Duration: int
+ Goal: string
+ Element: string
+ Action: string
+ Control_Var: string
+ Control_Rule: string
+ Control_Val: string
+ Percentage: int?
+ Time_Frame: int ?
+ Editions: int
+ Challenge_Editions: List<ChallengeEdition>
+ GetID(): int
+ GetName(): string
+ SetName(n: string): void
+ GetDescription():
+ SetDescription(n: string): void
+ GetPoints(): int
+ SetPoints(n: int): void
+ GetDuration(): int
+ SetDuration(n: int): void
+ GetGoal(): string
+ SetGoal(n: string): void
+ GetElement(): string
+ SetElement(n: string): void
+ GetAction(): string
+ SetAction(n: string): void
+ GetControl_Var(): string
+ SetControl_Var(n: string): void
+ GetControl_Rule(): string
+ SetControl_Rule(n: string): void
+ GetControl_Val(): string
+ SetControl_Val(n: string): void
+ GetPercentage(): int
+ SetPercentage(n: int): void
+ GetTime_Frame(): int
+ SetTime_Frame(n: int): void
+ GetEditions(): int
+ GetChallenge_Editions(): List<ChallengeEdition>
1 challenge
1..* editions
ChallengesController
+ Create(): ActionResult
+ Create(n: Challenge, m: int[]): ActionResult
+ CreateEdition(n: int?): ActionResult
+ CreateEdition(n: ChallengeEdition, m: int[]): ActionResult
+ Index(): ActionResult
+ Editions(): ActionResult
+ Details(n: int): ActionResult
+ Edit(n: int?): ActionResult
+ Edit(n: Challenge): ActionResult
+ EditEdition(n: int?): ActionResult
+ EditEdition(n: ChallengeEdition): ActionResult
+ StartChallenge(n: int): void
+ VerifyChallenge(n: int): ActionResult
+ VerifyChallenge(n: FormCollection): ActionResult
+ Delete(n: int?): ActionResult
+ DeleteConfirmed(n: int): ActionResult
+ DeleteEdition(n: int?): ActionResult
+ DeleteEditionConfirmed(n: int): ActionResult
+ Dispose(n: bool): void
ChallengeEdition
+ ID: int
+ Challenge_ID: int
+ State: bool
+ Release_Start_Date: DateTime
+ Release_End_Date: DateTime
+ Start_Date: DateTime?
+ End_Date: DateTime?
+ User_ID: List<int>
+ GetID(): int
+ GetChallenge_ID(): void
+ GetState(): bool
+ SetState(n: bool): void
+ GetRelease_Start_Date(): DateTime
+ SetRelease_Start_Date(n: DateTime): void
+ GetRelease_End_Date(): DateTime
+ SetRelease_End_Date(n: DateTime): void
+ GetStart_Date(): DateTime
+ SetStart_Date(n: DateTime): void
+ GetEnd_Date(): DateTime
+ SetEnd_Date(n: DateTime): void
+ GetUser_ID(): List<int>
+ SetUser_ID(n: List<int>): void
0 .. * challenges
OccupantsController
+ Index(): ActionResult
+ Edit(n: int?): ActionResult
+ Edit(n: Occupant): ActionResult
+ Delete(n: int?): ActionResult
+ DeleteConfirmed(n: int): ActionResult
+ Dispose(n: bool): void
AccountController
+ Login(n: string): ActionResult
+ Login(n: Occupant): ActionResult
+ Register(): ActionResult
+ Register(n: Occupant): ActionResult
+ LogOff(): ActionResult
SessionModel
+ User_ID: int
+ User_Email: string
+ User_Name: string
+ Role: string
+ Points: int
+ GetUser_ID(): int
+ SetUser_ID(n: int): void
+ GetUser_Email(): string
+ SetUser_Email(n: string): void
+ GetUser_Name(): string
+ SetUser_Name(n: string): void
+ GetRole(): string
+ SetRole(n: string): void
+ GetPoints(): int
+ SetPoints(n: int): void
<<Boundary>> Index
<<Boundary>> Edit
<<Boundary>> Login
<<Boundary>> Register
Occupant
+ ID: int
+ Name: string
+ Email: string
+ Points: int = 0
+ Weekly_Points: int = 0
+ Password: string
+ Workstation_ID: int
+ GetID(): int
+ GetEmail(): string
+ SetEmail(n: string): void
+ GetName(): string
+ SetName(n: string): void
+ GetPassword(): string
+ SetPassword(n: string): void
+ GetPoints(): int
+ SetPoints(n: int): void
+ GetWeekly_Points(): int
+ SetWeekly_Points(n: int): void
+ GetWorkstation_ID(): int
+ SetWorkstation_ID(n: int): void
1..* occupants
0..1 occupants
0..1 occupant
Warning
+ ID: int
+ Device_Type: string
+ Timestamp: DateTime
+ User_ID: int
+ Workstation_ID: int?
+ GetID(): string
+ GetDevice_Type(): string
+ SetDevice_Type(n: string): void
+ GetTimestamp(): DateTime
+ SetTimestamp(n: DateTime): void
+ GetUser_ID(): int
+ SetUser_ID(n: int): void
+ GetWorkstation_ID(): int?
+ SetWorkstation_ID(n: int): void
0..* warnings
WarningsController
+ Create(): ActionResult
+ Create(n: Warning): ActionResult
+ Index(): void
+ Report(n: int): ActionResult
+ Trade(n: int): ActionResult
+ Dispose(n: bool): void
<<Boundary>> Index
<<Boundary>> Create
<<Boundary>> CreateEdition
<<Boundary>> Edit
<<Boundary>> EditEdition
<<Boundary>> VerifyChallenge
<<Boundary>> Index
<<Boundary>> Details
<<Boundary>> Create
<<Boundary>> Create
<<Boundary>> Index
PopulateSelects
+ Assignment_Actions(): List<SelectListItem>
+ Assignment_Comparatives(): List<SelectListItem>
+ Assignment_Elements(): List<SelectListItem>
+ Assignments_Features(): List<SelectListItem>
+ BrightnessLevel(): List<SelectListItem>
+ Challenge_Actions(): List<SelectListItem>
+ Challenge_ControlRules(): List<SelectListItem>
+ Challenge_ControlValues(): List<SelectListItem>
+ Challenge_ControlVariables(): List<SelectListItem>
+ Challenge_Elements(): List<SelectListItem>
+ Challenge_Goals(): List<SelectListItem>
+ Challenge_Types(): List<SelectListItem>
+ GetAvailableWorkstations(n: List<Workstation>): List<SelectListItem>
+ GetWorkstations(n: List<Workstation>): List<SelectListItem>
+ OutSensorType(): List<SelectListItem>
+ SocketDeviceType(): List<SelectListItem>
+ WarningDeviceType(): List<SelectListItem>
<<Boundary>> Create
<<Boundary>> Index
<<Boundary>> Details
Workstation
+ ID: int
+ Workstation_ID: string
+ Light: Light
+ Outlet: ICollection<Outlet>
+ Occupant: Occupant
+ Beacon: Beacon
+ GetID(): int
+ GetLight(): Light
+ GetOccupant(): Occupant
+ GetOutlets(): List<Outlet>
+ GetBeacon(): Beacon
0..1 workstation
0..1 beacon
Beacon
+ ID: string
+ Workstation_ID: int
+ GetID(): string
+ SetID(n: string): void
+ GetWorkstation_ID(): int;
+ SetWorkstation_ID(n: int): void
<<Boundary>> Create
<<Boundary>> Index
<<Boundary>> Edit
BeaconsController
+ Create(): ActionResult
+ Create(n: Beacon): ActionResult
+ Index(): ActionResult
+ Edit(n: id?): ActionResult
+ Edit(n: Beacon): ActionResult
+ Delete(n:int?): ActionResult
+ DeleteConfirmed(n: int): ActionResult
+ Dispose(n: bool): void
WorkstationsController
+ Create(): ActionResult
+ Create(n: Workstation): ActionResult
+ Index(): ActionResult
+ Details(n: int?): ActionResult
+ Delete(n: int?): ActionResult
+ DeleteConfirmed(n: int): ActionResult
+ Dispose(n: bool): void
0..1 workstation
0..1 workstation
0..1 workstation
0..1 workstation
0..1 workstation
Lifx
+ Workstation_ID: int
+ GetWorkstation_ID(): int
+ SetWorkstation_ID(n: string): void
0..1 lifx
<<Boundary>> Edit
Light
+ ID: string
+ GetID(): string
+ SetID(n: string): void
LightsController
+ Create(): ActionResult
+ Create(n: Light): ActionResult
+ Index(): ActionResult
+ Edit(n: int?): ActionResult
+ Edit(n: Light): ActionResult
+ Delete(n: int?): ActionResult
+ DeleteConfirmed(n: int): ActionResult
+ Dispose(n: bool): void
+ Halo_TurnOff(n: string, m string, o: int): void
+ Halo_TurnOn(n: string, m string, o: int): void
+ Lifx_TurnOff(n: string, m: int): void
+ Lifx_TurnOn(n: string, m: int): void
+ Lifx_ChangeBrightness(n: string, m: int): void
+ Lifx_WhiteHue(n: string, m: int)
<<Boundary>> Create
<<Boundary>> Index
Halogen
+ Number: int
+ Row: int
+ GetNumber(): int
+ SetNumber(n: int): void
+ GetRow(): int
+ SetRow(n: int): void
OutletsController
+ Create(): ActionResult
+ Create(n: Outlet): ActionResult
+ Index(): ActionResult
+ Edit(n: int ?, m: int?): ActionResult
+ Edit(n: Outlet): ActionResult
+ Delete(n: int?): ActionResult
+ DeleteConfirmed(n: int): ActionResult
+ Dispose(n: bool): void
0..* outlets
Outlet
+ ID: string
+ Block: int
+ Number: int
+ Device: string
+ Workstation_ID: int
+ GetID(): string
+ SetID(n: string): void
+ GetBlock(): int
+ SetBlock(n: string): void
+ GetNumber(): int
+ SetNumber(n: int): void
+ GetDevice(): string
+ SetDevice(n: string): void
+ GetWorkstation_ID(): int?
+ SetWorkstation_ID(n: int): void
<<Boundary>> Create
<<Boundary>> Edit
<<Boundary>> Index
Task
+ ID: int
+ Name: string
+ Description: string
+ Feature: string
+ Element: string
+ Comparative: string
+ Action: string
+ I_Points: int
+ G_Points: int
+ Time_Span: int
+ Wskt_ID: int?
+ Task_Entries: List<TaskEntry>
+ GetID(): int
+ GetName(): string
+ GetDescription(): string
+ GetFeature(): string
+ SetFeature(n: string): void
+ GetElement(): string
+ SetElement(n: string): void
+ GetComparative(): string
+ SetComparative(n: string): void
+ GetAction(): string
+ SetAction(n: string): void
+ GetI_Points(): int
+ SetI_Points(n: int): void
+ GetG_Points(): int
+ SetG_Points(n: int): void
+ GetTime_Span(): int
+ SetTime_Span(n: int): void
+ GetWskt_ID(): int
+ SetWskt_ID(n: int): void
+ GetEntries(): List<TaskEntry>
0..* tasks
1 task
0..* entries
TaskEntry
+ ID: int
+ Task_ID: int
+ Release_Date: DateTime
+ Done_Date: DateTime?
+ State: bool?
+ User_ID: int
+ Reason: string
+ GetID(): int
+ GetTask_ID: int
+ GetRelease_Date(): DateTime
+ SetRelease_Date(n: DateTime): void
+ GetDone_Date(): DateTime
+ SetDone_Date(n: DateTime): void
+ GetState(): bool?
+ SetState(n: bool): void
+ GetUser_ID(): int
+ SetUser_ID(n: int): void
+ GetReason(): string
+ SetReason(n: string): void
0..* entries
<<Boundary>> History
<<Boundary>> Index
<<Boundary>> Create
<<Boundary>> Edit
TaskEntriesController
+ Trigger(n: int): ActionResult
+ Dispose(n: bool): void
<<Boundary>> Layout
<<Boundary>> Help
<<Boundary>> Index
<<Boundary>> Dashboard
<<Boundary>> Settings
HomeController
+ Dashboard(): ActionResult
+ Excel(): void
+ Help(): ActionResult
+ Settings(): ActionResult
+ Index(): ActionResult
+ GetData(): void
<<Boundary>> Create
AirConditioner
+ ID: string
+ GetID(): string
+ SetID(n: string): void
<<Boundary>> Index
AirConditionersController
+ Create(): ActionResult
+ Create(n: AirConditioner): ActionResult
+ Index(): ActionResult
+ TurnOn(n: int): void
+ TurnOff(n: int): void
+ ChangeTemperature(n: double, m: int): void
+ Delete(n: string): ActionResult
+ DeleteConfirmed(n: string): ActionResult
+ Dispose(n: bool): void
Utils
+ AC_GetState(n: string, m: string): List<Pair>
+ AC_GetTemperature(n: string, m: string): List<Pair>
+ Beacon_GetLuminosity(n: string, m: string, o: string): List<Pair>
+ Beacon_GetTemperature(n: string, m: string, o:string): List<Pair>
+ Beacon_Last(n: string): double[]
+ ConvertACList(n: List<AIR_CONDITIONER>): List<AirConditioner>
+ ConvertTaskHistoryList(n: List<HISTORY_ASSIGNMENT>): List<TaskEntry>
+ ConvertTaskList(n: List<TASK>): List<Task>
+ ConvertBeaconList(n: List<BEACON>): List<Beacon>
+ ConvertChallengeList(n: List<CHALLENGE>): List<Challenge>
+ ConvertEditionsList(n: List<CHALLENGE_EDITION>): List<ChallengeEdition>
+ ConvertLightList(n: List<LIGHT>): List<List<Light>>
+ ConvertOccupantList(n: List<OCCUPANT>): List<Occupant>
+ ConvertOutletList(n: List<OUTLET>): List<Outlet>
+ ConvertWarningList(n: List<WARNING>): List<Warning>
+ ConvertWorkstationList(n: List<WORKSTATION>): List<Workstation>
+ Lifx_GetState(n: string, m: string): List<Pair>
+ Lifx_GetTemperature(n: string, m: string): List<Pair>
+ Lifx_Last(n: string): double[]
TasksController
+ Create(): ActionResult
+ Create(n: Assignment, m: int?): ActionResult
+ Index(): ActionResult
+ History(): ActionResult
+ TaskStatus(n: FormCollection): ActionResult
+ Dispose(n: bool): void
OutsideSensorsController
+ Create(): ActionResult
+ Create(n: OutsideSensor): ActionResult
+ Index(): ActionResult
+ Edit(n: int?): ActionResult
+ Edit(n: OutsideSensor): ActionResult
+ Delete(n: string): ActionResult
+ DeleteConfirmed(n: string): ActionResult
GET_OutletStatus
+ ID: string
+ Values: ValuesOutletStatus
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesOutletStatus
+ SetValues(n: ValuesOutletStatus) void


CheckinsController
+ Index(): void
+ SetCheckin(): ActionResult
<<Boundary>>
Create
<<Boundary>>
Edit
<<Boundary>>
Index
OutsideSensor
+ ID: string
+ Type: string
+ GetID(): string
+ SetID(n: string): void
+ GetType(): string
+ SetType(n: string): void
Checkin
+ ID: int
+ Check_Event: bool
+ Timestamp: DateTime
+ User_ID: int
+ GetID(): string
+ GetCheck_Event(): bool
+ SetCheck_Event(n: bool): void
+ GetTimestamp(): DateTime
+ SetTimestamp(n: DateTime): void
+ GetUser_ID(): int
+ SetUser_ID(n: int): void
GET_LifxBrightness
+ ID: string
+ Values: ValuesLifxBrightness
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesLifxBrightness
+ SetValues(n: ValuesLifxBrightness):void
ValuesLifxBrightness
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ BrightnessSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetBrightnessSensor(): double
+ SetBrightnessSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_LifxPower
+ ID: string
+ Values: ValuesLifxColour
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesLifxPower
+ SetValues(n: ValuesLifxPower):void
ValuesLifxPower
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ PowerSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetPowerSensor(): double
+ SetPowerSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_BeaconTemperature
+ ID: string
+ Values: ValuesBeaconTemperature
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesBeaconTemperature
+ SetValues(n: ValuesBeaconTemperature):void
ValuesBeaconTemperature
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ TemperatureSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetTemperatureSensor(): double
+ SetTemperatureSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
ValuesOutletLast
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ CurrentSocketSensor: double
+ PowerSocketSensor: double
+ StatusSocketSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetCurrentSocketSensor(): double
+ SetCurrentSocketSensor(n: double): void
+ GetPowerSocketSensor(): double
+ SetPowerSocketSensor(n: double): void
+ GetStatusSocketSensor(): double
+ SetStatusSocketSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_OutletPower
+ ID: string
+ Values: ValuesOutletPower
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesOutletPower
+ SetValues(n: ValuesOutletPower):void
ValuesOutletPower
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ PowerSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetPowerSensor(): double
+ SetPowerSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_OutletCurrent
+ ID: string
+ Values: ValuesOutletCurrent
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesOutletCurrent
+ SetValues(n: ValuesOutletCurrent):void
ValuesOutletCurrent
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ CurrentSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetCurrentSensor(): double
+ SetCurrentSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_OutletLast
+ ID: string
+ Values: ValuesOutletLast
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesOutletLast
+ SetValues(n: ValuesOutletLast):void
ValuesOutletStatus
OUTLET
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ StatusSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetStatusSensor(): double
+ SetStatusSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
WARNING
GET_HaloPower
+ ID: string
+ Values: ValuesHaloPower
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesHaloPower
+ SetValues(n: ValuesHaloPower):void
ValuesHaloPower
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ PowerSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetPowerSensor(): double
+ SetPowerSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
Pair
+ Date: long
+ Value: dynamic
+ GetDate(): long
+ SetDate(n: long): void
+ GetValue(): dynamic
+ SetValue(n: dynamic): void
GET_OutsideTemperature
+ ID: string
+ Values: ValuesOutsideTemperature
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesOutsideTemperature
+ SetValues(n: ValuesOutsideTemperature):void
ValuesOutsideTemperature
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ ExternalTempSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetExternalTempSensor(): double
+ SetExternalTempSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_ACTemperature
+ ID: string
+ Values: ValuesACTemperature
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesACTemperature
+ SetValues(n: ValuesACTemperature):void
ValuesACTemperature
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ TemperatureSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetTemperatureSensor(): double
+ SetTemperatureSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_ACStatus
+ ID: string
+ Values: ValuesACStatus
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesACStatus
+ SetValues(n: ValuesACStatus):void
ValuesACStatus
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ StatusSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetStatusSensor(): double
+ SetStatusSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_OutsideLuminosity
+ ID: string
+ Values: ValuesOutsideLuminosity
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesOutsideLuminosity
+ SetValues(n: ValuesOutsideLuminosity):void
ValuesOutsideLuminosity
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ LuxSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetLuxSensor(): double
+ SetLuxSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_HaloLast
+ ID: string
+ Values: ValuesHaloLast
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesHaloLast
+ SetValues(n: ValuesHaloLast):void
ValuesHaloLast
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ HalogenStatusSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetHalogenStatusSensor(): double
+ SetHalogenStatusSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_SunTimes
+ Status: string
+ Results: SunResults
+ GetStatus(): string
+ SetStatus(n: string): void
+ GetResults(): SunResults
+ SetResults(n: SunResults):void
SunResults
+ Sunrise: string
+ Sunset: string
+ Noon: string
+ GetSunrise(): string
+ SetSunrise(n: string): void
+ GetSunset(): string
+ SetSunset(n: string): void
+ GetNoon(): string
+ SetNoon(n: string): void
GET_LifxColour
+ ID: string
+ Values: ValuesLifxColour
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesLifxColour
+ SetValues(n: ValuesLifxColour):void
ValuesLifxColour
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ ColourSensor: ColourSensor
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetColourSensor(): ColourSensor
+ SetColourSensor(n: ColourSensor): void
+ GetVersion(): string
+ SetVersion(n: string): void
ColourSensor
+ Hue: long
+ Kelvin: long
+ Saturation: long
+ GetHue(): long
+ SetHue(n: long): void
+ GetKelvin(): long
+ SetKelvin(n: long): void
+ GetSaturation(): long
+ SetSaturation(n: long): void
GET_BeaconLast
+ ID: string
+ Values: ValuesBeaconLast
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesBeaconLast
+ SetValues(n: ValuesBeaconLast):void
ValuesBeaconLast
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ LightSensor: double
+ TemperatureSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetLightSensor(): double
+ SetLightSensor(n: double): void
+ GetTemperatureSensor(): double
+ SetTemperatureSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_BeaconLuminosity
+ ID: string
+ Values: ValuesBeaconLuminosity
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesBeaconLuminosity
+ SetValues(n: ValuesBeaconLuminosity):void
ValuesBeaconLuminosity
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ LightSensor: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetLightSensor(): double
+ SetLightSensor(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void
GET_LifxLast
+ ID: string
+ Values: ValuesLifxLast
+ GetID(): string
+ SetID(n: string): void
+ GetValues(): ValuesLifxLast
+ SetValues(n: ValuesLifxLast):void
ValuesLifxLast
+ MetaDeviceId: string
+ MetaDeviceType: string
+ MetaOwner: string
+ MetaTime: long
+ BrightnessSensor: double
+ Hue: double
+ Kelvin: double
+ PowerSensor: double
+ Saturation: double
+ Version: string
+ GetMetaDeviceId(): string
+ SetMetaDeviceId(n: string): void
+ GetMetaDeviceType(): string
+ SetMetaDeviceType(n: string): void
+ GetMetaOwner(): string
+ SetMetaOwner(n: string): void
+ GetMetaTime(): long
+ SetMetaTime(n: long): void
+ GetBrightnessSensor(): double
+ SetBrightnessSensor(n: double): void
+ GetHue(): double
+ SetHue(n: double): void
+ GetKelvin(): double
+ SetKelvin(n: double): void
+ GetPowerSensor(): double
+ SetPowerSensor(n: double): void
+ GetSaturation(): double
+ SetSaturation(n: double): void
+ GetVersion(): string
+ SetVersion(n: string): void